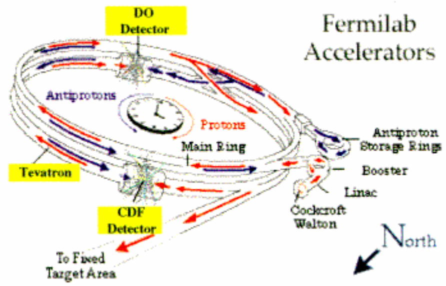
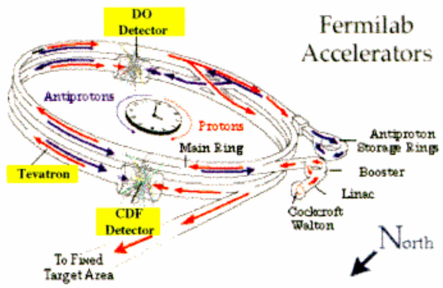


Fermilab Accelerators

Heavy Flavor Physics at the Tevatron

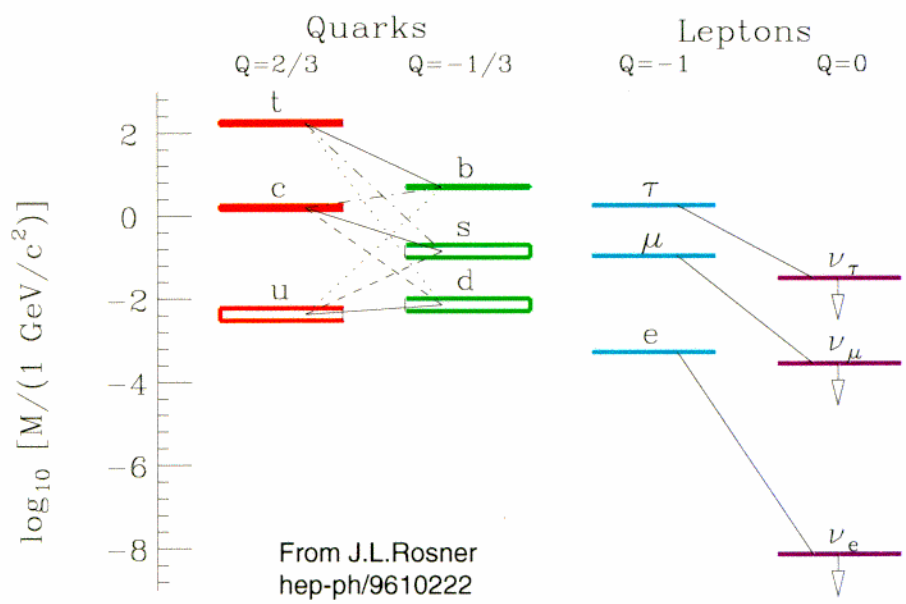
Giorgio Apollinari
Fermilab



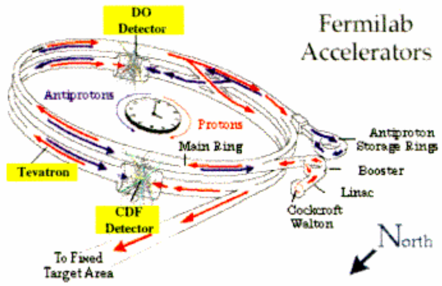
Introduction

"Heavy Flavor Physics" ⟷ "Third Quark Generation"

- Since the 1976 discovery of the τ, the third quark generation has been the "most anticipated" quark family:
  - Theoretical Indications:
    - In the S.M. ~~CP~~ exists only if three 3 quark families (and a phase in the mixing among the families) are present.
  - After the *b* quark was discovered (1977), the top quark existence was inferred:
    - The SM is anomaly free only if for any Q=-1/3 quark (like the b quark, found in 1977) there is a Q=+2/3 partner.
    - Experimental Indications:
      - CP violation in the K^0 system and the size of the B^0 mixing are possible only if top exists.
      - *b* isospin measurement in $Z^0 \to bb$

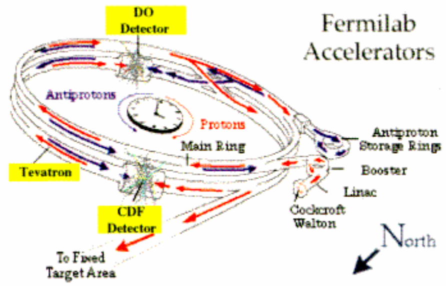


From J.L.Rosner
hep-ph/9610222



Introduction

- Content
  - Top Physics Results
    - $\sigma_{t\bar{t}}$
    - M_{top}
    - Decay properties of the $t\bar{t}$ system
      - W helicity
      - Mesurement of V_{tb}
      - Search for rare decays, FCNC
      - Single top
  - B Physics Results
    - B_c Discovery
    - Flavor tagging and sin2β measurement



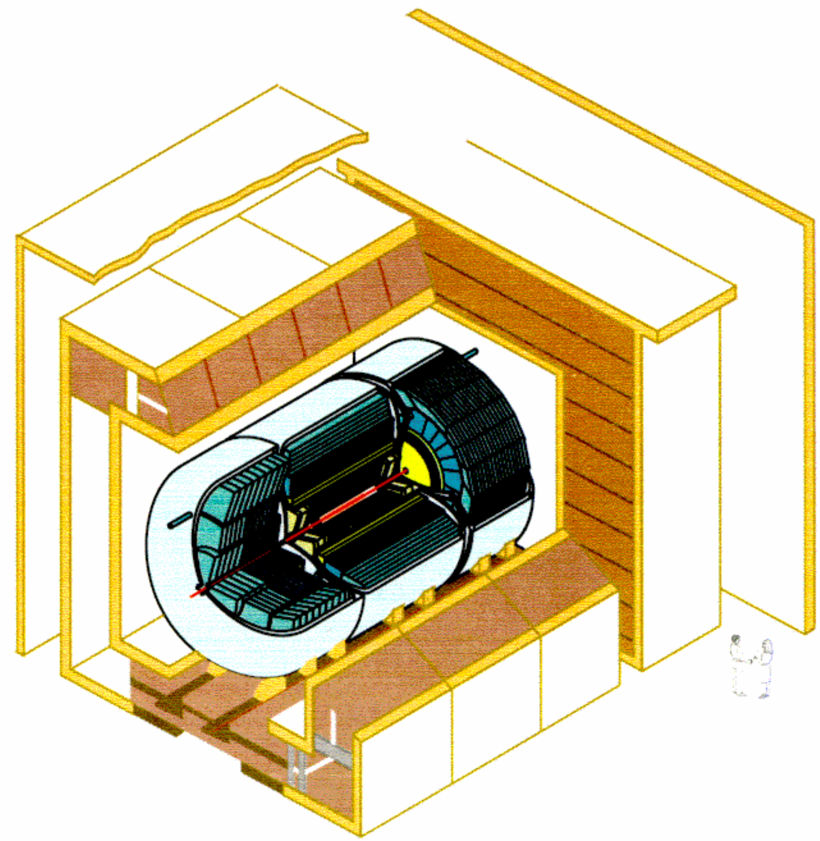
Tevatron Detectors

CDF

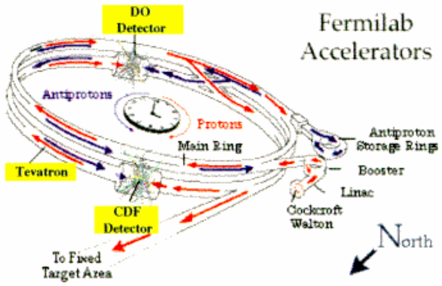
- Focus on tracking
  - 1.4 Tesla solenoid
  - Tracking chamber and secondary vertex detection
    - $\delta P_t / P_t = 0.1\% \, P_t \oplus 0.6\%$
    - $\sigma_{Imp.Par.} \approx 17\ \mu m$
  - μ detection ($|\eta|<1$) and calorimetry

DO

- Focus on calorimetry hermeticity and μ detection
  - LAr calorimeter
  - μ detection up to $|\eta| = 3$
    - $\delta P_t / P_t = 1\% \, P_t \oplus 20\%$

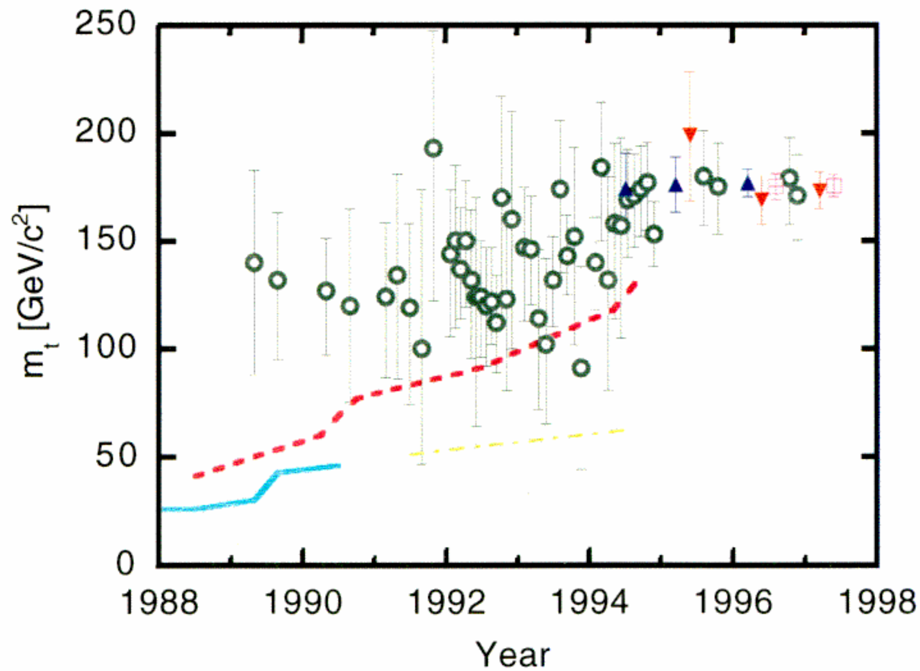


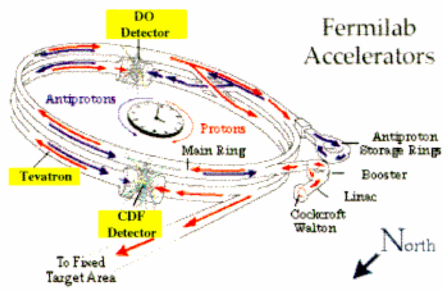
DØ Detector



Top Introduction

- The top has been sought since 1977 (b discovery).
  - APRIL 1994: First Evidence
    - PRD 50, 2966 (1994) CDF
      - M_{top}=174±16 GeV
      - $\sigma_{top}=13.9^{+6.1}_{-4.8}$ pb
  - FEBRUARY 1995:Observation
    - PRL 74, 2626 (1995) CDF
      - M_{top} =176±8±10 GeV
      - $\sigma_{top}=6.8^{+3.6}_{-2.4}$ pb
    - PRL 74, 2632 (1995) D0
      - $M_{top}=199^{+19}_{-21}\pm22$ GeV
      - σ_{top} =6.4±2.2 pb



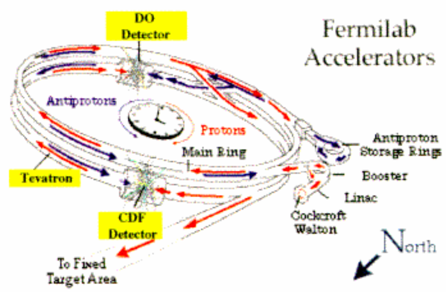


Top Introduction

- At M_{top} ~ 175 GeV, the last (expected) quark is the heaviest known elementary particle. The large top mass implies:
  - M_{top} is of the same order of magnitude of the electroweak symmetry breaking scale. The Yukawa coupling for top is $G_{top} \sim 1$, while for the electron $G_e \sim 10^{-6}$.
  - The coupling to the Higgs is large.
  - The lifetime is short. Since:
    - $\tau_{top} \sim 1/M^3 \sim 10^{-24}$ sec
    - $\tau_{QCD} \sim \Lambda^{-1} \sim 10^{-23}$ sec

$\Rightarrow$ the top decays before it hadronizes

Expect accurate cross-section predictions from perturbative QCD.

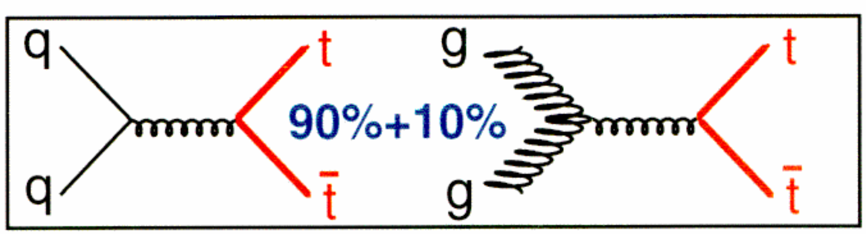


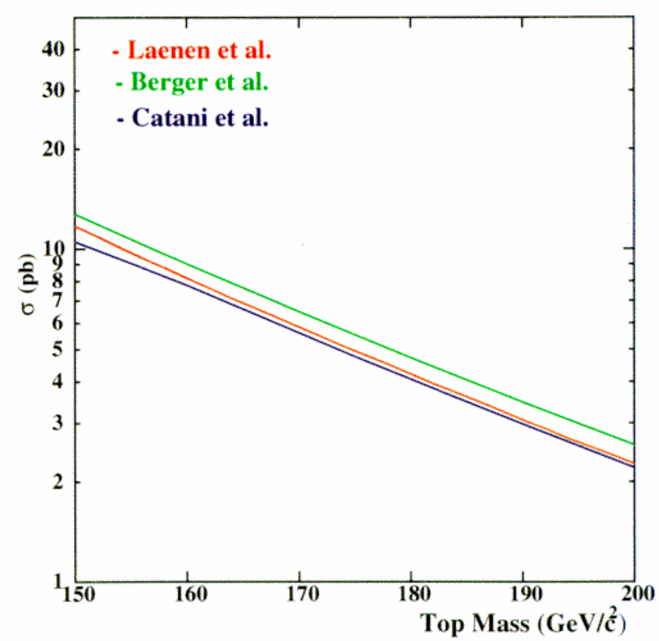
Top Introduction

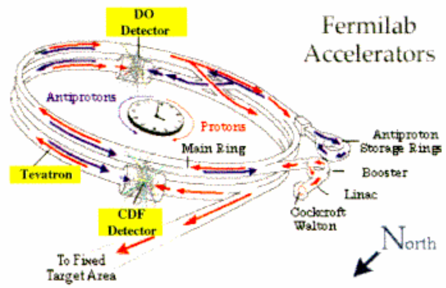
- Perturbative QCD:

$$\sigma(p\bar{p} \rightarrow t\bar{t}) = \Sigma_{ik} \int dx_i\, F_i(x_i)\ dx_k\, F_k(x_k)\ \sigma_{i,k}(s)$$

  - NLO corrections $O(\alpha^3_s)$ contribute about 25% to $\sigma_{t\bar{t}}$.
  - Logarithmic contributions in the initial and final state radiation (soft gluon resumation) contribute another 10-20%.
  - No single-top production has been observed yet.

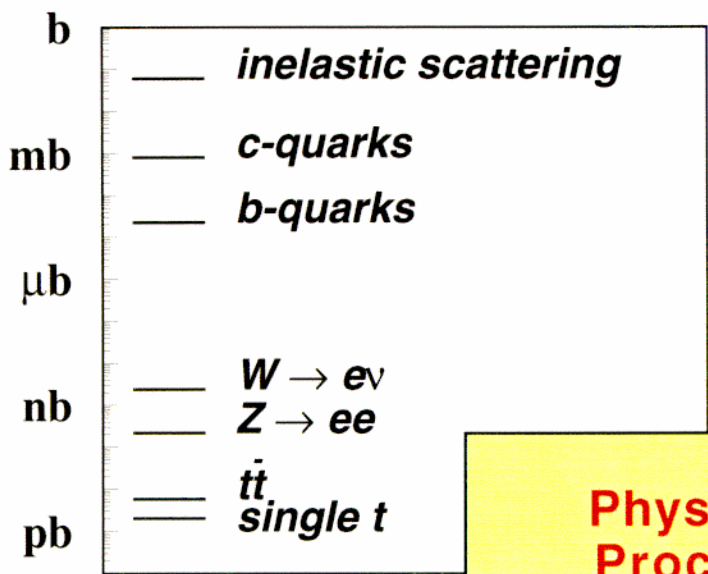




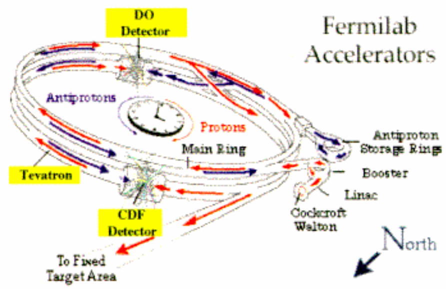


Top Introduction

Production rates for the Tevatron Run I



Physics Process	Production rates at L=10^{31}	# of events at ∫L=100 pb^{-1}
$p\bar{p} \to$ anything	600 KHz	10^{12} events
$p\bar{p} \to b\,b$	20 Hz	10^{9}
$p\bar{p} \to WX$	2Hz	10^{6} events
$p\bar{p} \to ZX$	0.6 Hz	10^{5} events
$p\bar{p} \to t\bar{t}$	4/day	500 events



Top Introduction

- In the SM, assuming V-A coupling and $|V_{tb}| \sim 1$, for the $t \rightarrow Wb$ decay one obtains:

  $\Gamma(t \rightarrow Wb) \quad \sim 175\ \text{MeV}\ (M_t/M_W)^3$

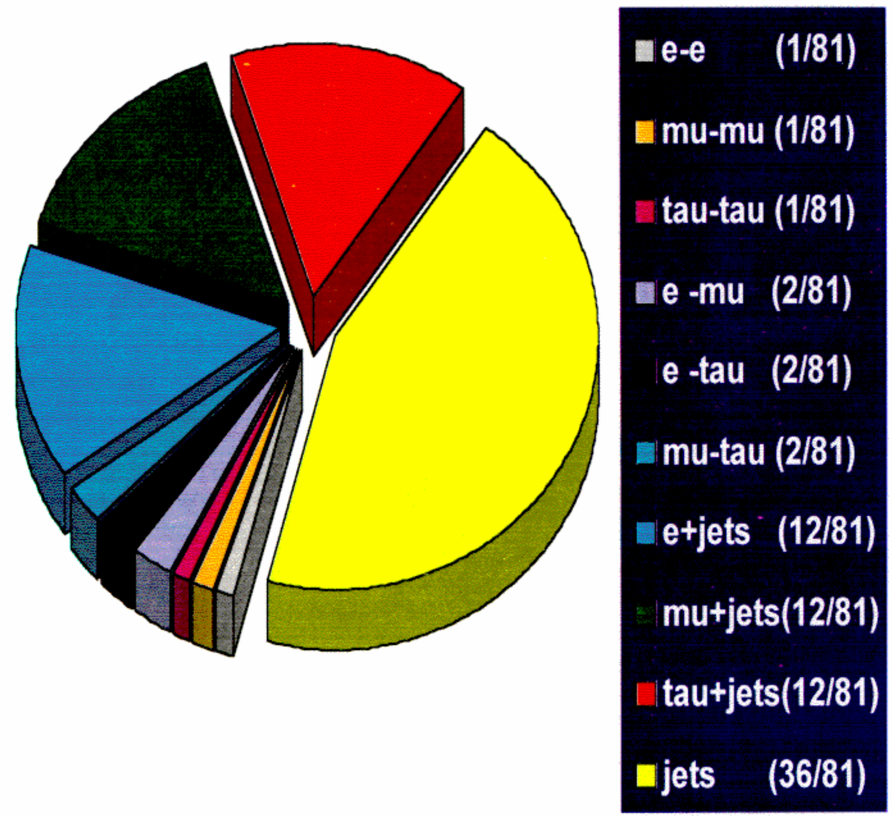
  $\sim 1.8\ \text{GeV}$

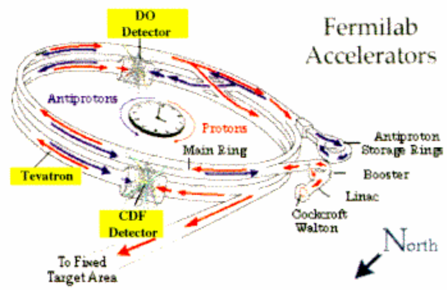
- $t \rightarrow Ws$ and $t \rightarrow Wd$ are allowed but suppressed by factors

