CDF Status and Plans

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Entry to CDF Physics
http://www-cdf.fnal.gov/physics/physics.html

The CDF Collaboration

North America

3 Natl. Labs
28 Universities

3 Universities

Europe

1 Research Lab
6 Universities

1 University

4 Universities

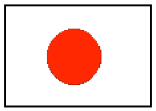
2 Research Labs

1 University

1 University

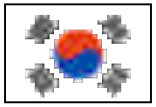
1 University
1 lab

Asia



5 Universities
1 Research Lab

1 University



3 Universities

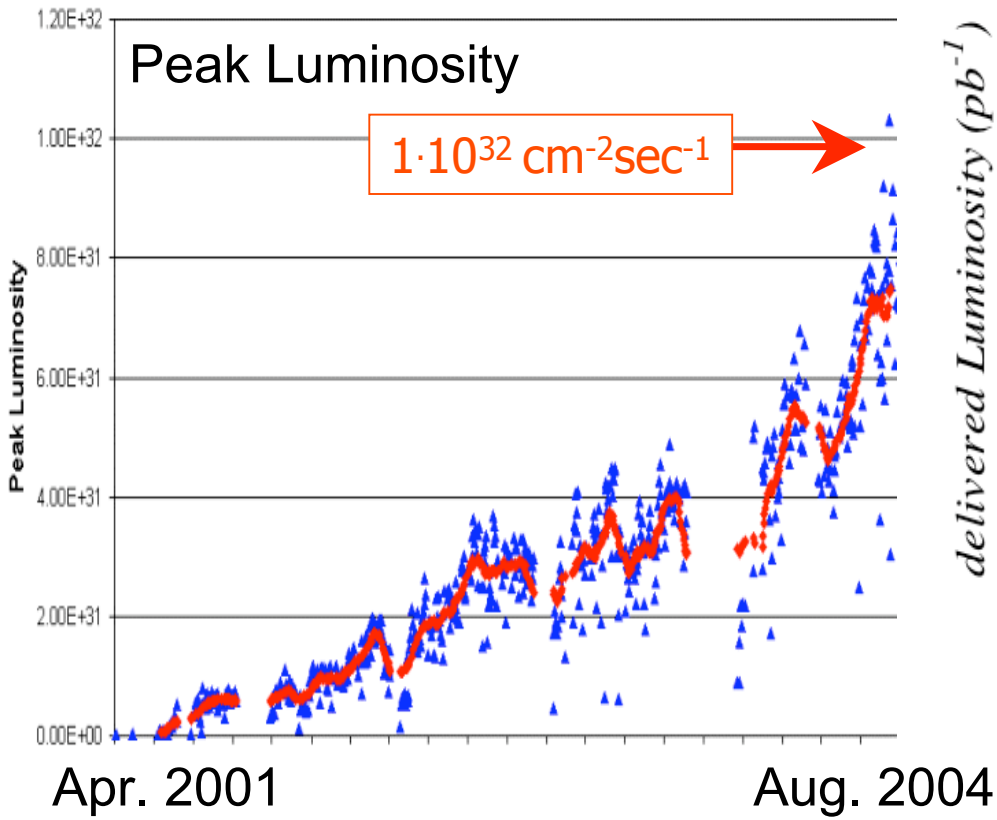
12 countries, 61 institutions, ~800 physicists

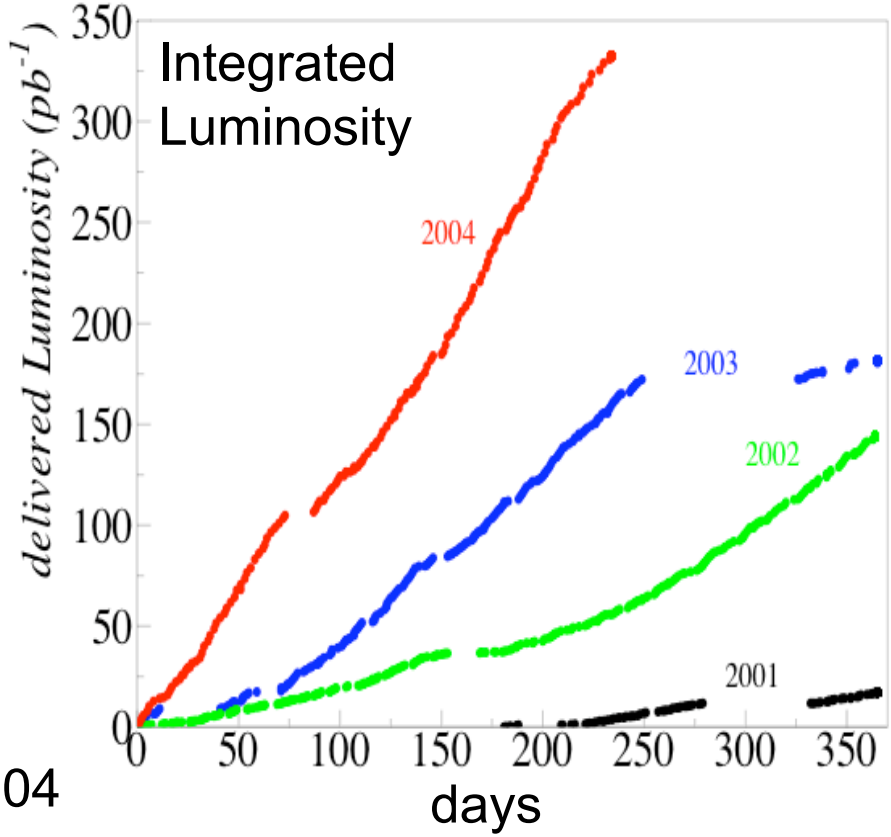
CDF Operations

- MOUs with institutions good through 2005 (written ~2001).
- Many groups being “downsized”
  - By pressures from funding agencies
  - Need to ramp up on LHC
- Renegotiating current MOUs and MOUs beyond 2005.
- Will get very difficult to operate detectors and do physics.

- Institutions have been hiring CDF/LHC postdocs - do service work on LHC and physics/operations on CDF.
  - Postdocs need physics analysis for career advancement.
- LPC (LHC Physics Center) - promise to mitigate sudden flow
  - Postdocs can find critical mass of people at Fermilab preparing for LHC.
  - Maintain a role in both CDF and LHC.

Accelerator Performance



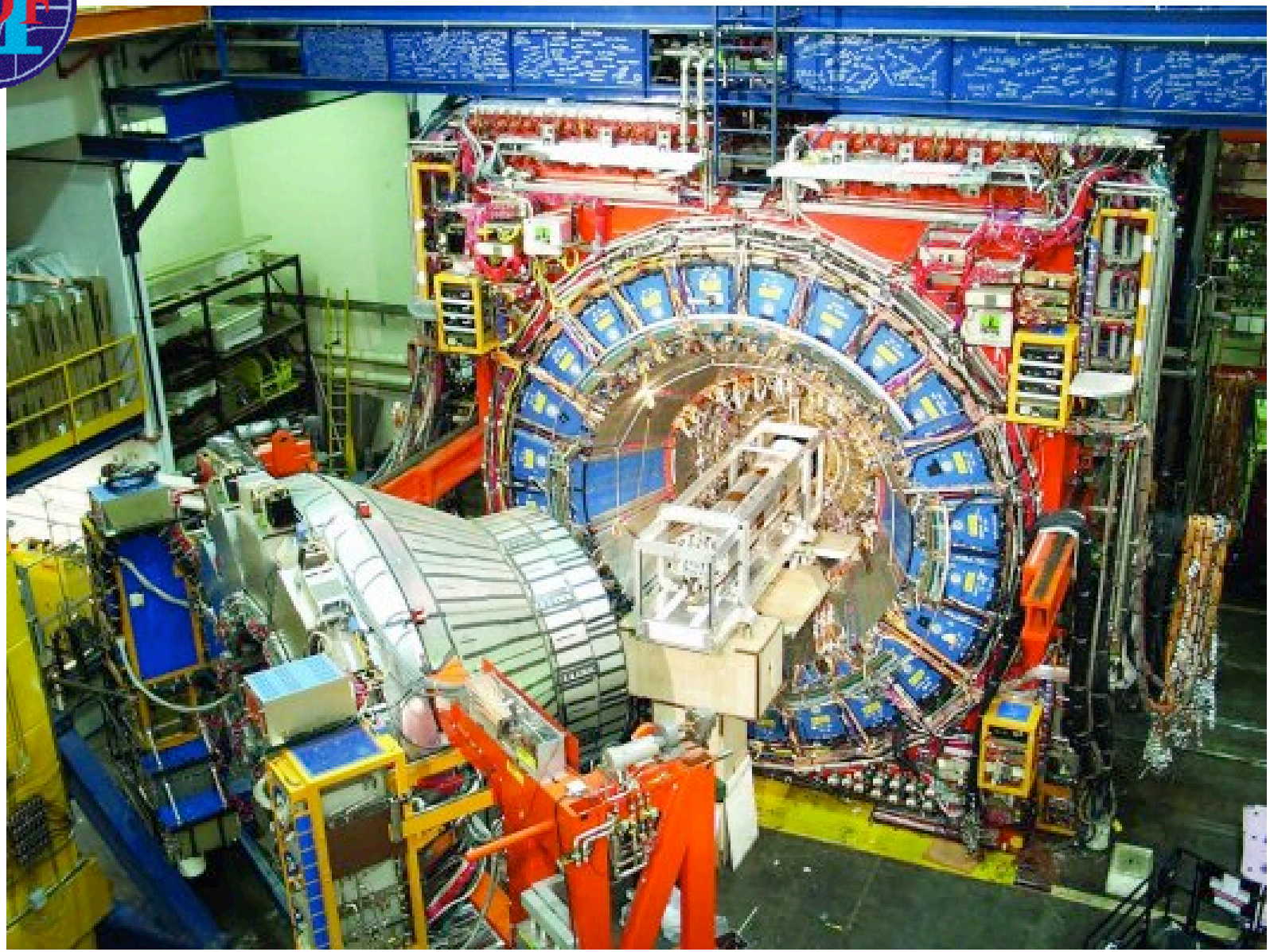


Peak luminosity > 10^{32} cm^{-2} sec^{-1}

Total ~0.7 fb^{-1} delivered so far, ≥ 4 fb^{-1} by 2008

Installing electron cooling during present shutdown
x2 improvement if this works.

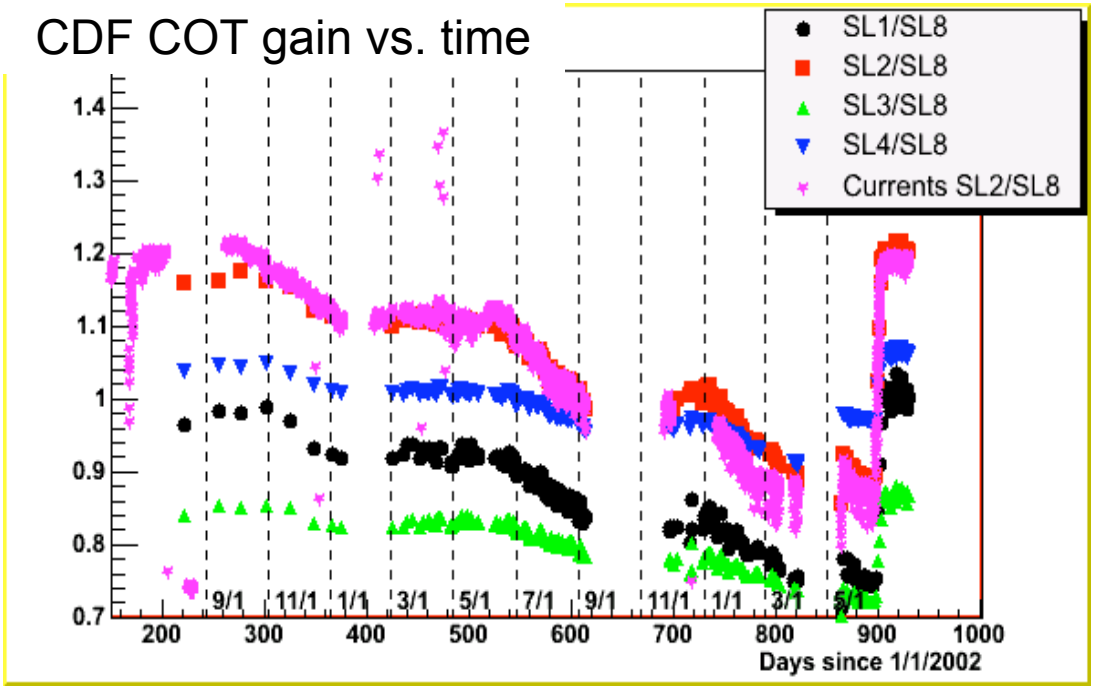
CDF Detectors



CDF Detectors

- Working well but
  - We had major gain loss problems with drift chamber.

CDF COT gain vs. time



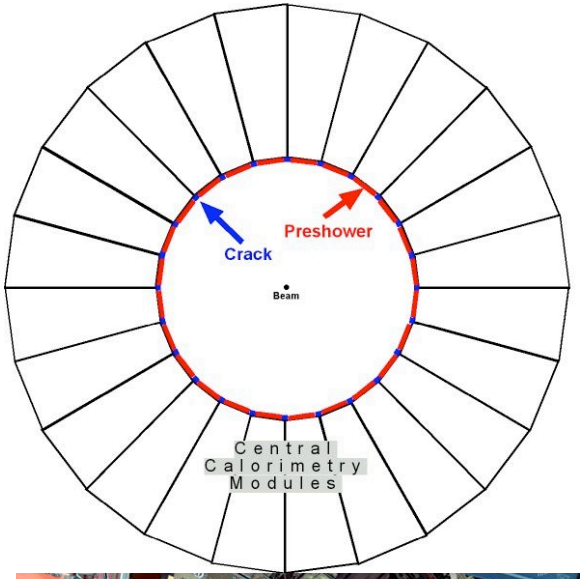
Feb.2002 Aug.2004

Oxygen fixed it!
(late May, 2004)

  - We are always concerned about Silicon safety.
    - Beam incidents highlight concerns.
  - Many minor issues require continual vigilance.

Run IIb Detector Upgrades: Calorimeter

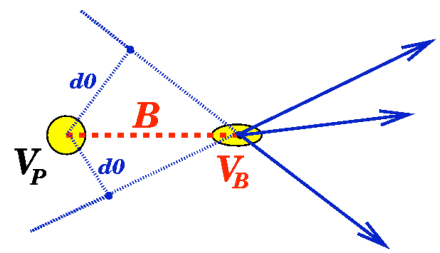
- Pre-radiator detector (scintillator) in the central region
  - Argonne, Fermilab, Pisa, Roma, Trieste/Udine, Dubna, Korea, Tsukuba, Michigan State, Purdue, Rockefeller



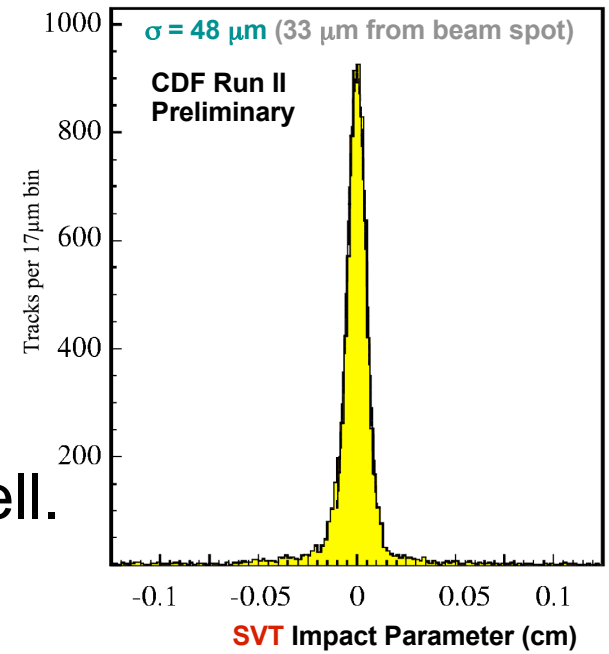
- Timing in the electromagnetic calorimeter
  - Texas A&M, Chicago, Frascati
  - Plug region: done Fall '03.
  - Central region: fully instrumented during Fall '04 shutdown - currently being tested.

