Tevatron Physics Prospects

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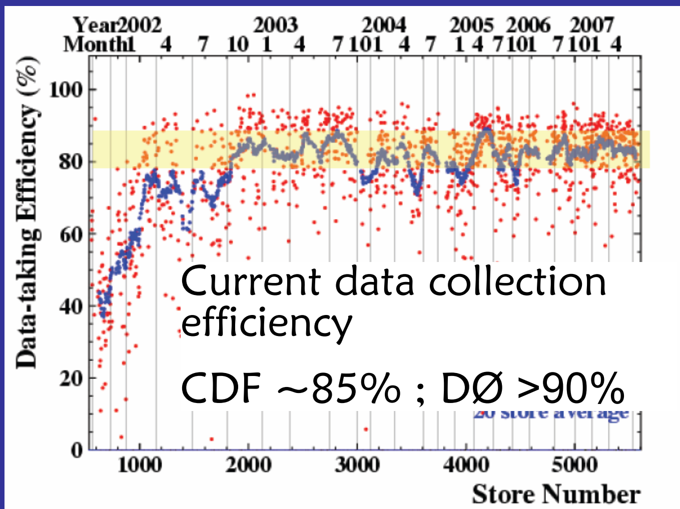
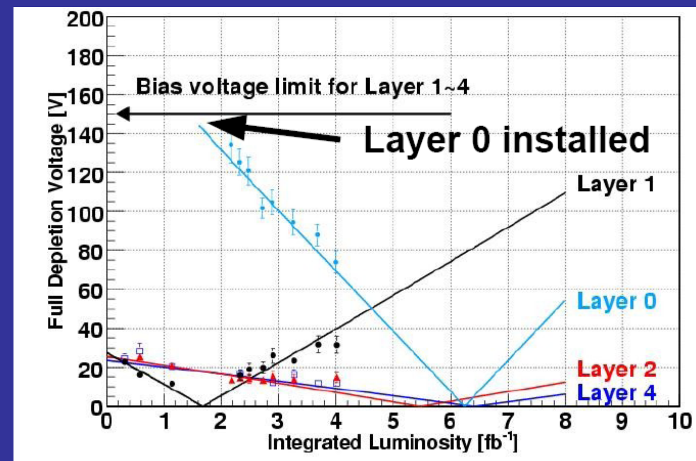
ICFA Seminar, Oct. 29 2008

CDF and DØ Operations

❖ Fermilab is planning to run CDF and DØ through FY2010. The Tevatron is now delivering close to its upper projection. We expect 7.7 – 8.8 fb^{-1} delivered per experiment. This corresponds to between 6.2 – 7.0 fb^{-1} in analyzed data sets.



❖ CDF and DØ are running very stably and efficiently. Net efficiency (live time, good data quality) ~80%.



Total $\mathcal{L}$ for Run II

❖ All detector subsystems should survive for 8 fb^{-1} of data (DØ silicon shown here)

❖ Projected manpower covers needs.

CDF

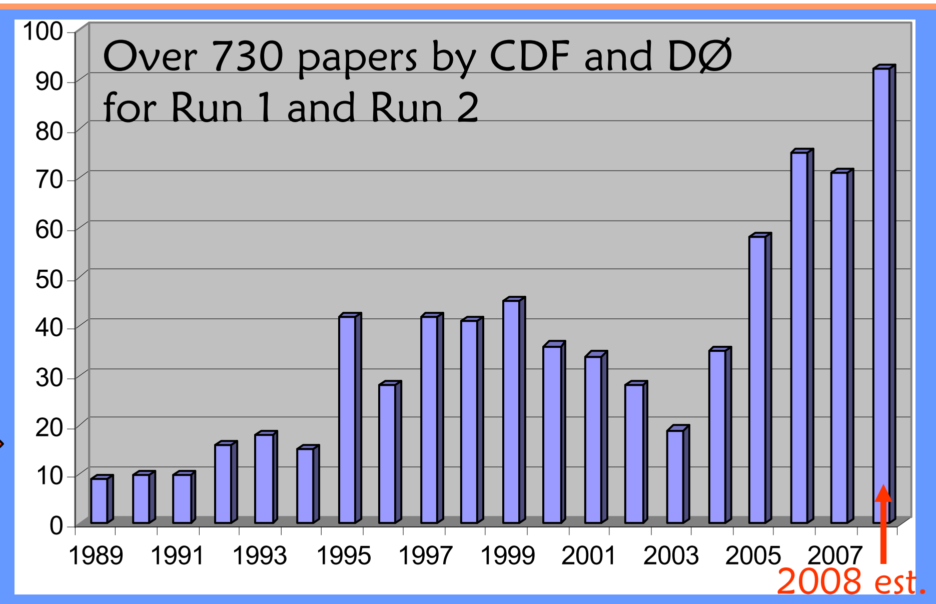
	CY 07	CY 09
Detector Ops	50	45
Offline	26	20
Algorithms	32	21
Management	10	10
Total	118	96
Resources Available	392	236
FTE for Physics	392 – 118 = 284	140

DØ

Physicist FTE's	2007	2008	2009	2010	2011
2007-2009 MoU data	357	272	184		
2009-2011 MoU data			240	185	119

Physics projections

Insets will show results to date – the springboard for discussing future physics



Over 5 fb^{-1} now delivered to both experiments. Physics analyses to date typically use 1.5–3 fb^{-1}, so final results full data set will have 2.5 – 4 times more statistics.

