SM Tests at the Tevatron Collider

Cecilia E. Gerber

University of Illinois-Chicago

Pheno 2008 Symposium

LHC Turn on

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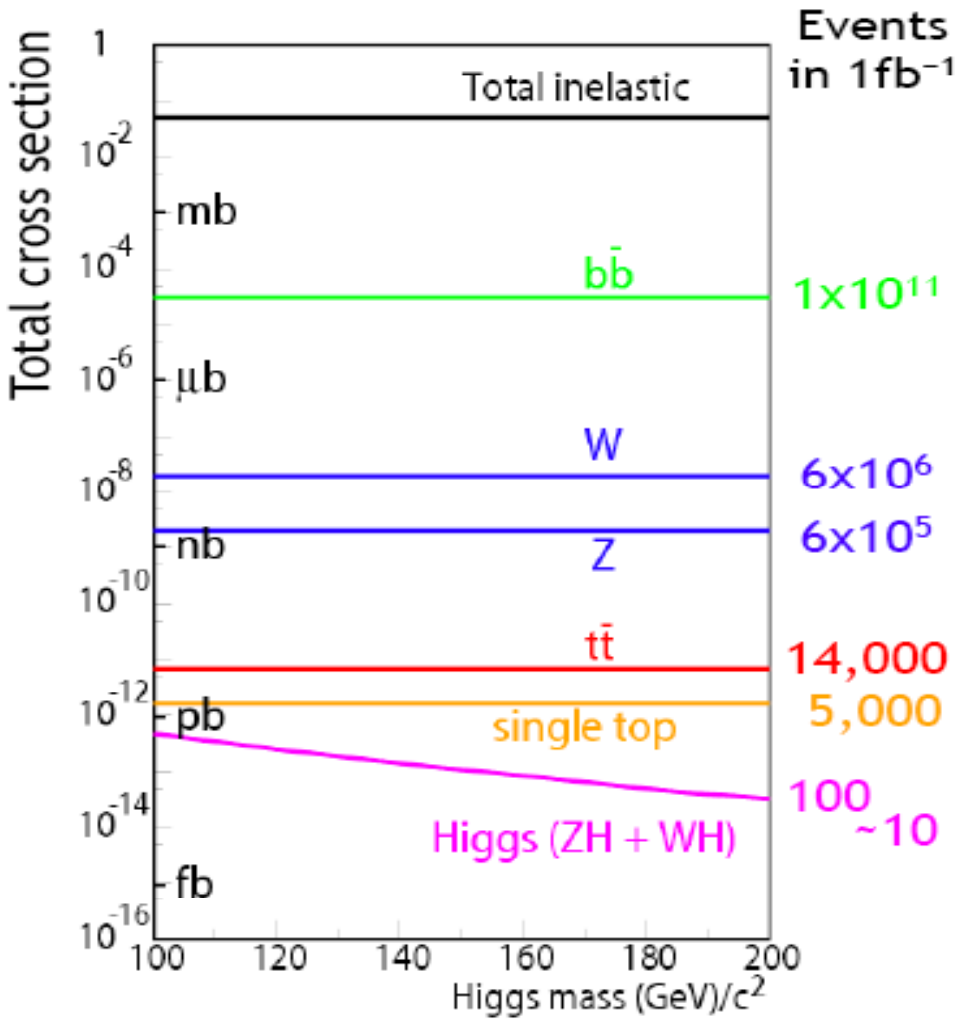
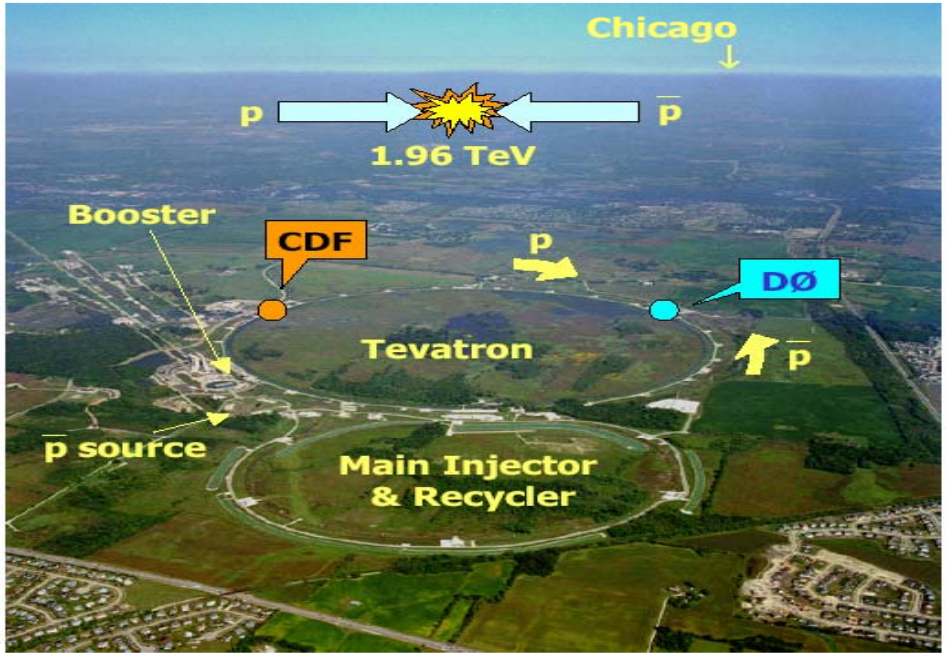
Outline

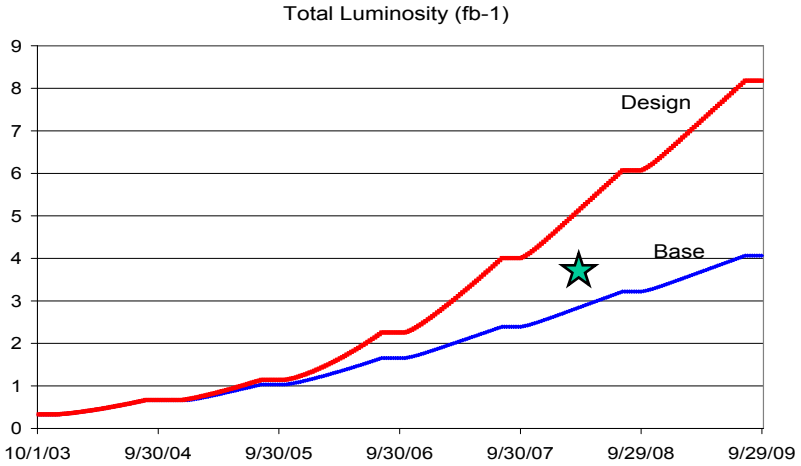
- Selected new results presented by rate:
  - High p_T jets
  - W&Z bosons
  - Top quark
  - ZZ
  - SM Higgs
- See parallel sessions for more results!