Trigger/DAQ/Offline Systems

- CDF trigger rates:
  - Level-1 25 kHz (Si deadtimeless readout chip)
  - Level-2 400 Hz (Silicon Vertex Trigger)
  - Level-3 60 Hz



- Trigger Paths
  - over 100 trigger paths
    - e, μ, τ, γ, track, jet, B, ν, …
    - Combinations of these objects



- Efficiency to tape ~ 85%.
- Offline production proceeding very well.
  - ~10 million events / day

Trigger/DAQ Upgrades

	Run IIa Specification	Run II Achieved	Run IIb Specification
Luminosity	8.6×10^{31}	1×10^{32}	3×10^{32}
Level-1 Accept	45 kHz	25 kHz	30 kHz
Level-2 Accept	300 Hz	400 Hz	1000 Hz
Event Builder	75 MB/s	75 MB/s	500 MB/s
Level-3 Accept	75 Hz	80 Hz	100 Hz
Rate to Storage	20 MB/s	20 MB/s	40 MB/s(*)
Deadtime Trigger	5%	10%	5% + 5% (**)

- Run IIa Level-1 Acceptance rate not achieved due to higher than specified Silicon readout + Level-2 execution times.
- (*) Pushing to ~60 MB/s to maintain B physics program at high lum.
- (**) Assume ~5% from readout and ~5% from Level-2 processing

Run IIb DAQ/Trigger Upgrades

- COT (Drift Chamber) TDC Improvements
  - Chicago, Fermilab, Duke, and Texas A&M
- Level-1 COT Tracking Trigger
  - Illinois, Ohio State, Fermilab, Purdue, Baylor
- Level-2 Trigger
  - Chicago, Fermilab, Penn
- SVT (Silicon Vertex Trigger)
  - Chicago, Ferrara, Pisa, Fermilab, Rome, Siena, Tsukuba, Wisconsin
- Event Builder
  - MIT, Fermilab
- Level-3 Processors

Physics Group Organizatioin

Physics Groups: QCD | B | Electroweak (W,Z + …) | Top | Exotic (New Phenomena)

Analysis Groups: dilepton | l+jets | mass | single top

Common Tools, Issues:

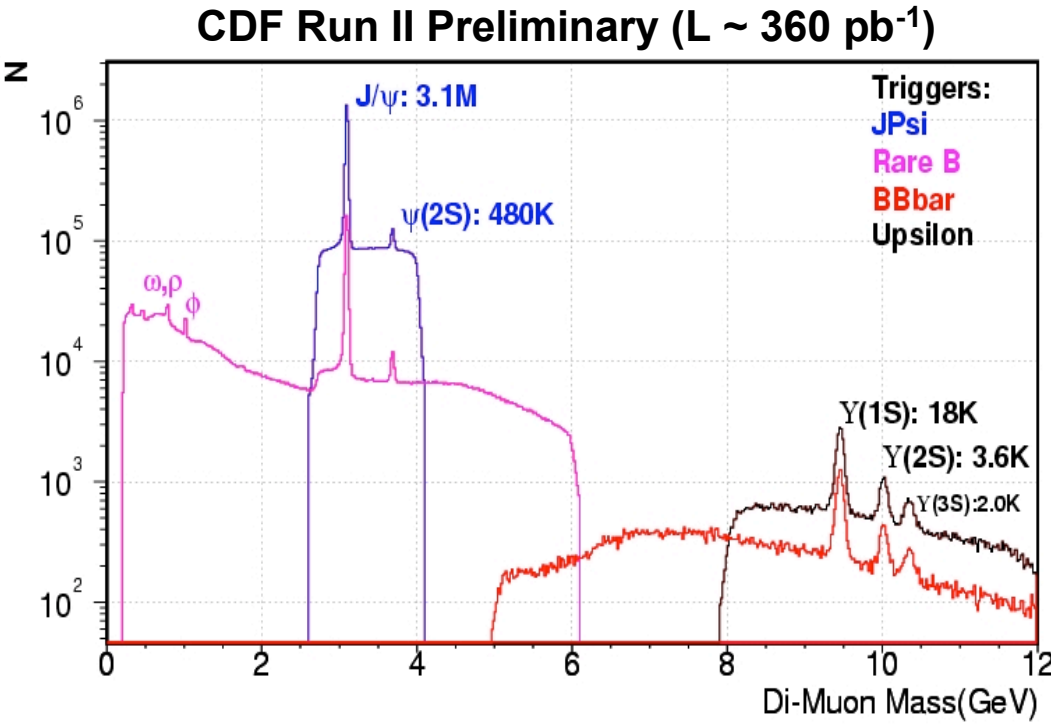
Working groups:
Tracking, e, μ, τ, γ, b-tagging, jet calibration, …

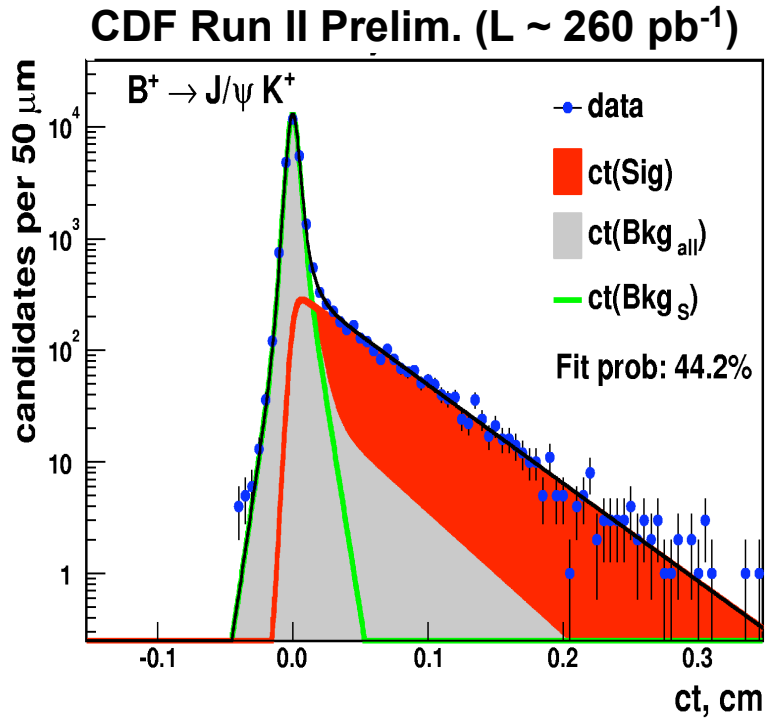
Final results discussed at Joint Physics Meeting

Detector Calibrations
Offline Reconstructions
Monte Carlo Generations, Simulation, Productions

Detector and Trigger Performance

Triggers, COT and Silicon Tracking





$\tau(B^{\pm}) = 1.662 \pm 0.033(\text{stat}) \pm 0.008(\text{syst})$ ps

COT tracking: over 99% efficient

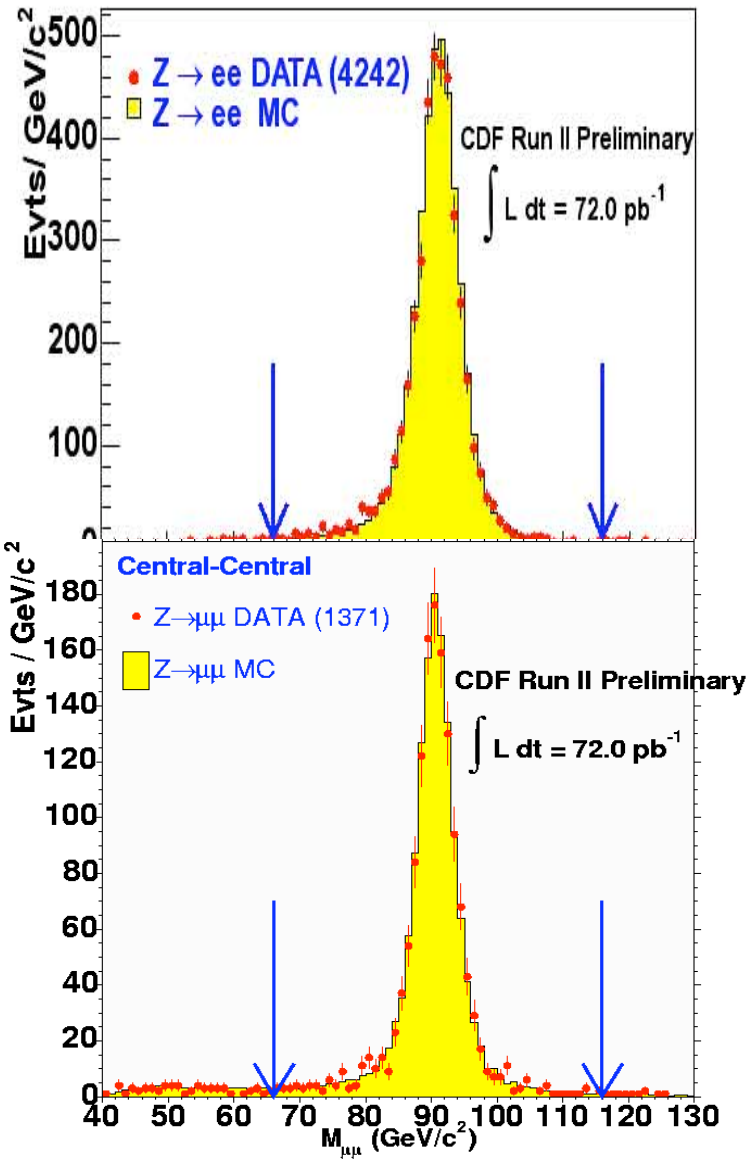
Silicon tracking: 85-97% depending on cuts in $|\eta| < 1$ (fake tracks ~1%)

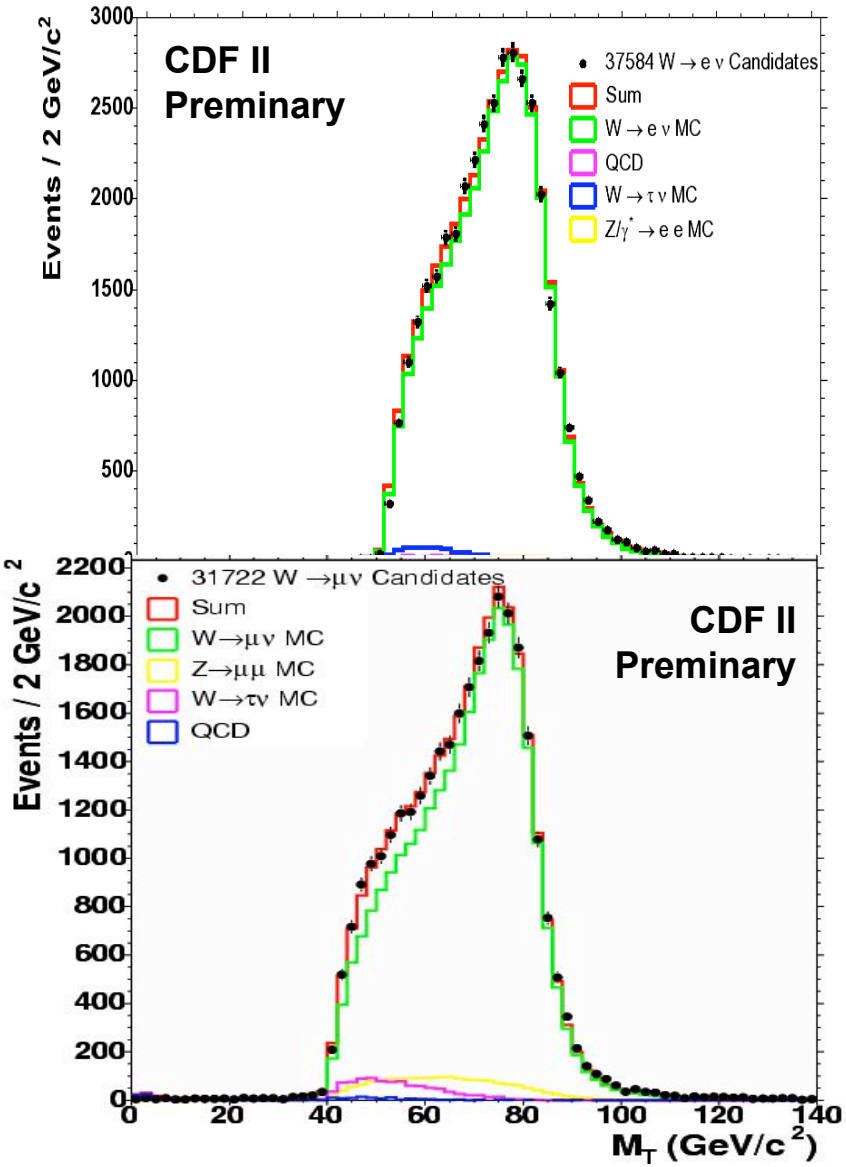
~80% at $|\eta|$~1.2 - ~40% at $|\eta|$~2

Just started to include L00.

Performance keeps improving.

COT Tracking and Calorimeter





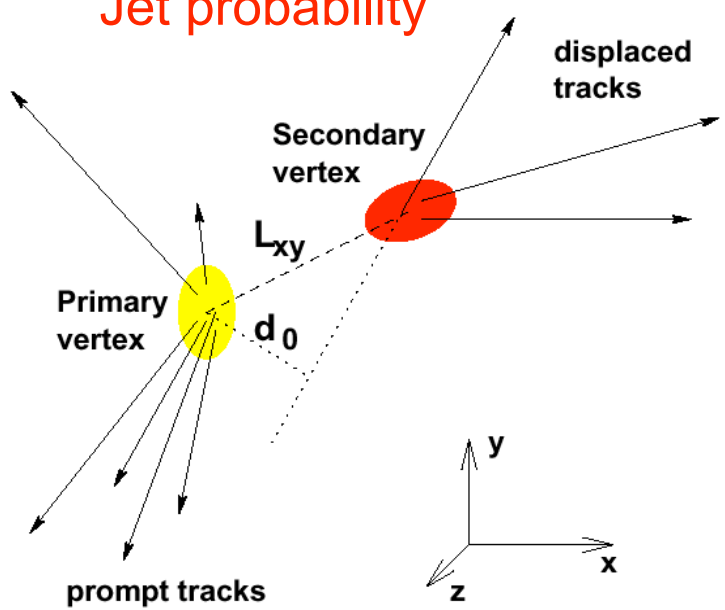
B-jet Tagging - vertices or soft leptons

Improve S:B by exploiting knowledge that B hadrons

are long-lived and massive

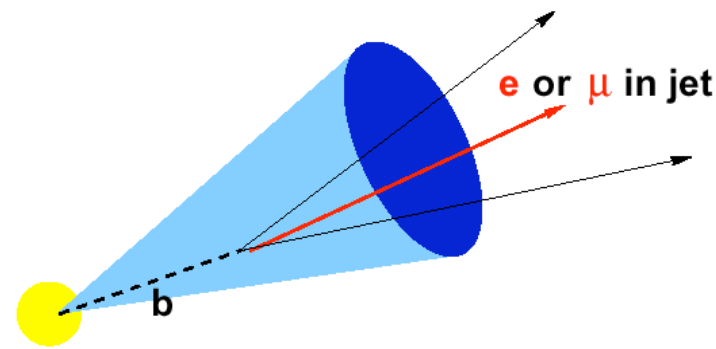
Vertex displaced tracks

Jet probability



may decay semileptonically

Identify low-p_T muon

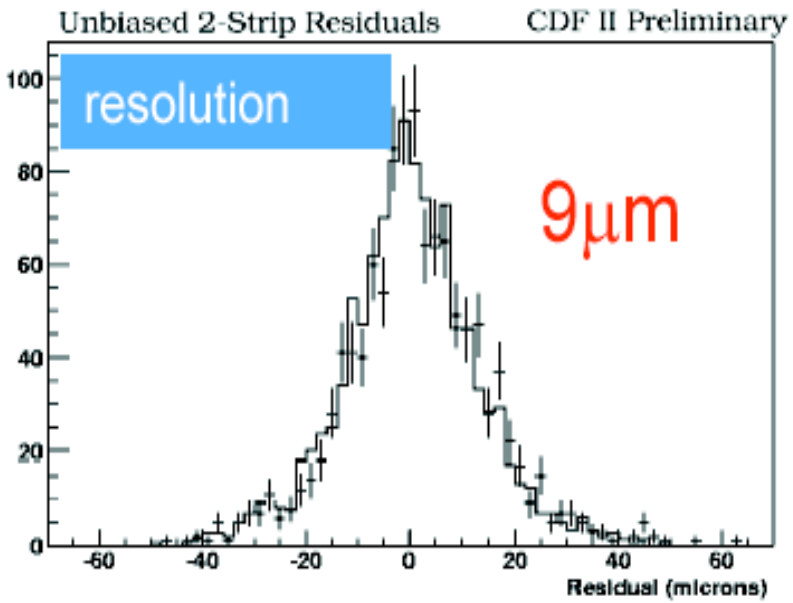


- $b \to \ell\nu c$ (BR $\sim$ 20%)
- $b \to c \to \ell\nu s$ (BR $\sim$ 20%)