- Most analyses still improving faster than $1/\mathcal{L}^{1/2}$ due to improvements in techniques

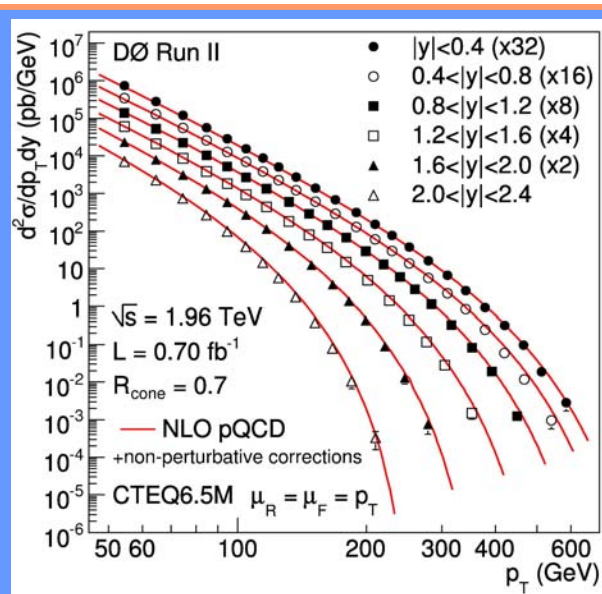
No further upgrades to detectors; triggers are now stable.

Physics analyses in CDF and DØ based in six working groups:

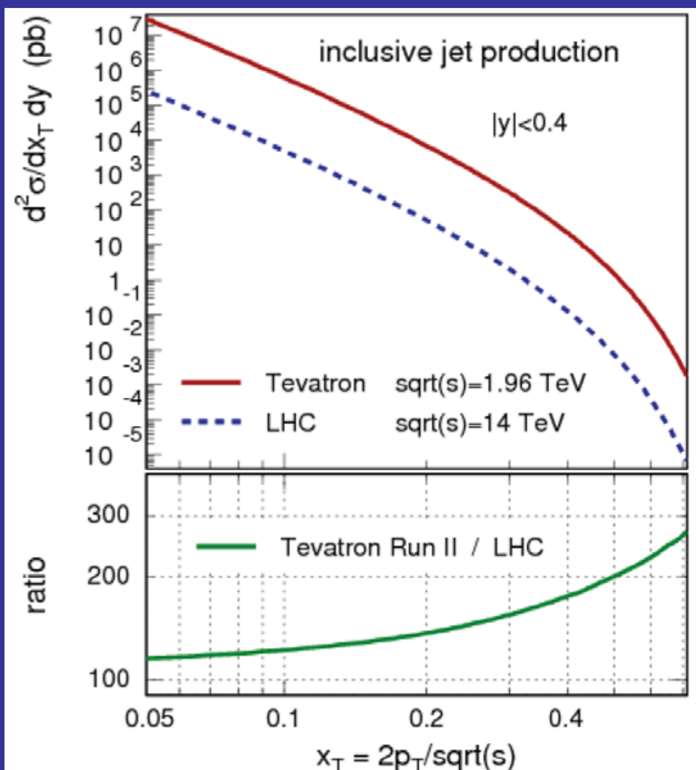
- QCD studies
- Heavy flavor (b,c) states
- Electroweak bosons
- Top quark properties
- Higgs boson searches
- Searches for phenomena beyond the SM

QCD studies

Studies of perturbative and non-perturbative QCD have extended HERA and LEP measurements. The well calibrated detectors give Tevatron an edge for some time.



Inclusive jet production to very large p_T and rapidity favoring lower gluon content at large x.

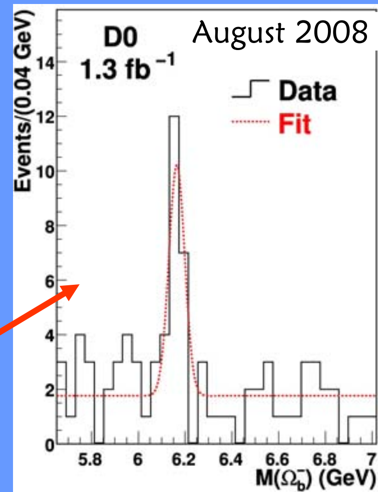


- Jet production at Tevatron is essential input on PDFs for LHC. LHC will need ~200 fb^{-1} to reach Tevatron precision at high x. The 1% precision on jet energy scale will take years for LHC to achieve.
- Dijet angular distributions are a sensitive probe of new physics; already extending limits on many models of extra dimensions, compositeness. Still statistics limited. W decay asymmetry constrains (u–d) distribution.
- Measurements of W+jets/ Z+jets/ γ+jets (including V+heavy flavor) are essential to understand bkgds and tune event generators, both for Tevatron and LHC. These are currently statistics limited.