  $|V_{ts}|^2 / |V_{tb}|^2 \sim 10^{-3}$ and

  $|V_{td}|^2 / |V_{tb}|^2 \sim 5 \times 10^{-5}$

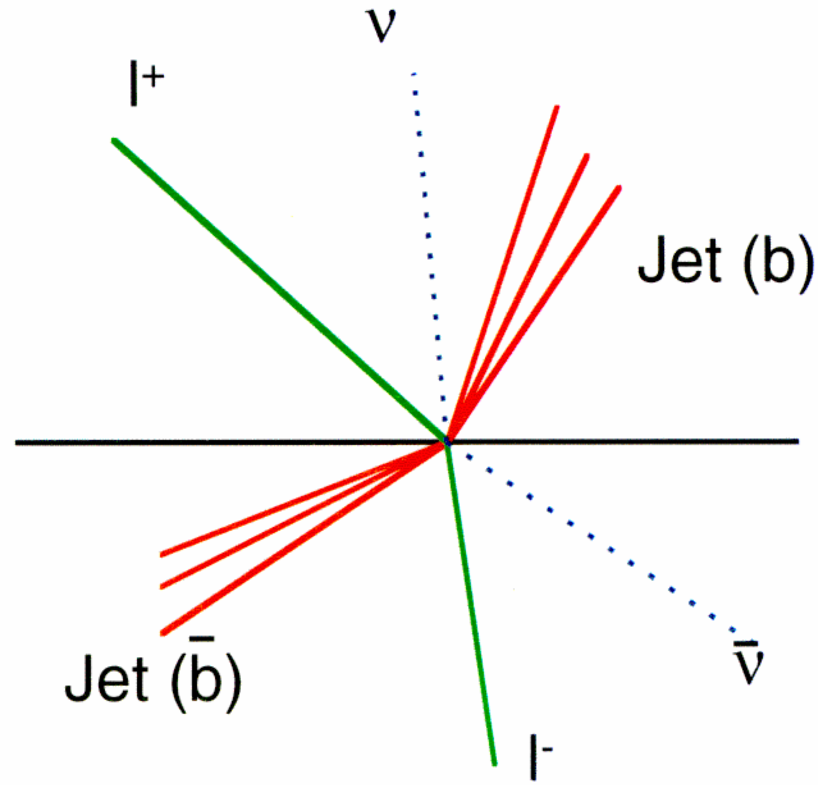
- The W decay defines the final event signature:
  - Dilepton
  - Lepton+jets
  - Total Hadronic

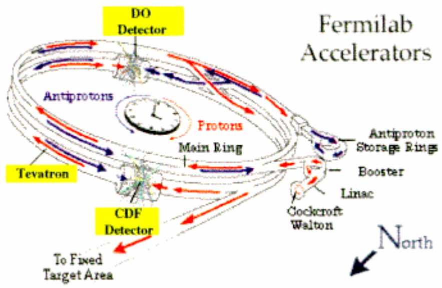




Dilepton Channels

- Signature
  - Two isolated high P_t leptons (e,μ or τ)
  - Missing Transverse Energy from ν's
- Dominant Backgrounds:
  - WW, $Z\rightarrow\tau\tau$,Drell-Yan
- Features:
  - Good S/N
    - Low Statistic
    - Not ideal (yet!) for mass determination





Dilepton Channel Selection Criteria

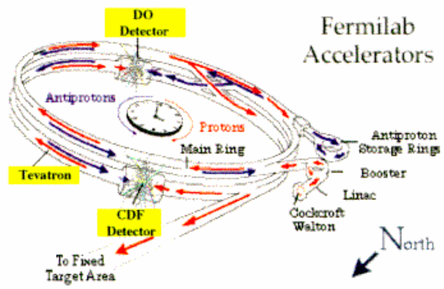
CDF

- Two high P_t leptons
  - $P_t > 20$ Gev
  - Central ($|\eta|<1.1$)
  - Opposite Charge
- At least one isolated lepton
- M_{ll} not in Z region (75-105 GeV)
- $\not{E}_T>25$ GeV + $\Delta\phi$ cut
- 2 Jets, $E_t>10$ GeV, $|\eta|<2$
- $H_T>170$ GeV (top mass only)

D0

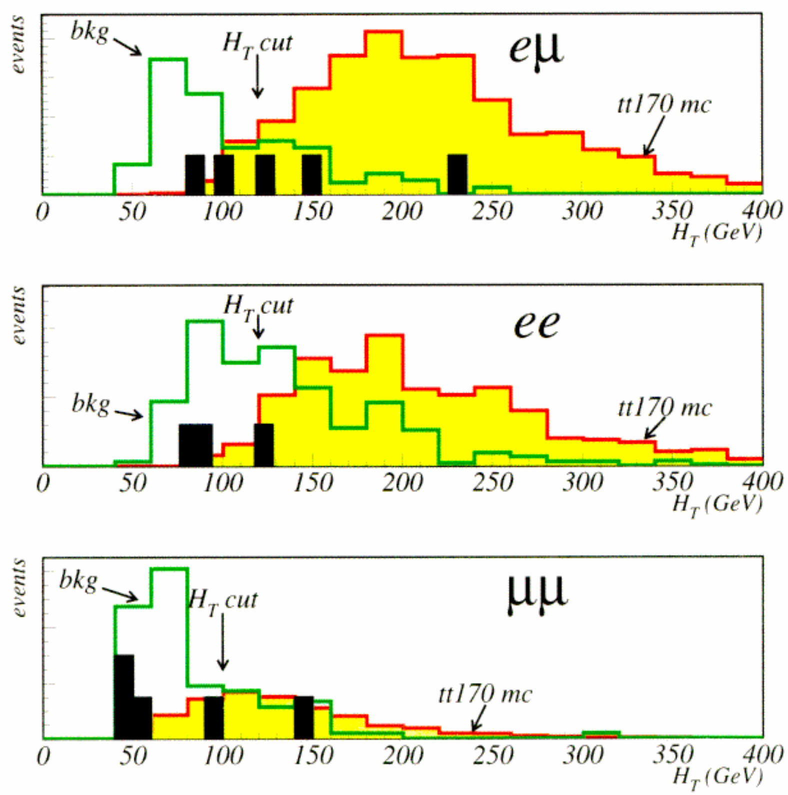
- Two isolated high P_t leptons
  - $P_t>15(20)$ GeV for $e\mu,\mu\mu$ (ee)
  - $|\eta|<2.5$ (1.7) for e (μ)
- $\not{E}_T>20$ (25) GeV for $e\mu$ (ee)
- 2 Jets, $E_t>20$ GeV, $|\eta|<2.5$
- $H_T=\Sigma\, p_T{}^{jet} >100$ GeV ($\mu\mu$)

  $H_T{}^e=\Sigma\, p_T{}^{jet} + p_T{}^e >120$ GeV

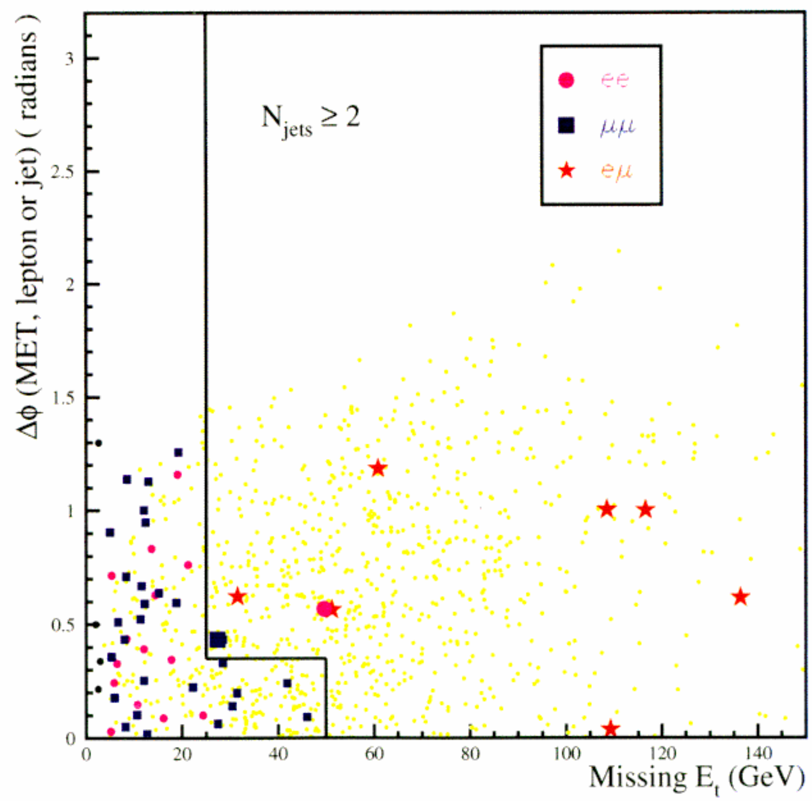


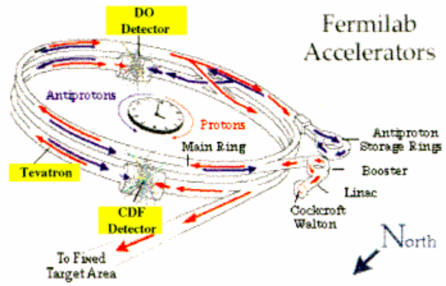
Dilepton Channel

D0



CDF





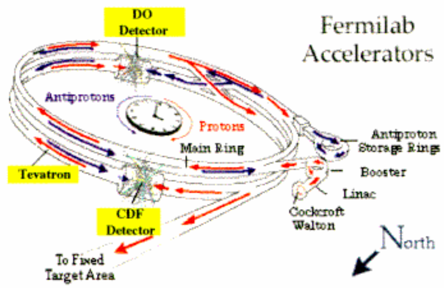
Dilepton Channel

$\sigma_{t\bar{t}}$

SAMPLE		D0	CDF
$e\mu$	OBSERVED	3	7
	BACKGROUND	0.3 ± 0.1	0.76 ± 0.21
	EXPECTED	1.7 ± 0.3	2.4 ± 0.2
ee or $\mu\mu$	OBSERVED	2	2
	BACKGROUND	1.1 ± 0.4	1.23 ± 0.36
	EXPECTED	1.4 ± 0.1	1.6 ± 0.2
$e\tau - \mu\tau$	OBSERVED	-	4
	BACKGROUND	-	1.96 ± 0.35
	EXPECTED	-	0.7 ± 0.1

$\sigma_{t\bar{t}}=8.2^{+4.4}_{-3.4}$ pb (CDF m_{top}=175 GeV)

$\sigma_{t\bar{t}}=5.0 \pm 3.3$ pb (D0 m_{top}=175 GeV)

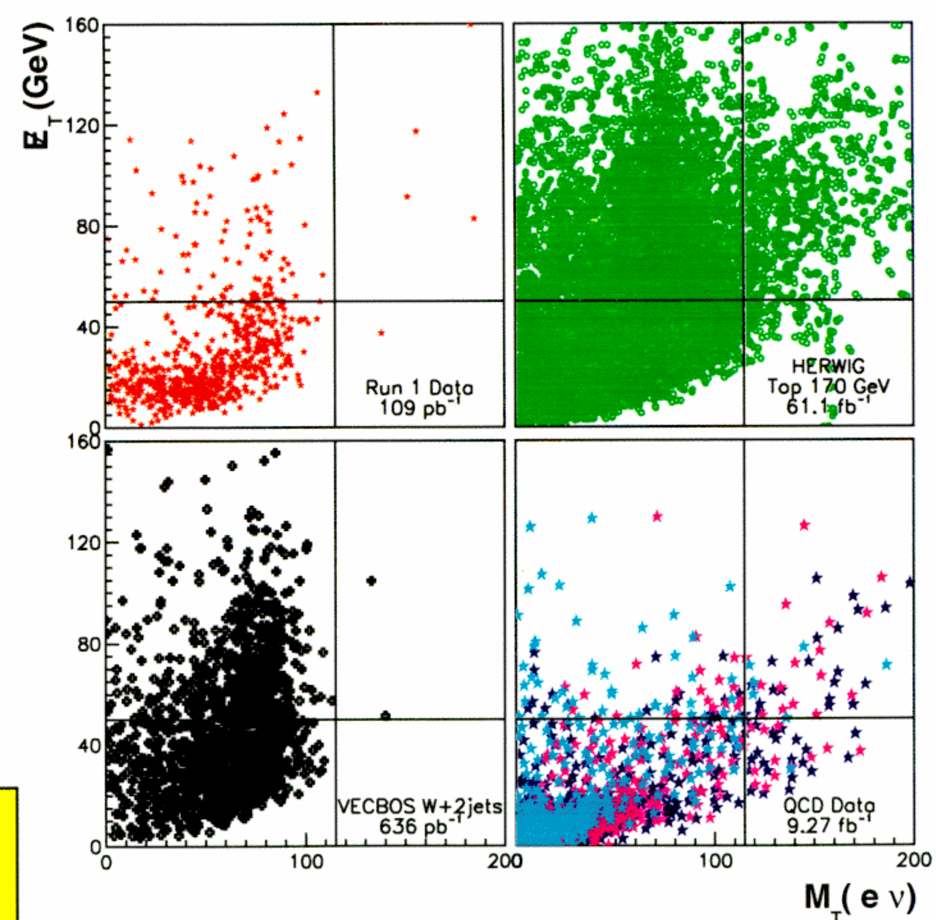


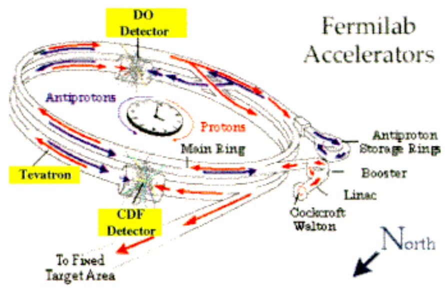
Dilepton Channel

eν events (D0)

- Increase top acceptance
  - One isolated electron
  - 2 or more jets, p_T>30 GeV
  - E_T> 50 GeV
  - $M_T(e\nu)$>115 GeV
- Sample composition:
  - 50% eμ+ee, 33%e+jets, 17%eτ
- Observed 4 events
  - bkg=1.2±0.4

$\sigma_{t\bar{t}} = 9.6 \pm 7.5$ pb (D0-eν)





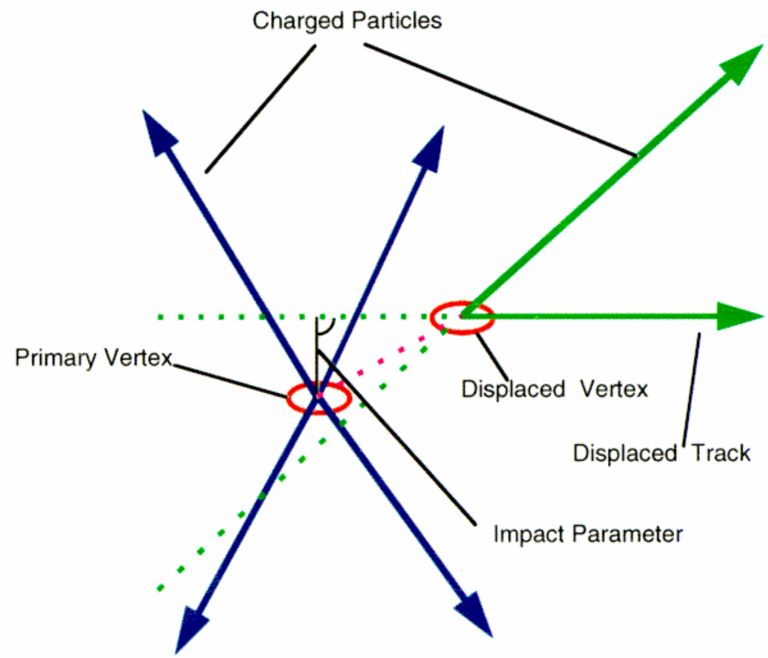
l+jets Channel

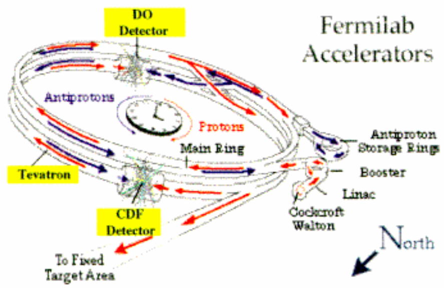
- Selection criteria:
  - Isolated and energetic (E_T>20 GeV) lepton and Large $\not{E}_T$
  - 3 or more jets

⬇

S/N ~ 1/5

  - Dominant bkg: W + QCD-jets
- Need background rejection:
  - Event Shape (for heavy top) (D0)
  - b-quark tagging using semileptonic decays (D0 and CDF)
  - b-quark tagging using displaced vertices or displaced tracks (CDF)



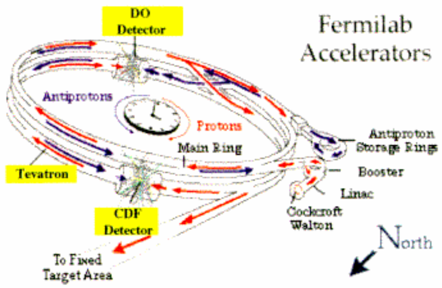


Fermilab Accelerators

b-quark tagging tools

- Properties of:
  - ➤SECVTX (displaced vertex)
  - ➤JPB (displaced track)
  - ➤SLT (semileptonic decay tag)

	ε(b)	ε(c)	fake
SECVTX	23.1%	4.0%	0.1%
JPB	22.0%	9.0%	0.5%
SLT	7.3%	3.7%	1.1%



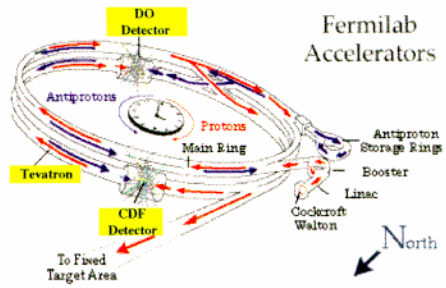
l+jets Selection

CDF

- One high P_t lepton
  - P_t > 20 Gev and Isolated
  - Central ($|\eta|<1.1$)
- $\not{E}_T$>20 GeV
- At least 3 jets with E_T>15 GeV and $|\eta| < 2.0$
- Z and di-lepton removal
- b-identification:
  - SECondary VerTeX (ε=40%)
  - Semilep. decay (SLT) (ε=20%)

D0

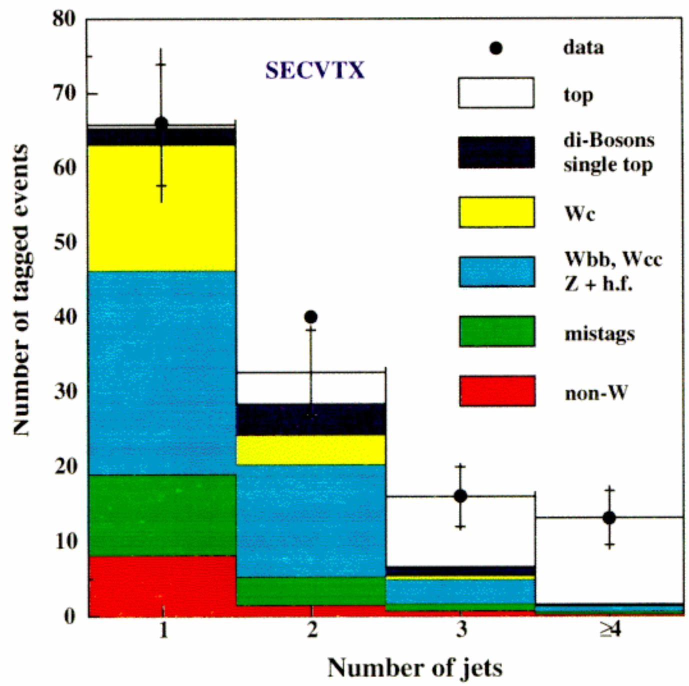
	l+jets	l+jets/μ
p_t	>20	>20 GeV
$\not{E}_T$	>25(e) >20(μ)	>20 GeV
4 Jets, E_T	>15	>20 GeV
A	>0.065	>0.040
H_T	>180	>110 GeV
l- p_t + E_T	>60 GeV	
η_W	<2.0	