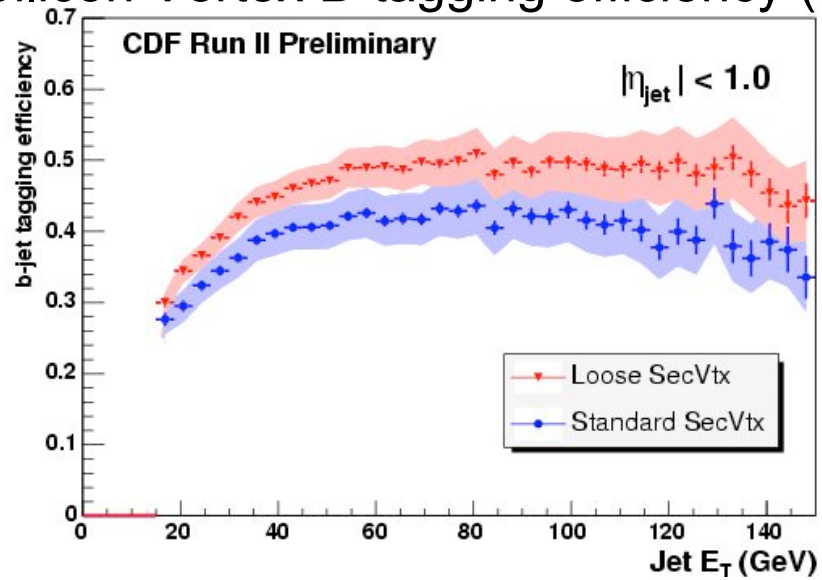
55%	**Top Event Tag Efficiency**	**15%**
0.5%	**False Tag Rate (QCD jets)**	**3.6%**

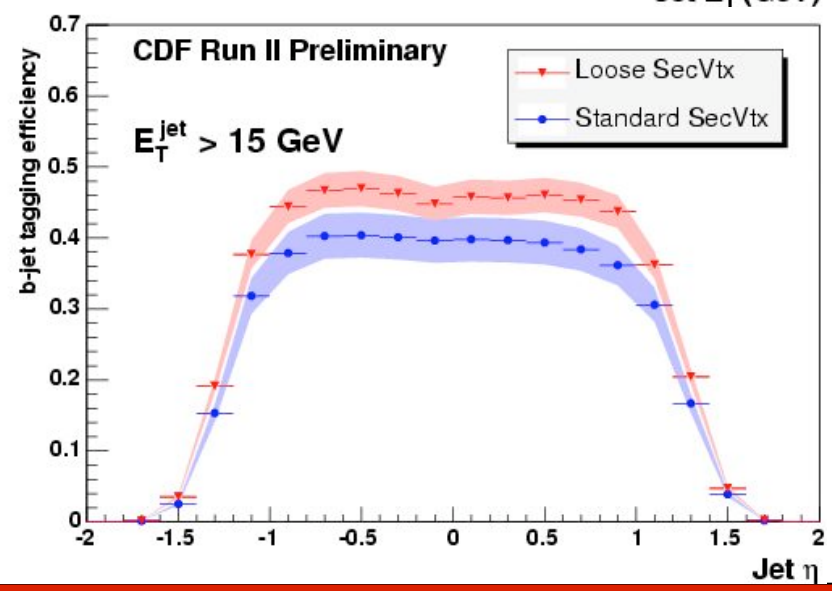
B-jet Tagging (Displaced Vertices with Silicon)

Silicon position resolution



Silicon Vertex B-tagging efficiency (top)



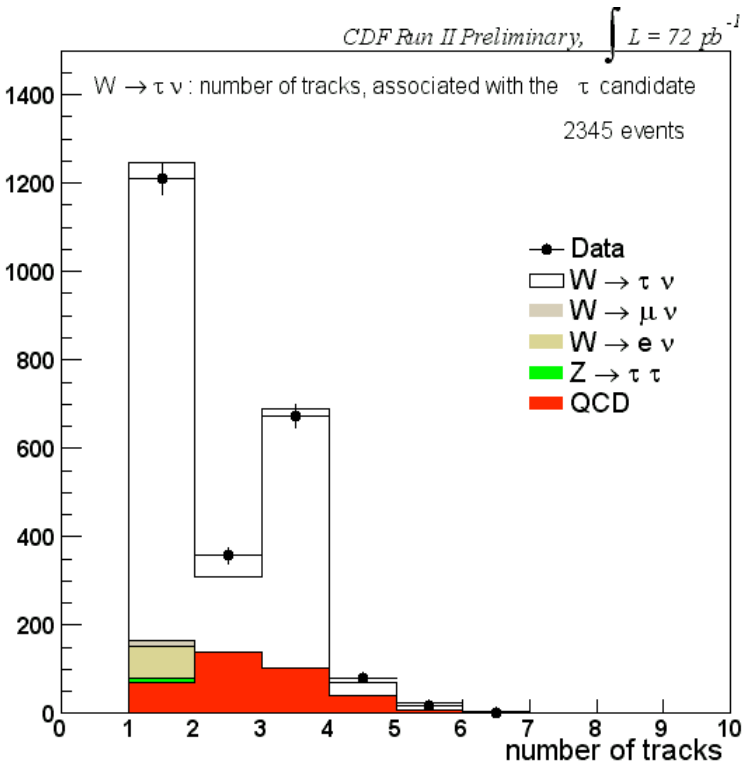


Tau Identification

Important for Physics beyond the Standard Model:
many models with enhanced τ couplings

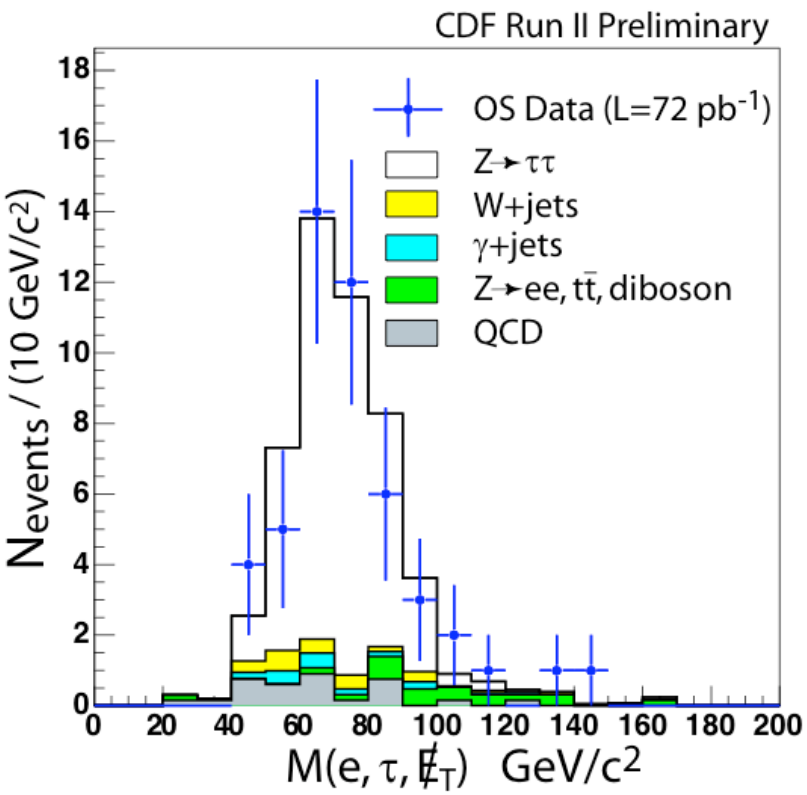
$W \rightarrow \tau\nu$

$\tau \rightarrow$ hadrons + ν



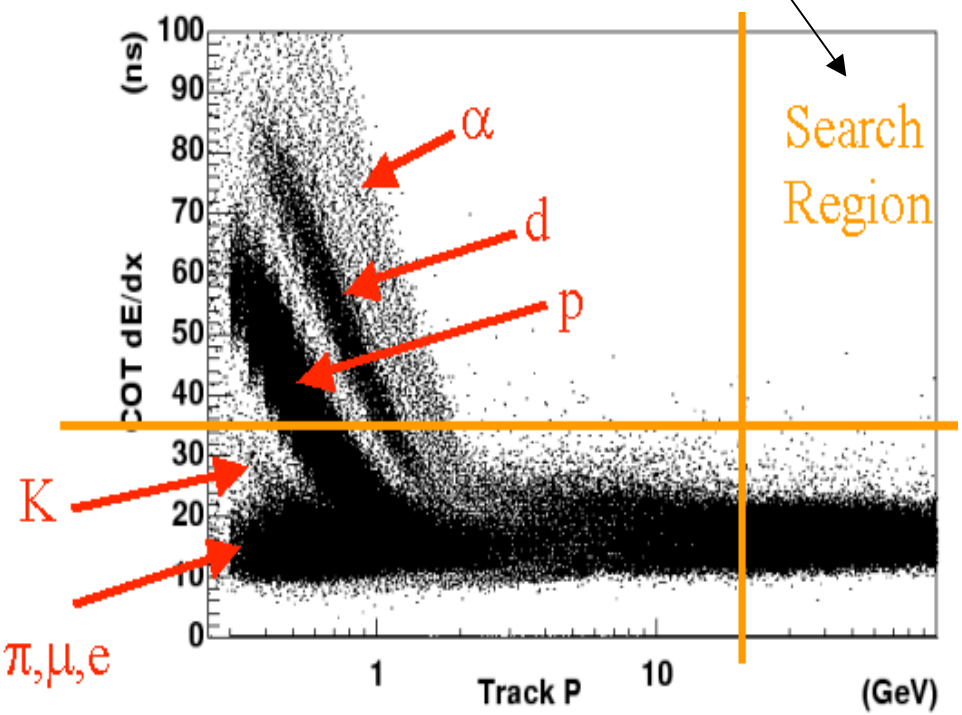
$Z \rightarrow \tau\tau$

$\tau \rightarrow e\nu\nu$, $\tau \rightarrow$ hadrons

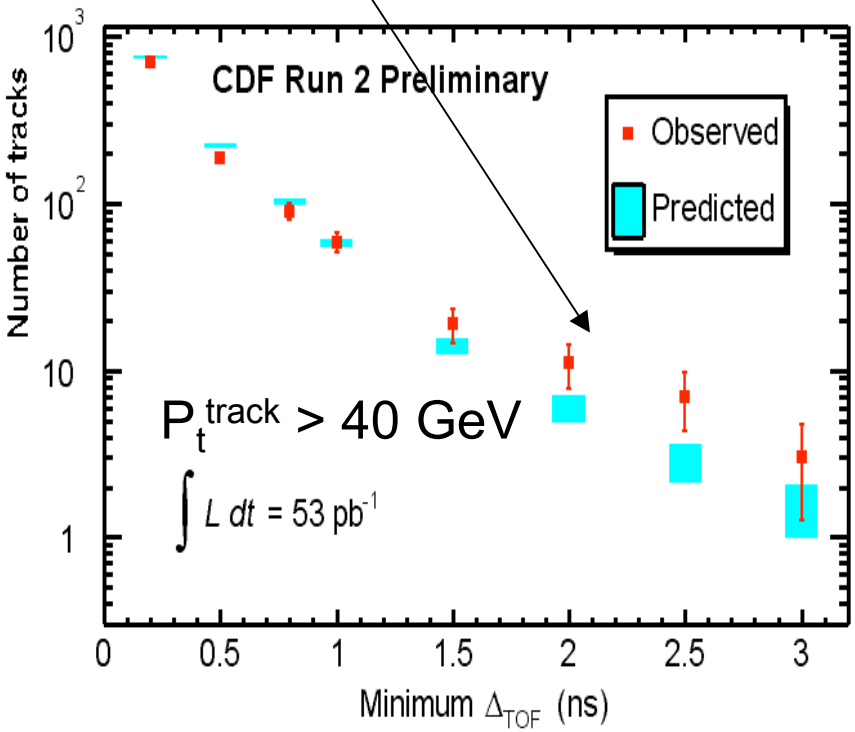


Hadron Identification

- dE/dx from Drift Chamber
  - B physics
    - K-π separation low P_T
  - New particle searches
    - charged massive particles

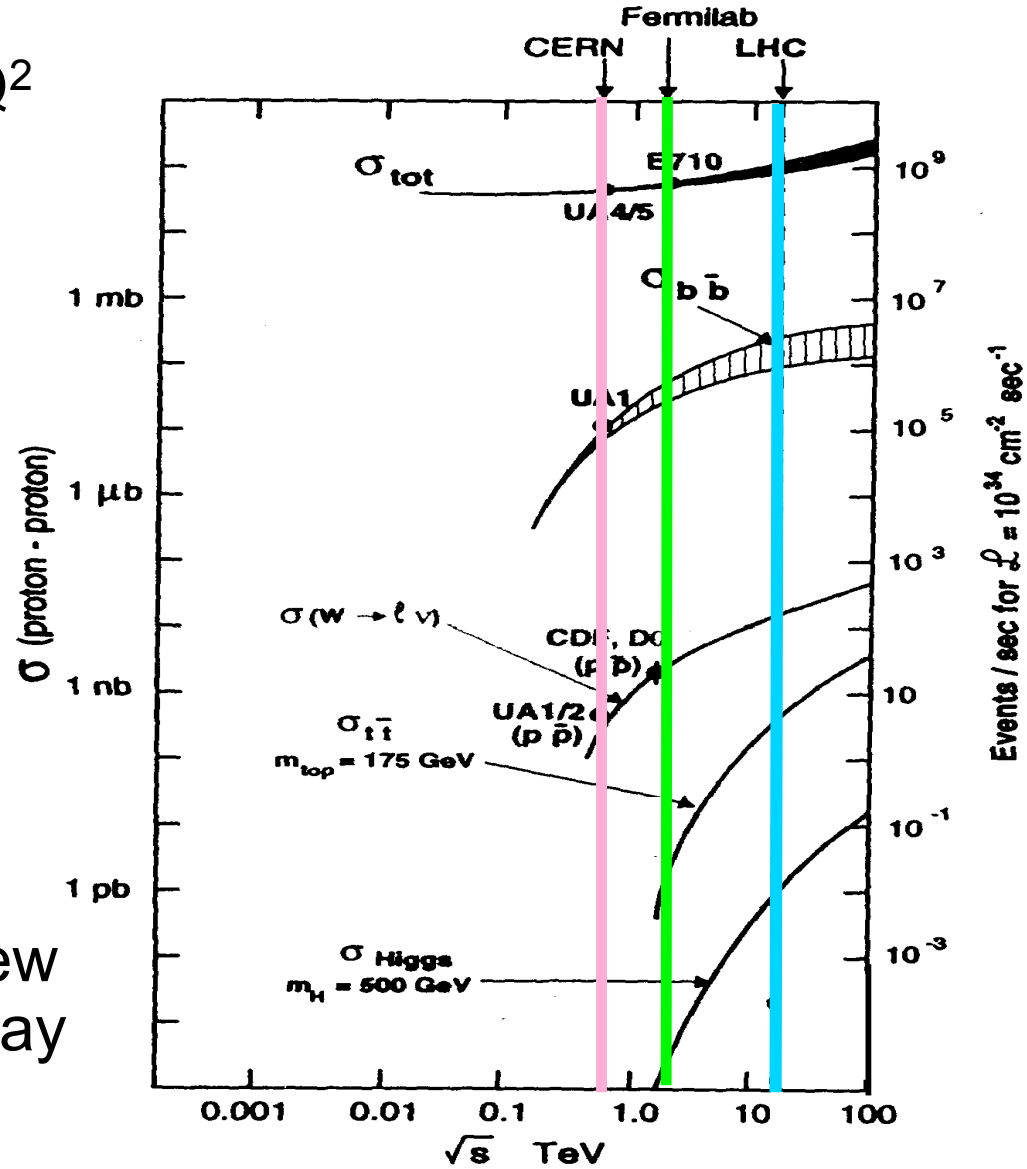


- Time-of-Flight System
  - B physics
    - K-π separation low P_T
  - New particle searches
    - charged massive particles



Physics at Tevatron

- Probes physics at high Q^2
  - Direct searches
  - Top physics
  - High E_T jets
- … to intermediate Q^2
  - Precision electroweak physics
- … to low Q^2
  - B and charm physics
- Selected topics (only a few highlights) discussed today ($L = 50 - 350\ pb^{-1}$)



Run II Publications

- 52 papers - published, submitted, or under collaboration' review (many of them use data up to early 2004)
  - 6 papers published
    - 5 PRL and 1 PRD
  - 1 paper accepted
    - 1 PRL
  - 5 papers submitted
    - 4 PRL and 1 PRD
  - 4 papers about to be submitted
    - 1 PRL, 2 PRD, 1 PRD-RC
  - 4 second drafts out to the CDF collaboration
  - 4 first drafts out to the CDF collaboration
  - 28 under godparents review
- Time scales for publication vary due to different degrees of sophistication required by each particular analysis.