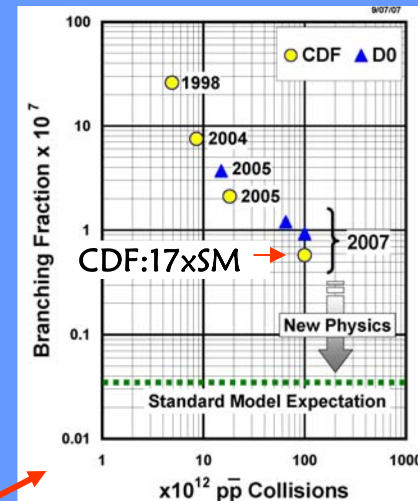
b-quark physics

Tevatron produces heavy b-quark hadrons inaccessible at B-factories:

- Have added to Λ_b(udb) seen by UA1: $\Sigma_b^{\pm}$ (uub, ddb), Ξ_b(dsb), Ω_b(ssb)
- Extensive study of B_C, B_S mesons



Ω_b discovery



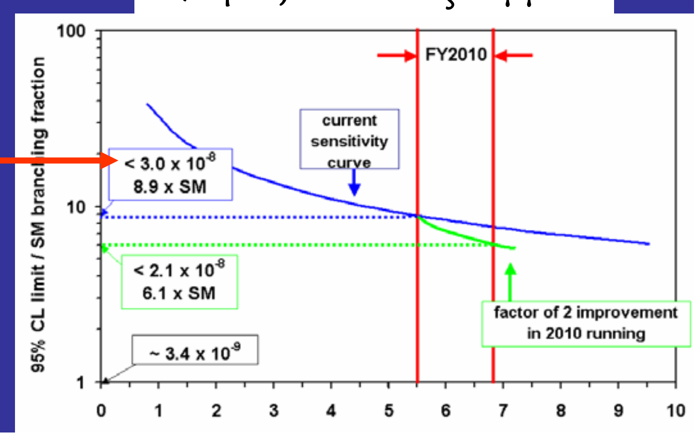
$B_S \rightarrow \mu\mu$ limits

~4-fold increase in statistics will give improved heavy flavor mass determinations, lifetime measurements, production cross sections (and ratios). All of these are important for confronting Heavy Quark Effective Theory predictions and understanding of the strong interactions of bound heavy flavor.

Rare b-hadron decays probe new non-SM physics. In MSSM, $B_S \rightarrow \mu\mu$ rate is enhanced by $\tan^6\beta$. Expect about 6xSM per experiment with 8 fb^{-1}.

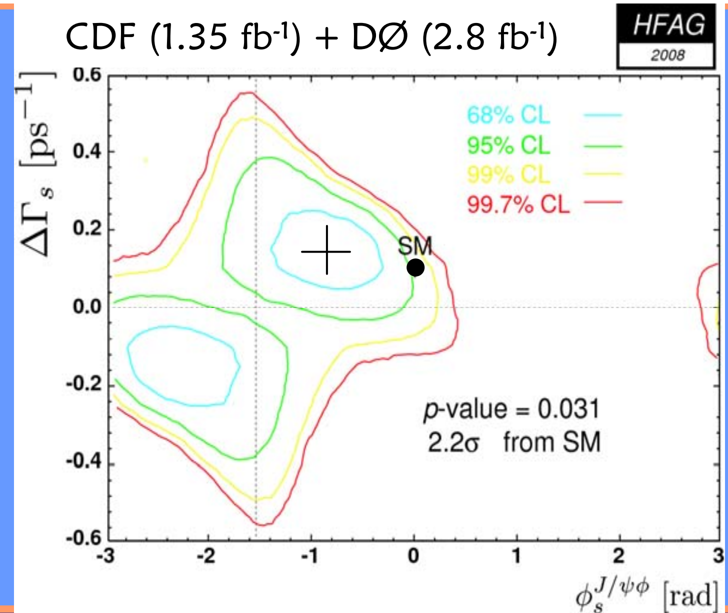
Also pushing limits for $B_S \rightarrow e\mu$, $D \rightarrow \mu\mu$, etc.

DØ projection: $B_S \rightarrow \mu\mu$



$\not{C}\!\!\not{P}$ in B_s system

CDF+DØ see <u>2.2σ deviation from SM</u> in joint fit of $\Delta\Gamma_s$ vs. ϕ_s for $B_s \to J/\psi\ \phi$ thus hinting at new phenomena beyond the SM.



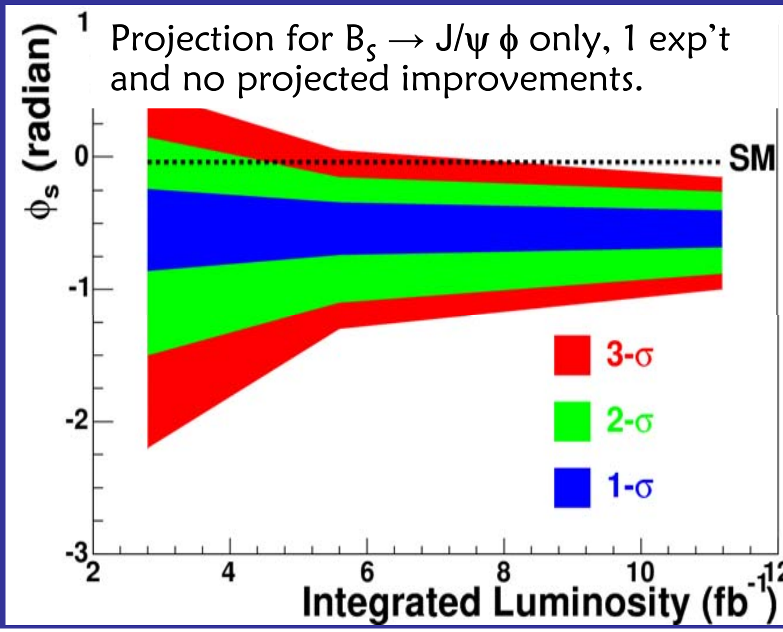
$$\Delta\Gamma_s = \Gamma_L - \Gamma_H = 2|\Gamma_{12}|\cos\phi_s$$