The Fermilab Tevatron



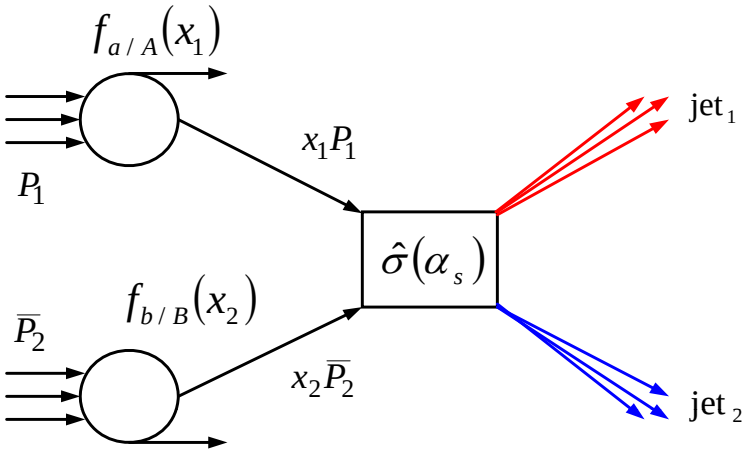
- Highest-energy accelerator currently in operation
  - only place where Top quarks have been produced
- Data delivered >3.5fb^{-1}
  - expect to reach 6- 8 fb^{-1} by the end of the run.



Results based on ~2fb^{-1}

	Run I	Run IIa	**Run IIb**
Bunches in Turn	6 × 6	36 × 36	**36 ×36**
√s (TeV)	1.8	1.96	**1.96**
Peak L (cm^{-2}s^{-1})	1.6 ×10^{30}	9 ×10^{31}	**3 ×10^{32}**
∫ Ldt (pb^{-1}/week)	3	17	**50**
Bunch crossing (ns)	3500	396	**396**
Interactions/ crossing	2.5	2.3	**8**

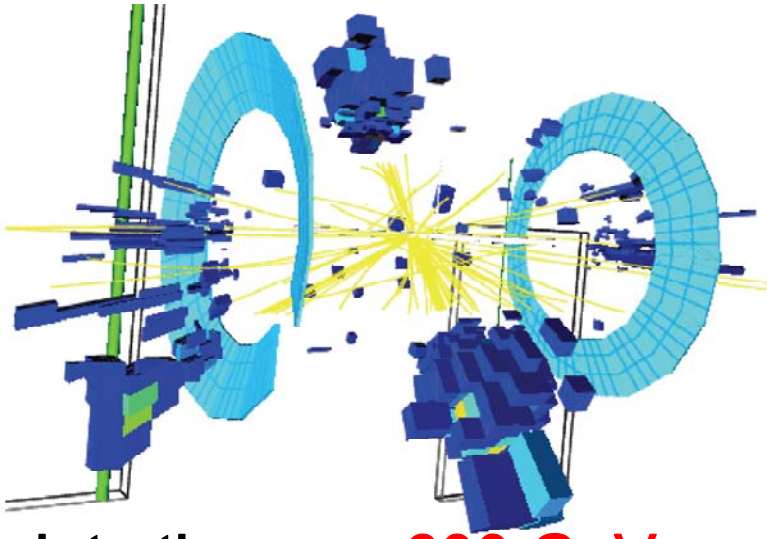
Jet Production



$$\sigma(p_1\bar{p}_2 \to 2 \text{ jets}) = \sum_{abcd} \int dx_1 dx_2 \, f_{a/A}(x_1) f_{b/B}(x_2) \hat{\sigma}(ab \to cd)$$

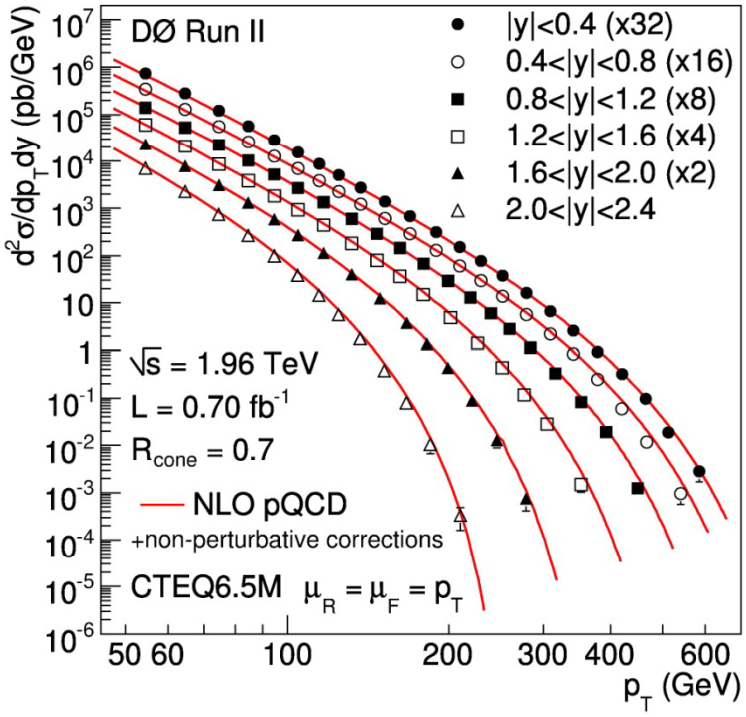
- Inclusive Jet Cross Section
  - Most basic test of QCD
  - Sensitive to the value of α_s
  - PDFs at high Q^2
  - proton structure at large x

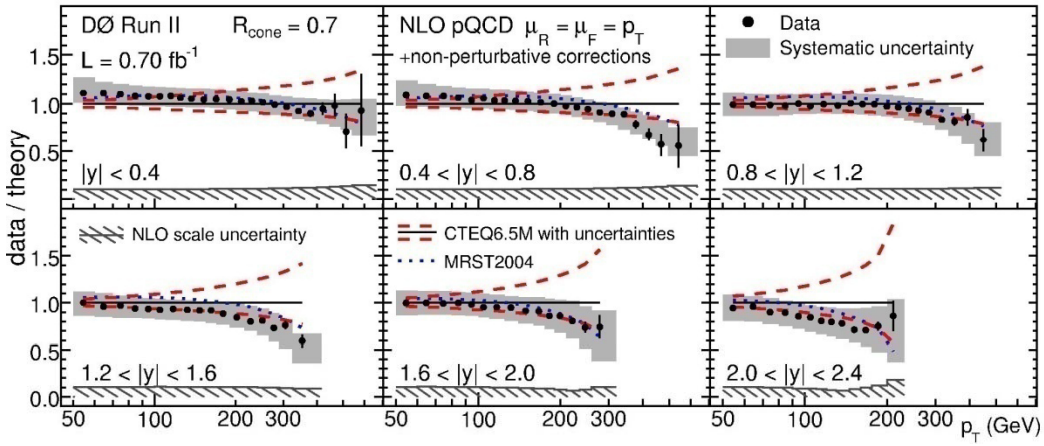
DØ jet coverage $|\eta|<2.4$ →very forward jets are available!