Top Physics Publication Status

- 2 papers published or submitted
  - Top pair cross section in dilepton (Phys. Rev. Lett.)
  - Top pair cross section in lepton+jets with Si b-tag & kinematics (Phys. Rev. D)
- 11 papers godparent publication review
  - Top pair cross section in lepton+jets with Si b-tag
  - Single top search
  - Anomalous kinematic distribution in top dilepton
  - Top pair production in lepton+jets with kinematics
  - Top pair production in lepton+jets with soft-muon tag
  - Top pair production in e/μ + tau
  - Top branching ratios
  - W helicity
  - Top mass in lepton+jets with dynamical likelihood method
  - Top mass in lepton+jets with template method
  - Top mass in lepton+jets with multivariate method

Publications from Electroweak & QCD Physics

- Electroweak Physics
  - 2 papers submitted or published
    - W cross section, Z cross section (e, m)
    - Wgamma, Zgamma cross section
  - 5 papers godparent publication review
    - Forward-Backward Asymmety in dielectron
    - ZZ+ZW cross section
    - WW cross section
    - W Asymmetry
    - W Mass
- QCD
  - 2 papers godparent publication review
    - Di-photon cross section
    - Jet shape analysis

Bottom and Charm Physics Publication Status

- 5 papers published or submitted
  - D_s, D^+ mass difference (Phys. Rev. D68, 072004, 2003)
  - Search for D -> $\mu\mu$ (Phys. Rev. D68, 091101, 2003)
  - Prompt Charm cross sections (Phys. Rev. Lett 91, 241804, 2003)
  - Observation of X(3872) (Phys. Rev. Lett 93, 072001, 2004)
  - D^* relative Br and CP asymmetry (Phys. Rev. Lett.)
- 11 Papers in godparent publication review
  - Pentaquark search
  - Inclusive J/ψ cross section
  - B hadron masses (including B_s and Λ_b)
  - Br of Λ_b -> Λ_c p
  - Br of B_s -> D_s p
  - B_s/B_0 branching fraction ratio
  - B_s lifetime difference
  - Ratio of Br($B^\pm$ -> J/ψ K) / Br($B^\pm$ -> J/ψ π)
  - Hadronic moments in semileptonic B decays
  - B -> hh and CP violation
  - L_b-> Kp, πp

New Phenomena Publication Status

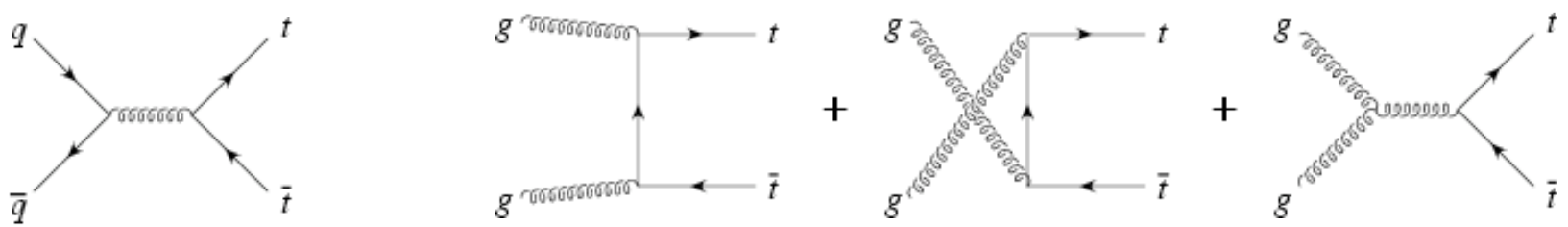
- 3 paper published or submitted
  - B_d, B_s -> $\mu\mu$ (Phys. Rev. Lett.)
  - e* -> e gamma (Phys. Rev.. Lett.)
  - H^{++} -> ee, $\mu\mu$, eμ
- 11 papers godparent publication review
  - Diphoton + missing E_T
  - Search for Z' -> ee, mm (high mass dilepton)
  - Search for W' -> enu
  - Search for 1st and 2nd generation leptoquarks
  - Search for leptoquarks in missing E_T
  - H^{++} -> ee, mm, em
  - WH -> Wbb Standard Model Higgs search
  - WH -> WWW* Standard Model Higgs search
  - H -> WW Standard Model Higgs search
  - Gluino / Stottom search

Physics with Top Quarks

Luciano Ristori and Young-Kee Kim

Top Quark

- Is it the Standard Model Top Quark?
- Does its large mass probe new physics?
- Probes:
  - Decay mode: 100% to *Wb* in SM
  - V-A coupling: W helicity in top decays
  - Event topology
  - Comparing cross sections in different decay modes and methods
  - Top mass
- Top pair production via strong interaction

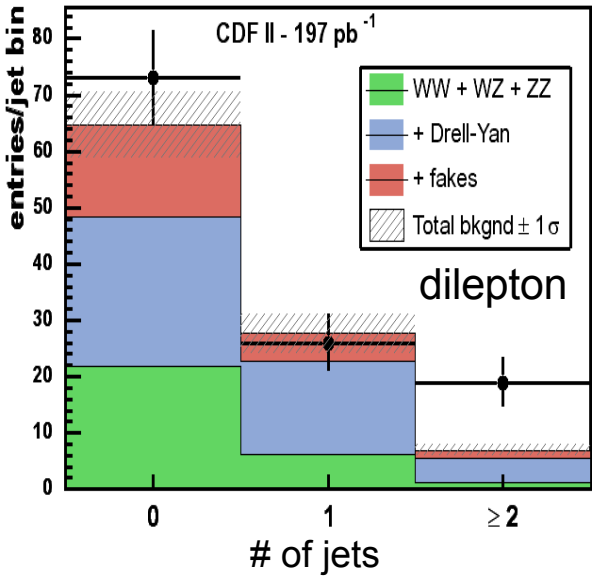


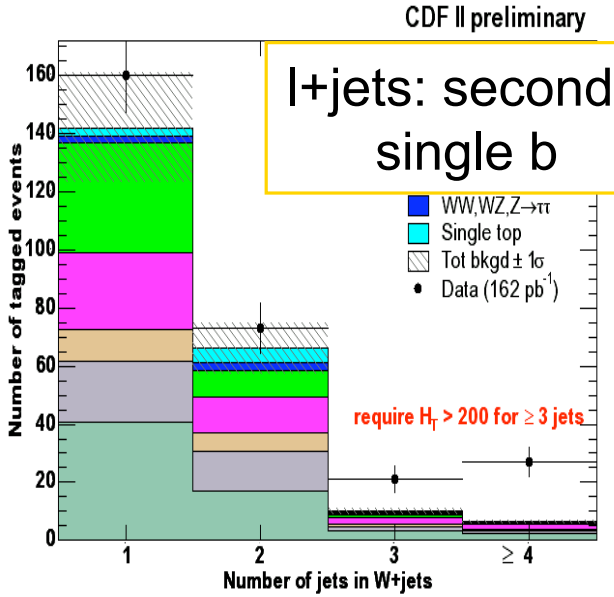
85% qq 15% gg at Tevatron
0.8 event / hour at recent lum

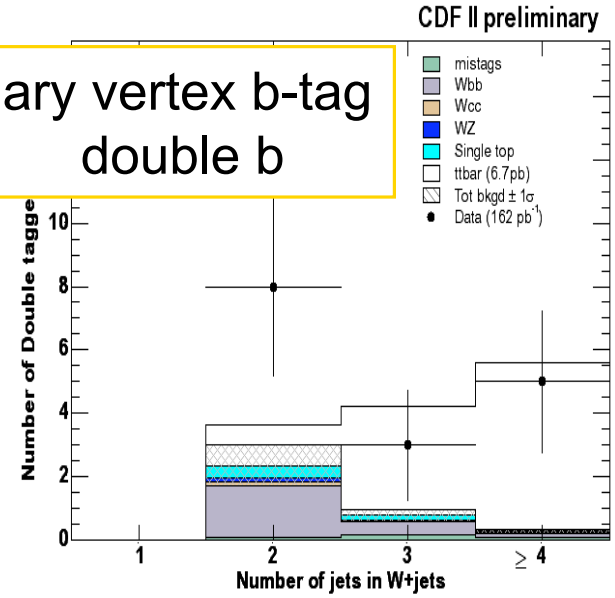
10% qq 90% gg at LHC

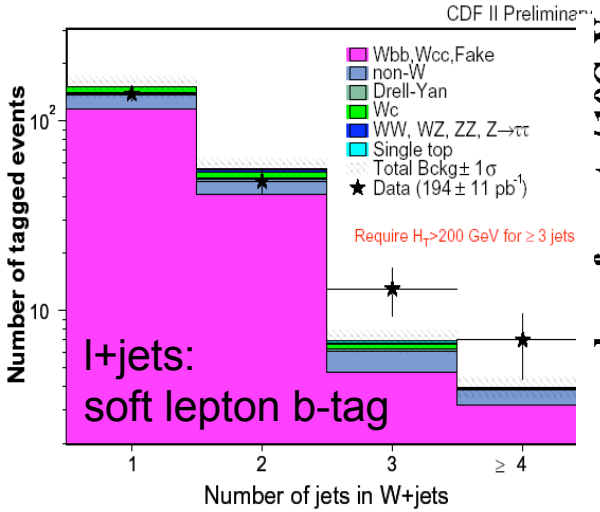
Top Pair Production - Cross Section

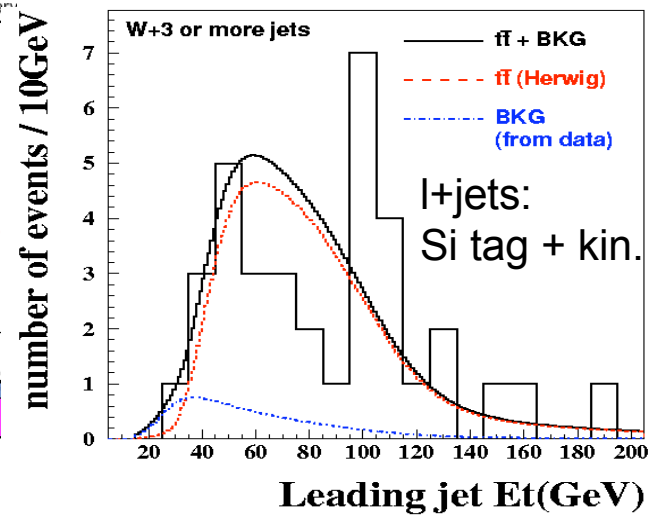
Different measurements: Test different assumptions, Look for new physics

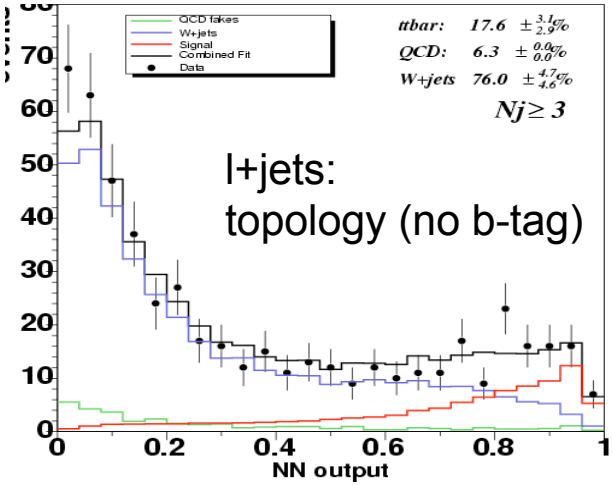








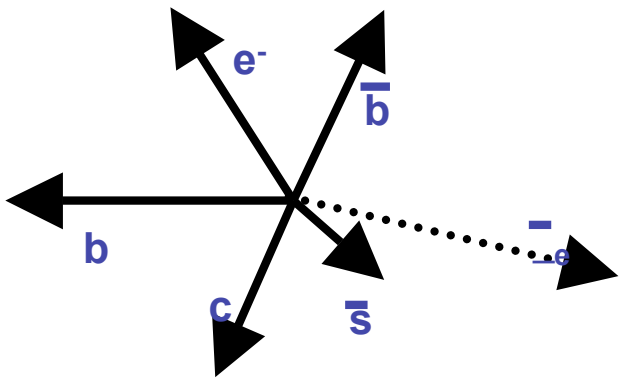




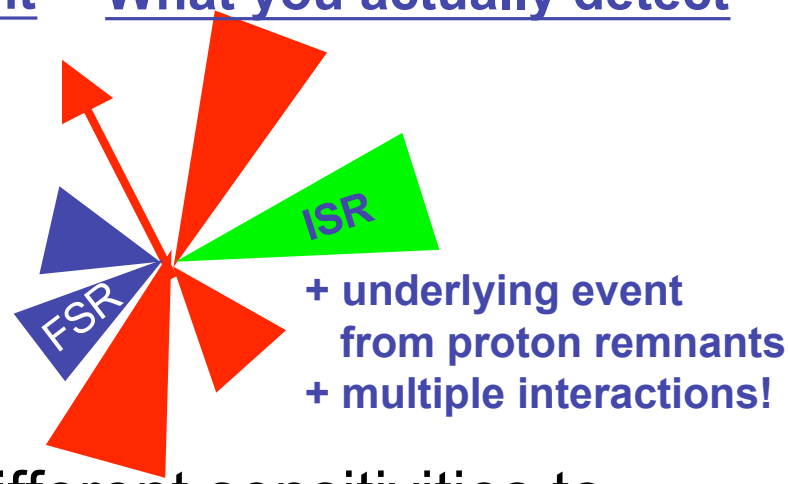
Top Quark Mass

- Important Standard Model parameter
- Ingredient of indirect Higgs mass constraint
- Complicated event topology

Final state from LO matrix element



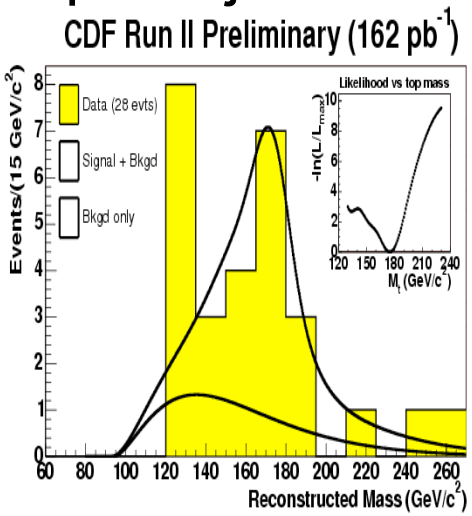
What you actually detect

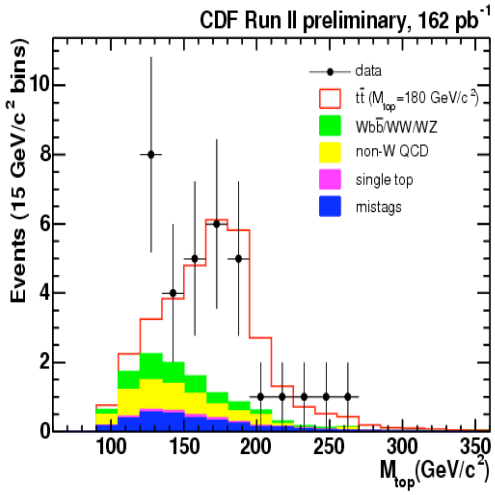


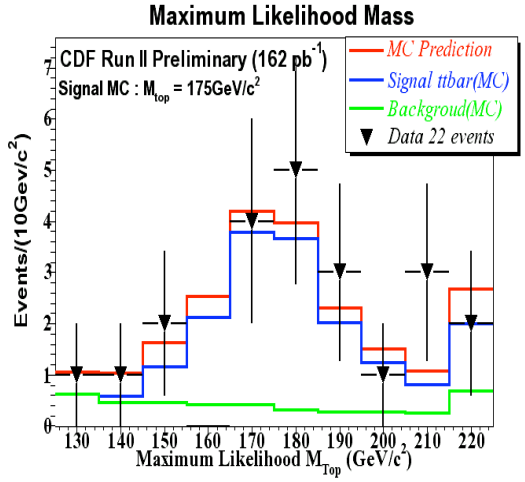
- Many fitting techniques with different sensitivities to modeling
  - Histogram & template-fitting method
  - "per-event" mass extraction method