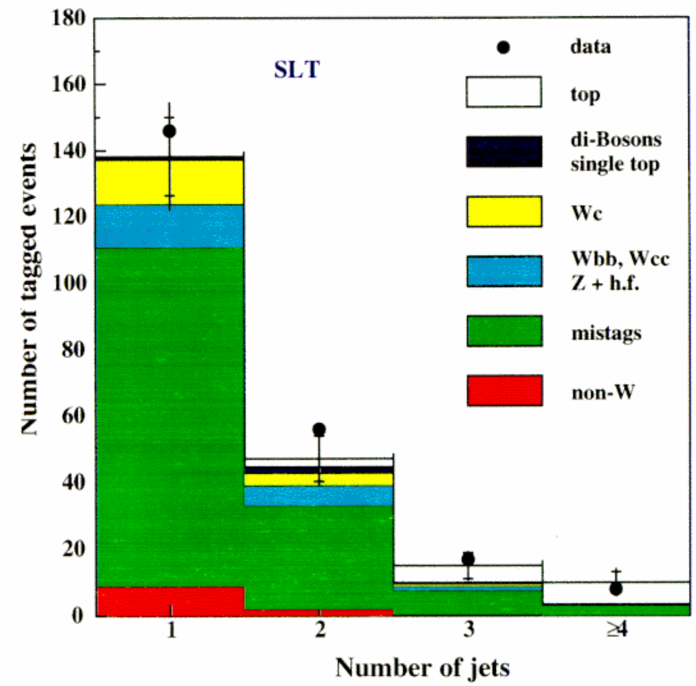


Fermilab
Accelerators

l+jets

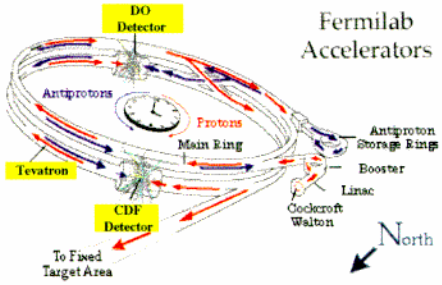
CDF





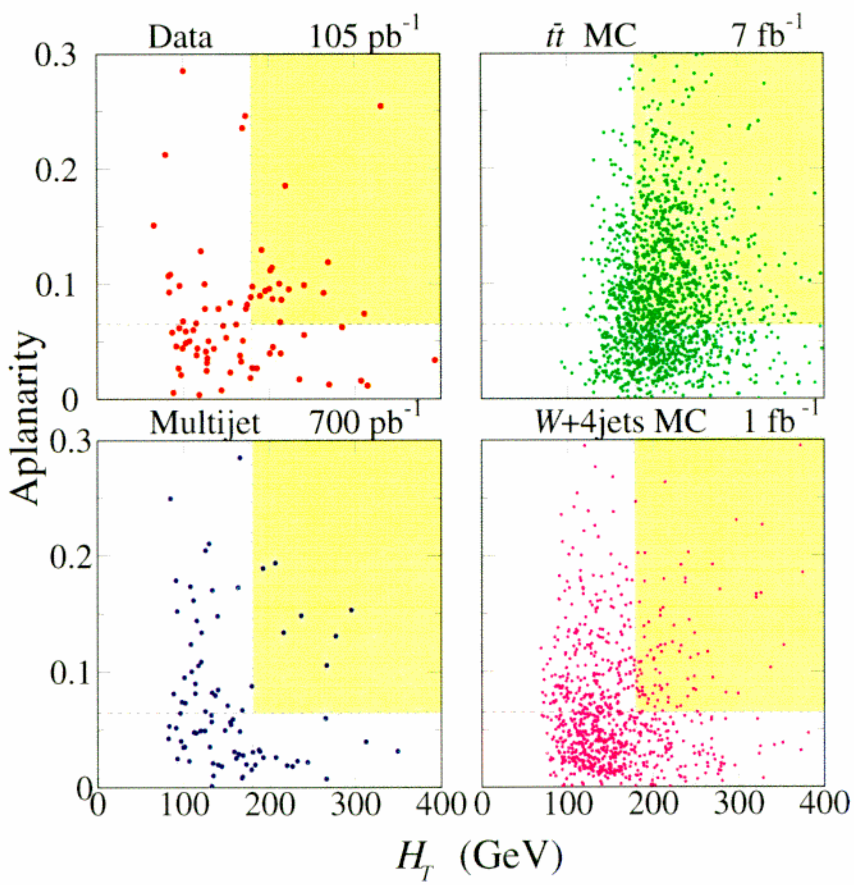
$\sigma_{t\bar{t}} = 6.2^{+2.1}_{-1.7}$ pb (CDF-SVX)

$\sigma_{t\bar{t}} = 9.2^{+4.3}_{-3.6}$ pb (CDF-SLT)



l+jets

D0

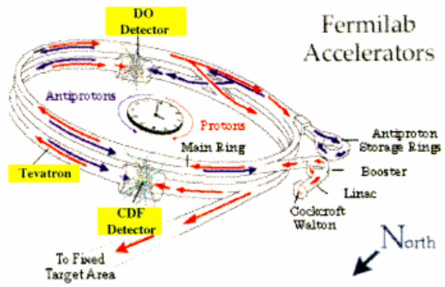


$\sigma_{t\bar{t}}$=4.1 ± 2.1 pb

(D0 - l+jets)

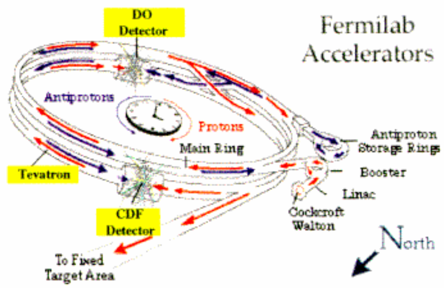
$\sigma_{t\bar{t}}$=8.3 ± 3.6 pb

(D0 - l+jets/μ)



l+jets Events Summary

SAMPLE		D0	CDF
Event Shape	OBSERVED	19	22
	BACKGROUND	9.7 ± 1.7	7.2 ± 2.1
	EXPECTED ($M_{top} \approx 170$)	14.1 ± 3.1	
$b \to lX$	OBSERVED	11	40
	BACKGROUND	2.4 ± 0.5	24.3 ± 3.5
	EXPECTED ($M_{top} \approx 170$)	5.8 ± 1.0	9.6
Disp. Vertex	OBSERVED	-	34 Ev. (42 Tags)
	BACKGROUND	-	8.0 ± 1.4
	EXPECTED ($M_{top} \approx 170$)	-	19.8 ± 4.0



All hadronic

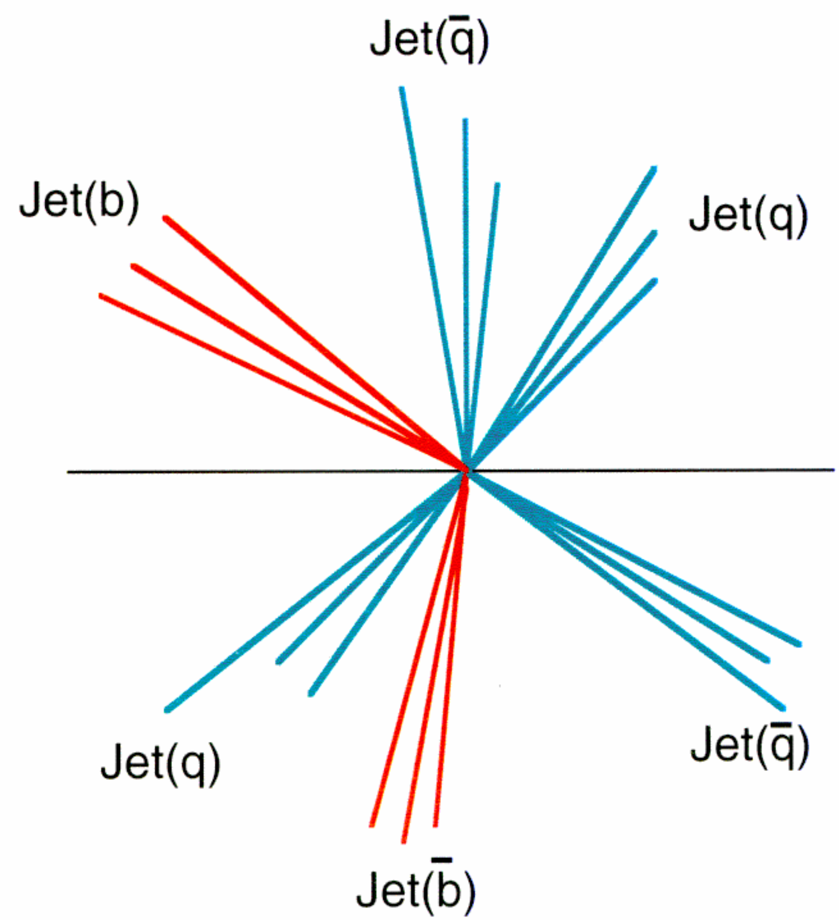
- Signature:
  - 6 or more jets, 2 from b-quarks
  - No missing ν's
- Dominant background:
  - QCD multijet production

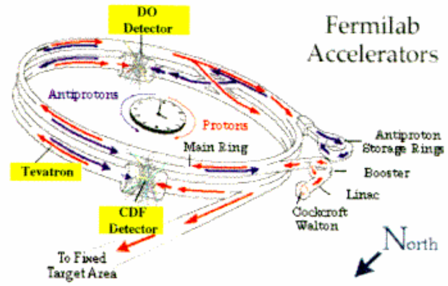
CDF

- Selection Criteria:
  - $N_{jet} \geq 5$ and $\Sigma E_t^{jet} > 300$ GeV
  - $\Delta R_{min} > 0.5$
  - Two analyses:
    - ≥1 SECVTX tags+kinematic cuts
    - ≥2 SECVTX tags, no kin. cuts

D0

- Selection based on 14 kin. variables
  - ≥1 SLT tags





All Hadronic

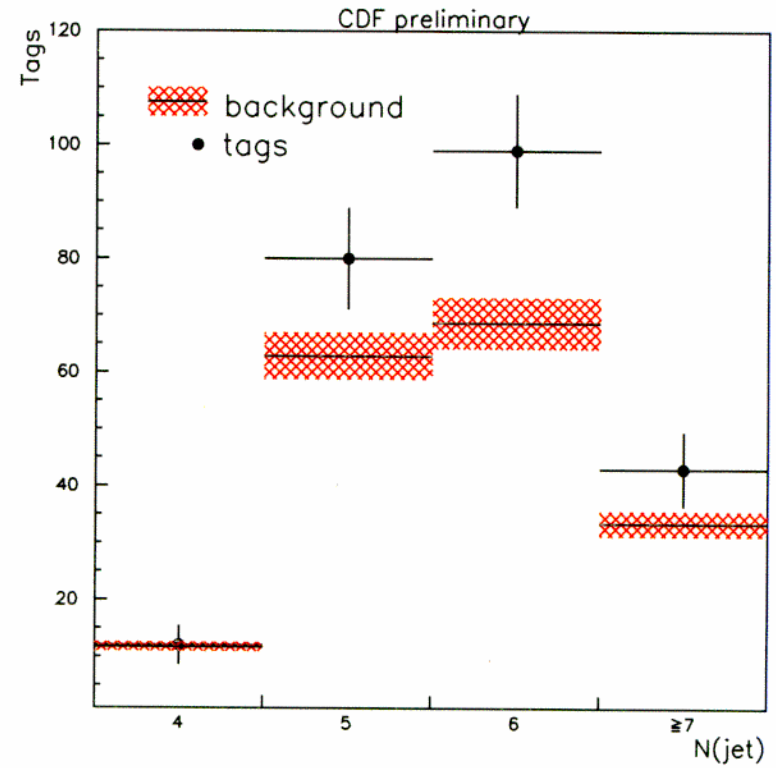
- **Results:**

	CDF Events
➤ Observed	187
➤ Background	142±12
➤ Expected	27±7

(for M_{top}=175 GeV)

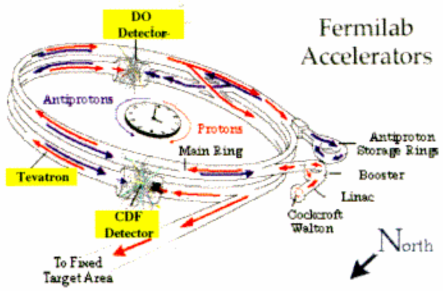
$\sigma_{t\bar{t}}(1\ SVX)=9.6^{+4.4}_{-3.6}$ pb

$\sigma_{t\bar{t}}(2\ SVX)=11.5^{+7.7}_{-7.0}$ pb

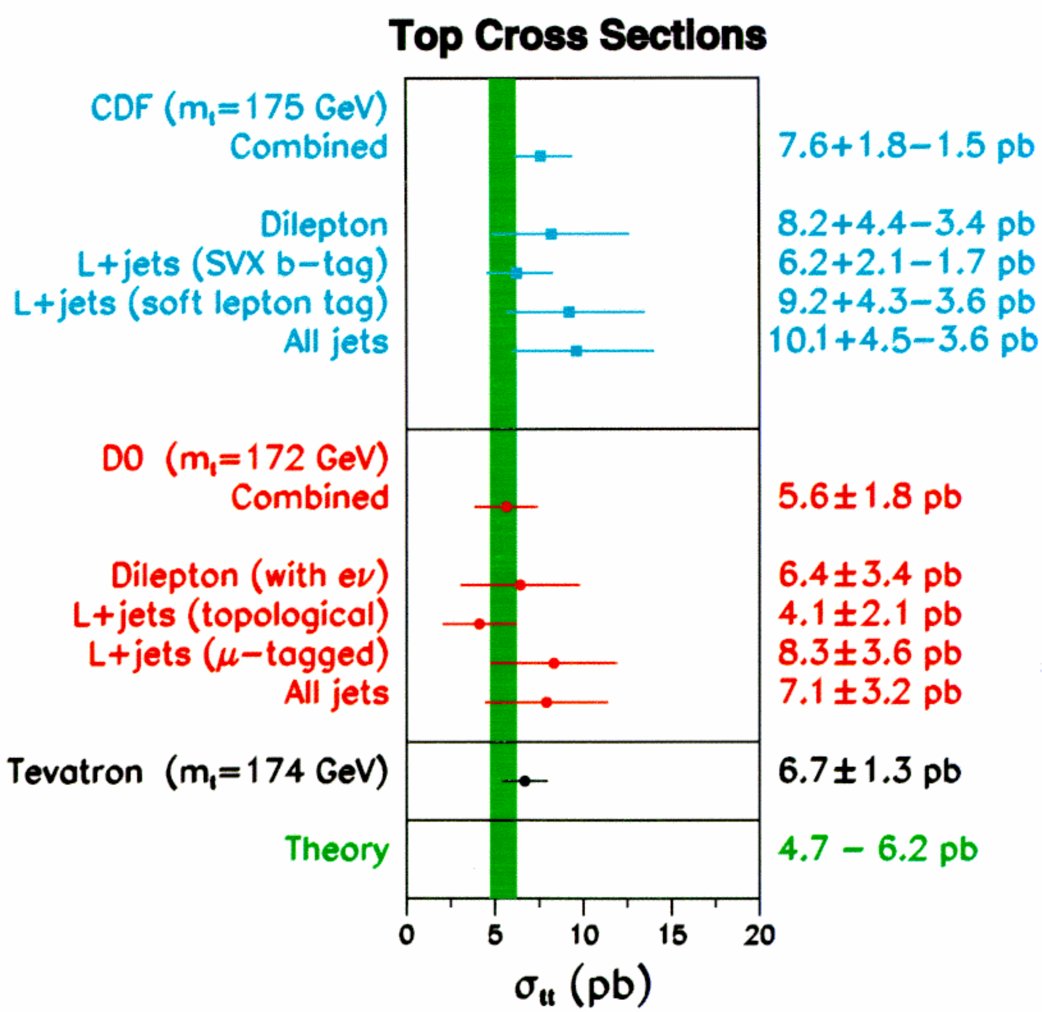


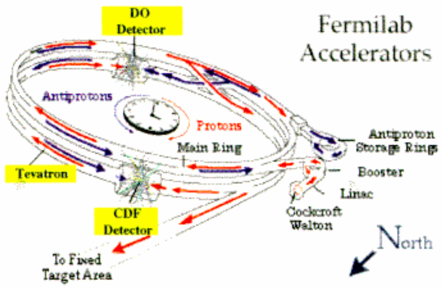
$\sigma_{t\bar{t}}=10.1^{+4.5}_{-3.6}$ pb (CDF - All Had.)

$\sigma_{t\bar{t}}=7.1\pm2.8$ (stat.)±1.5 (sys.) (D0 - All Had.)



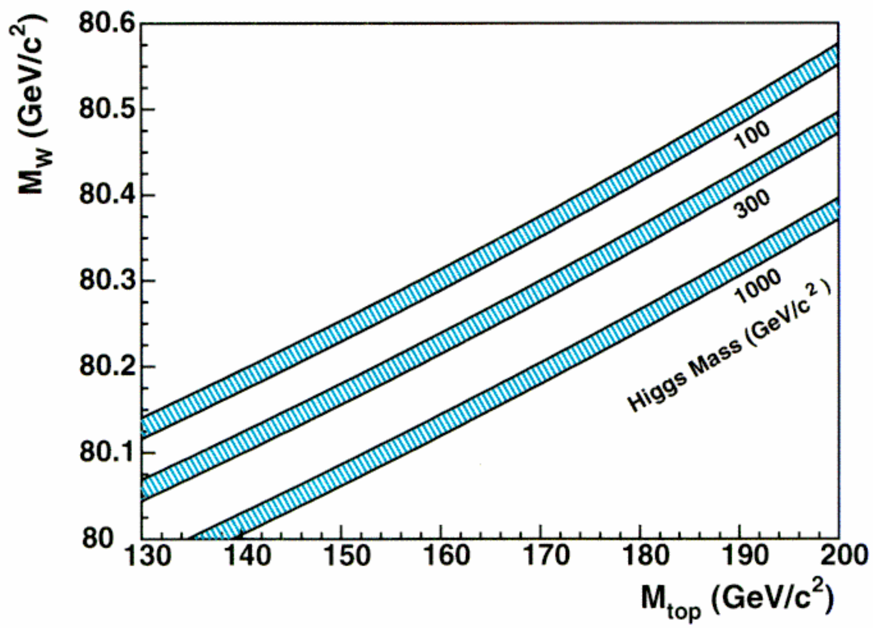
$\sigma_{t\bar{t}}$ Summary

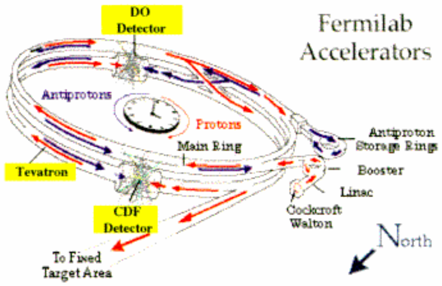




Top Mass

- Since M_{top} is a SM parameter involved in many perturbative effects through the presence of virtual loops, a precise measurement of M_{top} provides a stringent test of the SM.
- M_W and M_{top} are probably the most important measurements of the recent Tevatron Run, given their ability to constrain the value of M_{H^0}.
- Goals for CDF and D0:
  - measure M_{top} as accurately as possible
  - in many different channels as check of methods,statistics,ecc..
- D0 and CDF improved the error on M_{top} from 10% (1995) to ~3% (1998).





Top Mass - Dilepton Events

- Dilepton Samples have a good signal to background ratio (S/N ~7/1)
- However, since both W's decay leptonically, the system is under-constrained due to the presence of 2 ν's

D0

- Calculate a probability as a function of an assumed top mass.
  - Matrix Element Weighting
    - Assume M_{top} and solve. Assign a weight to the event using the PDF's and the lepton P_T's
  - Neutrino Weighting
    - Assume M_{top} and rapidity of each ν and solve. Assign a weight based on the matching of ν's P_T and the measured E_T

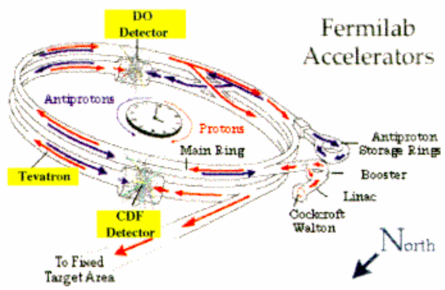
σ_m(sys.)~4 GeV

CDF

- Find kinematic variables which have a mass dependence.
  - b-jet energy spectrum:
    - $<E_b>\sim M_{top}$
  - invariant mass of l and b-jet pairs:
    - $M^2_{top} = f(M^2{}_b, M^2_{lb}, <\cos\theta_{l\,b}>)$

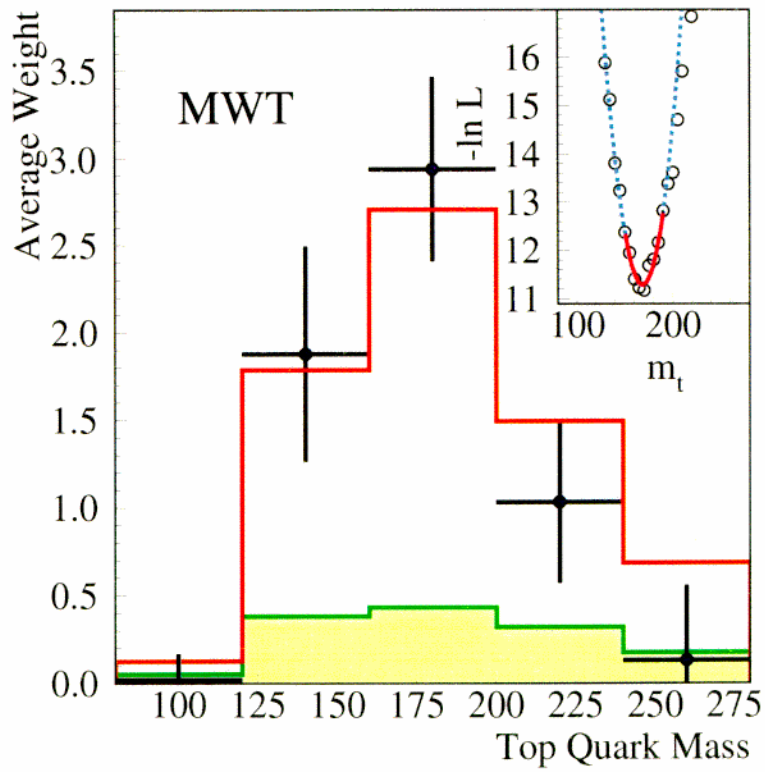
  σ_m(sys.)~10 GeV
- Neutrino Weighting.