Jet pt's are ~ 600 GeV

Inclusive Jet x-section



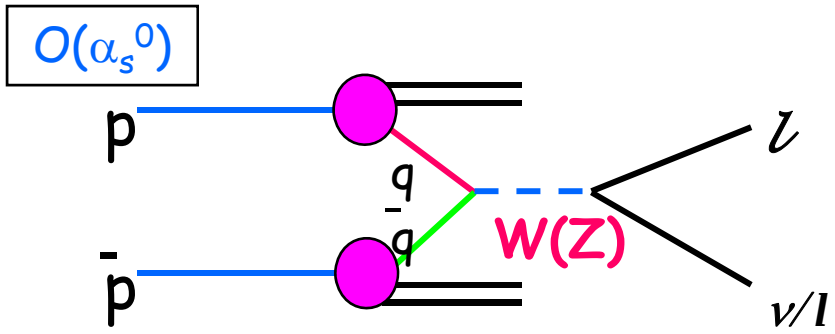


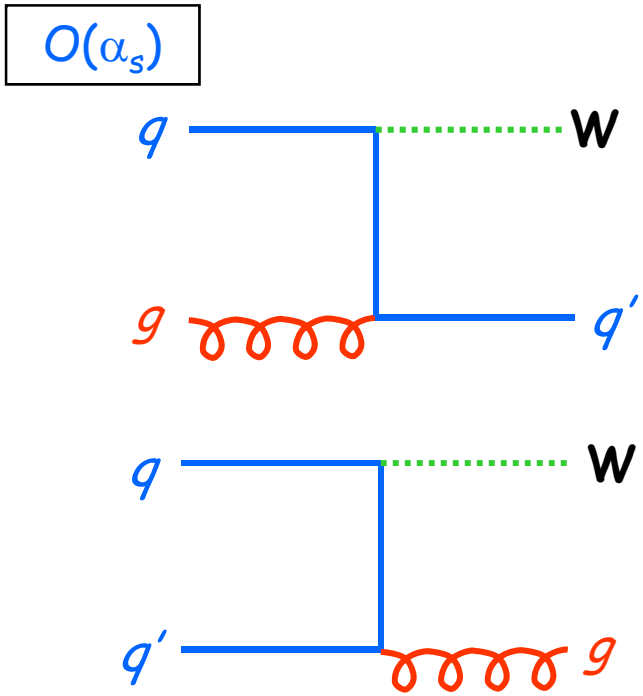
Data corrected to particle level is compared to NLOJET++ with CTEQ6.5M

Agrees well with NLO QCD over the entire range ($\mu_R=\mu_F=p_T$)

Most precise measurement to date.
Result is already included in MRSTW08 PDF.
hep-ex 0802.2400 - submitted to PRL

W/Z Production





- Production dominated by qq annihilation
- Due to very large pp→ jj production, need to use leptonic decays
  - (BR ~ 11% (W), ~3% (Z) per mode)

Modifications due to QCD corrections:

- Boson produced with transverse momentum
- Boson + jet events possible – main bkgd to top/Higgs
- Inclusive cross sections larger
- Boson decay angular distribution modified

Benefits of studying QCD with W&Z bosons:

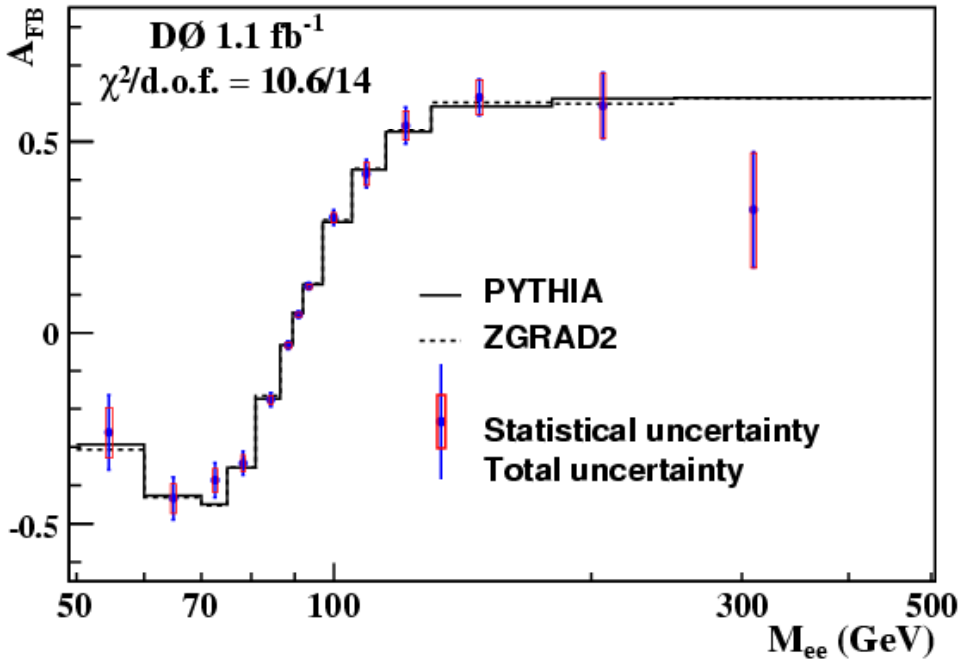
- Distinctive event signatures
- Low backgrounds
- Large Q^2 (Q^2 ~ Mass^2 ~ 6500 GeV^2)
- Well understood Electroweak Vertex

Z Boson Forward-Backward Charge Asymmetry

$$A_{FB}^{i} = \frac{\left(\frac{d\sigma}{dM_i}\right)^{+} - \left(\frac{d\sigma}{dM_i}\right)^{-}}{\left(\frac{d\sigma}{dM_i}\right)^{+} + \left(\frac{d\sigma}{dM_i}\right)^{-}}$$

+/- correspond to hemispheres of e^- w.r.t. proton in Collins-Soper frame

arXiv:/0804.3220 [hep-ex]



Unfolded data is compared with theory → good agreement

Background subtracted raw AFB is compared to templates generated with different input values of $\sin^2\theta_W^{eff}$ to extract

$$\sin^2\theta_W^{eff} = 0.2327 \pm 0.0018\ (\text{stat.}) \pm 0.0006\ (\text{syst.})$$

NEW !