Top Quark Mass Measurements

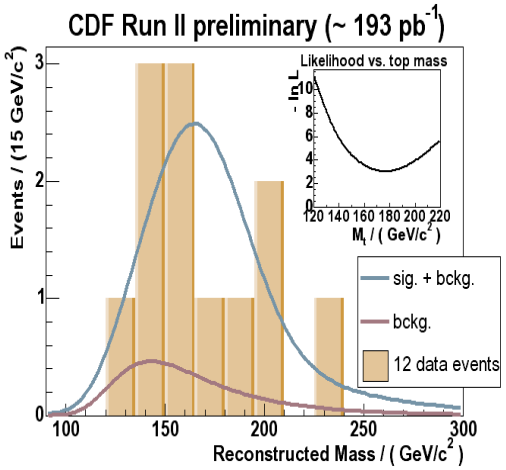
Lepton+jets:

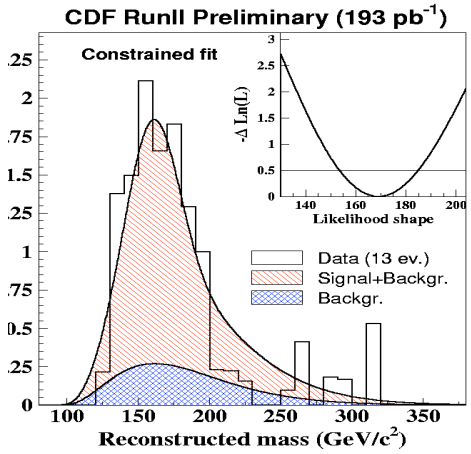


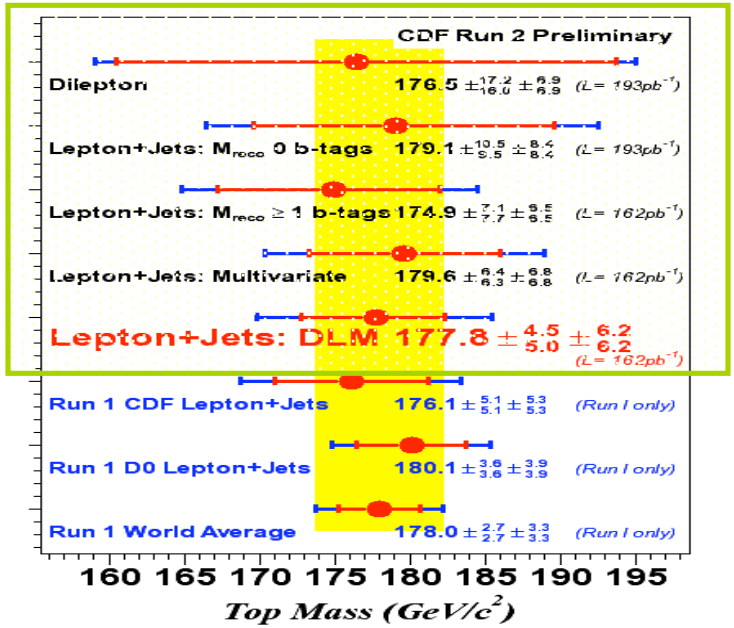




Dilepton:

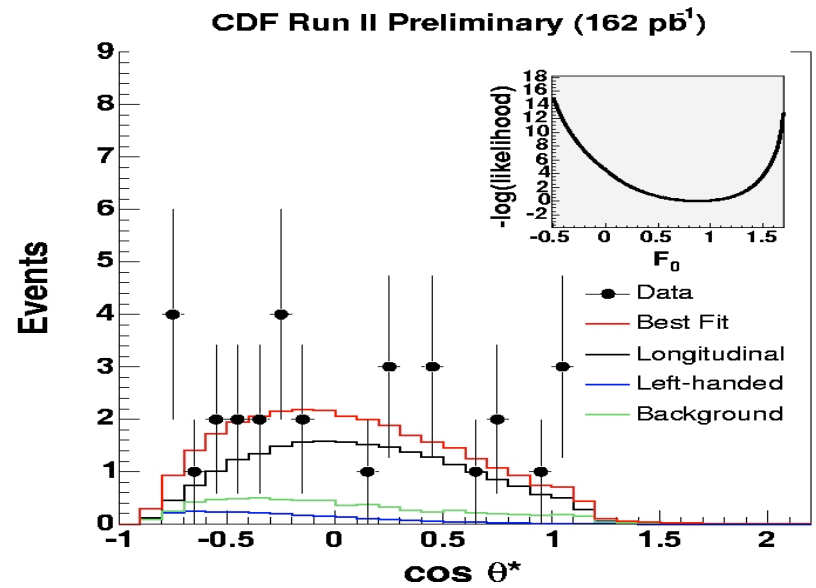


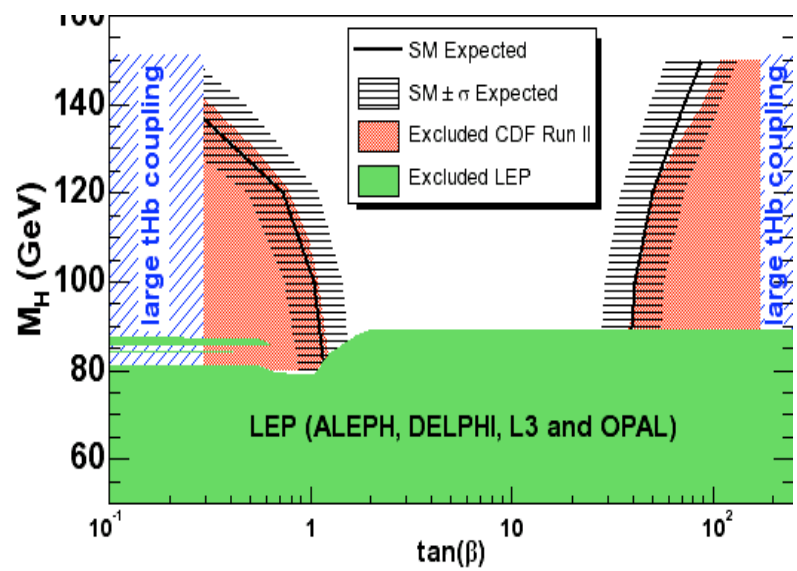




Top Quark Properties

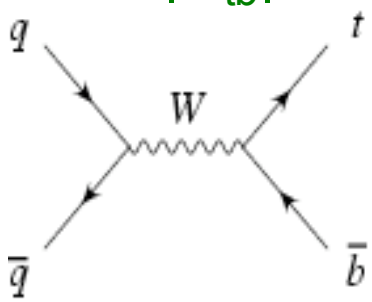
- Is *tWb* vertex SM? - W helicity
  - SM is V-A theory:
    - F_0 = 70% longitudinal
    - F_- = 30% left-handed
  - Assume F_+=0 (ie no V+A)
    - Measure F_0
    - $F_0 > 0.25$ @ 95% C.L.
- Unexpected top decay modes?
  - 3 gen. CKM matrix unitarity
    - $|V_{tb}|$~1.0
    - BR(t→Wb)/BR(t→Wq) ~1.0
    - BR(t→Wb)/BR(t→Wq) > 0.62 at 95% C.L. (CDF)
- t → H^+b instead of W^+b ?



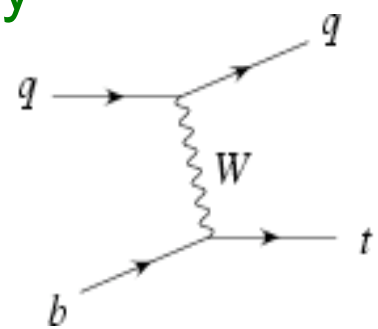


Single Top Production (via weak interaction)

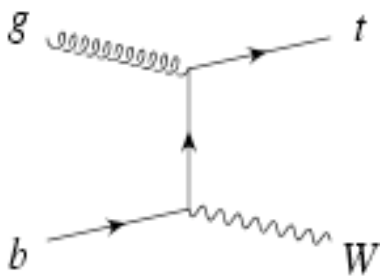
- Why search for single top?
  - Probe $|V_{tb}|$ directly



0.88 ± 0.11 pb



1.98 ± 0.25 pb

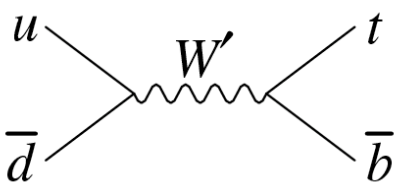


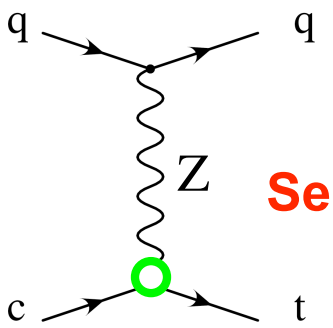
< 0.1 pb

  - New physics!

s-channel

Sensitive to resonances





t-channel

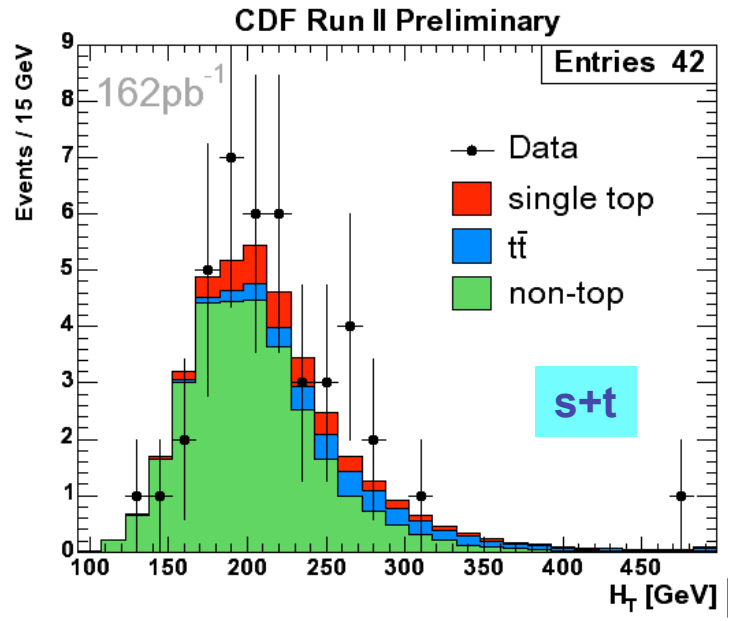
Sensitive to FCNCs

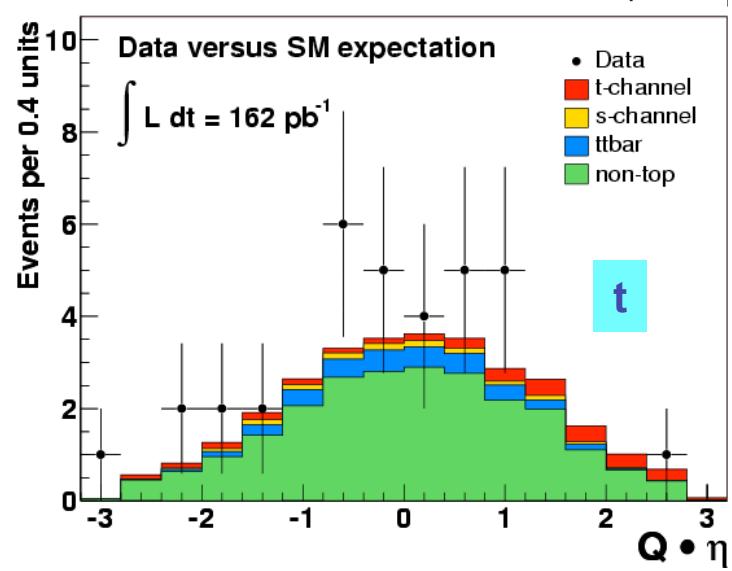
  - Similar topology to Higgs Signature (WH → Wbb)

Search for Single Top

Topology:

Somewhere between W+jets and top pair





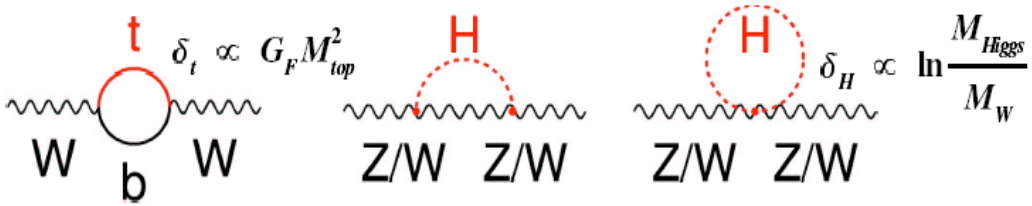
95% C.L. limits Observed (Expected)

Channel	CDF (pb)
s	< 13.6 (12.1)
t	< 10.1 (11.2)
s+t	< 17.8 (13.6)

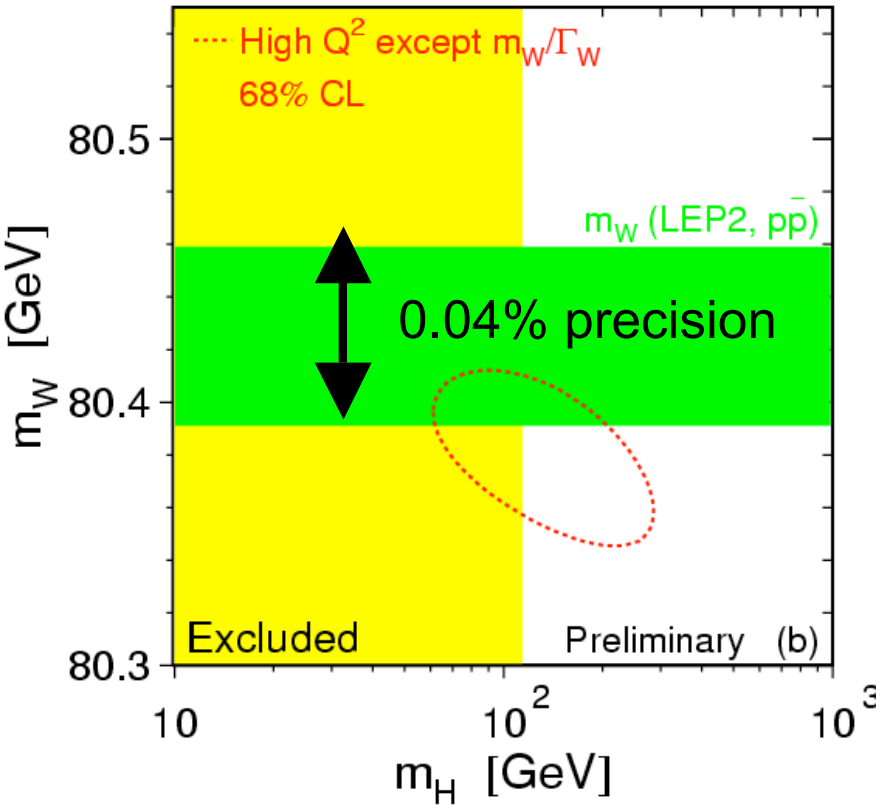
Physics with Vector Bosons

SM Prediction for W Mass

Radiative corrections make W mass sensitive to top and Higgs mass



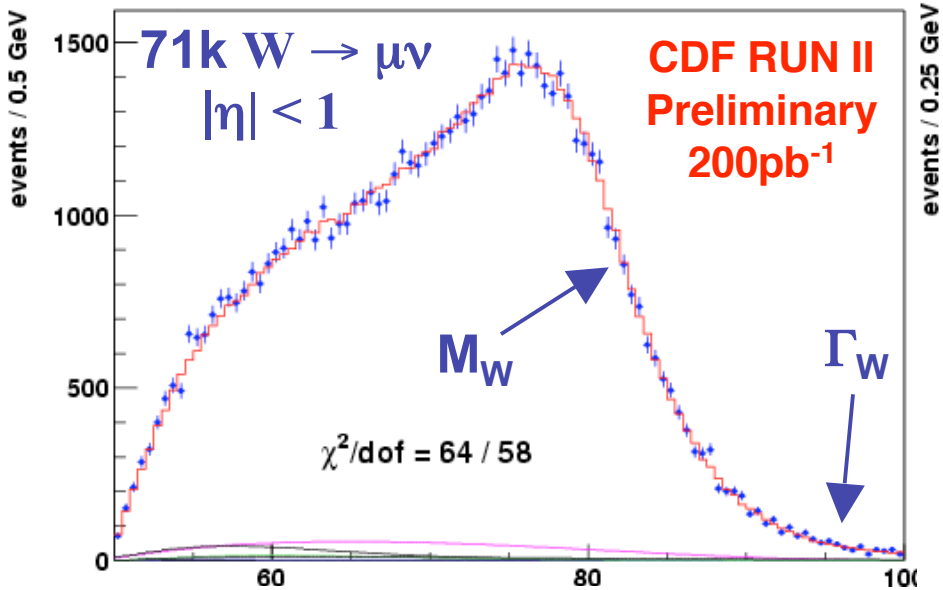
$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r)$$