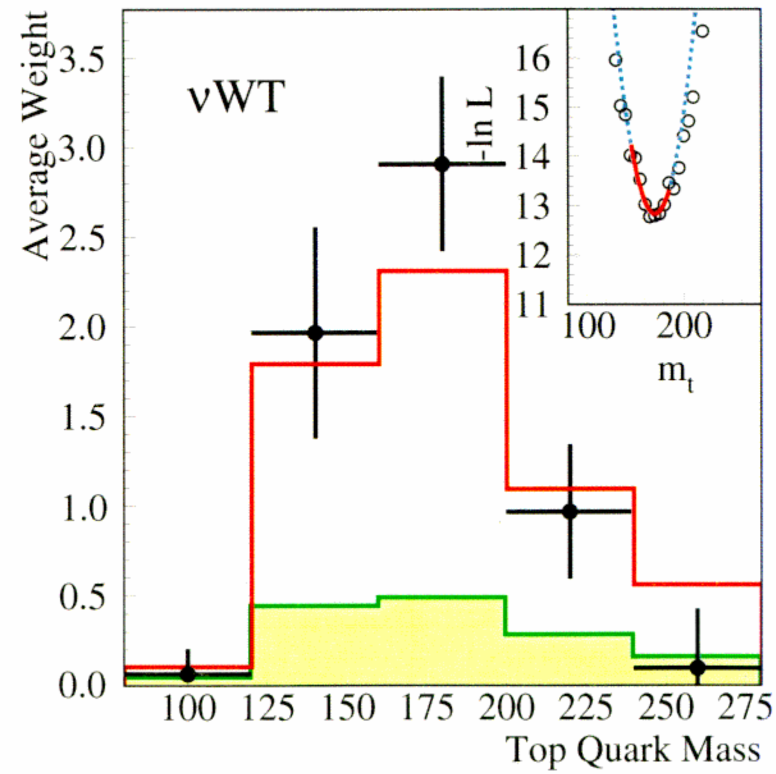
  σ_m(sys.)~5 GeV



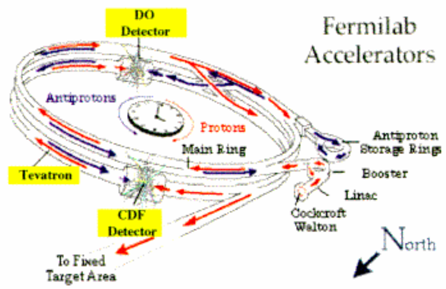
Top Mass Dilepton Events

D0



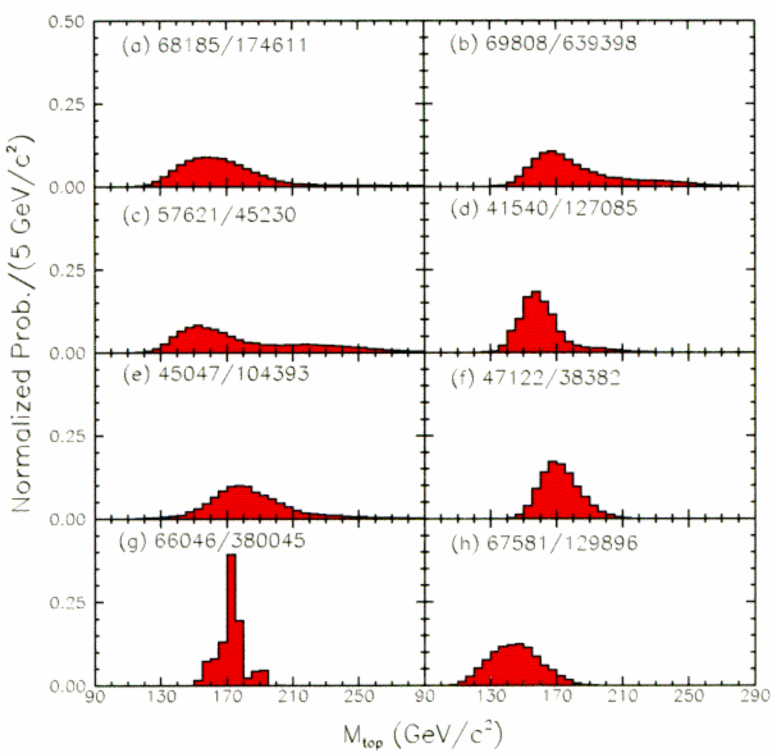


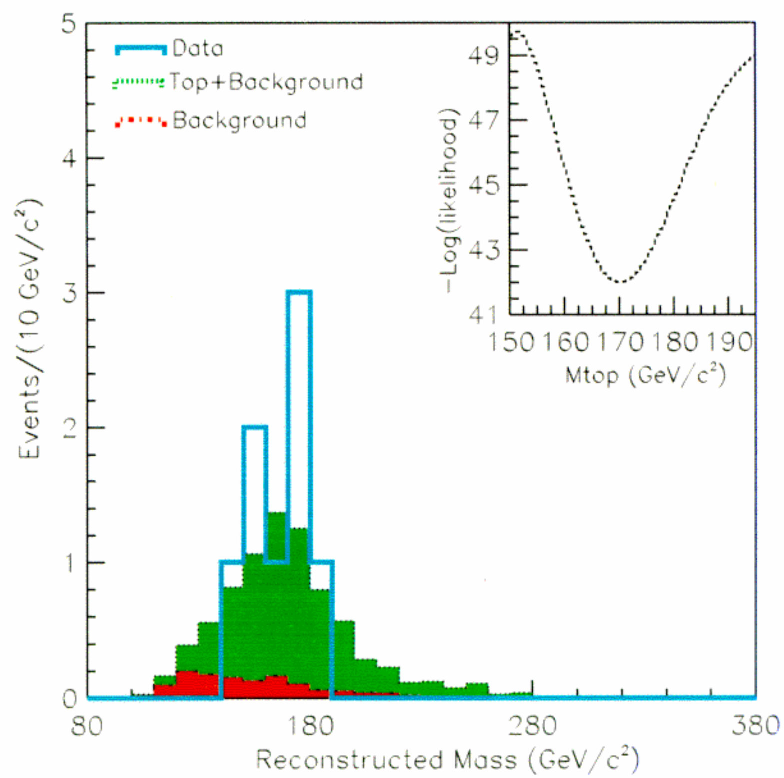
$M_{top} = 168.4 \pm 12.3\ (stat.) \pm 3.6(syst.)\ GeV$



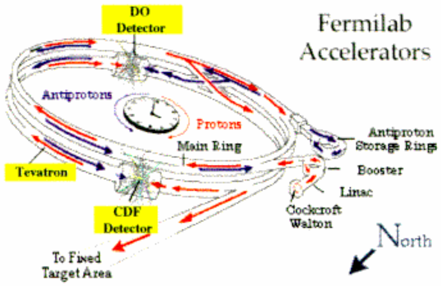
Top Mass - Dilepton Events

CDF



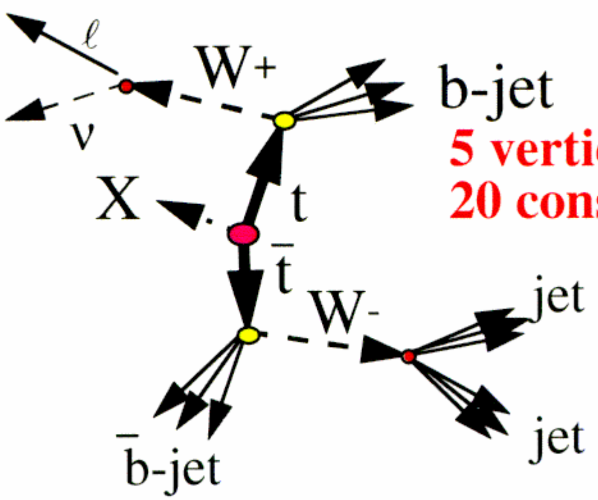


M_{top}=167.4 ±10.3 (stat.)±4.8 (syst.) GeV

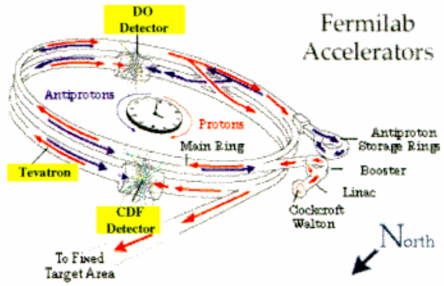


Top Mass - l+jets

- l+4 jets events:
  - 24 combinations:
    - 12 correspond to the jet-parton assignment
    - every combination has 2 solutions for the ν p_z momentum
    - impose $M_{t1}=M_{t2}$, $M(jet,jet)=M(l,\nu)=M_W$
  - 2-C fit. The combination with the lowest χ^2 is chosen.
  - The mass resolution from MC is $\sigma_M \sim 14$ GeV.



Particles	Unknowns
t's	7
X	2
W's	6
b's	0
q's	0
l	0
ν	3
Total	18



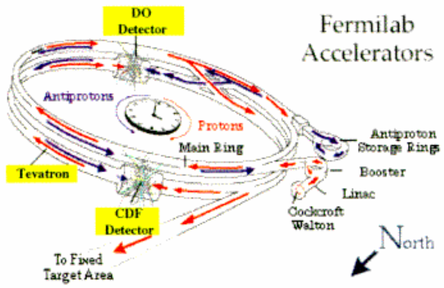
Top Mass - l+jets Events

CDF

- Divide data into 4 sub-samples to benefit, when possible, from better S/N:
  - SECVTX double tagged
  - SECVTX single tagged
  - SLT w/o SVX tags
  - non-tagged, 4 jets with E_T>15 GeV.
- Compare mass distribution to templates, multiply the likelihoods and combine the results from the 4 samples.

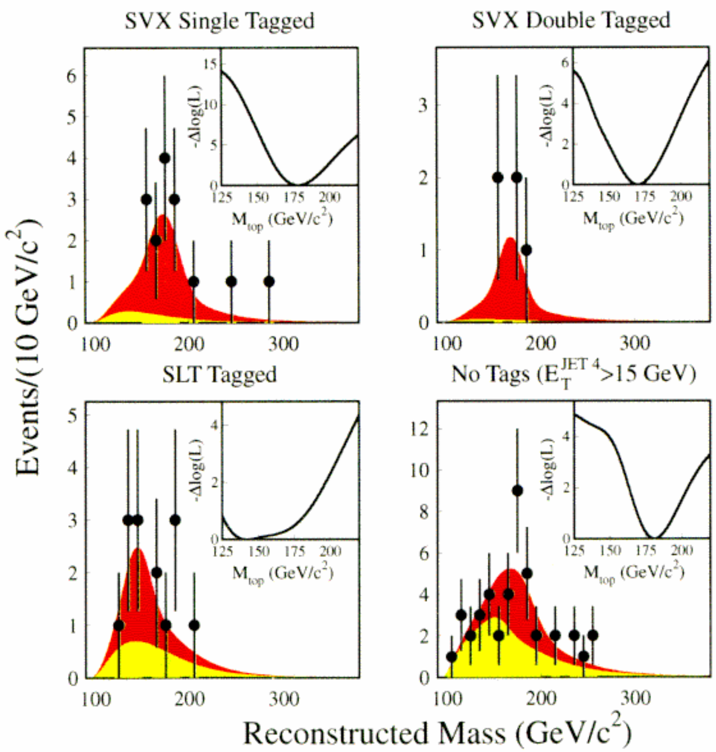
D0

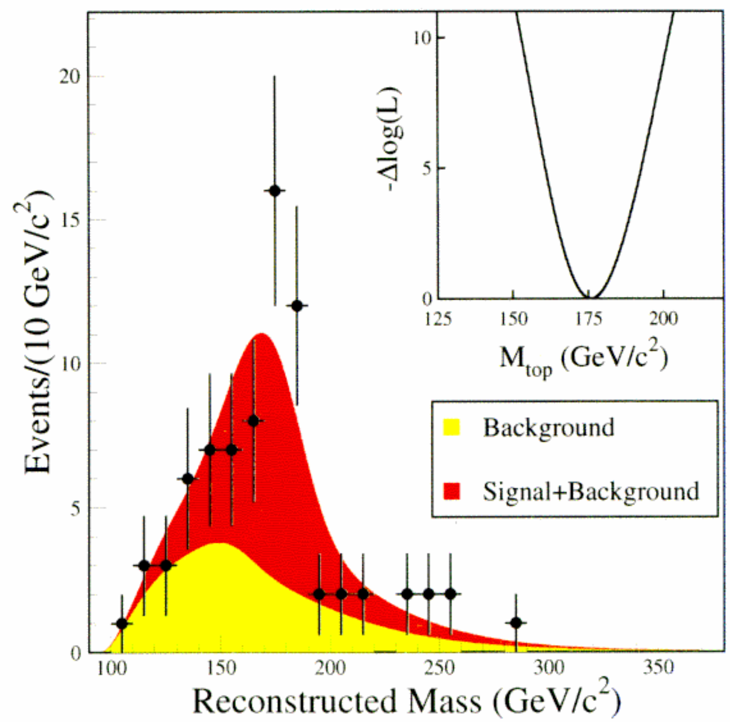
- Perform a 2C fit to the top hypothesis,
- use 4 mass-independent variables to separate top from background,
- combine the 4 probabilities into a discriminant:
  - DLB (no correlations)
  - DNN (Neural Net)
- fit data with background+top templates



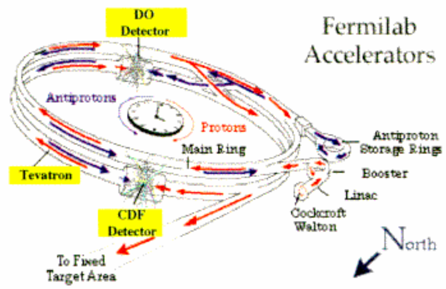
Top Mass l+jets

CDF



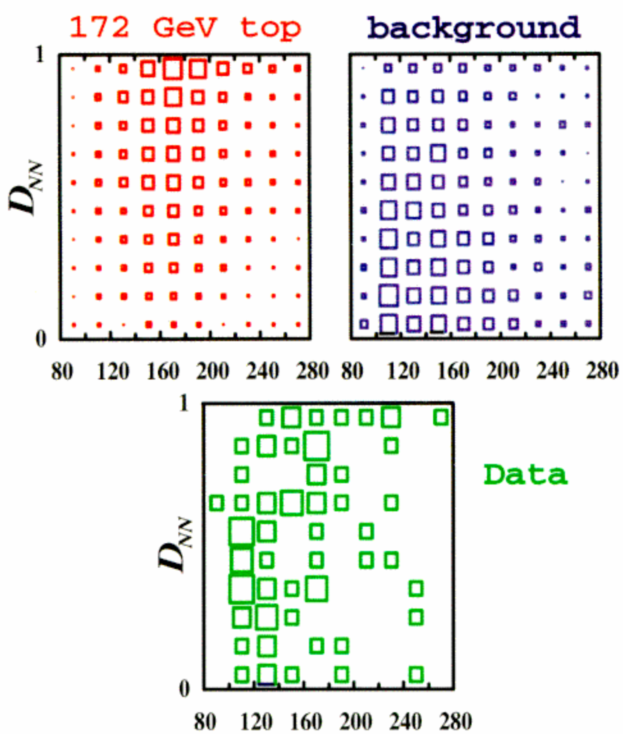


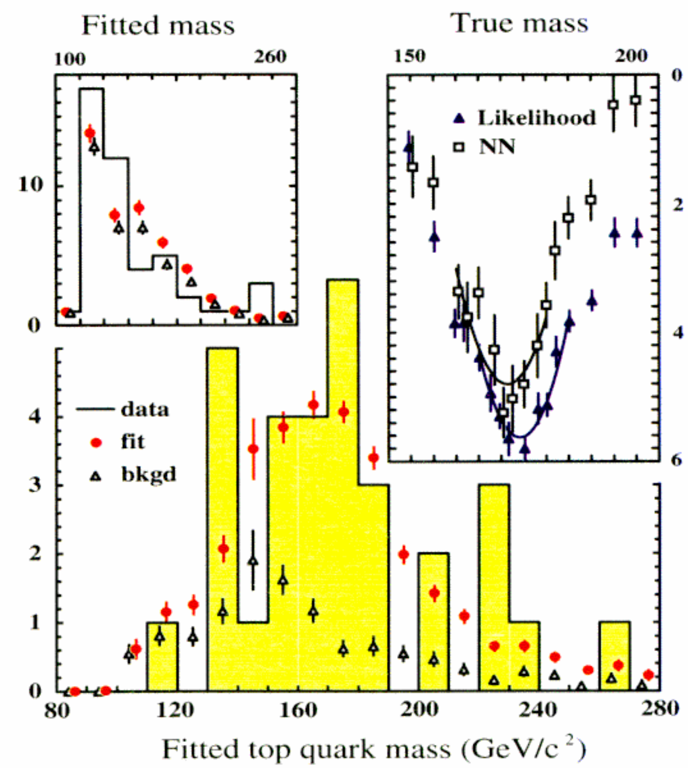
M_{top}=175.9 ± 4.8 (stat.) ± 4.9 (syst.) GeV



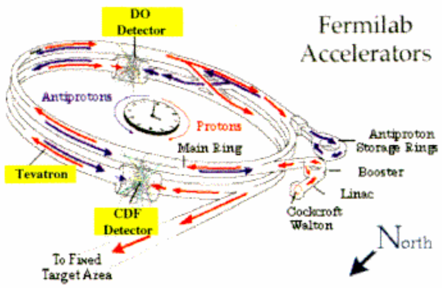
Top Mass l+jets

D0





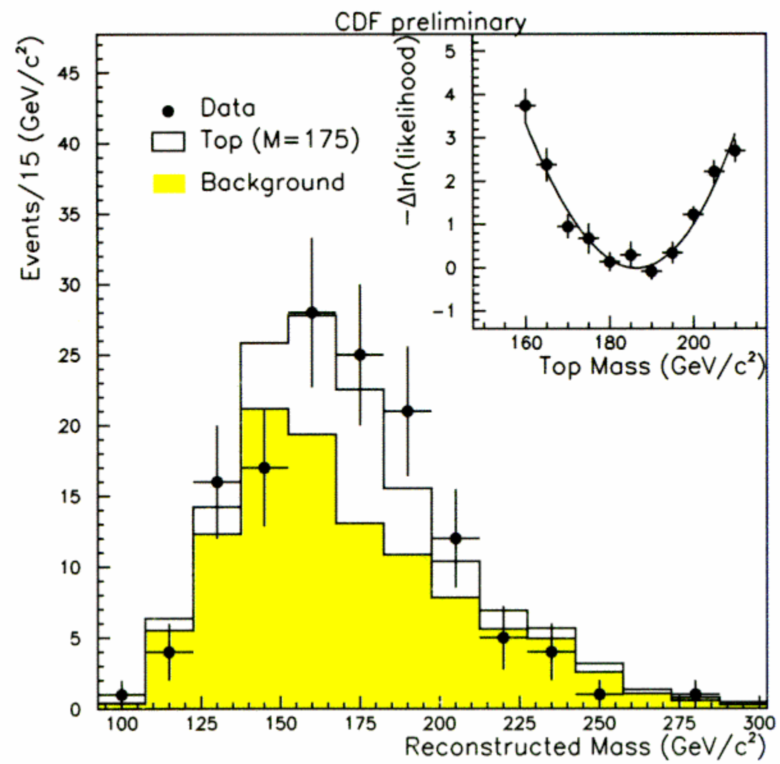
M_{top}=173.3 ± 5.6 (stat.) ± 5.5 (syst.) GeV



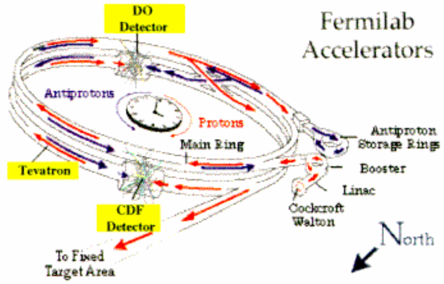
Top Mass - All Hadronic

CDF

- No ν's in the event, all particles are measured and a 3-C kinematic fit to individual events can be performed. The combination with lowest χ^2 is chosen.
- The experimental mass distribution is compared to Herwig $t\bar{t}$ MC and to background samples.