$$\phi_s = \phi_s^{SM} + \phi^{NP}$$
$$\phi_s^{SM} = 0.04 \pm 0.013$$

$B_s \to J/\psi\ \phi$, $B_s \to D_s^{\mp}\mu^{\pm}$ charge asymmetry and dimuon charge asymmetry ($\mu^+\mu^+$ vs. $\mu^-\mu^-$), time dependent $B_s \to D_s^-\mu^+X$ all provide further constraints on ϕ_s:

$$\phi_s = -0.76\ ^{+0.37}_{-0.33} \text{ radian} \quad (B_s \to J/\psi\ \phi)$$

More data, use of multiple analyses, and improved event selection and $B_s - \overline{B}_s$ tagging can give significant non-SM indication.



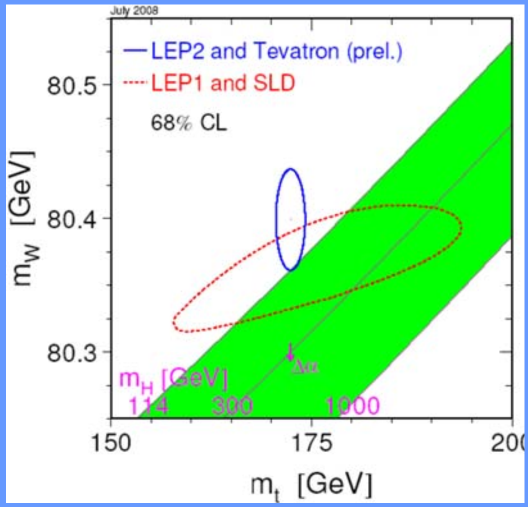
W boson mass

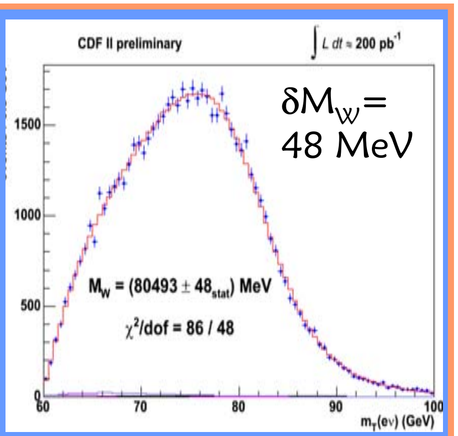
Constraint on SM Higgs is now dominated by W mass error.

M_W uncertainty is dominated by statistics of the Z sample used for calibrating and parametrizing the result, so more statistics will help. Theoretical uncertainties are ~10–15 MeV. With full data sample expect CDF+DØ combined error of ~15–20 MeV.

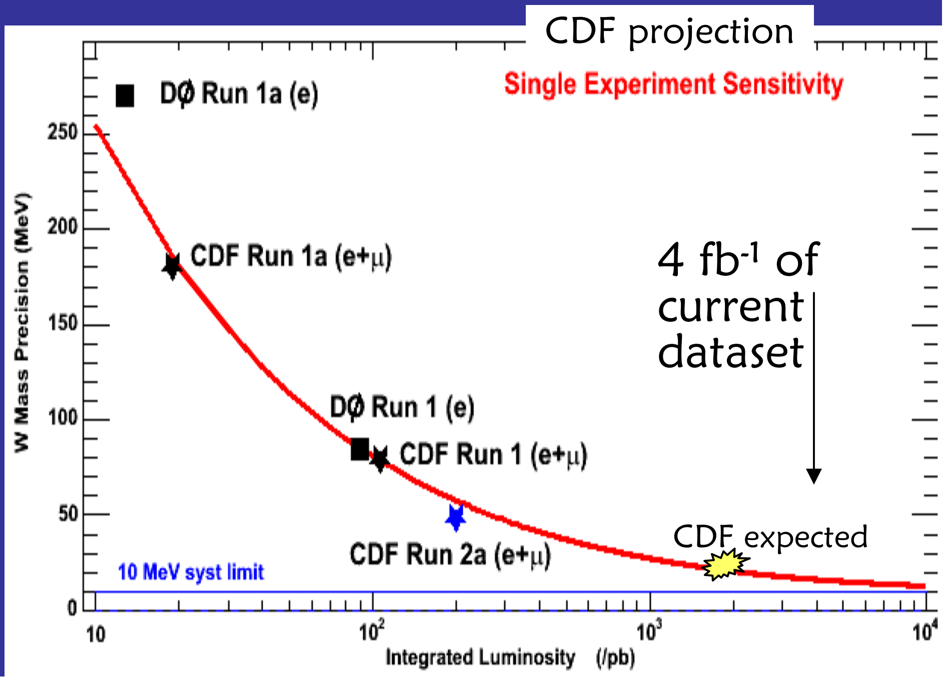
Require control of uncertainties on lepton energy scale, resolution, hadronic recoil, underlying event and pileup to a few MeV for quantities $\mathcal{O}(40)$ GeV !