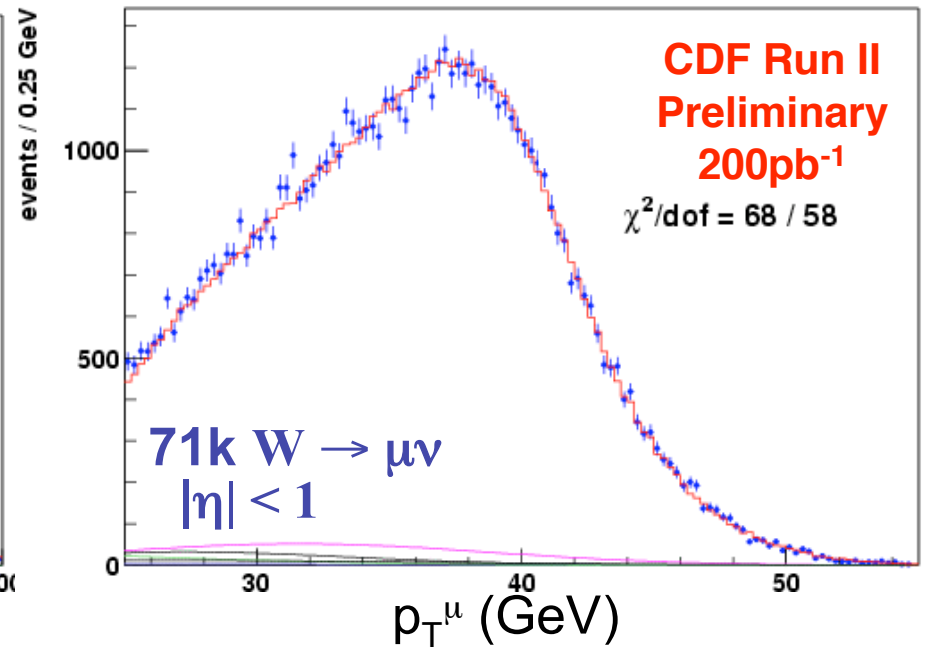
SM prediction for W mass dominated by error on top mass

	Experiment ΔM_{top}(GeV)	Prediction ΔM_W (MeV)
Tevatron Run I	4.3	26
Tevatron Run II	2.5	15
LHC	1.3	8
LC	0.1	-

W Mass Measurement

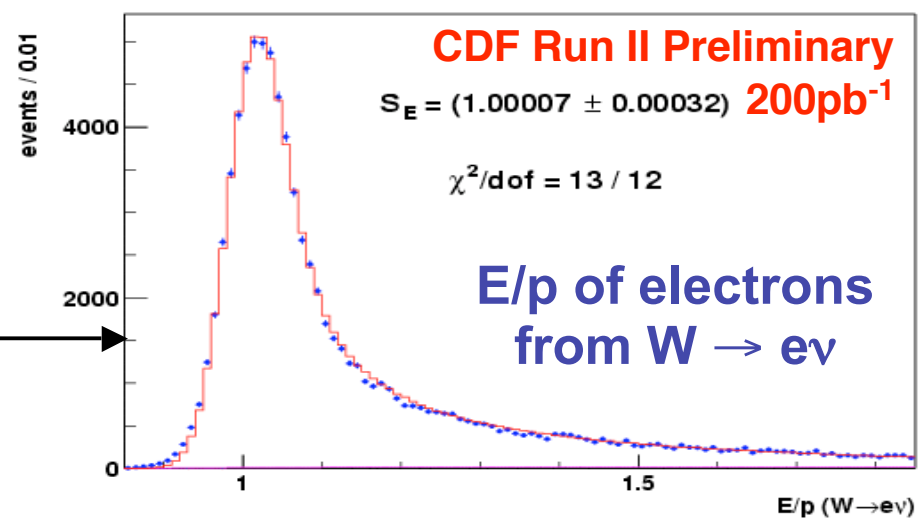


$$M_T = \sqrt{2E_T^{l}E_T^{\nu}(1-\cos\phi_{l\nu})} \quad \text{(GeV)}$$

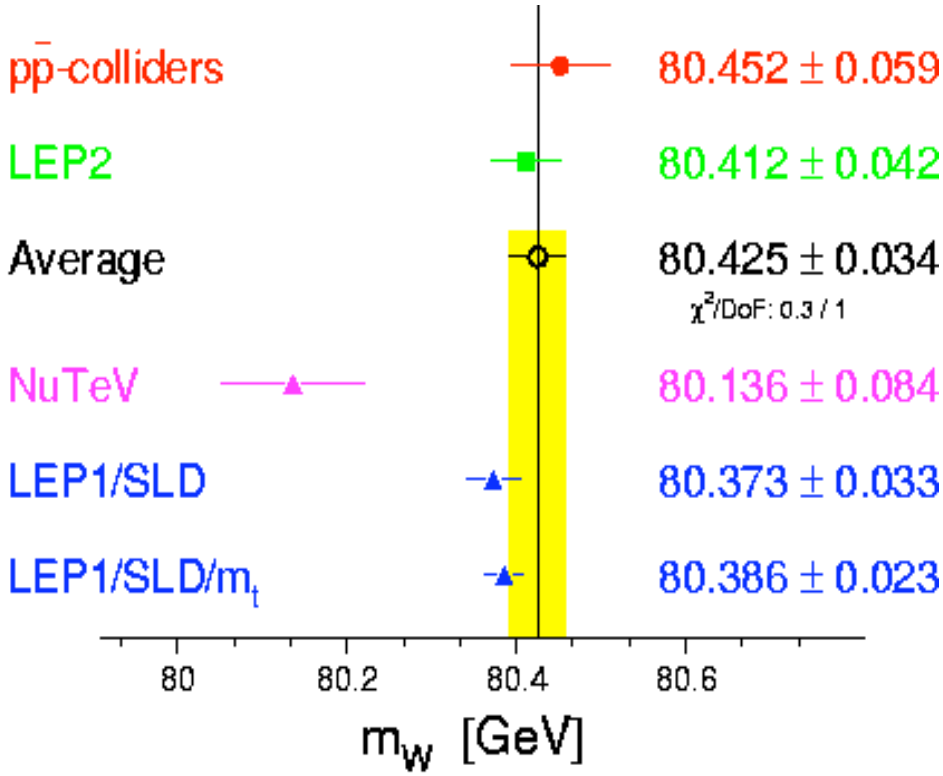


Statistical uncertainty ~ 35 MeV

Systematic uncertainty:
- Dominated by lepton E scale
- Most time and effort spent on detector calibration



W Mass Measurement



Experiment	ΔM_W
Run I Combined	59 MeV
Run I CDF	79 MeV
Run I D0	84 MeV
LEP-II Combined	42 MeV
ALEPH (Single Best)	58 MeV

CDF Run II W Mass:

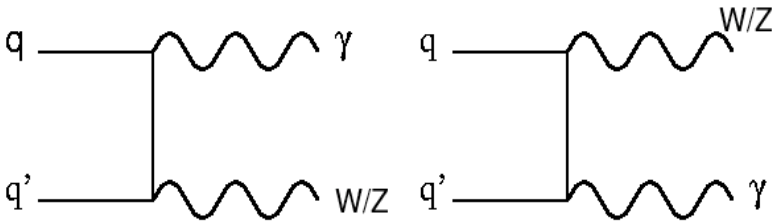
~76 MeV by this Winter (~200 pb^{-1}) - slightly better than Run I CDF

~50 MeV by Summer 2005 (~360 pb^{-1}) - single best

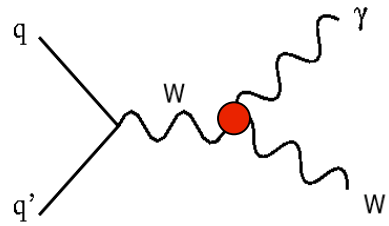
Under Godparents Review.

Wγ, Zγ Production

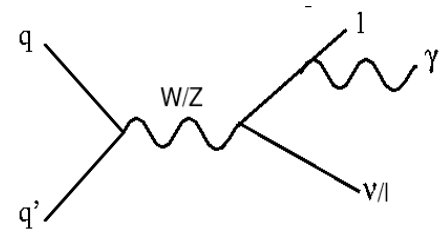
u- or t-channel

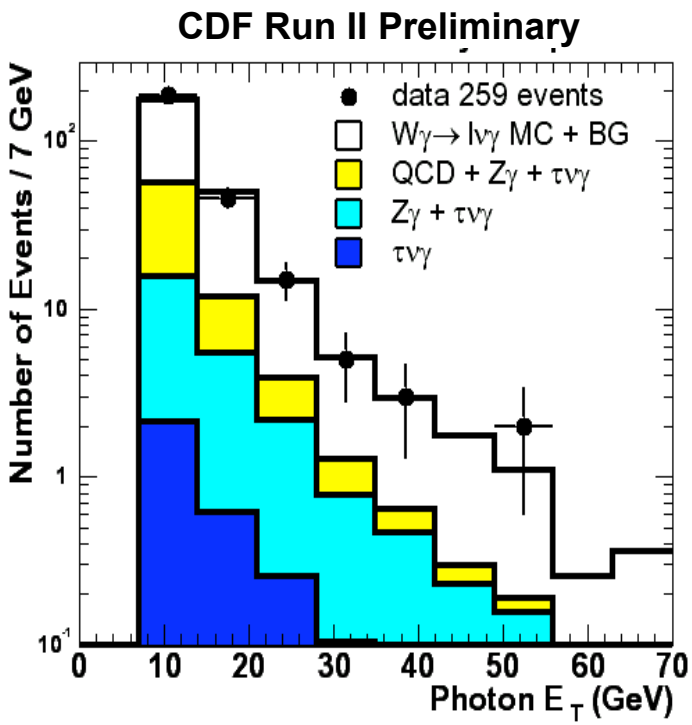


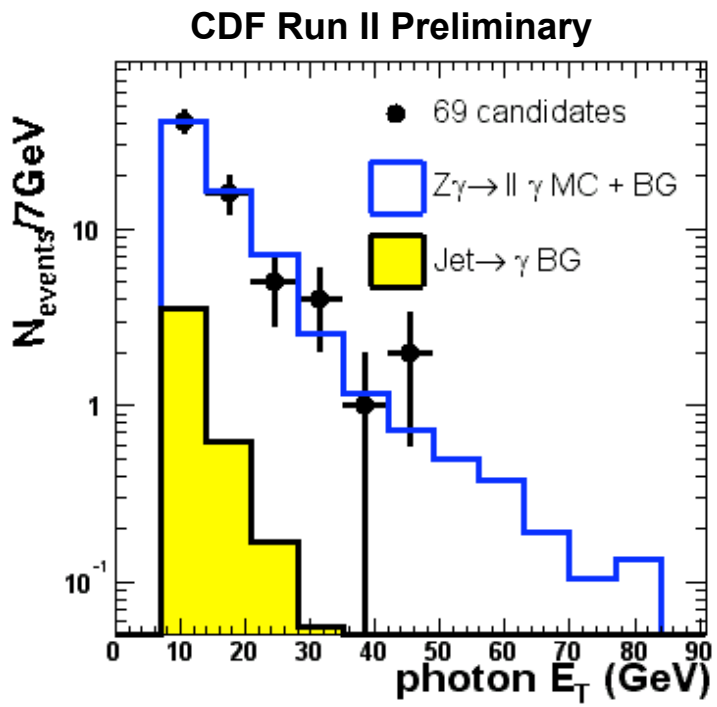
s-channel



final-state radiation

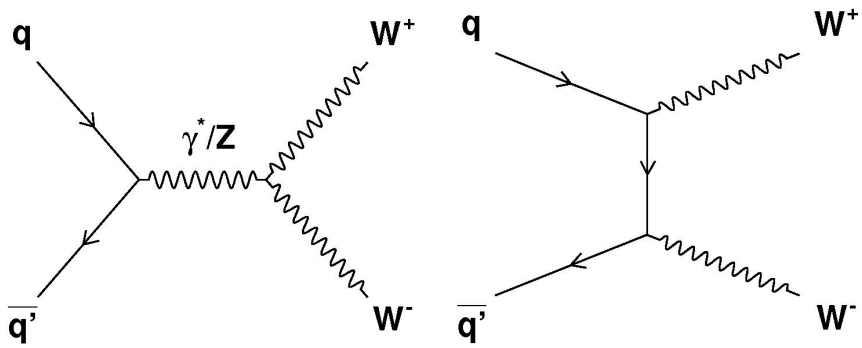




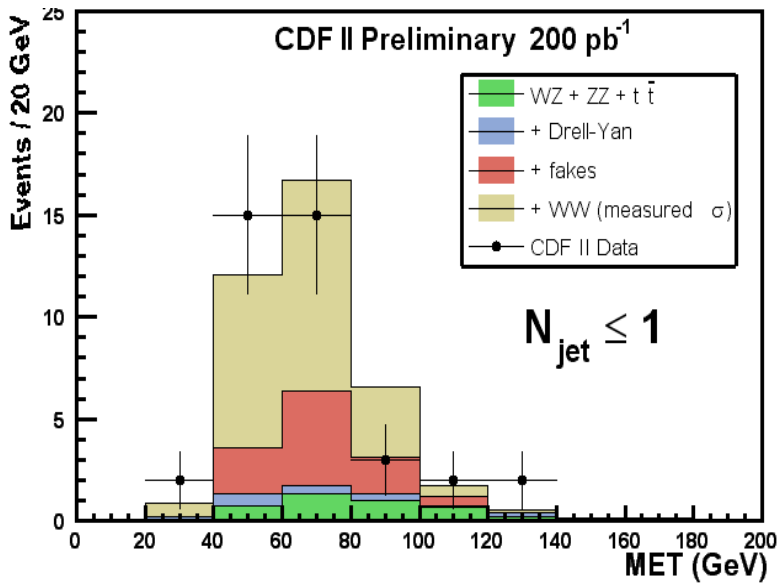


WW, WZ, ZZ Production

- WW (SM 12.5 ± 0.8 pb)
  - Trilinear Gauge Coupling - hard to beat LEP (40k WW)
  - Tevatron can produce higher mass than LEP.
  - Important backgrounds to Higgs search (H -> WW)!