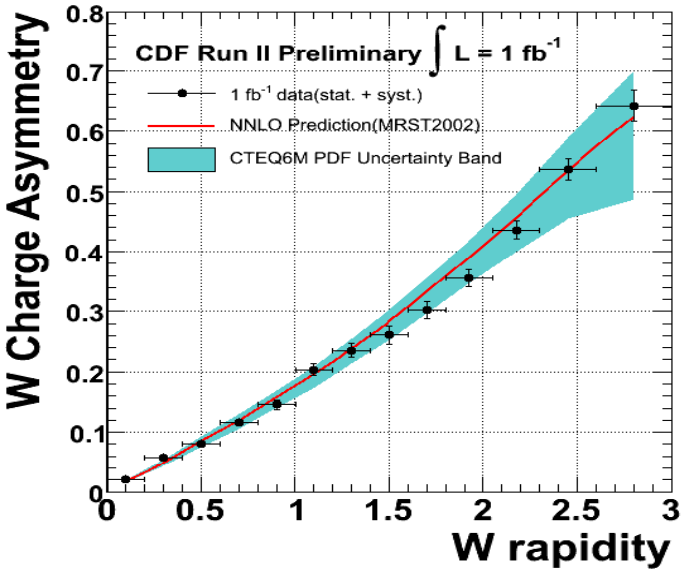
Comparable in precision to the LEP combination.

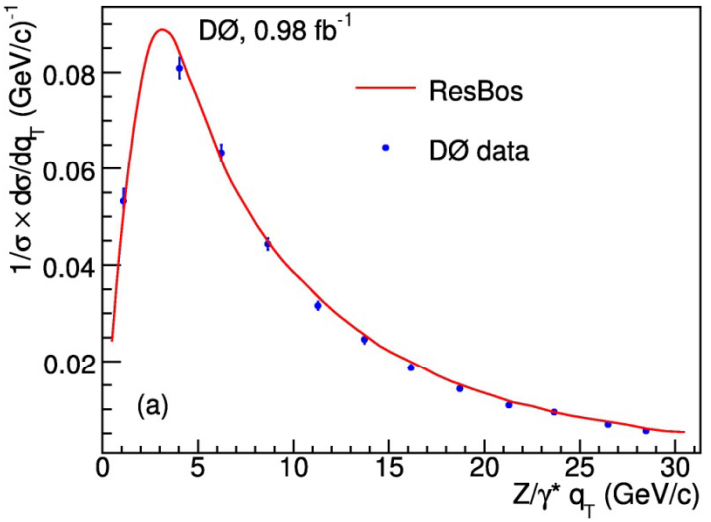
W/Z Properties

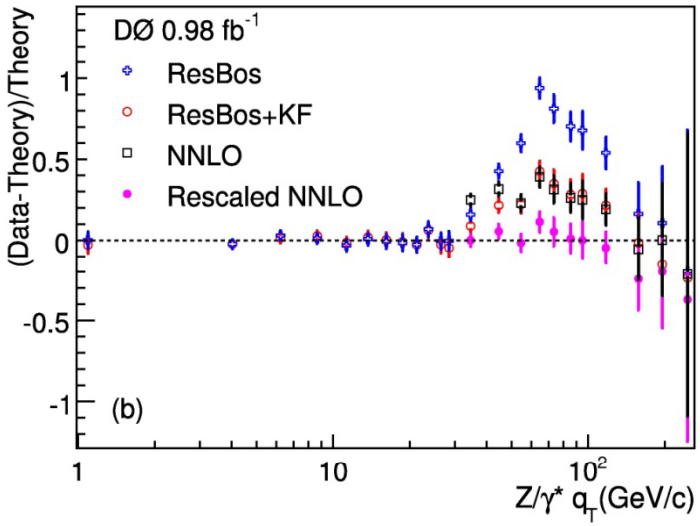
$\frac{1}{\sigma}\frac{d\sigma}{dq_T}$ for $e^+ e^-$ pairs ($70 < M_{ee} < 110$ GeV)

W production Charge Asymmetry

Provides input on the momentum fraction dependence of the u and d quark PDF within the proton.







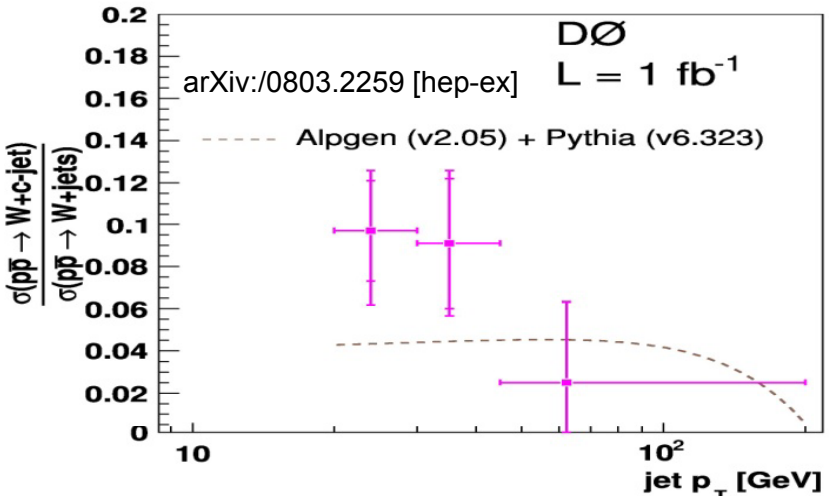
Consistent with the resummation prediction at low p_T, but above the pQCD calculation for p_T>30 GeV

Phys. Rev. Lett. 100 , 102002 (2008)

W/Z + Heavy Flavor Production
(dominant background for top&Higgs)

W $\rightarrow \ell\nu$ + c-jet

- select W's with a muon-jet
- muon & W have opposite charge
- sensitive to s quark PDF

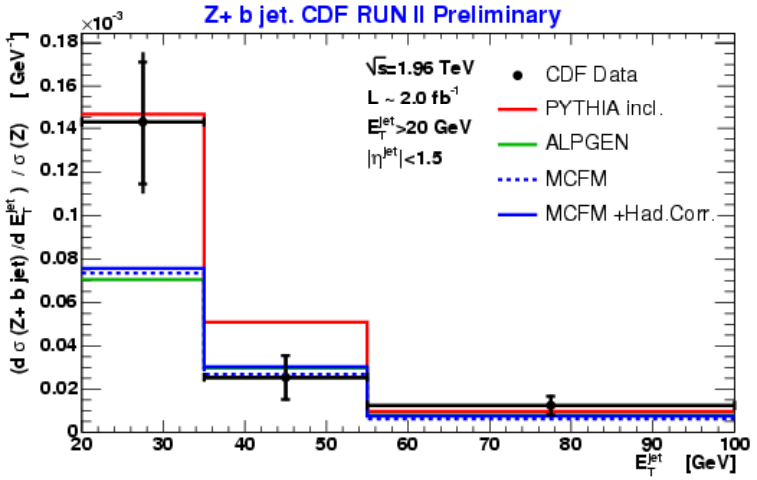


$$\frac{\sigma\,[W + c\text{-jet}]}{\sigma\,[W + \text{jets}]} = 0.074 \pm 0.019(\text{stat.})^{+0.012}_{-0.014}(\text{syst.})$$

Agrees with SM expectation.