This requires <u>very</u> well understood detectors, excellent control of noise & pileup. LHC expts will be challenged to reach the Tevatron precision.



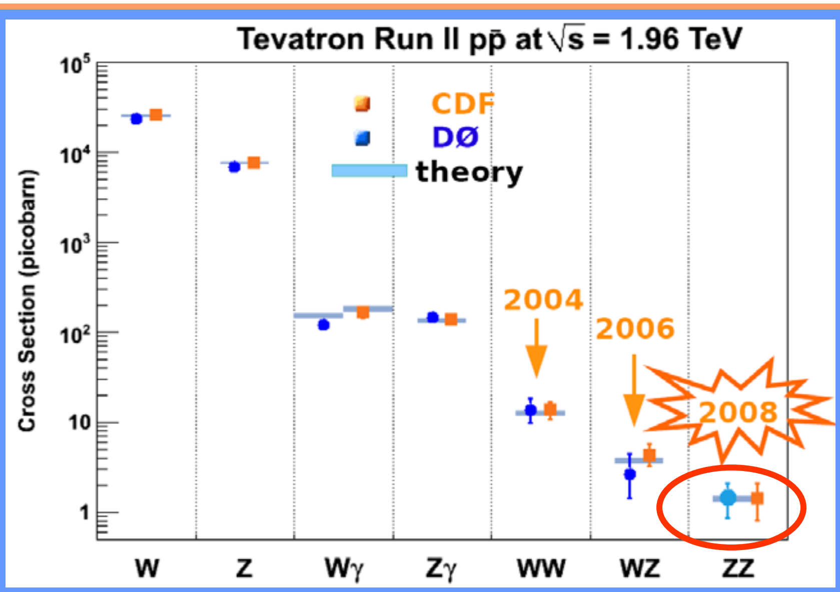


CDF W mass (200 pb^{-1}) is best single expt measurement



Diboson cross sections

At Tevatron, Wγ, Zγ, WW, WZ, ZZ processes have the smallest SM cross sections apart from Higgs. With the DØ 5.7σ observation of ZZ this summer, all have now been observed.



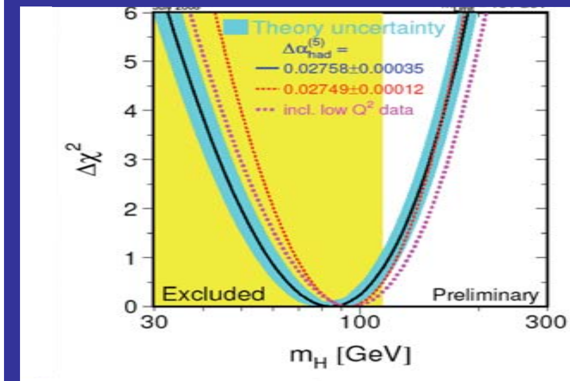
The diboson processes are important for several reasons:

- Search for anomalous trilinear couplings
- They are backgrounds for even rarer processes (EW production of top, Higgs, …). Experimental guidance on NLO/LO k-factors.
- Demonstration of techniques for Higgs search (e.g. W/Z+W → qq' $\ell\,\nu$)

Diboson measurements are dominated by statistics, so x(3–4) increase in data samples will help considerably.

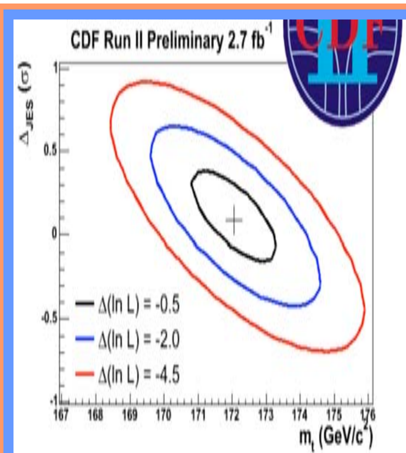
Top quark

Top quark mass is a key ingredient in predicting SM Higgs boson mass; now known to 0.7%. Top Yukawa coupling is special: $g_{tHw} = 0.991 \pm 0.007$!



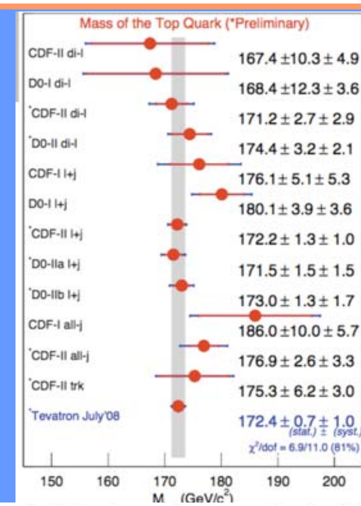
$m_H < 154$ GeV @ 95% C.L.

< 185 GeV with LEP2 limit



Best single meas.