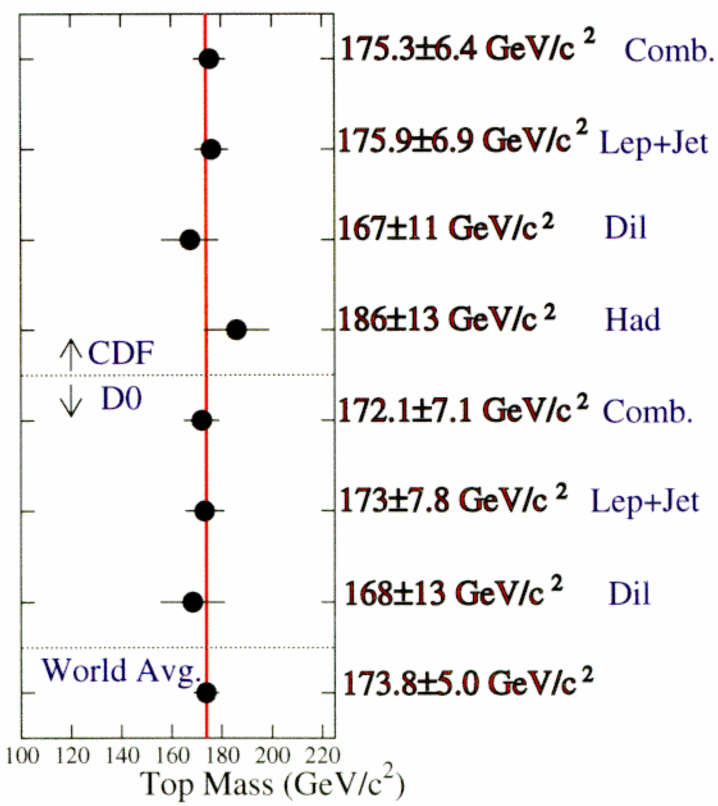
M_{top}=186 ± 10 (stat.) ± 8.2 (syst.) GeV



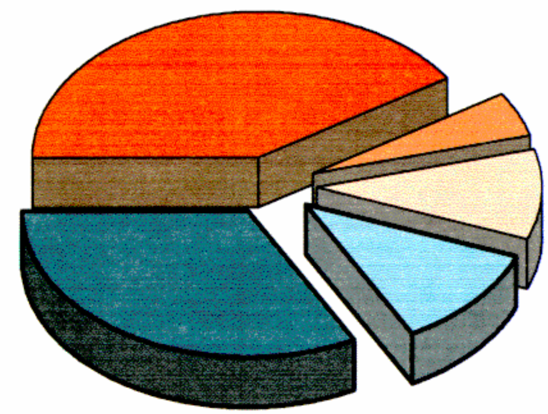
Fermilab Accelerators

Top Mass Summary

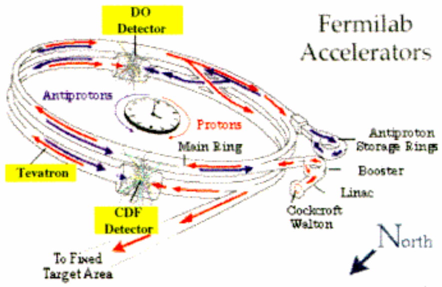
M_{top} - World (Batavia) Average



Relative weight in top mass average

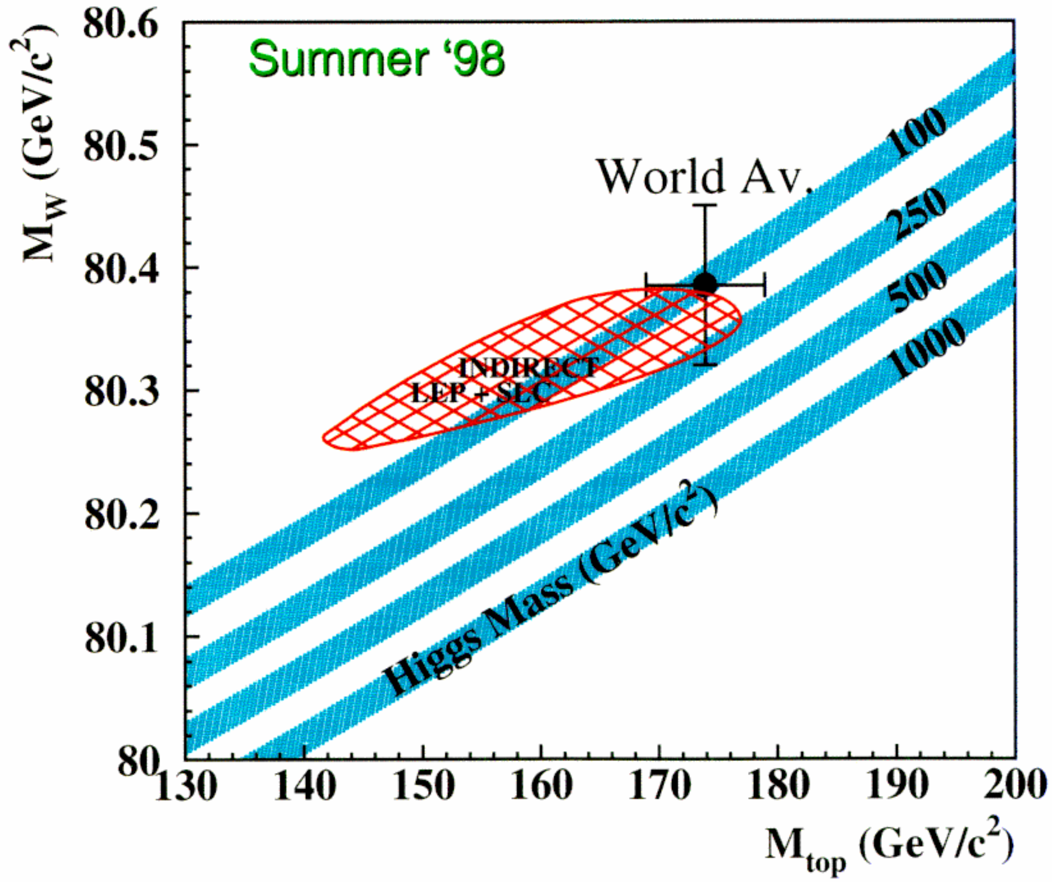


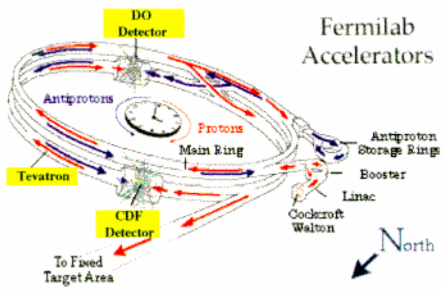
$<M_{top}>_{world}=173.8 \pm 5.0$ GeV



Fermilab Accelerators

Top Mass Summary



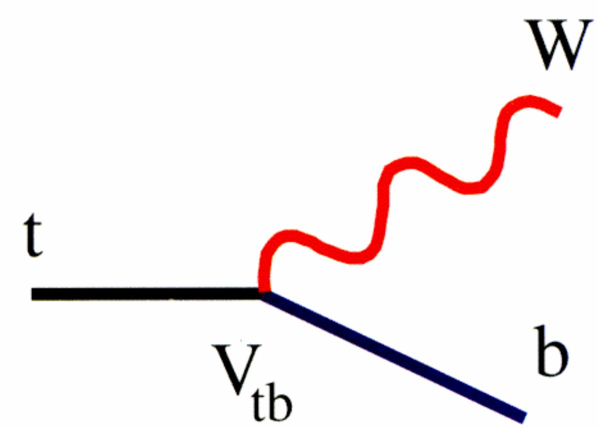


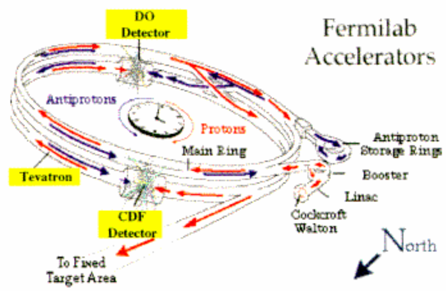
Measurement of V_{tb}

- Unitarity in the 3-generations CKM matrix implies $|V_{tb}| \sim 1$
- CDF used the l+jets and dilepton sample to
  - measure the ratios of the number of events with 0,1 and 2 b-tags
  - use them to extract the ratio $R_b = Br(t \to Wb) / Br(t \to WX)$
- The result is independent of $\sigma_{t\bar{t}}$ and of the W branching ratio.
- A likelihood fit to the data yields:
  - $R_b = 0.99 \pm 0.29$ or $R_b > 0.64$ at 95% C.L.
- Assuming 3-generations unitarity:

$|V_{tb}| = 0.99 \pm 0.15$

$|V_{tb}| > 0.76$ @ 95%C.L.





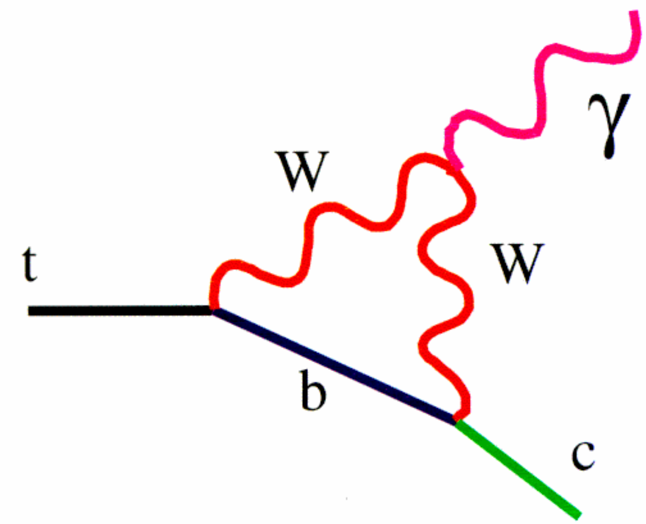
Fermilab Accelerators

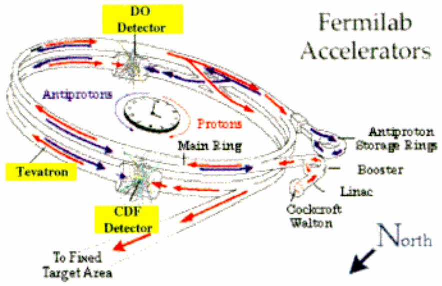
Search for Rare Top Decays

- Two FCNC t-decays ($t \rightarrow Zq$ and $t \rightarrow \gamma q$ where q=u or c) were investigated as a probe of non-Standard Model physics.
- Within the S.M. these decays are suppressed at the $10^{-8} \div 10^{-12}$ level
  - $t \rightarrow Zq$: search for events where at least one top decays via this mode
    - Observe 1 event ($Z \rightarrow \mu\mu$+4jets)
    - Bkg: 0.2+/-0.2 from WW/ZZ+jets

    $Br(t \rightarrow Zq) < 33\%$ @ 95% C.L.
  - $t \rightarrow \gamma q$: Search for events consistent with a final state of $tt \rightarrow Wb\gamma Q$
    - observe 1 event (γ,l,E_T and 2 jets)
    - Bkg: 0.5($W \rightarrow l\nu$) and 0.5($W \rightarrow qq$) events.

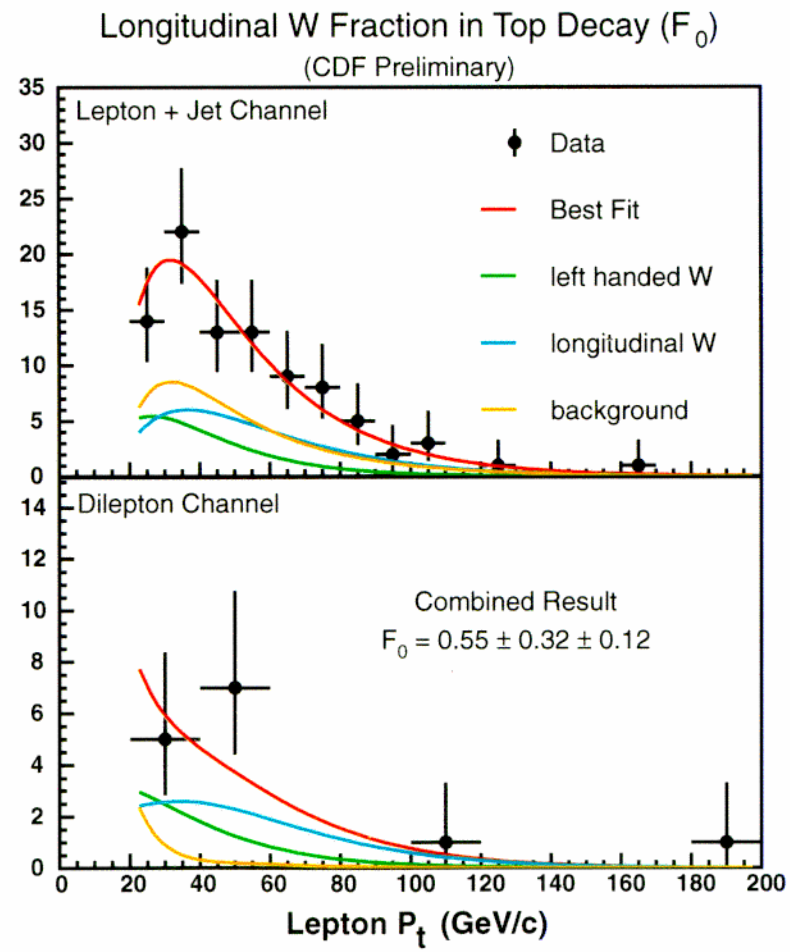
    $Br(t \rightarrow \gamma q) < 3.2\%$ @ 95% C.L.



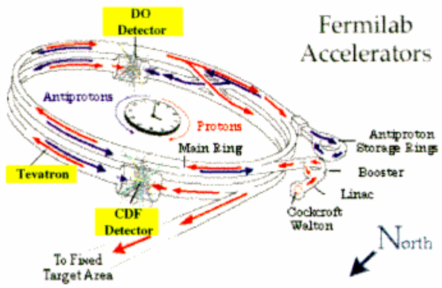


W Helicity in top Decays

- The S.M. has a specific prediction for the number of decay W's produced with longitudinal polarization:
  - $F(W_{long\ pol}) = m^2_t / (2M^2_W + M^2_t)$
  - $F(W_{long\ pol}) = 0.70 \pm 0.01$ for $M_{top} = 173.8 \pm 5$ GeV
- Fit to the distribution of the lepton p_t using MC templates.



$F(W_{long\ pol}) = 0.55 \pm 0.32$ (stat.) $\pm\ 0.12$ (syst.)



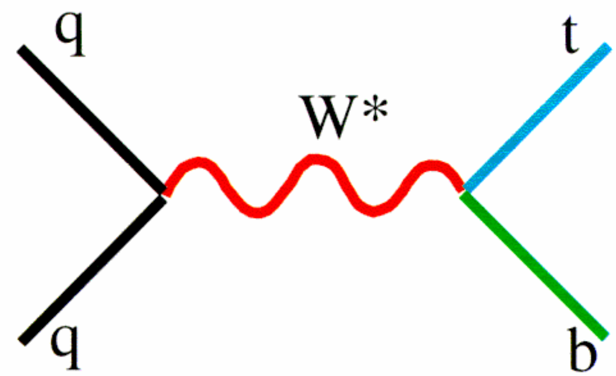
Single Top Production

- Signal sample is W+2 jets
- In the s-channel W* process, both final jets are *b* jets:
  - σ_{theory}=0.7 pb
- In the W-gluon fusion, one final jets is a *b* jet, the other is a light quark jet.
  - σ_{theory}=1.7 pb

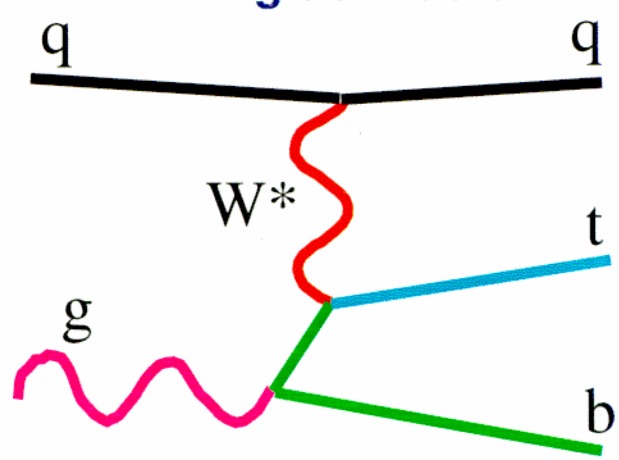
Process	# of Events
Total bkg.	12.9 ± 2.1
Signal	1.2 ± 0.3
Observed	1 5

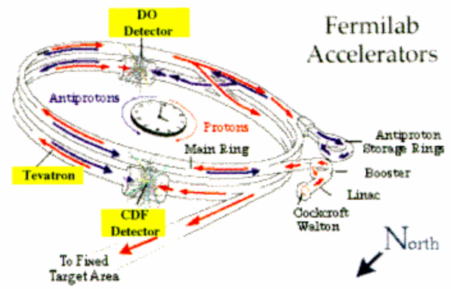
- $\sigma_{single\ top}$<15.4 pb at 95% CL

s-channel W*



W-gluon fusion



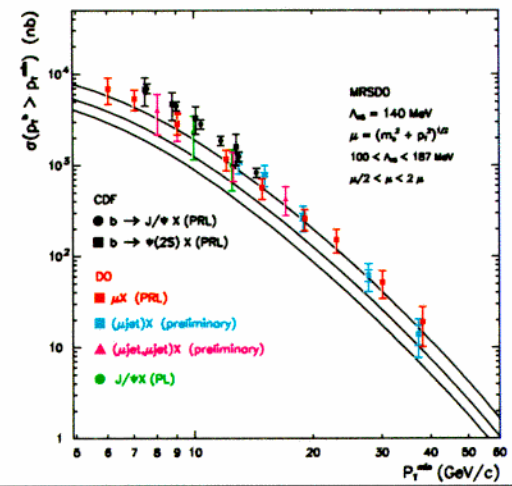


B Physics at the Tevatron

- Tevatron Advantage
  - Large $b\bar{b}$ cross-section ~ 100 μb

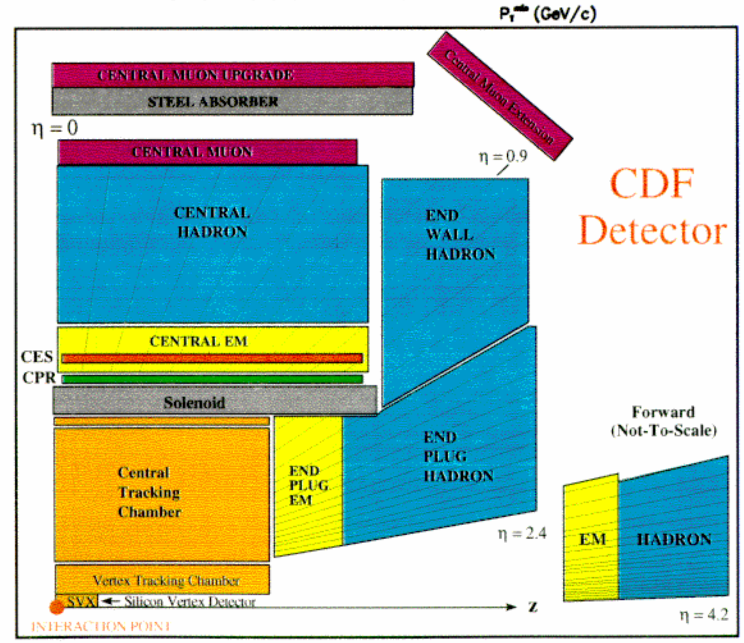
    $\sigma(\Upsilon(4S) \rightarrow b\bar{b})$ ~ 1nb

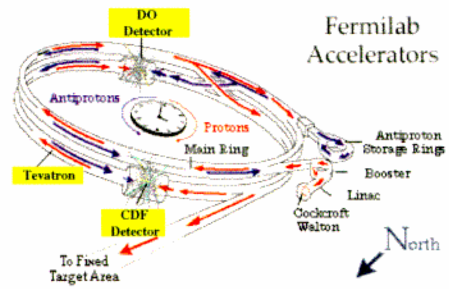
    $\sigma(Z^0 \rightarrow b\bar{b})$ ~ 7 nb
- Tevatron disadvantage:
  - Large background ($\sigma_{in.} \approx 1000 \times \sigma(b\bar{b})$)
  - b -production peaked at low p_t



Specialized Triggers

- Dilepton (μμ,ee,eμ) ⇒ $<p_t(B)>$~5-10 GeV
  - J/ψ, ψ' to select exclusive decays
  - B0 mixing and rare decay searches
- Single Lepton (μ,e) ⇒ $<p_t(B)>$~20 GeV
  - Semiexclusive b-hadron semileptonic decays
- Precise secondary vertex reconstruction (off.)