Z$\rightarrow \ell\ell$ + 2 b-jets

- b-jets tagged with SVT
- fraction fitted from the invariant mass of the tracks
- data is corrected to hadron level & compared to theory

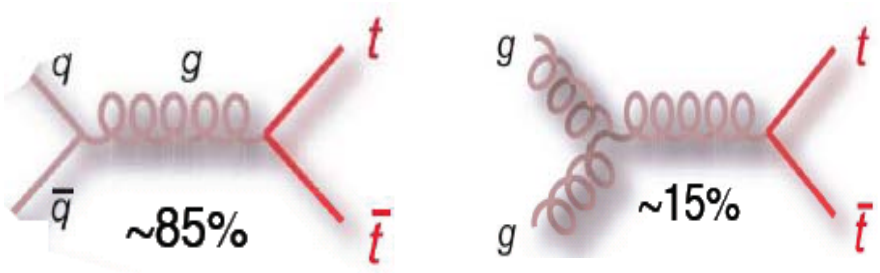


Differential distributions available for the first time.

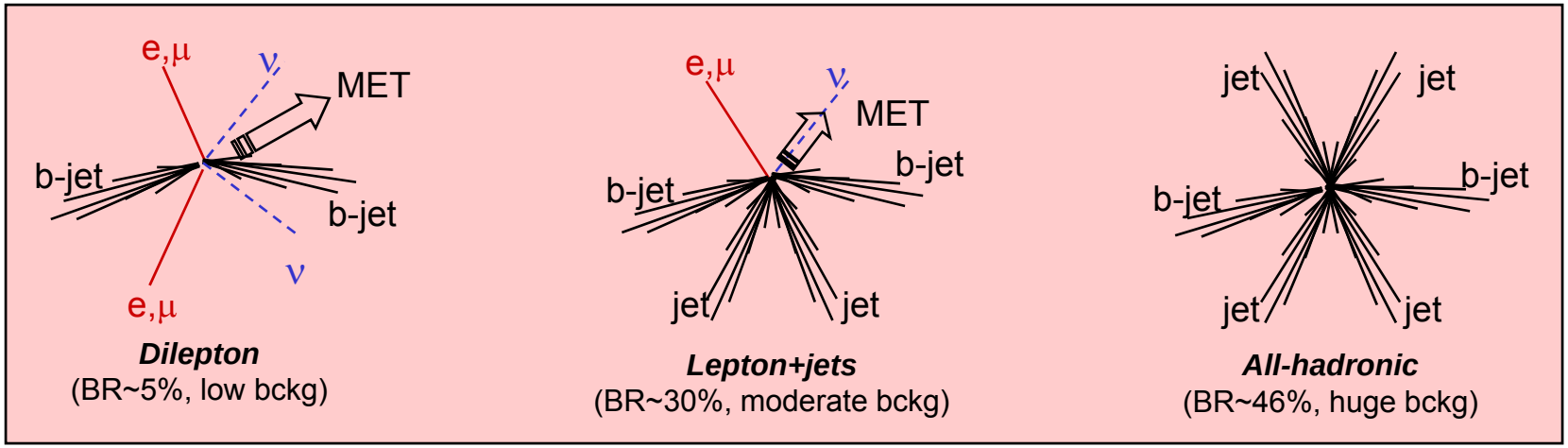
Top quark Pair Production & Decay

- Top quarks are mainly produced in pairs, via the strong interaction

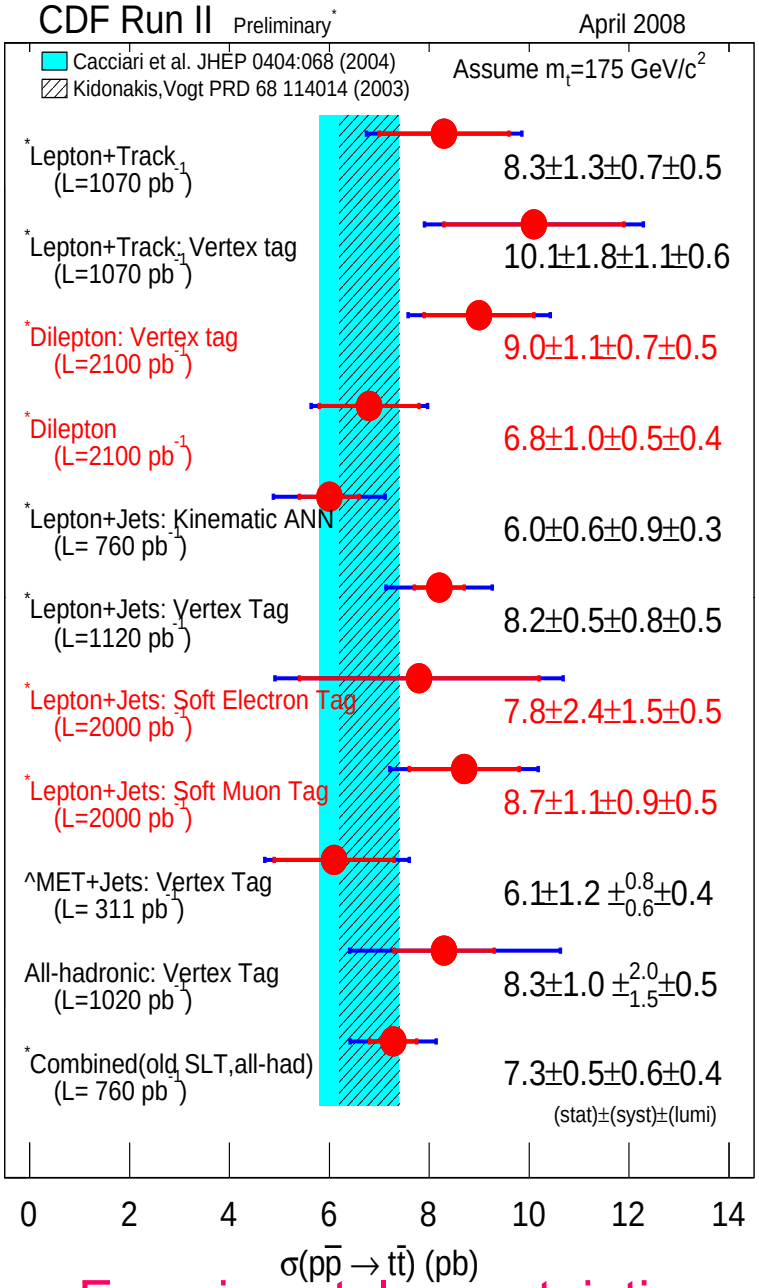
σ_{tt}=6.8±0.6 pb (Kidonakis, Vogt)
σ_{tt}=6.7+0.7-0.9 pb (Cacciari et al.)