$$\sigma(WW) = 14.3 \pm^{5.6}_{4.9} \pm^{1.8}_{1.8} pb$$



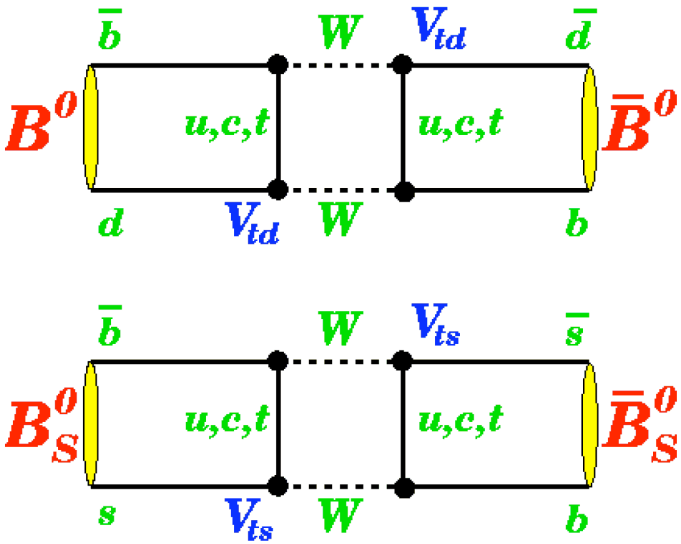
- Still searching for WZ, ZZ (SM WW 5.2 ± 0.4 pb)

$$\sigma(WZ) < 13.9 pb @ 95\% \ C.L.$$

Physics with Beauty and Charm Hadrons

Luciano Ristori and Young-Kee Kim

B Mixing

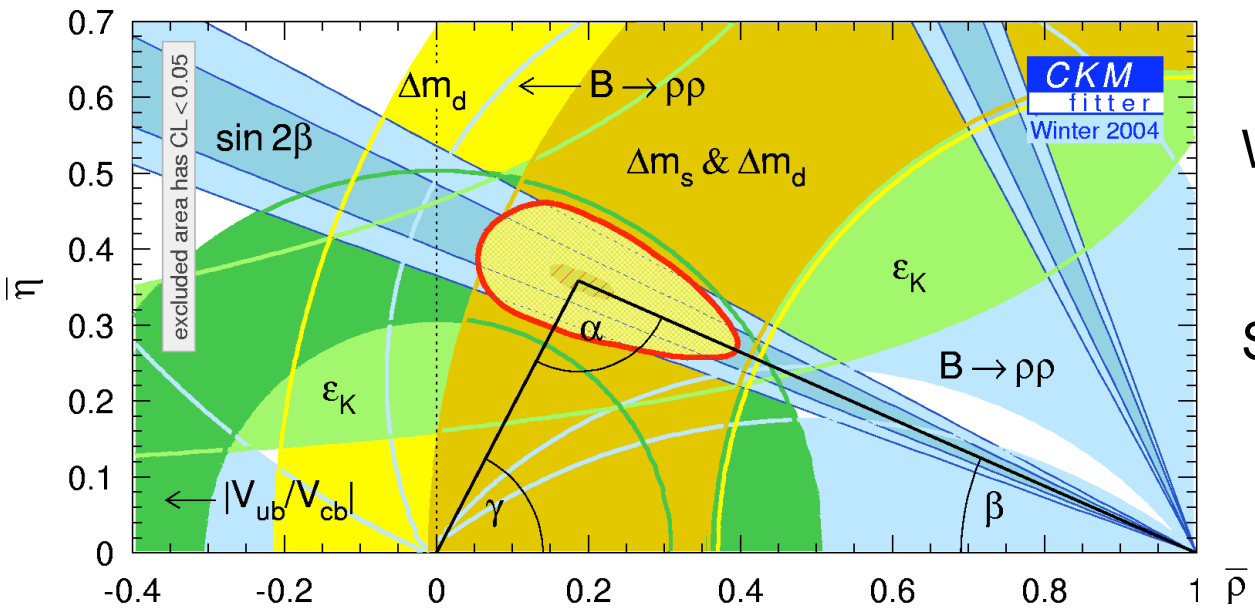


- B_d , B_s oscillations are sensitive to $|V_{td}|$, $|V_{td}|$
- Compromised by hadronic uncertainties
- Most cancel in B_d/B_s oscillation ratio

$$\frac{|V_{td}|}{|V_{ts}|} = 1.01\xi\sqrt{\frac{\Delta m_d}{\Delta m_s}}$$

$|V_{ts}| >> |V_{td}|$ ⇨ $\Delta m_s >> \Delta m_d$

- New physics may affect $\Delta m_s/\Delta m_d$
- .Δm_s prerequisite for time-dependent B_s CP violation measurement



World limit:

$\Delta m_s > 14.4\ ps^{-1}$

SM pred. (99% prob.):

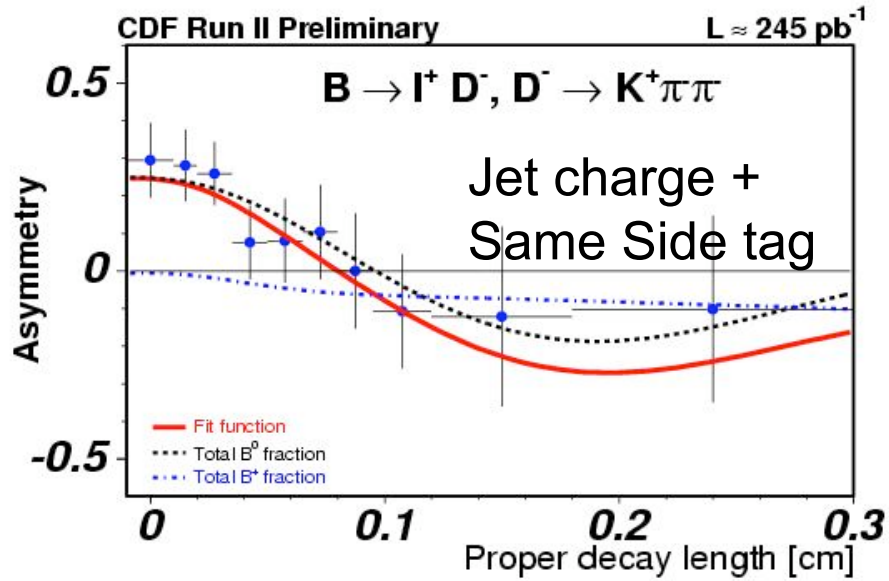
$15 < \Delta m_s < 27\ ps^{-1}$

B_d Mixing Measurements

prepare machinery for B_s mixing analysis

semileptonic modes:

flavor (B or $\bar{B}$) tagging efficiency
at production $\varepsilon D^2 \sim$ 2-3% (CDF, D0)



Δm_d(CDF) = 0.536 ± 0.037(stat) ± 0.017(syst) pb^{-1}

fully reconstructed modes:

$B_d \rightarrow J/\psi\ K^{*0} \rightarrow \mu^+\mu^-\ K^+\pi^-$, $B_d \rightarrow D^-\pi^+$, $D^{*-}\pi^+$, $D^-\pi^+\pi^-\pi^+$, $D^{*-}\pi^+\pi^-\pi^+$

Δm_d (CDF) = 0.526 ± 0.056(stat) ± 0.005(syst), $\varepsilon D^2 \sim$ 1%(SST)

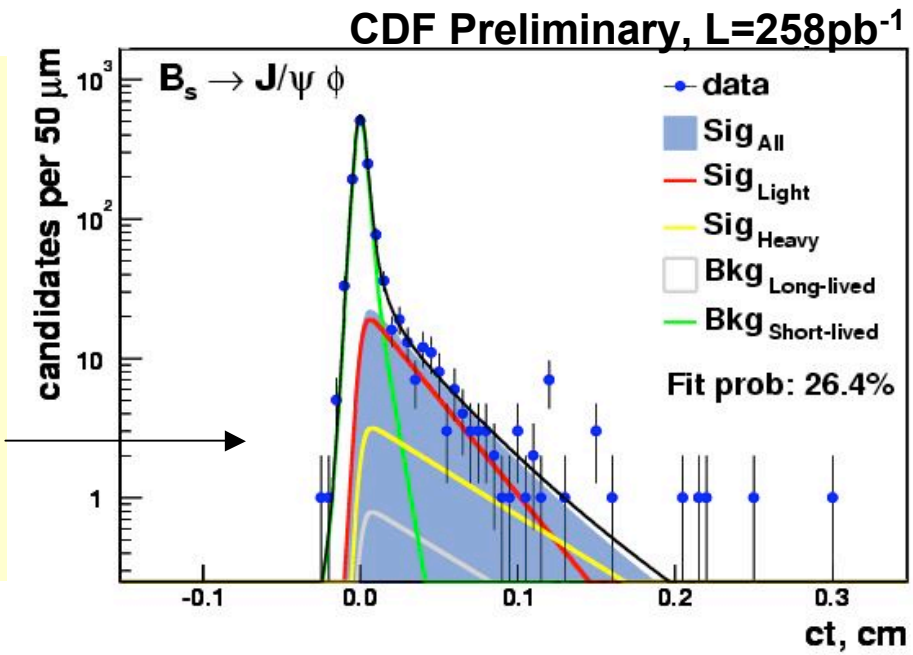
$\Delta\Gamma_s$ and Δm_s

$\tau(B_s)$ = 1.37 ± 0.10 ± 0.01 ps

$\Delta\Gamma_s$ Lifetime difference ($\Delta\Gamma_s$) between B_s eigenstates.
CP-odd(B_{heavy}) and CP-even(B_{light}) have different angular distributions.

SM:
$\Delta\Gamma_s / \Gamma_s$ (SM) = 0.12 ± 0.06
(hep-ph/0012219)

CDF:
$\Delta\Gamma_s$ = 0.46 ± 0.18 ± 0.01 ps^{-1}
$\Delta\Gamma_s / \Gamma_s = 0.71\ ^{+0.24}_{-0.28} \pm 0.01$
(with $\Gamma_s = \Gamma_d$ constraint)



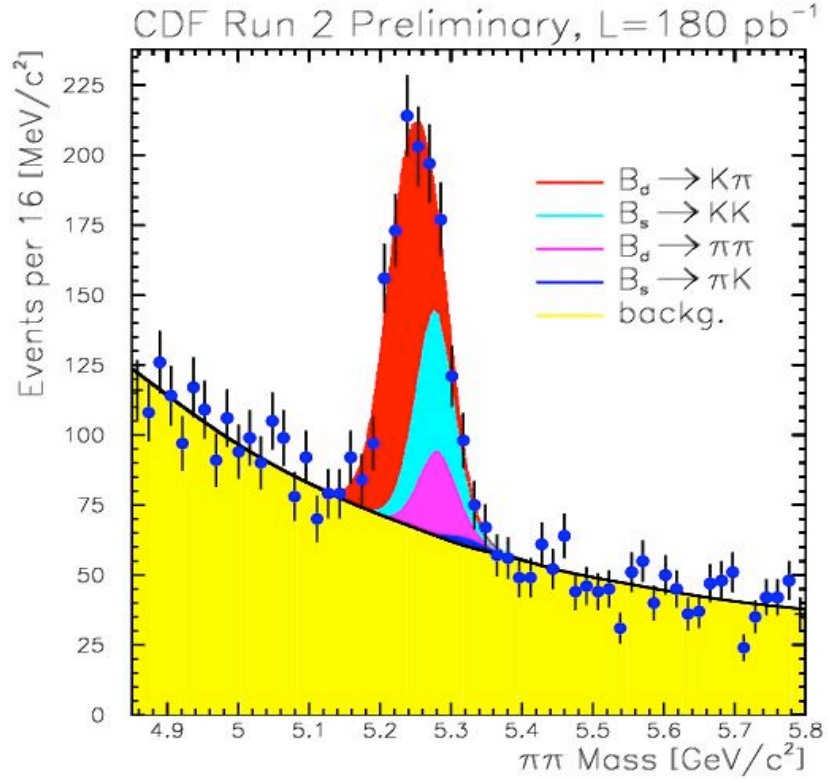
Δm_s To first approx: $\Delta\Gamma_s / \Delta m_s = 1.5\pi\ m_b^2 / m_t^2 = 3.7\ ^{+0.8}_{-1.5} \times 10^{-3}$
(see Beneke et al. for full form NLO analysis, hep-ph/9808385)

Δm_s (indirect) = $125\ ^{+69}_{-55}\ ps^{-1}$ (SM 99%: $15 < \Delta m_s < 27\ ps^{-1}$)

Charmless B Decays $B_{s,d} \to h^+h^-$

- ***$B_{s,d} \to h^+h^-$***
  - $B_d \to \pi\pi$ and $B_s \to KK$ modes: sensitive to CP angle γ (Fleischer)
  - $B_{d,s} \to \pi\pi$, $K\pi$, KK are separated statistically by kinematics and particle ID.

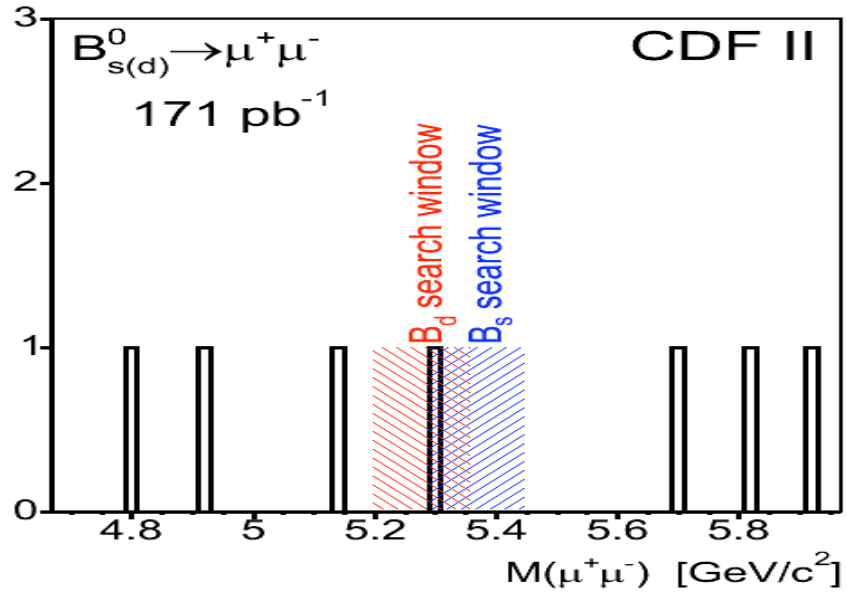
$B^0 \to \pi\pi$	134	15%
$B^0 \to K\pi$	509	57%
$B_s \to KK$	232	26%
$B_s \to K\pi$	18	2%

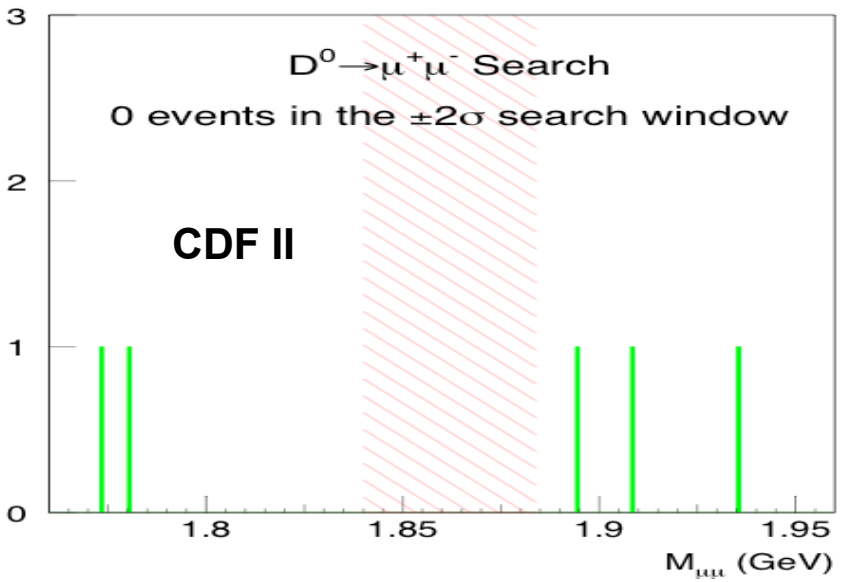


$$Br(B_d \to \pi\pi) / Br(B_d \to K\pi) = 0.24 \pm 0.06 \pm 0.05$$
$$f_s\, Br(B_s \to KK) / f_d\, Br(B_d \to K\pi) = 0.50 \pm 0.08 \pm 0.07$$
$$Br(B_s \to \pi\pi) / Br(B_s \to KK) < 0.10 \text{ @90\% CL}$$
$$f_s\, Br(B_s \to K\pi) / f_d\, Br(B_d \to K\pi) < 0.11 \text{ @90\% CL}$$
$$A_{CP} = [N(B_d \to K^-\pi^+) - N(B_d \to K^+\pi^-)] / N(B_d \to K^-\pi^+, K^+\pi^-) = -0.04 \pm 0.08 \pm 0.01$$

$$A_{CP}^{BaBar} = -0.133 \pm 0.030 \pm 0.009,\ A_{CP}^{Belle} = -0.101 \pm 0.025 \pm 0.005$$