$m_t = 172.2 \pm 1.0 \pm 1.3$ GeV



$m_t = 172.4 \pm 0.7 \pm 1.0$ GeV

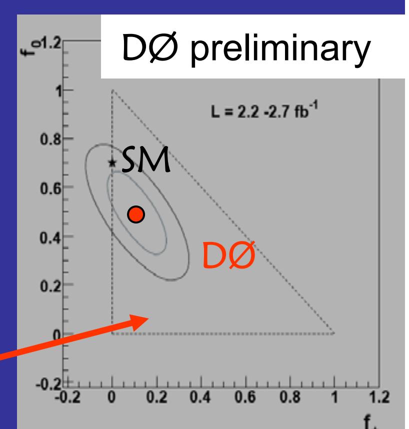
0.7 % precision

Top-antitop cross section measured to ~10%; consistent with theory for the measured M_t. We are near the limit from luminosity uncertainty

Top mass measurement can improve with statistics, but is nearing systematic uncertainty limits from jet energy scale & resolution, heavy quark modeling & PDFs. Estimate ultimate precision is ~0.5 GeV. LHC will have big samples, but higher p_T brings different systematics.

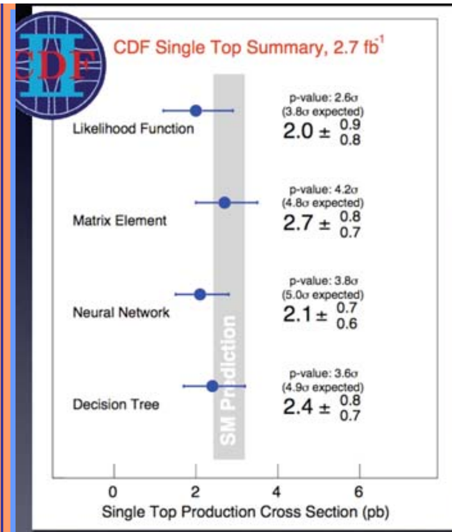
Search for tt resonances, t' quark, forward-backward asymmetry, spin correlations to search for non–SM processes will gain with statistics.

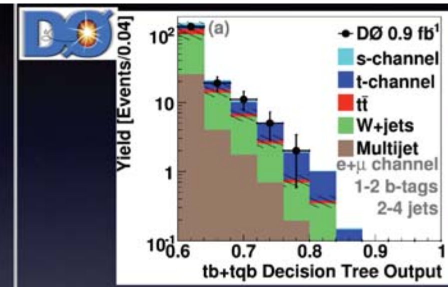
Top couplings to W (expect 70% longitudinal and 0% right-handed) show mild discrepancy with SM; x3 in statistics will help.



EW single top production

EW production (s- and t-channel W exchange) production of single top quark is ~ ½ (!!) that for tt strong production. Both experiments use sophisticated multivariate techniques to dig out a signal.

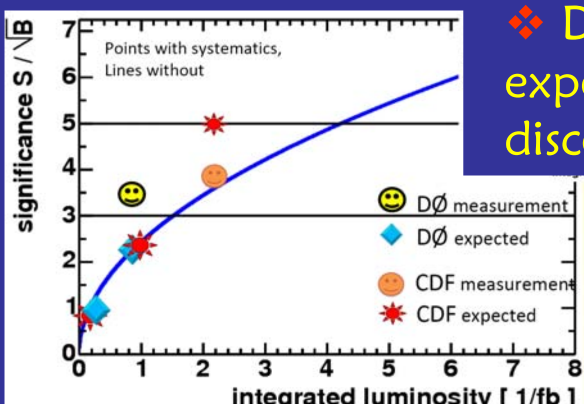




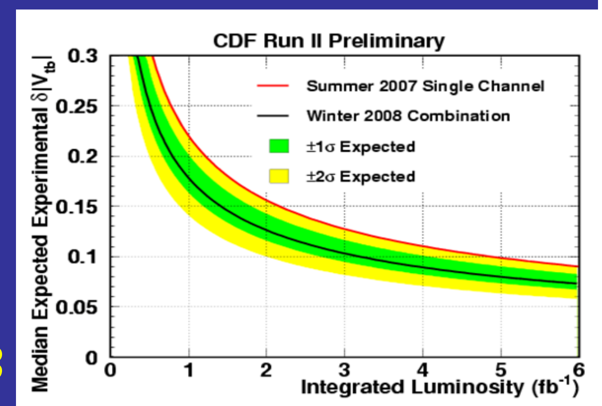
- Combining methods:

DØ: $\sigma = 4.7 \pm 1.3$ pb
3.6σ significance (obs)
2.3σ significance (exp)
$|V_{tb}| > 0.68$ @ 95% C.L.

Both expts have evidence for single top

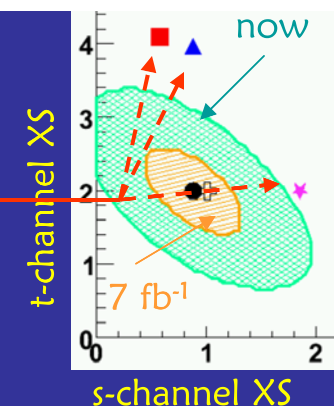


❖ Doing better than original expectation; project 5σ discovery with ~3 fb^{-1}



❖ In full dataset, expect direct measurement of $\delta V_{tb}/V_{tb}$~0.08

❖ Full dataset will allow disentangling s- and t-channel processes and give sensitivity to new physics.