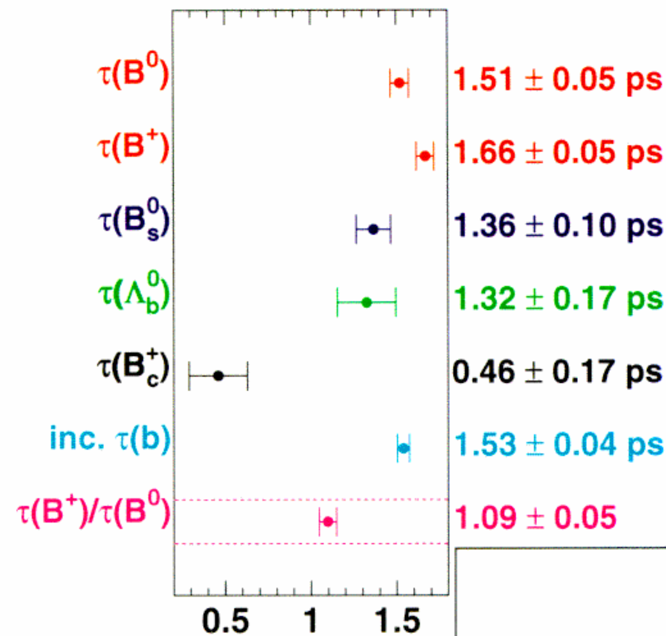


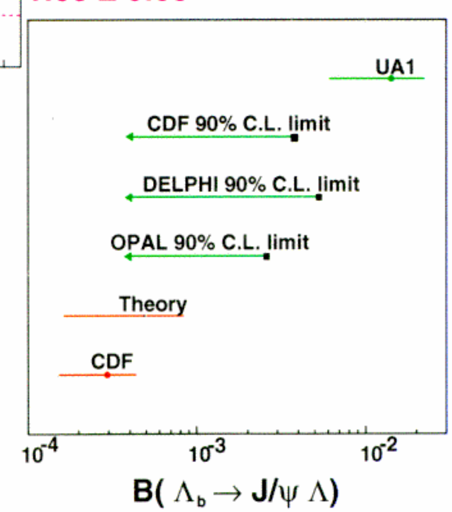


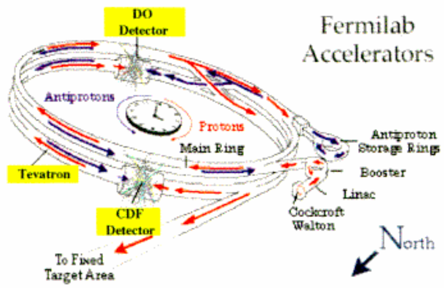
B Physics at the Tevatron

- Many measurement performed by CDF and D0 on *b* -physics:
  - Production Studies (B^+, B^0_d, B^0_s, B^+_c, B^{**}, Λ_b, J/ψ, inclusive l)
    - FERMILAB-Pub-98/237-E (D0)
  - Spectroscopy (B^+_u, B^0_d, B^0_s, Λ_b, B^+_c)
  - Lifetimes (B^+_u, B^0_d, B^0_s, B^+_c, Λ_b)
    - Phys. Rev. D57, 5382 (1998) (CDF)
    - FERMILAB-Pub-98/172-E (CDF)
  - Rare Decays ($B^0 \to \mu^+\mu^-$, $B^0 \to \mu^+\mu^- K$)
    - Phys. Rev. D57, R3811 (1998) (CDF)
    - Phys. Lett. B423 (1998) (D0)
  - B^0-$\bar{B}^0$ Mixing (B^0_d & B^0_s)
    - Phys. Rev. Lett. 80, 2057 (1998) (CDF)

B_c Discovery
SST and sin2β measurement

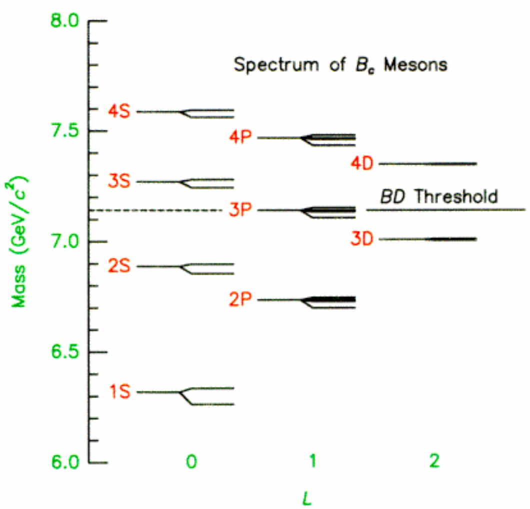




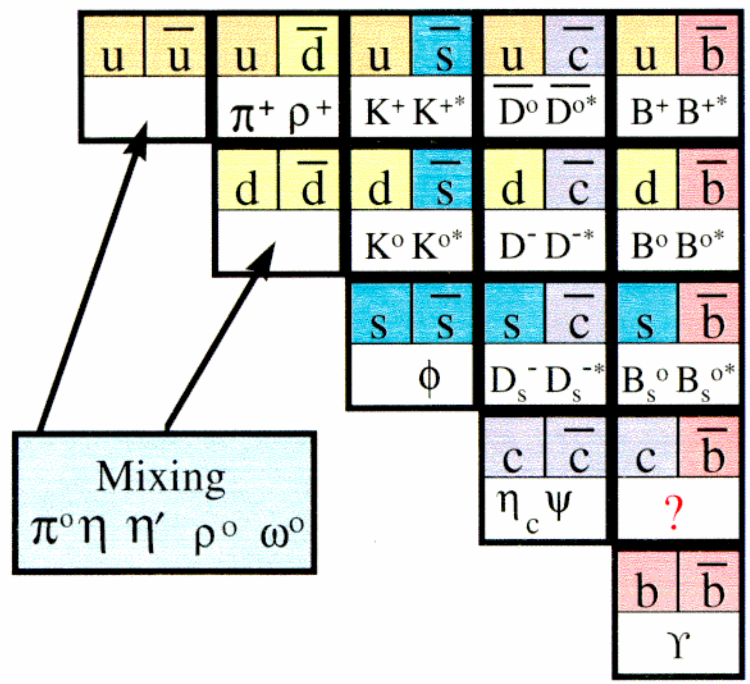


B_c Discovery
Introduction

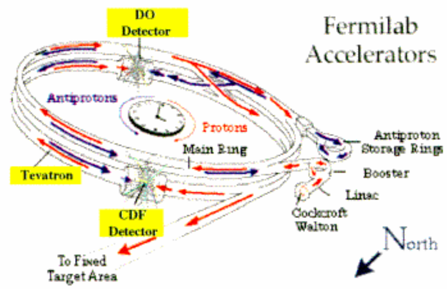
- B_c meson: bound state of two heavy quarks (b, c) with $Br(B_c \to J/\psi X)$~10-20%
- Theoretical calculations believed reliable:
  - expect:
    - Ground state mass $6.19<M(B_c)<6.32$ GeV
    - Naively, factorization is expected to apply
      - $\Gamma=\Gamma_b+\Gamma_c+\Gamma_{bc}$ τ~0.4-0.7 ps
      - bound state effects may be large τ~1.3 ps
    - Rich spectroscopy of narrow states



"Periodic Table"

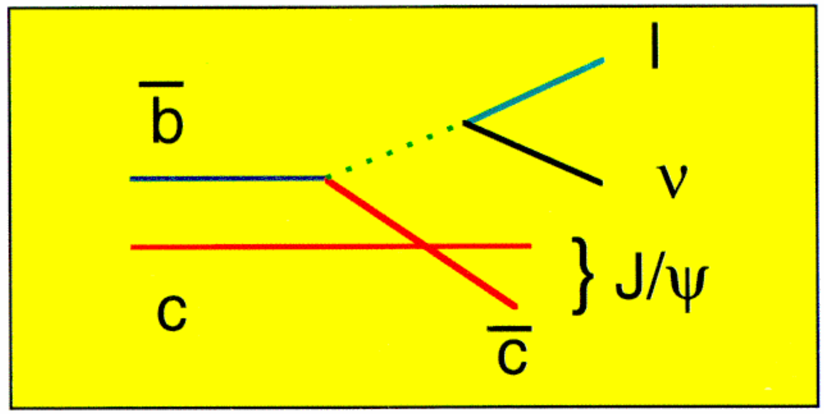


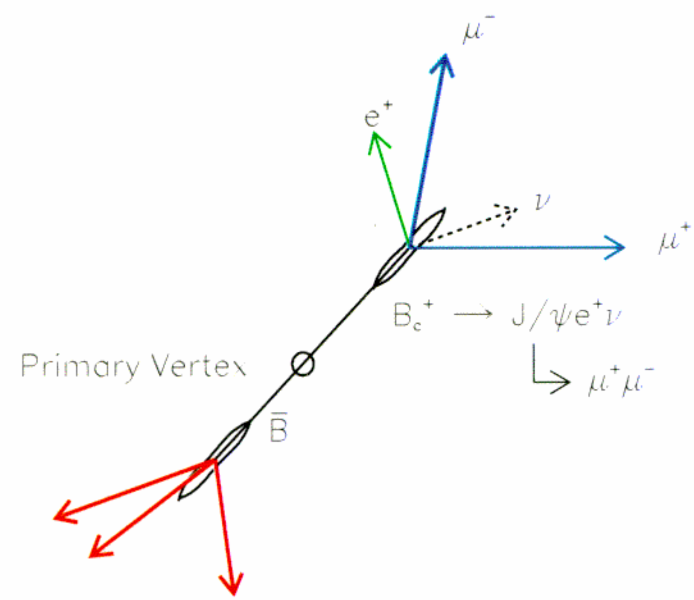
FERMILAB-Pub-98/121-E
FERMILAB-Pub-98/157-E
Accepted for publication in PRD

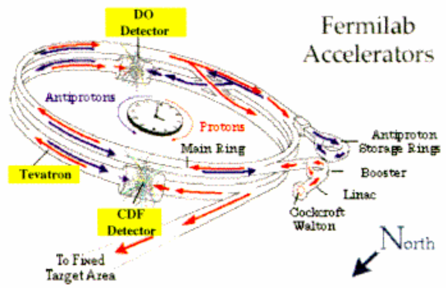


B_c Discovery History

- LEP and CDF have searched for the B_c in J/ψ decay modes:
  - LEP
    - $B_c \to J/\psi\pi^+$, $B_c \to J/\psi l^+\nu$, $B_c \to J/\psi\pi^+\pi^+\pi^-$, $B_c \to J/\psi a^+_1$
  - CDF
    - $B_c \to J/\psi\pi^+$
- Many upper limits on B_c production from previous searches
- For this search, CDF looked for displaced tri-lepton vertices consistent with $B_c \to J/\psi l\nu$

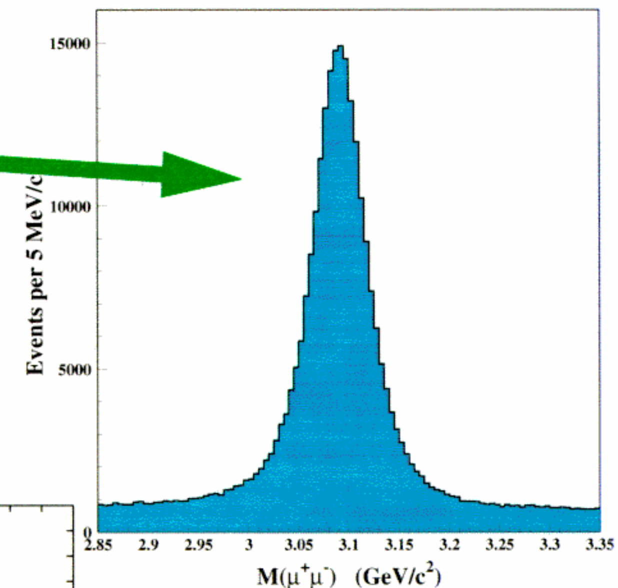


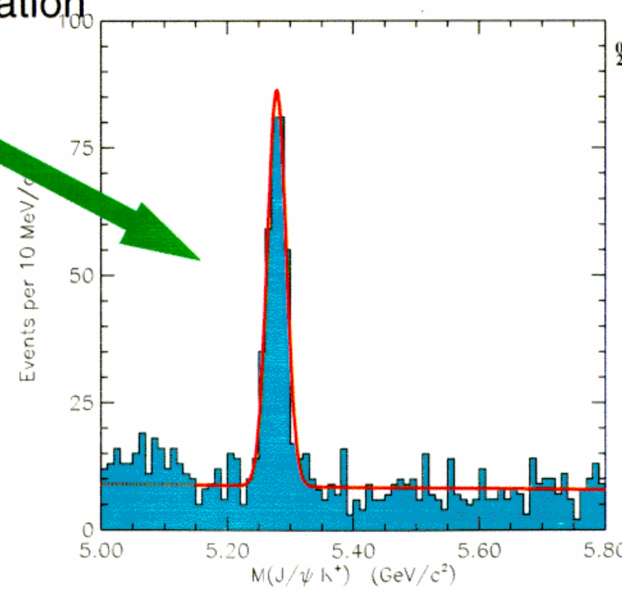


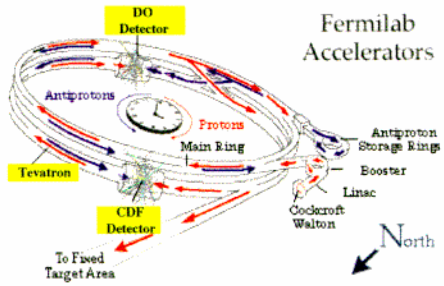


B_c Discovery Event Selection

- $J/\psi \to \mu\mu$ Sample
  - $P_t(\mu) > 2$ GeV
- J/ψ+track selection
  - J/ψ constrained to known PDG mass
  - Common decay vertex with $CL(\chi^2) >$ 1%
  - Use $B_d \to J/\psi K^+$ for σ normalization
- B_c signal region
  - 3-lepton system mass
    - $4 < m(J/\psi\, l) < 6$ GeV
  - *Pseudo*-proper decay length
    - $c\tau^* (J/\psi\, l) > 60\ \mu m$
  - e and μ selection cuts

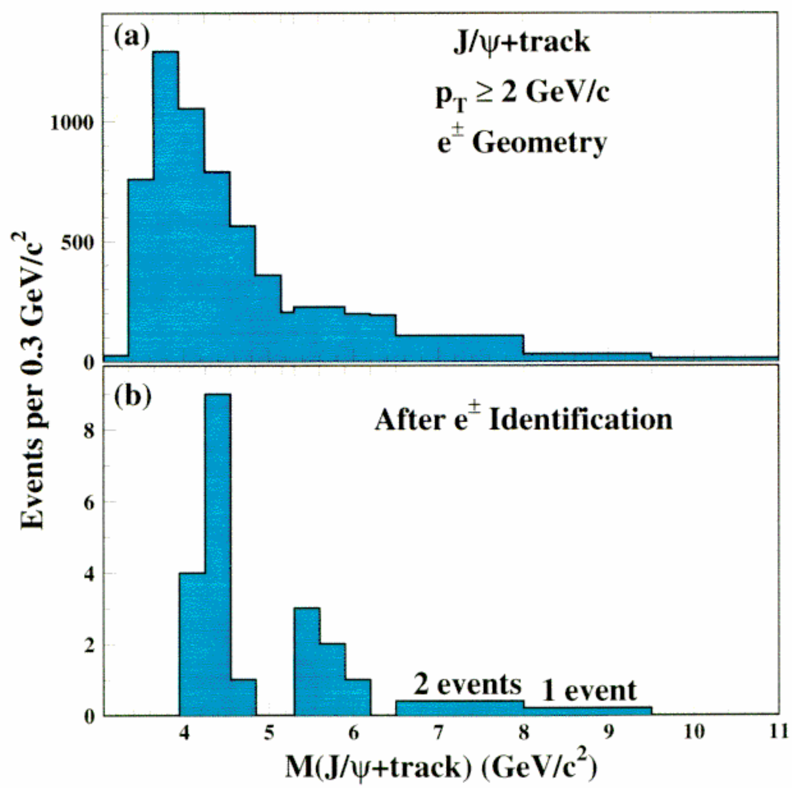


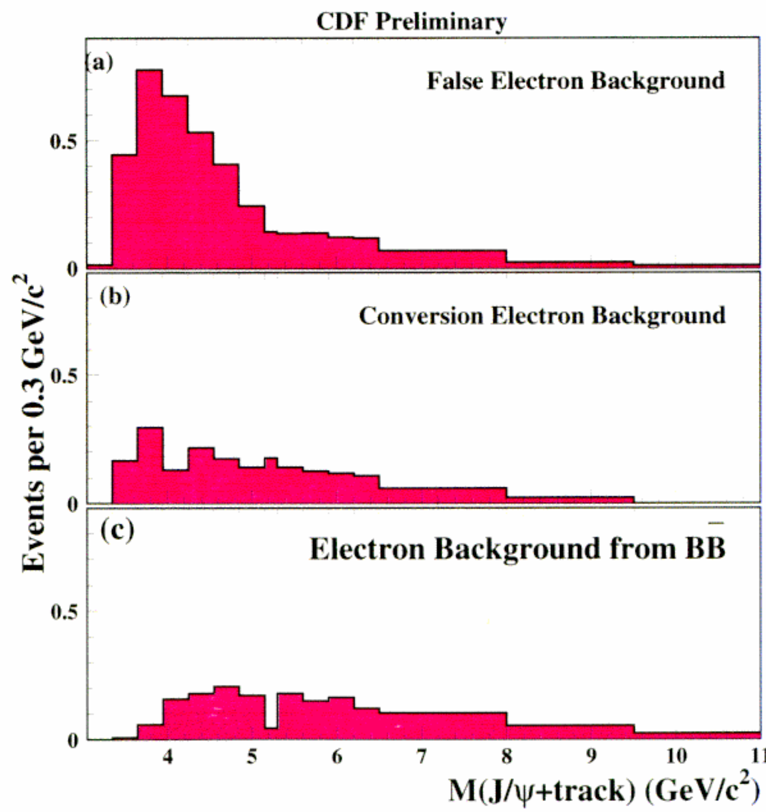


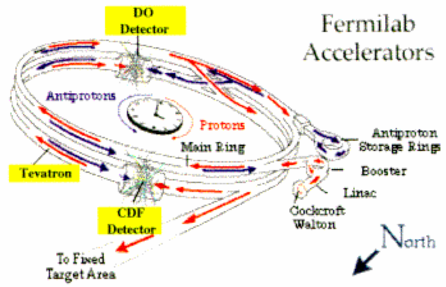


B_c Discovery

- e Sample





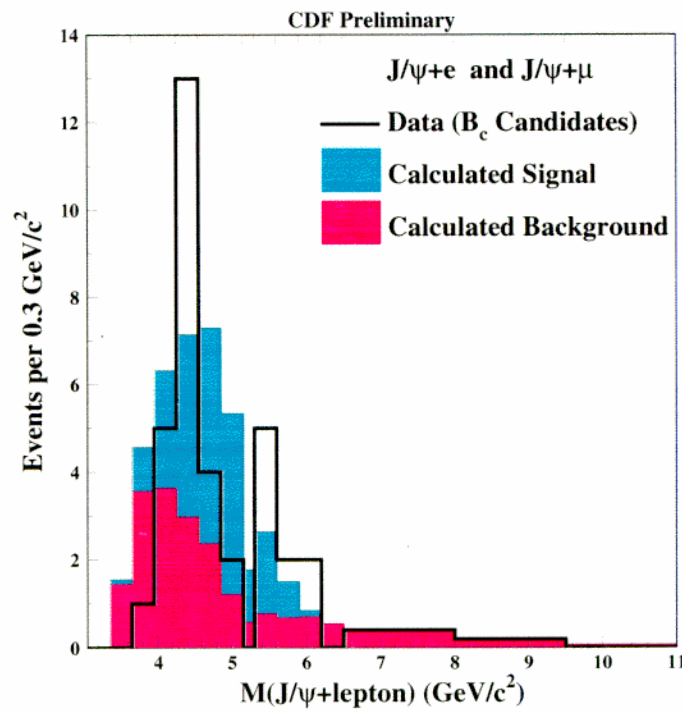


B_c Discovery

Event Yield for 4<m(J/ψl)<6 GeV

	$J/\psi\, e$ results	$J/\psi\, \mu$ results
Misidentified leptons		
False Electrons	$2.6 \pm 0.05 \pm 0.3$	
Conversions	$1.2 \pm 0.8 \pm 0.4$	
Punch-through		$0.88 \pm 0.13 \pm 0.33$
Decay-in-flight		$5.5 \pm 0.5 \pm 1.3$
$B\bar{B}$	1.2 ± 0.5	0.7 ± 0.3
Total Background	5.0 ± 1.1	7.1 ± 1.5
Events observed in data	19	12
Net Signal	14.0	4.9
Combined	18.9	
$P_{Counting}$(Null)	2.1×10^{-5}	0.084

Fit to Mass Distribution



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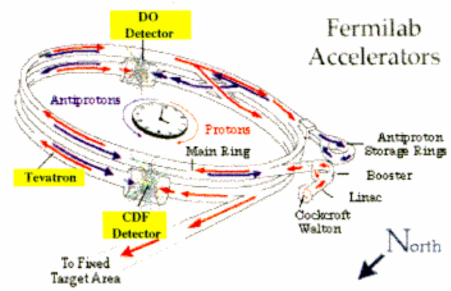
Accepted for publication in PRD

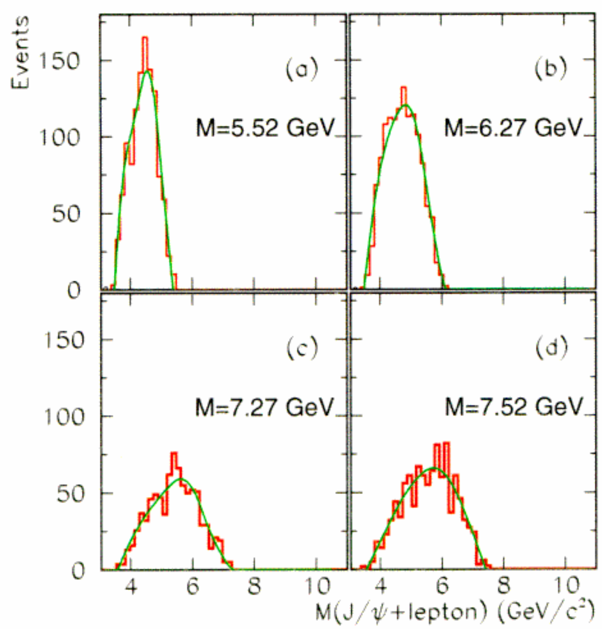
$N(B_c)=20.4^{+6.2}_{-5.5}$ events
Prob.(null)=6.3×10^{-7} (4.8σ)

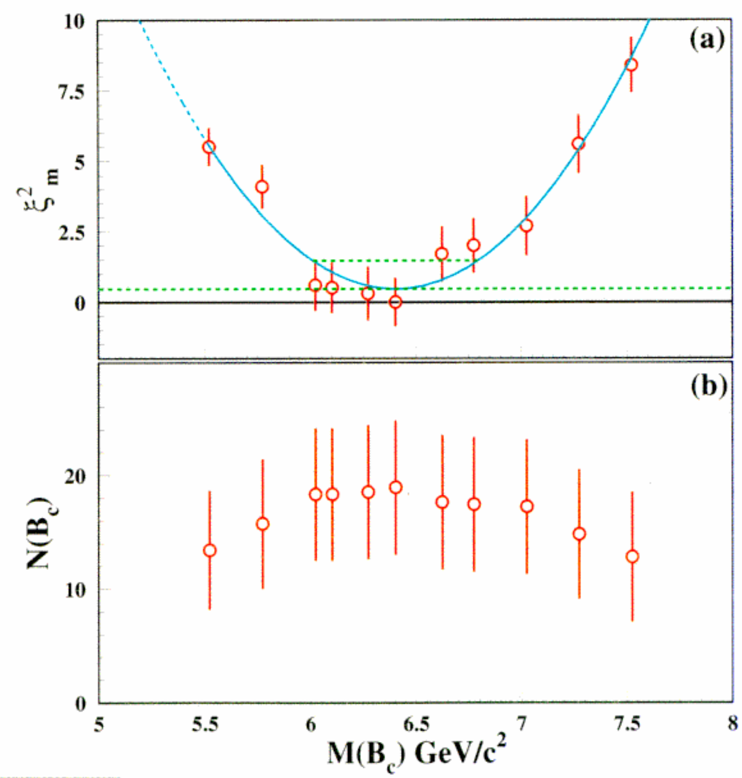


B_c Discovery Mass Determination

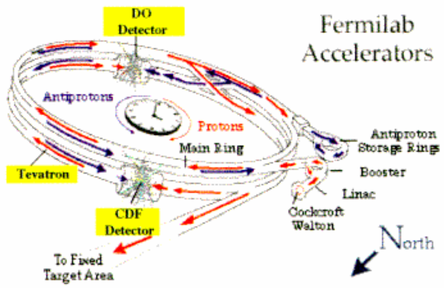
- The observed J/ψl mass distribution is fit to a sum of the background and various templates for different assumed B_c masses.