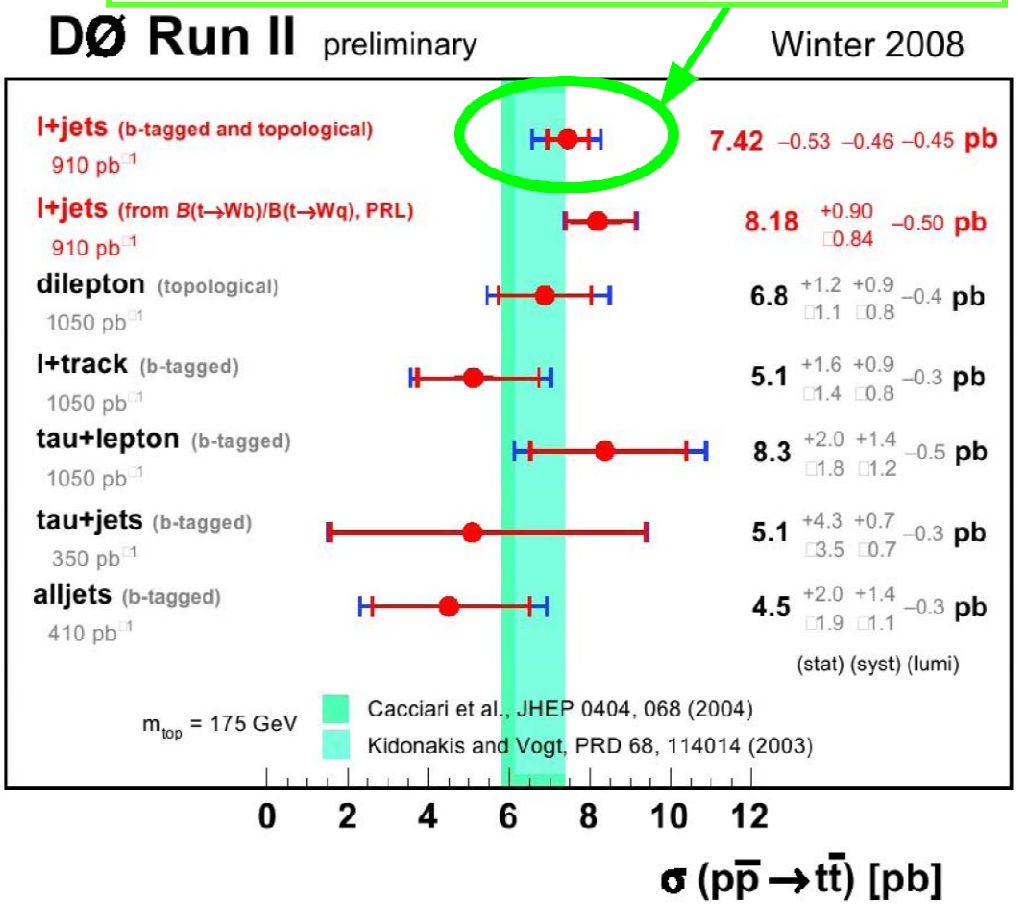
- $m_t > m_W + m_b \Rightarrow$ dominant 2-body decay $t \rightarrow Wb$
- $\Gamma_t^{SM} \approx 1.4$ GeV at $m_t = 175$ GeV
  - Top decays before top-flavored hadrons or **tt**-quarkonium bound states can form
  - Top spin and kinematics is transferred to the final state



Top pair Prod. x-section



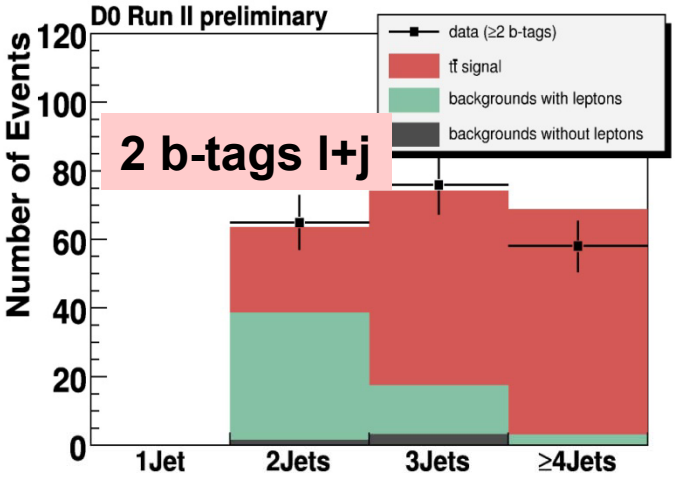
Combined b-tag + topological 0.9fb-1
Most precise to date