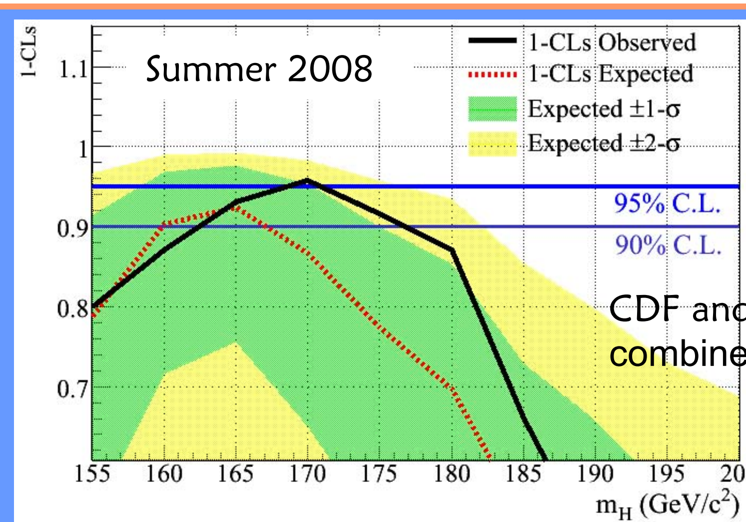
❖ Single top event sample allows searches for charged Higgs with $M_H > M_{TOP}$, anomalous top couplings, W'…

Higgs boson

Low mass Higgs (M_H < 135 GeV): mainly produced in associated WH/ZH production; high mass (M_H > 135) mainly gluon fusion:

WH:	e/μ ν	bb	
	τ ν	bb	*
	qq'	ττ	*
	e/μ ν	W(e/μ)W(e/μ)	
ZH:	ee/μμ	bb	
	νν	bb	
	ττ	bb	*
	qq	ττ	*
ttH:	ℓνb qq'b	bb	*
gg→H:		W(e/μ)W(e/μ)	
		γγ	
		ττ (+ 2 jets)	*
WW →H:		ττ (+ 2 jets)	*

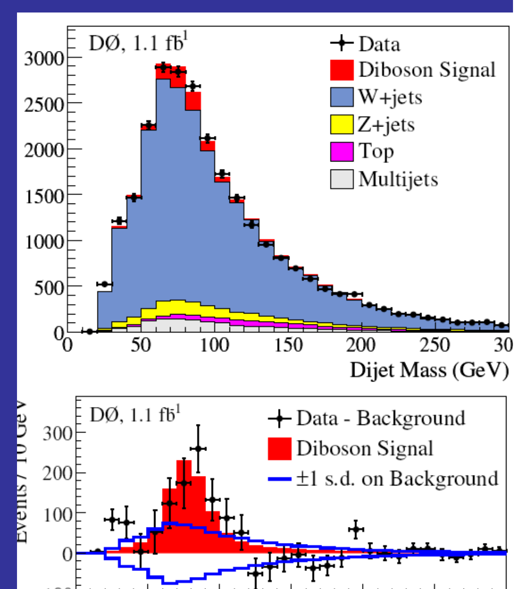
* Not yet included in combinations



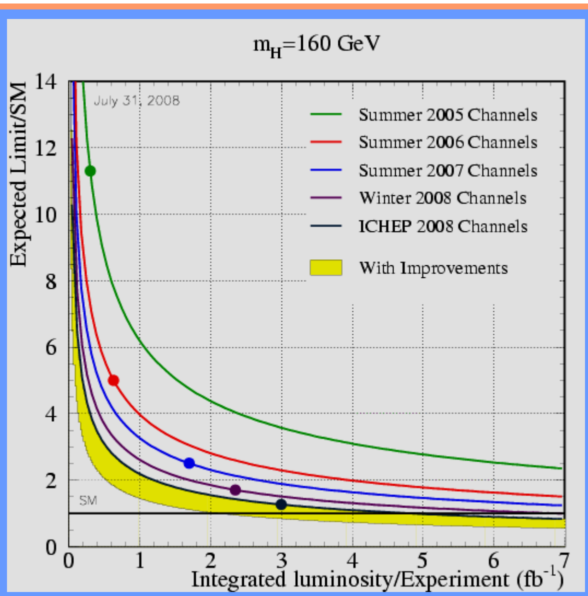
Tevatron expts exclude 170 GeV Higgs (95% CL)

Low Higgs mass combination later this year

Advanced multivariate and statistical techniques used for the W/Z +H(bb) search are now verified in the similar W(ℓν) W/Z(qq) production. Measure 20.2±4.4 pb (16.1±0.9 SM) : 4.4σ significance.