(CDF Monte Carlo)



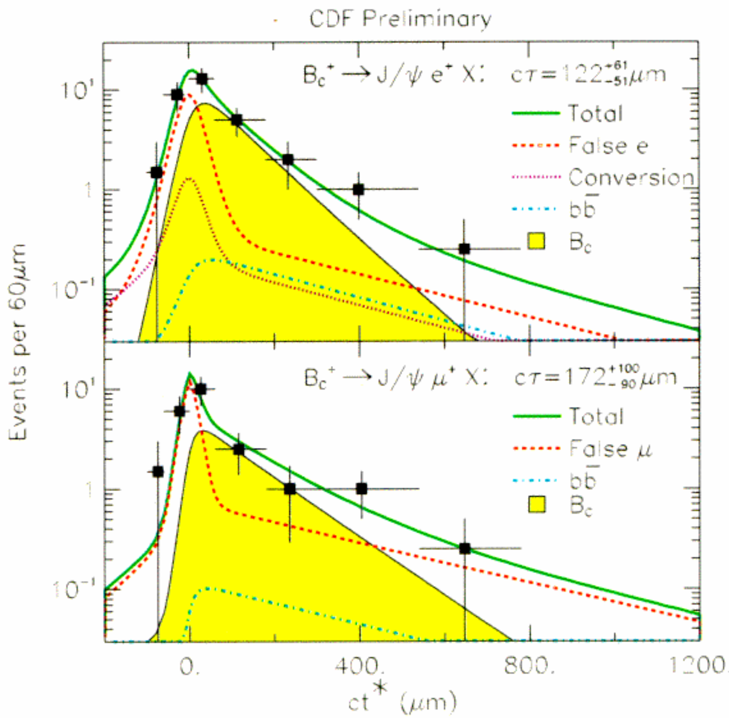


$m(B_c)=6.40\pm0.39(stat.)\pm0.13(syst.)$ GeV

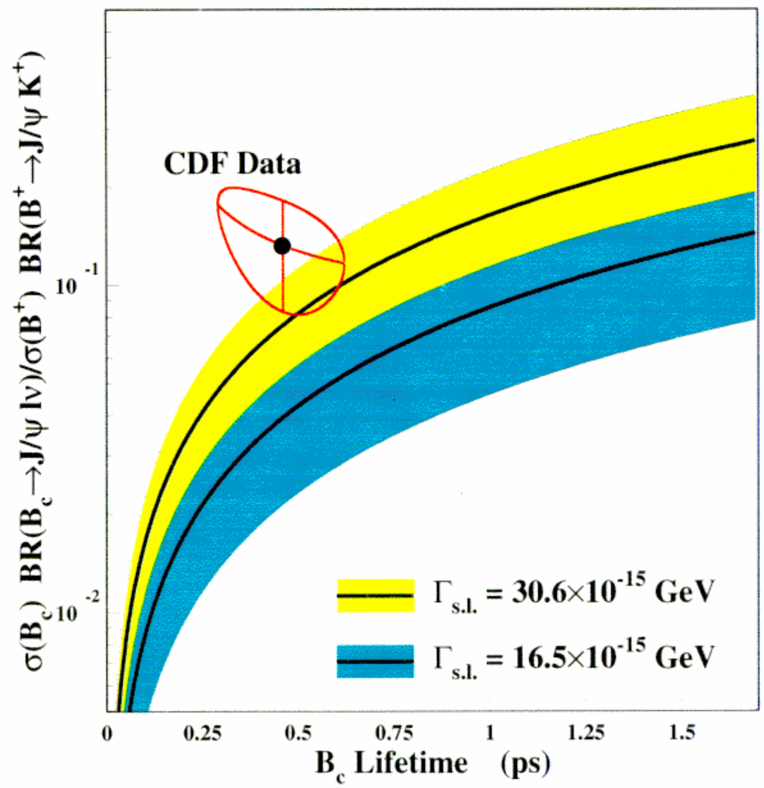


B_c Discovery
τ_{B_c} and σ_{B_c}

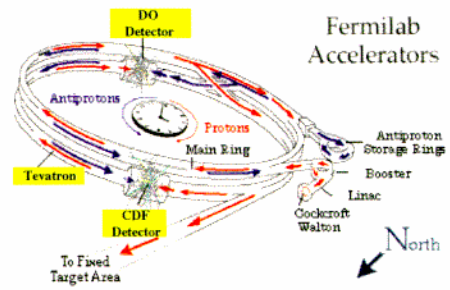
- Fit *pseudo*-$c\tau$ distribution to a sum of signal+background:



- Production cross-section normalized to $\sigma(B+)$:

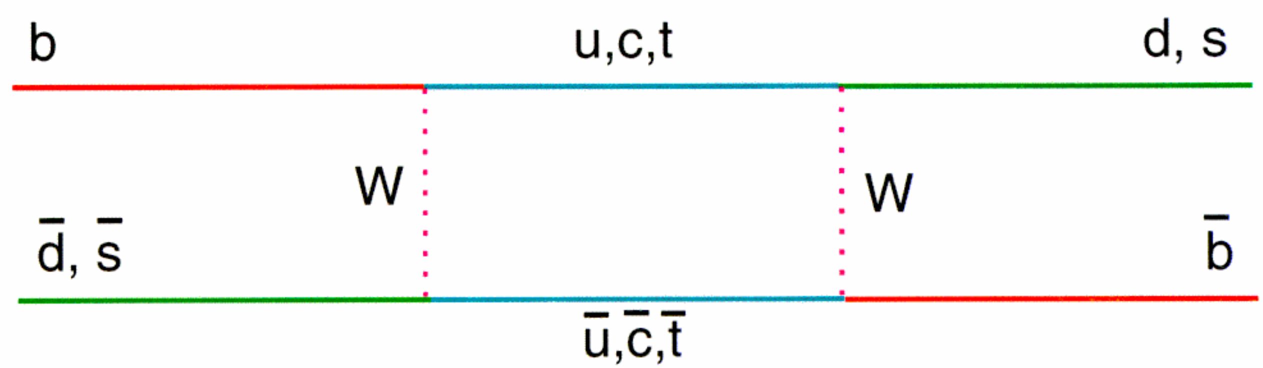


$\tau(B_c)=0.46^{+0.18}_{-0.16}(stat.)\pm0.03(syst.)$ ps



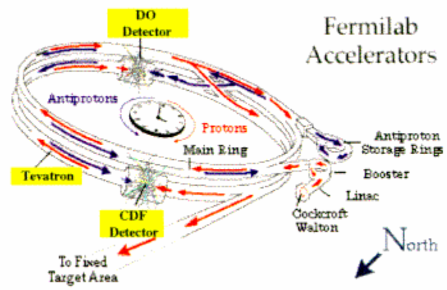
b Mixing and CP Violation

- B^0 - $\bar{B}^0$ mixing:
  - Like in the K_s system, higher order weak interactions mix meson and antimeson states:



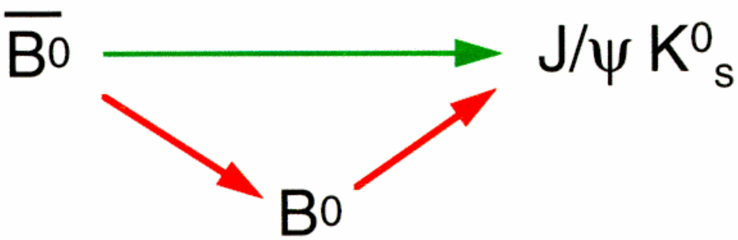
$$\frac{N_{\bar{B}^0 \to \bar{B}^0}(t) - N_{\bar{B}^0 \to B^0}(t)}{N_{\bar{B}^0 \to \bar{B}^0}(t) + N_{\bar{B}^0 \to B^0}(t)} = \cos \Delta m\, t$$

  - $\Delta m_d \propto m^2_t \, |V^*_{tb} \, V_{td}|^2$
  - $\Delta m_s \propto m^2_t \, |V^*_{tb} \, V_{ts}|^2$



b Mixing and CP violation

- for a CP-eigenstate final state, there are two decay paths:



- The interference between the two paths leads to a time dependent asymmetry with an amplitude proportional to sin2β:

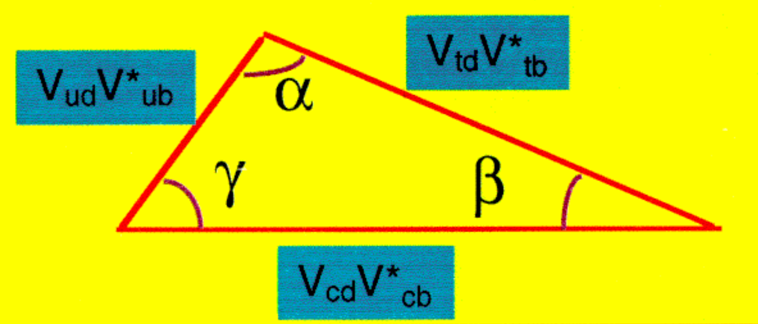
$$\mathrm{CKM}=\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V_{ud}V^*_{ub}+V_{cd}V^*_{cb}+V_{td}V^*_{tb} = 1$$

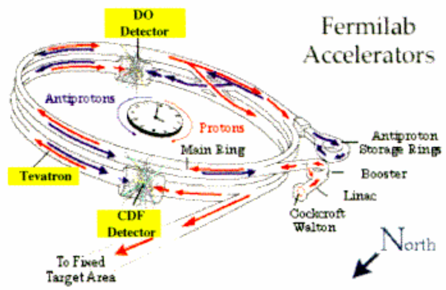
↓

Wolfenstein parameters space

↓

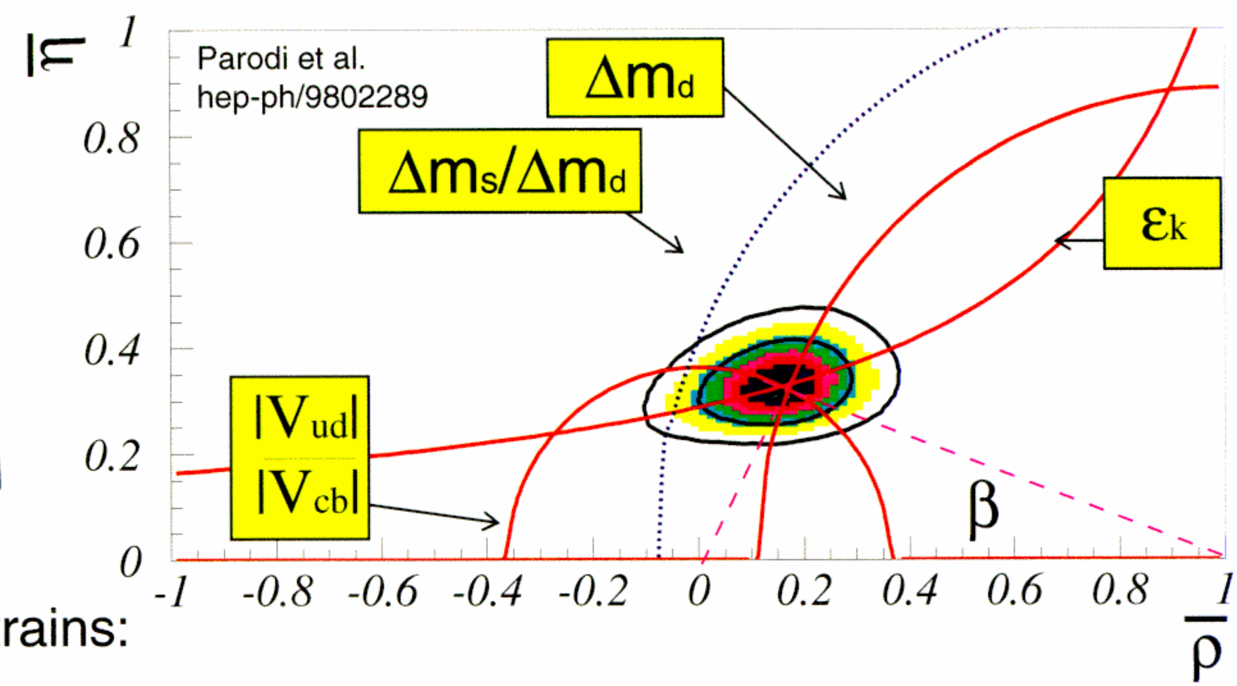


$$A(t) = \frac{N_{\overline{B}^0\to J/\psi K^0_s}(t) - N_{B^0\to J/\psi K^0_s}(t)}{N_{\overline{B}^0\to J/\psi K^0_s}(t) + N_{B^0\to J/\psi K^0_s}(t)} = \sin 2\beta \sin \Delta m_d t$$

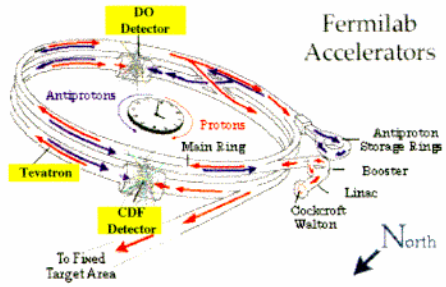


b Mixing and CP Violation

$$\beta \equiv \arg\left(-\frac{V_{cd}V^*_{cb}}{V_{td}V^*_{tb}}\right)$$



- Indirect evidence constrains:
  - $\sin 2\beta \approx 0.6 \pm 0.1$
- Experimental Measurements:
  - $\sin 2\beta = 3.2\,^{+1.8}_{-2.0} \pm 0.5$ (OPAL)



b Mixing and CP violation

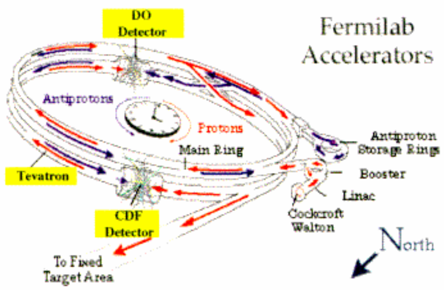
- Need 3 pieces of information for each decaying meson:
  - Flavor of original meson
    - Use *flavor tagging* →
  - Proper time of decay
    - Reconstruct the B vertex (partial or complete)
  - Flavor at time of decay
    - Determined from decay products

      $B^0 \rightarrow e^- \nu D^+$

      $\bar{B}^0 \rightarrow e^+ \nu D^-$

    - Not available for CP studies

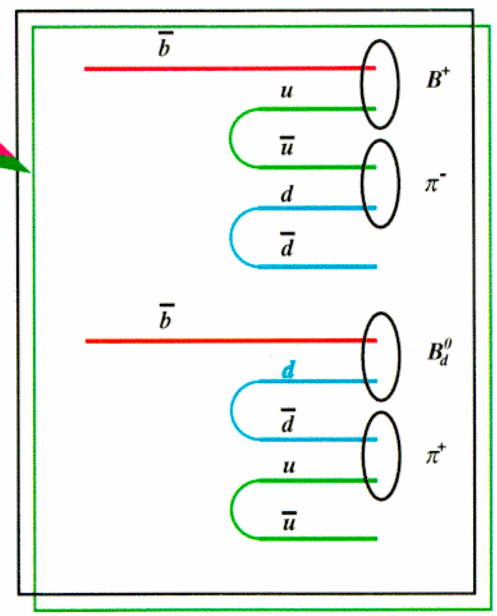
- Opposite Side Lepton and/ or Kaon tagging
  - Use decay of the away-side B-hadron
- Opposite Side Jet-Charge tagging:
  - Reconstruct the away-side B-hadron and use statistical methods to determine the flavor
- Same Side tagging:
  - Uses correlation with π produced along with the B-hadron being tagged.
  - Correlations from B^{**} and fragmentation

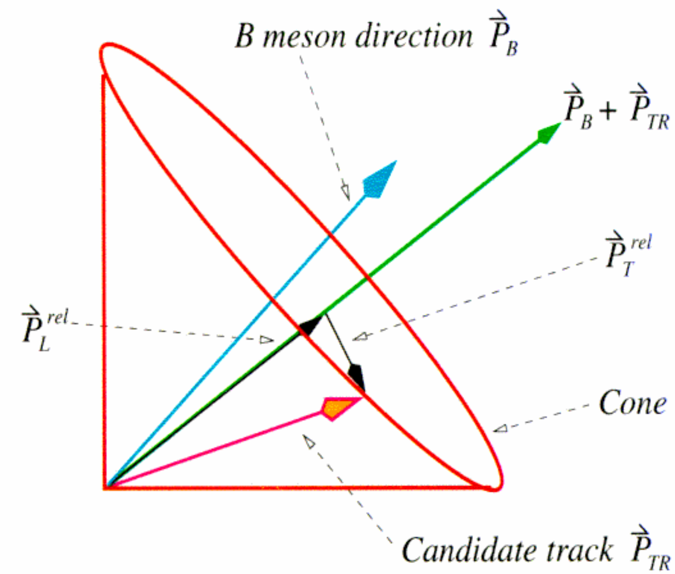


Same Side Tagging

- Correlations are expected from:
  - Fragmentation

    (Gronau et al.)
  - B** Decay
    - $B^{0**} \to B^+\pi^-$
    - $B^{+**} \to B^0\pi^+$



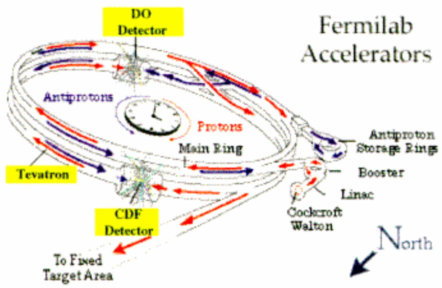


- The tagger is not perfect:

$$A(c\tau)=\frac{N_{RS}-N_{WS}}{N_{RS}+N_{WS}}=D_0 \cos \Delta m_d t$$

where D_0=2P-1 and P≡Fraction of correct tags

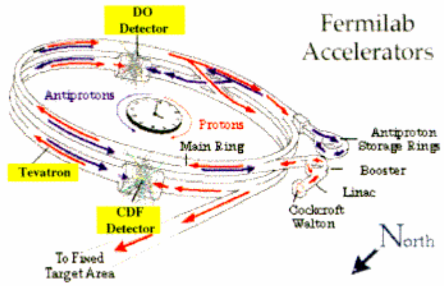
- Track Selection:
  - $\Delta R < 0.7$ from B Meson
  - $p_T > 400$ MeV
  - ≥3 SVX hits
  - consistent with primary vertex in r-ϕ and z
  - minimum p^{rel}_T



Same Side Tagging

Plan of the Analysis

- Show that the technique works in the lepton+charm sample
  - Measure dilution (*D*) and efficiency (ε)
  - Measured B mixing parameter Δm_d
- Show that the technique works for fully reconstructed modes, like $B^+ \rightarrow J/\psi K^+$
  - Again measure dilution (*D*) and efficiency (ε)
- Look at $B^0 \rightarrow J/\psi K^0_s$
  - Measure ε and A
  - Use Monte Carlo (pinned by data) to calculate *D*
  - Extract sin 2β



b Mixing

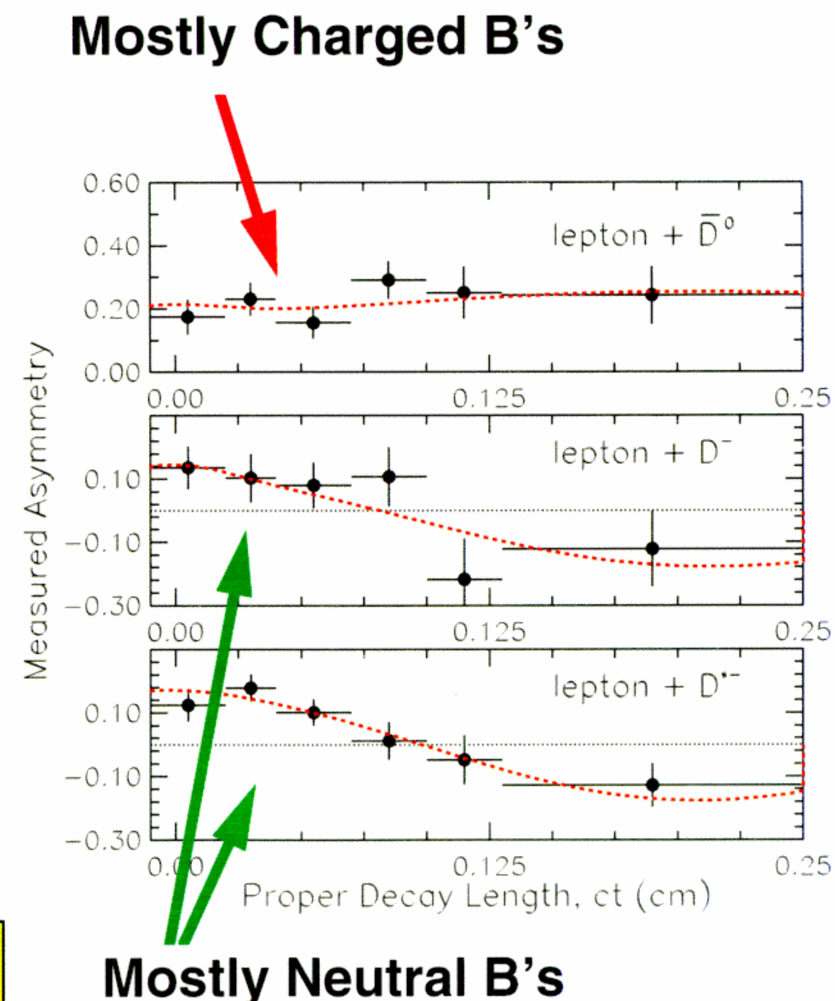
- In a sample of B^+ and B^0 decays, the measured asymmetry is a linear combination of:
  - $A^0(c\,\tau)=D_0 \cos \Delta m\, t$
  - $A^+(c\,\tau)=D_+=Const.$