B_s, B_d, $D^0 \rightarrow \mu^+\mu^-$





SM expectations:

$Br(B_s \rightarrow \mu\mu) \sim 3.5 \times 10^{-9}$

$Br(D^0 \rightarrow \mu\mu) \sim 10^{-13}$

SUSY: $Br(B_s \rightarrow \mu\mu) \sim \tan^6\beta$

Can be enhanced by 10-1000.

e.g. $\tan\beta \sim 40$ for $Br \sim 10^{-7}$

95% CL $\mu^+\mu^-$ Br limits:

B_s : 7.5×10^{-7} (unique to Tevatron)

B_d : 1.9×10^{-7}

D^0 : 2.5×10^{-6}

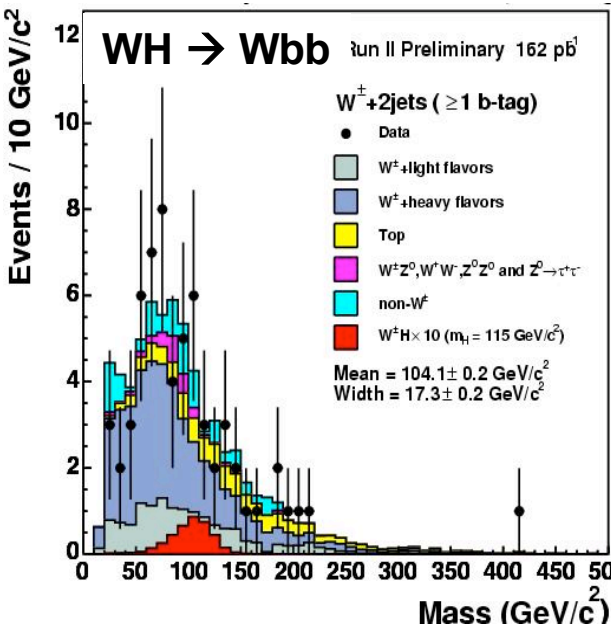
Excludes SO_{10} space(hep-ph/0304101), large parts of R-parity violating SUSY. Smaller exclusion in mSUGRA MSSM

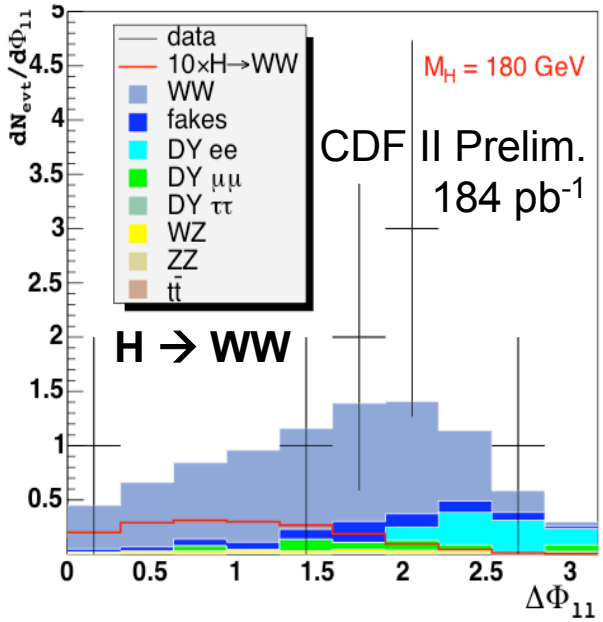
Improved limits with full data sample by this winter.

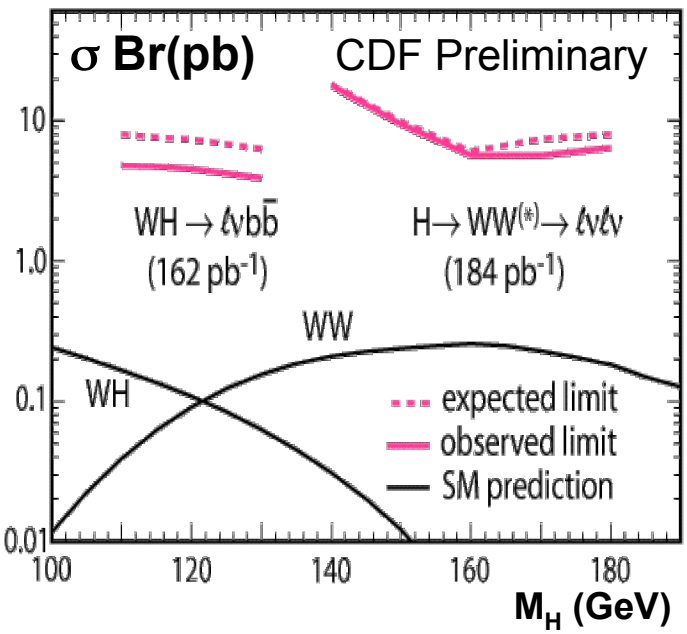
Standard Model Higgs Searches
SUSY Searches
Other Searches

Standard Model Higgs Search

M_H < 130 GeV: W,Z + H (→ bb) M_H > 130 GeV: H → WW







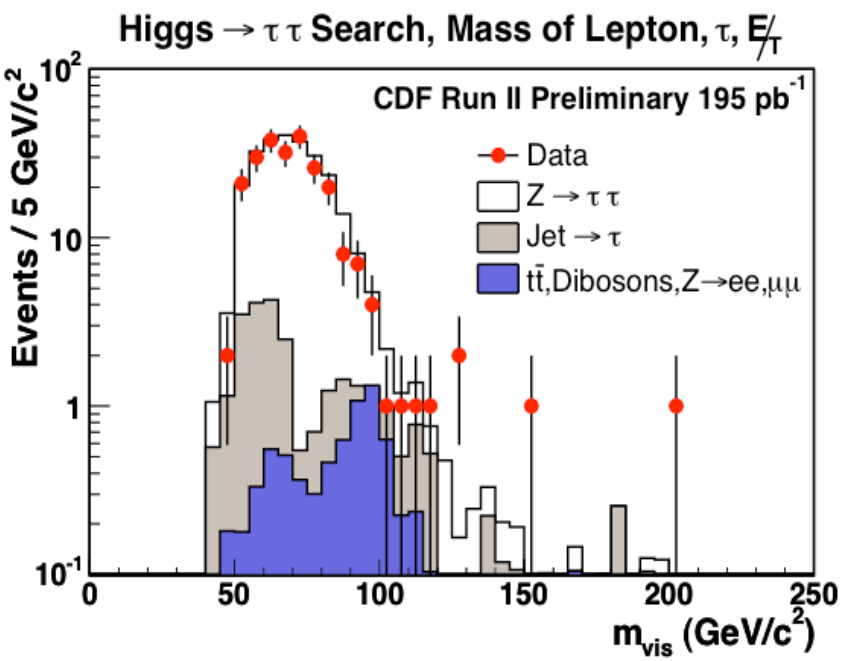
- SM: Limits already exceeding Run I results.
  Sensitivity beyond LEP exclusion starts at ~2 fb^{-1}.
- New Physics: Interesting sensitivity to other new physics sooner?
- Improvements expected from
  - Better *b* tagging, topological (spin 0) information, more channels(ZH), better mass resolution (Z → bb sample)

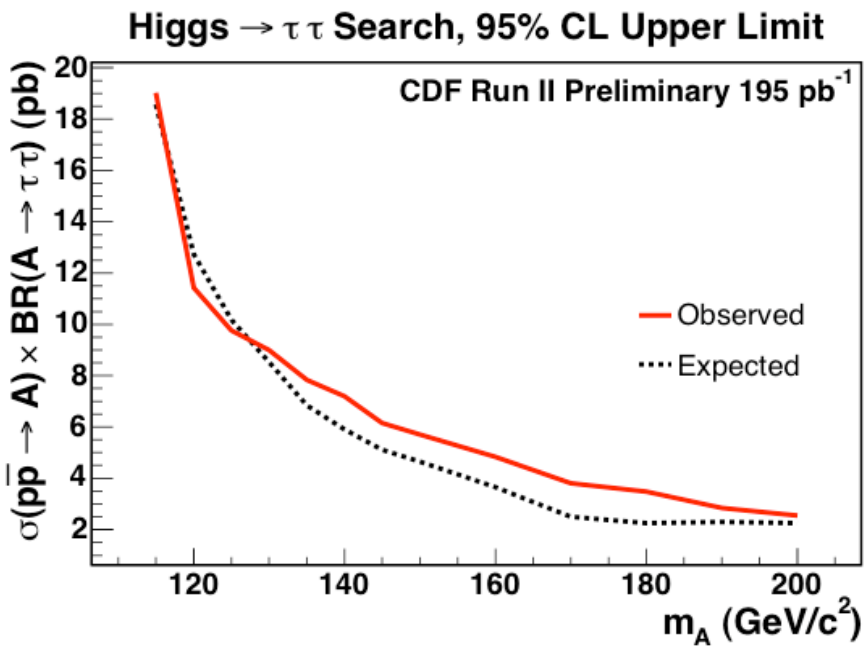
MSSM Higgs Search

at high tanβ:

- enhanced x-sections
- heavy flavor (b, τ) preferred

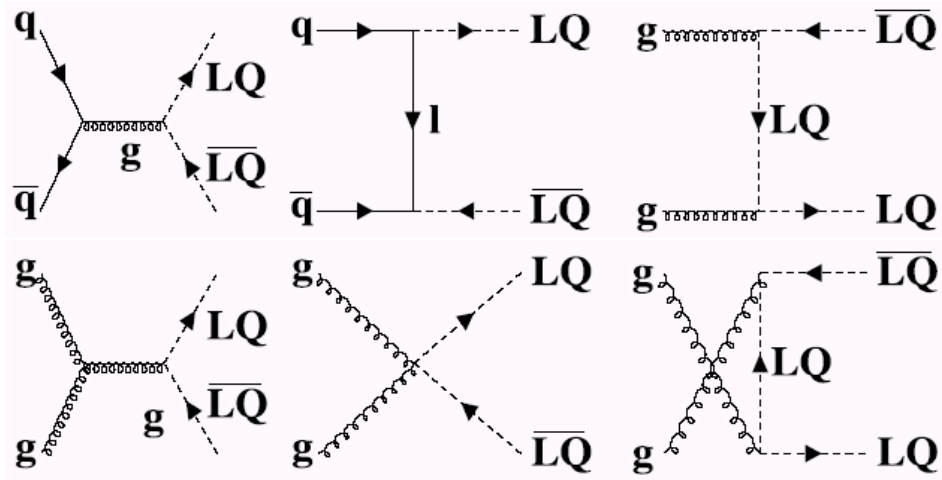
φ (from gg or qq) or bbφ production with φ → ττ

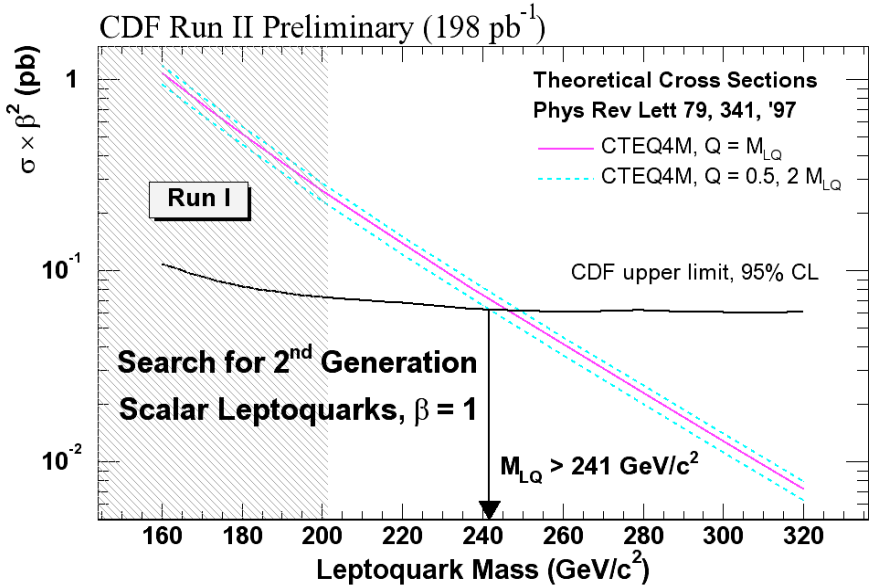




Leptoquarks

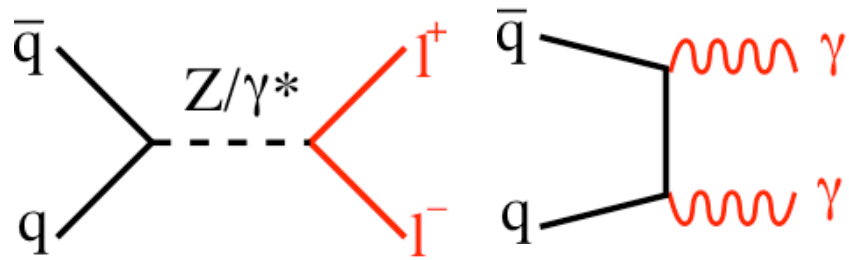
- Leptoquarks appear in many SM extensions.
  - LQ carry both lepton and baryon number
- Limits
  - First generation:
    - $LQ_1 \rightarrow eq$ (100%)
      - 230 GeV at 95% CL
    - $LQ_1 \rightarrow eq$ (50%)
      - 176 GeV at 95% CL
  - Second generation:
    - $LQ_2 \rightarrow \mu q$ (100%)
      - 241 GeV at 95% CL





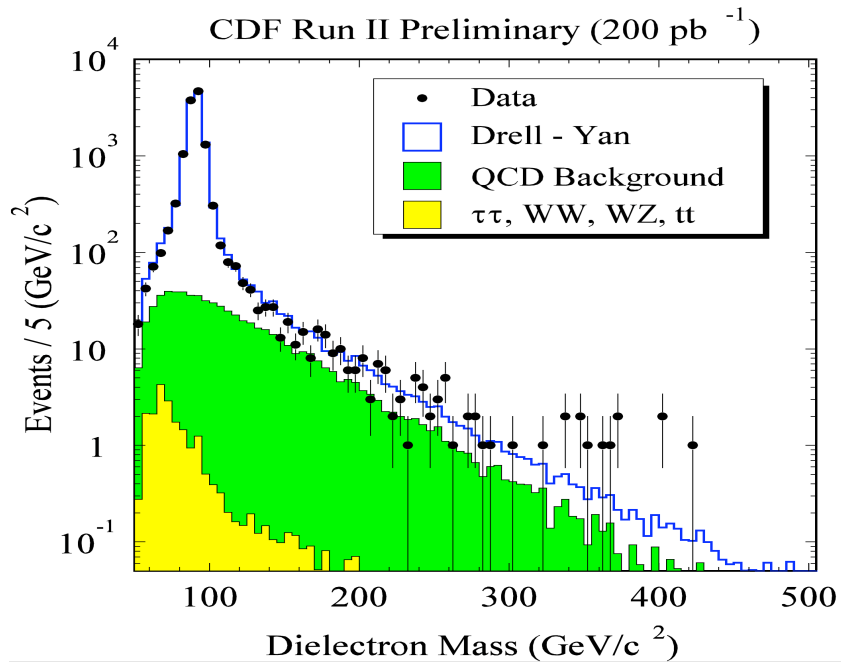
Very High P_T Physics

SM High Mass Production:



New Physics at high mass:

- Resonance Signature
  - Spin-1: Z'
  - Spin-2: Randall-Sundrum (RS) Graviton
- Tail Enhancement
  - Large Extra Dimensions: Arkani-Hamed, Dimopoulos, Dvali (ADD)
  - Contact interaction



Z' by CDF with ee + μμ

(815 GeV w/ SM decays)

Conclusions

- Detectors
  - CDF detectors are performing well.
  - Triggers & DAQ - continuously improving

- Data analysis
  - Producing many physics results. Publications from all physics groups - making good progress
  - currently analyzing ~400 pb^{-1} data (4 x Run I data)
    - doubled data up to summer 2003.
  - understanding detectors and backgrounds
  - developing and optimizing physics algorithms
  - much better measurements will come soon.

- Coming year
  - Double the data again by summer 2005 hopefully (8 x Run I)
  - Opportunity for discovery good with new confident in luminosity.