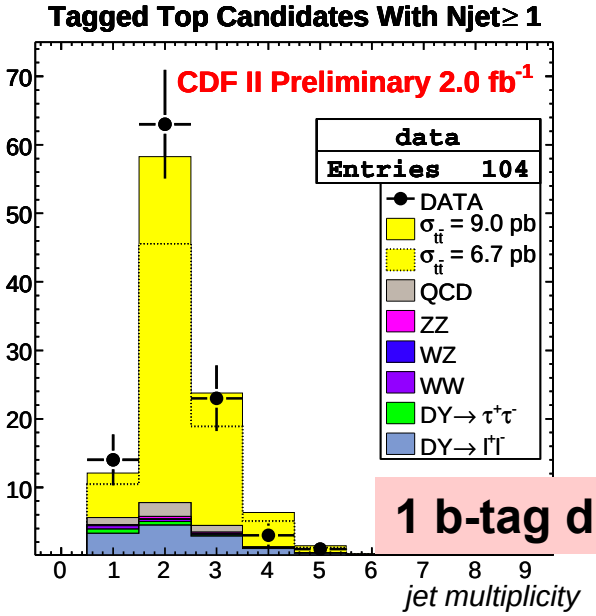


Test of pQCD at high Q^2

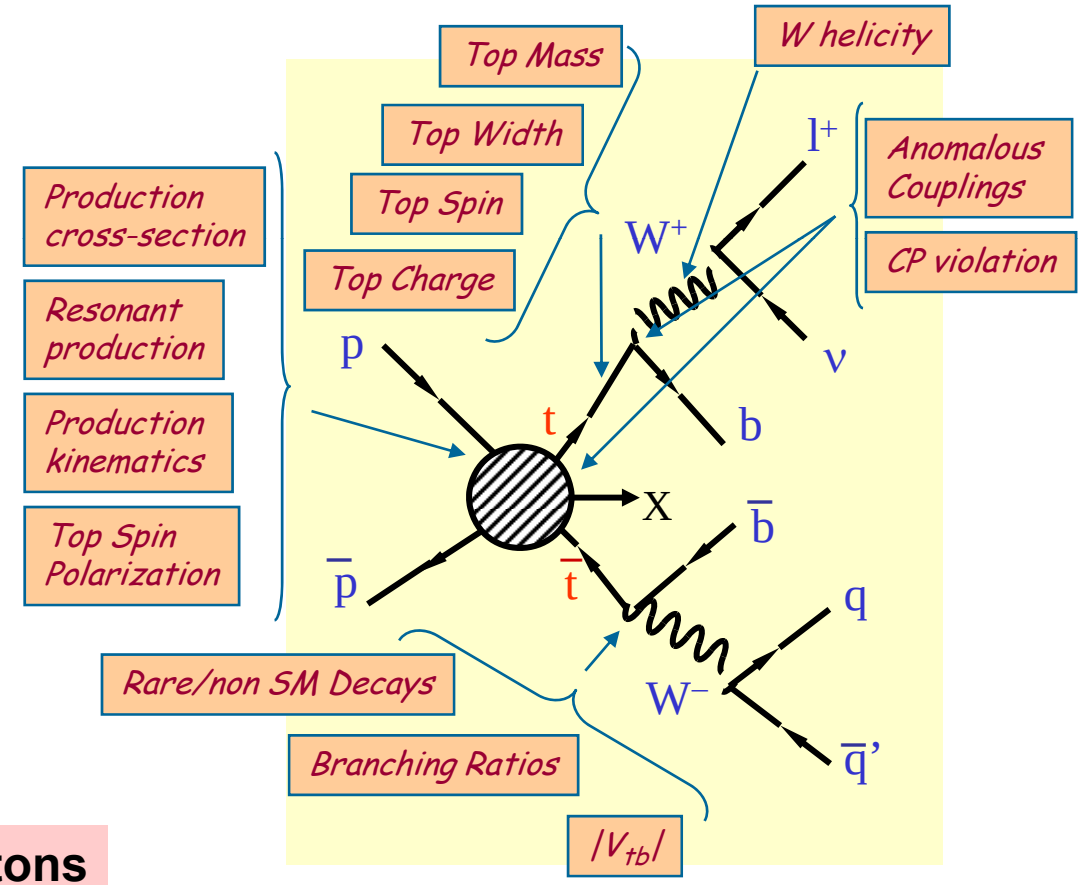
Experimental uncertainties reaching precision in theoretical prediction.

Top quark Properties



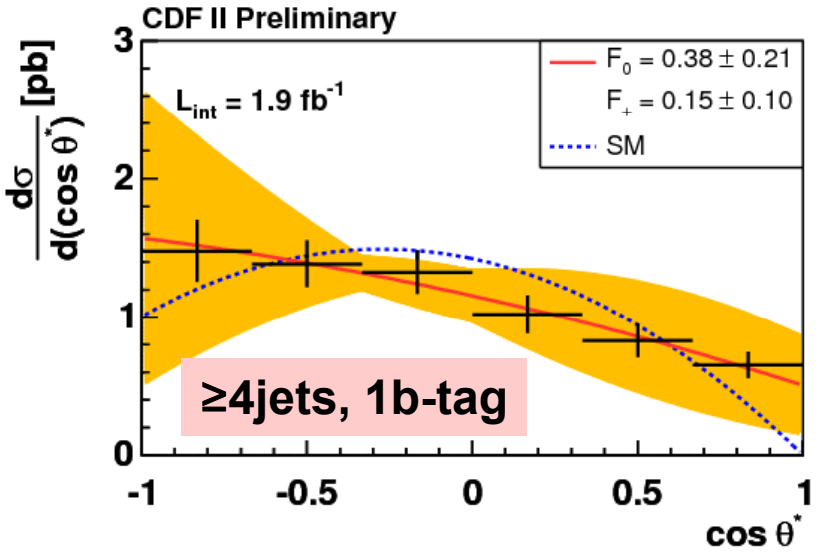


b-tagging provides pure sample of top quarks for properties measurements

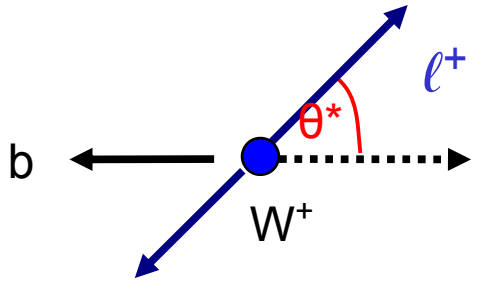


Sample of Top quark Properties

W Helicity in ttbar l+j events



cosθ* used as sensitive observable

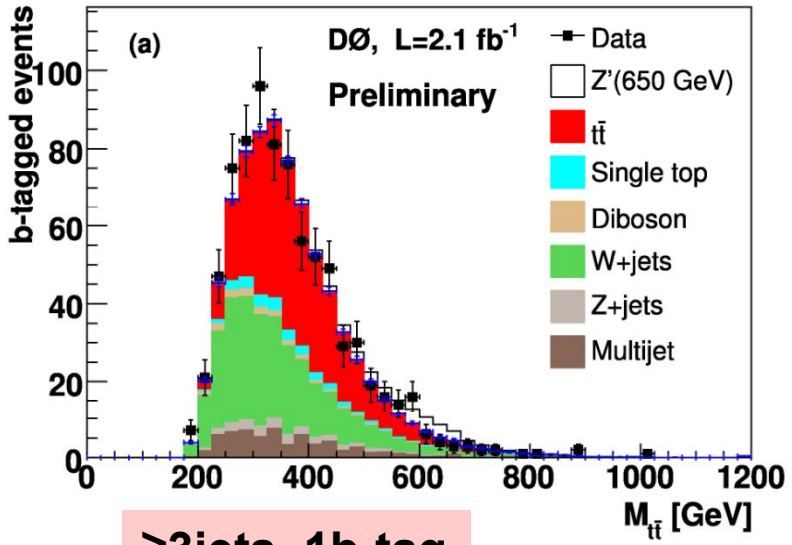


2-parameter fit for fraction of longitudinal (F^0) and right-handed (F^+) polarized W bosons in top decays
Statistically limited: agrees with the SM prediction