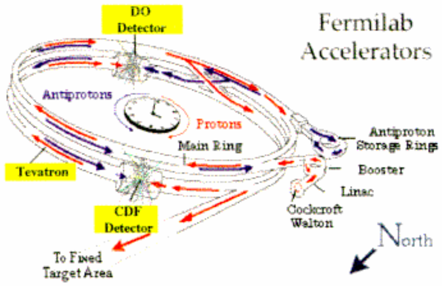
$\varepsilon \sim 85\%$

$D^+=0.27\pm0.04\pm0.02$

$D^0=0.18\pm0.03\pm0.02$

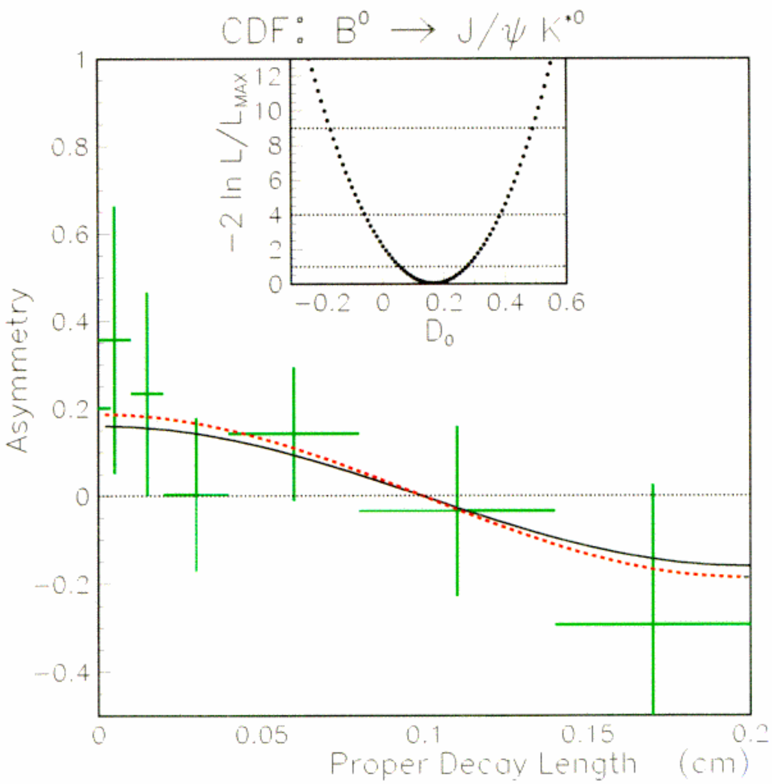
$\Delta m_d=0.471^{+0.078}_{-0.068}\pm0.034\ ps^{-1}$



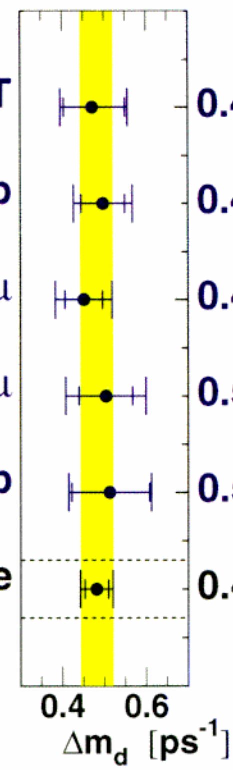


b Mixing

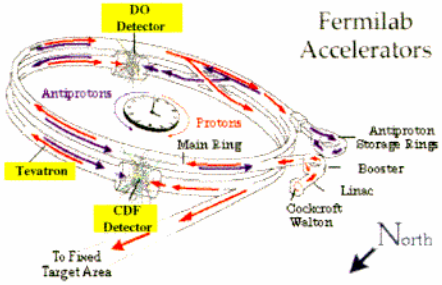
- Cross-check on J/ψ K* sample



CDF Δm_d results - Preliminary



D*lep / SST	$0.471\ ^{+0.078}_{-0.068} \pm 0.034$ ps^{-1}
lep / Q^{jet},lep	$0.496 \pm 0.052 \pm 0.048$ ps^{-1}
e / μ	$0.450 \pm 0.045 \pm 0.051$ ps^{-1}
μ / μ	$0.503 \pm 0.064 \pm 0.071$ ps^{-1}
D*lep / lep	$0.512\ ^{+0.095\ +0.031}_{-0.093\ -0.038}$ ps^{-1}
Average	$0.481 \pm 0.028 \pm 0.027$ ps^{-1}



Tagging $J/\psi K^0_s$

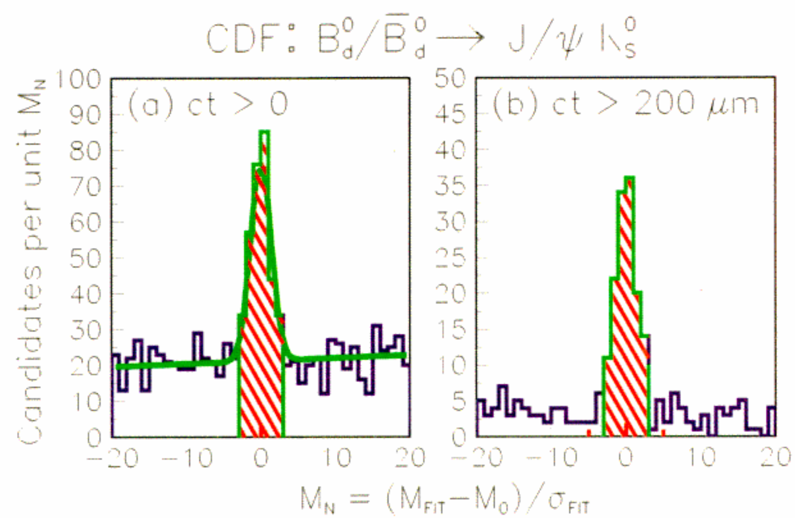
Statistical Power of Tagger:

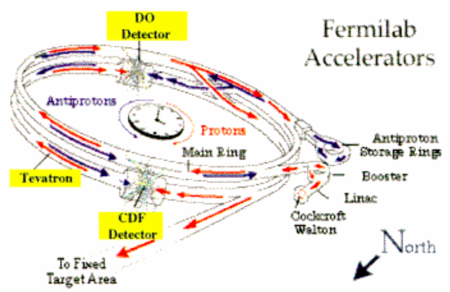
- $\varepsilon D^2_0 = 2.4 \pm 0.7^{+0.6}_{-0.4}$ %

- Use same side tagging:

$$A(c\tau)=\frac{N_{RS}-N_{WS}}{N_{RS}+N_{WS}}=D \sin 2\beta \sin \Delta m_d t$$

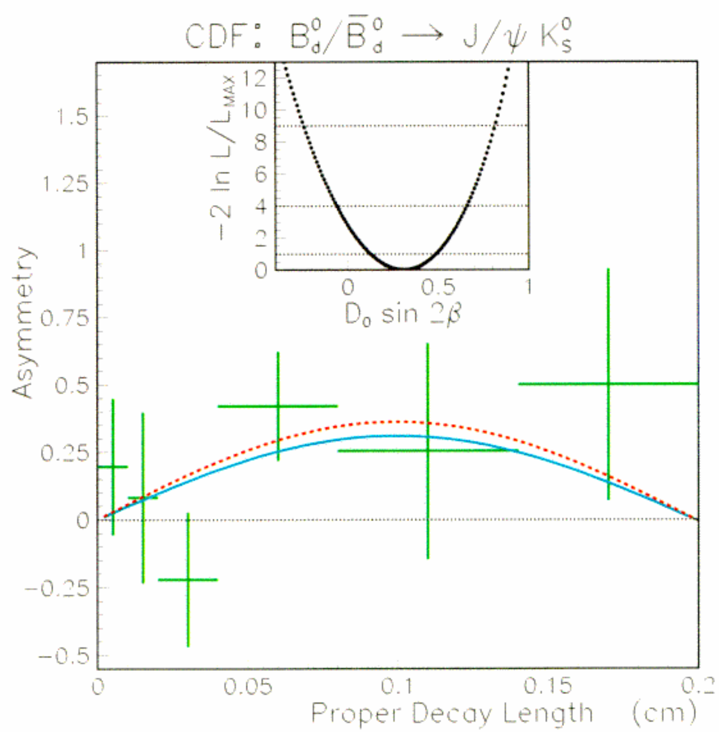
- Dilution:
  - $J/\psi K^+$: $D=0.185 \pm 0.052^{+0.003}_{-0.004}$
  - $J/\psi K^{*0}$: $D=0.165 \pm 0.112^{+0.018}_{-0.021}$
- Combine these with measurement from charged B mesons using MC:
  - $D(J/\psi K^0_s) = 0.166 \pm 0.018 \pm 0.013$(MC)





Tagging $J/\psi K^0_s$

Asymmetry vs ct



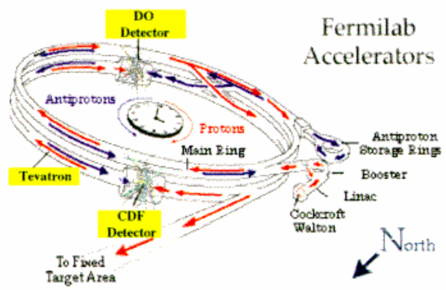
- Dashed curve: simple χ^2 fit
- Solid curve: unbinned maximum likelihood fit.

$D\sin2\beta=0.31\pm0.18$

- Systematic Uncertainties:
  - Δm_d $\Rightarrow \delta D \sin2\beta={}^{+0.029}_{-0.025}$
  - $c\tau(B^0_d)$ $\Rightarrow \delta D \sin2\beta=\pm0.001$
  - Detector biases

    $\Rightarrow \delta D \sin2\beta={}^{+0.016}_{-0.019}$

$D\sin2\beta=0.31\pm0.18(\text{stat.})\pm0.03(\text{syst.})$



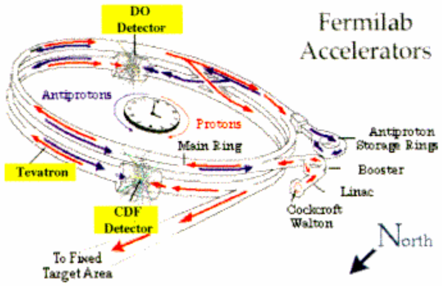
Fermilab Accelerators

$J/\psi\ K^0_S$ Asymmetry

Exclusion of sin2β<0

- The uncertainty and the central value for sin 2β both scale with 1/*D*
  - The exclusion of sin 2β ≤ 0 does not depend on *D*, and can be calculated from the *raw* asymmetry.
- We exclude sin 2β ≤ 0 at 90% C.L.
  - (i.e. if CP were conserved in the B sector, 10% of the experiments would still see a result as lasrge as ours)
- For sin2β=1, on average we would exclude sin2β<-0.89
  - Sensitivity of the measurements
- Using the value previously determined for *D*, we find:

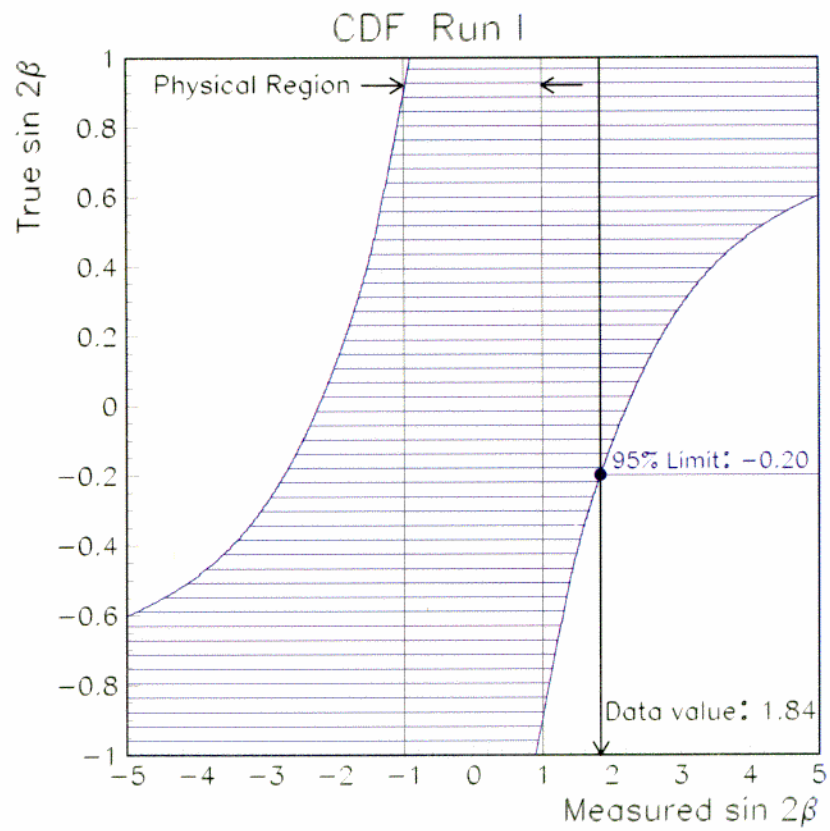
$\sin 2\beta = 1.8 \pm 1.1(\text{stat.}) \pm 0.3(\text{syst.})$

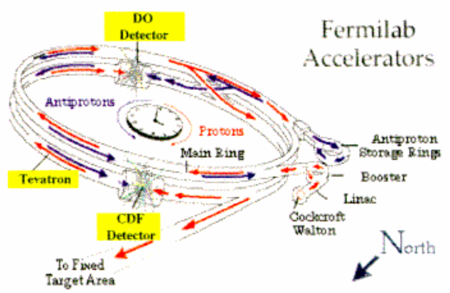


$J/\psi\, K^0_S$ Asymmetry

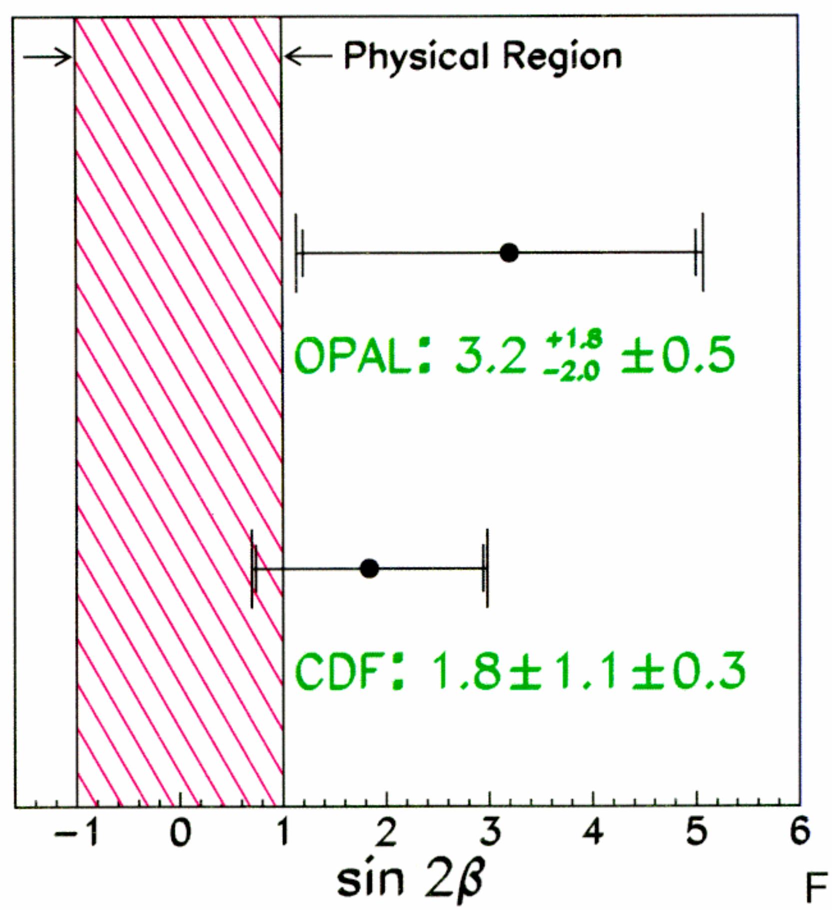
- Using the prescription of Feldman and Cousins to calculate the 95% C.L.

exclude sin 2β≤-0.20 at 95% C.L.





$J/\psi K^0_S$ Asymmetry



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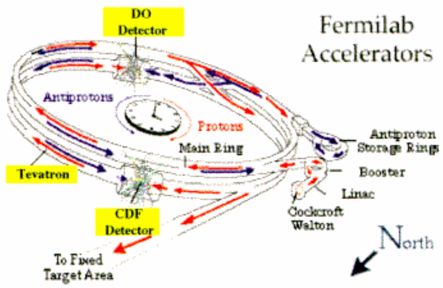
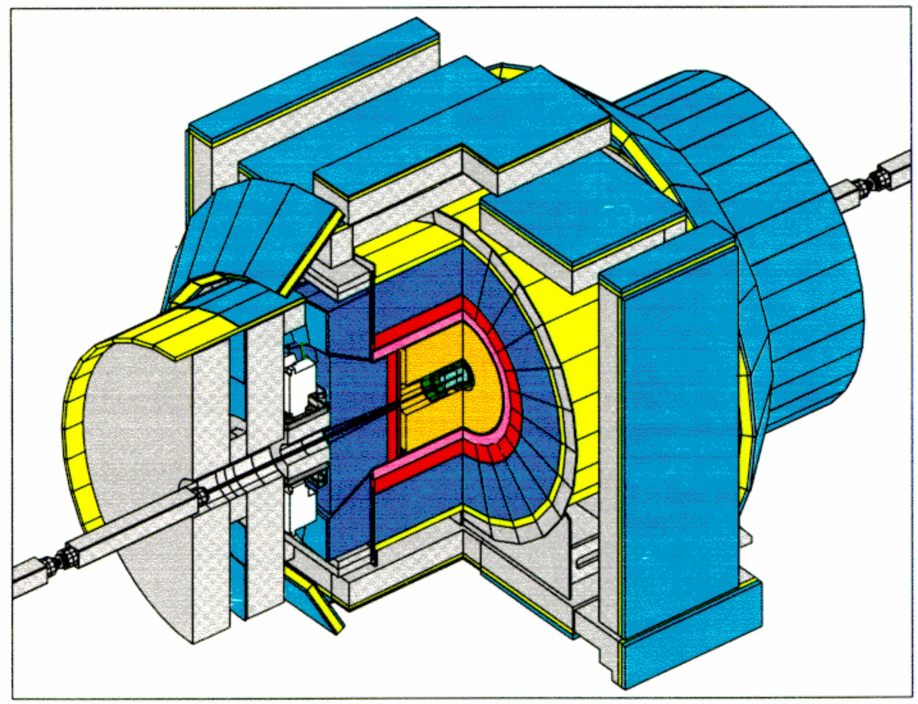
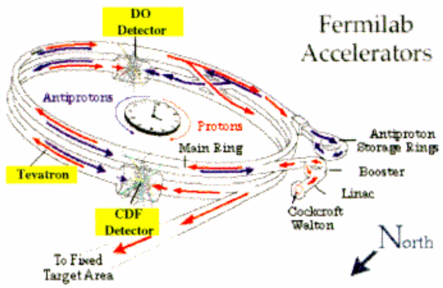


Fermilab Accelerators

Run II Expectations

- Upgraded Tevatron
  - ($\int L = 2\ fb^{-1}$)
- Upgraded detectors
  - CDF
    - bigger SVX (more acceptance)
    - Larger μ acceptance
    - Better calorimetry for $|\eta|>1$
    - Sec. Vertex trigger
  - D0
    - Added tracking+solenoid
    - Silicon Vertex Detector
    - Better *e* ID (preshower)





Run II Expectations

- **TOP Physics**
  - Mass to 1% → M_H to 30%
  - σ_{tt} to 9%
  - Γ_{top} to 25%
  - limits on $t \rightarrow Wb$ to few %
  - V_{tb} to 10%

Check that top is SM object to few %

- **B Physics**
  - $\delta(\sin 2\beta)= .09$
  - B_s mixing
  - B_c states
  - b baryons and rare decays
  - possibility of $B \rightarrow \pi\pi$ and $\delta(\sin 2\alpha)=.10$

Collaborate with other *b*-factories on the b-sector studies

Most Important Results: haven't thought of yet !