Higgs boson



Expected limit (M_H=160) as a function of time (and sample size)

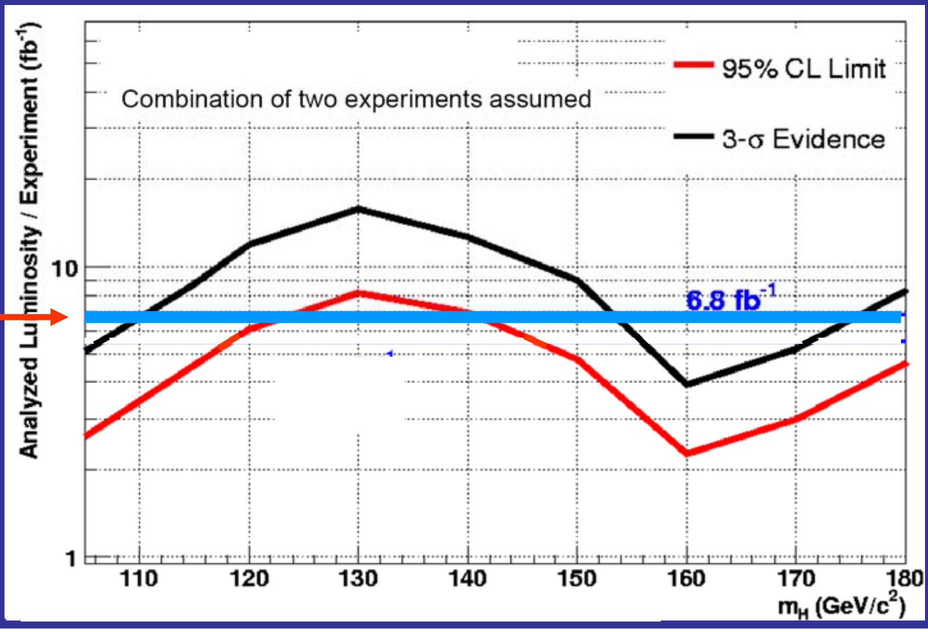
Limits have improved more rapidly than $\mathcal{L}^{-1/2}$ due to analysis improvements

Cross sections are very small; need sophisticated multivariate techniques (neural networks, boosted decision trees etc.) and statistical methods (Bayesian, modified Frequentist)

Improvements continue:

- Better b-tagging algorithms
- Improved di-jet mass resolution
- Extend kinematic search space
- Better background modelling
- Improved lepton identification
- Adding new channels

Projected reach with 8.5 fb^{-1} delivered (6.8 fb^{-1} used in analyses). There is a band of possibilities around these lines.

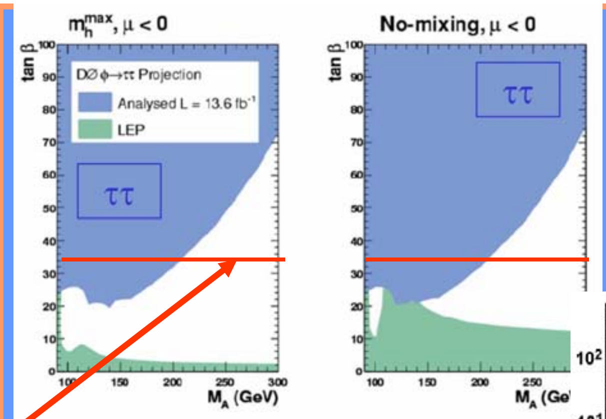


- Exclude at 95% CL over almost full mass range; evidence at low and high mass.
- Tevatron complements LHC at low mass

Searches for new phenomena

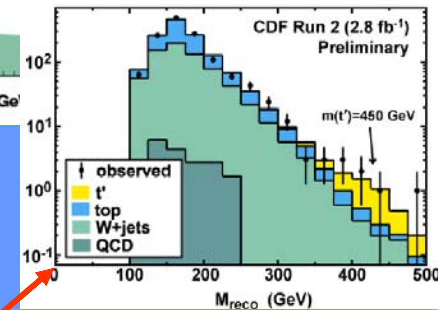
CDF and DØ have searched for many states expected in **Susy, strong coupling, large extra dimension models** with no clear signals to date.

Susy Higgs searches are now pushing into the interesting range $\tan\beta < m_t/m_b = 35$.



Search H $\to \tau\tau$. Comparable exclusion from Hb(b), H$\to \tau\tau$ or bb

CDF hint of t' quark in 2.8 fb^{-1}



- Some hints do exist: CDF sees fluctuation of high mass excited top quark that will clearly benefit from more statistics.
- New categories of searches: heavy Dirac monopoles, massive stable particles, $H^+ \to t\, b$ with $M_H > M_t$), etc. are being pursued.
- Model independent searches to ensure not missing something unexpected.

Frontier for high mass new phenomena searches will pass to LHC, but the well understood CDF & DØ detectors still make contributions through precision measurements. The well understood Tevatron data sets will be invaluable for cross checking early indications from LHC.

Conclusions

We expect the delivered luminosity from the Tevatron to increase to >8 fb^{-1} by the end of the run. Analyzed luminosity will increase by a factor of ~2.5–4. Analysis improvements will add sensitivity. These allow substantial improvements for:

- Low mass Higgs search ★
- W mass ★
- Diboson production
- Top quark mass ★
- Electroweak production of single top, V_{tb} ★
- Heavy b-quark states and CP violation in B_s
- Resolving hints of new phenomena

★ Difficult for LHC

The CDF and DØ experiments are running smoothly and efficiently. There are no indications of detector problems. The collaboration strengths are sufficient to carry out the program.