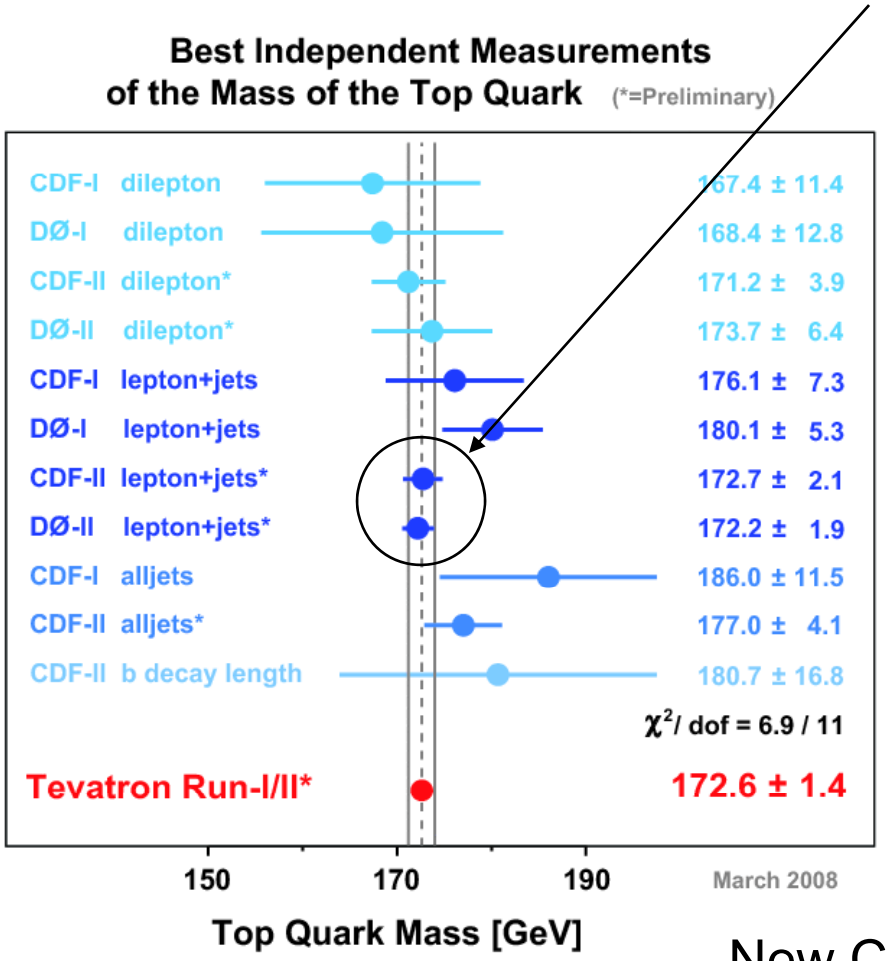
Search for ttbar resonances

Study invariant mass spectrum of l+j events

No evidence for narrow resonance decaying into ttbar



Top quark Mass



Best results obtained by ME Method

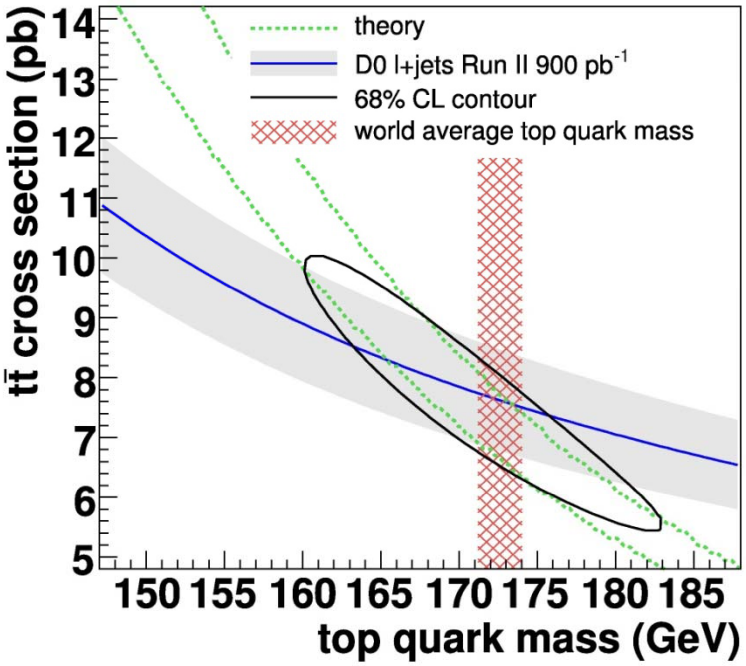
- event by event weight calculated according to quality of agreement with SM top and background differential cross-sections
- Product of all event probabilities gives the most likely mass
- JES constrained in-situ by the hadronic decay of the W→jj

Errors: ~1%

New CDF result not included in the combination (ME with NN selection)

171.4 ± 1.1 (stat) ± 1.0 (JES) ± 1.0 (syst) GeV

Top Mass from x-section



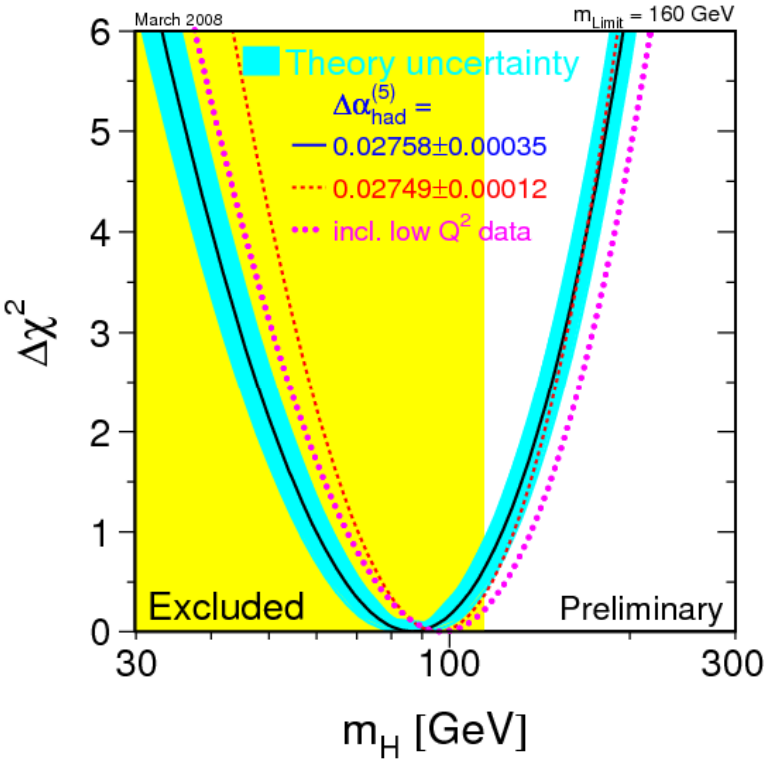
$$m_{top} = 170 \pm 7 \text{ GeV}$$

Top quark mass can be extracted comparing the measured x-sec with theory

Measurement has different experimental and theoretical uncertainties than direct measurements.

Results between two methods are in agreement

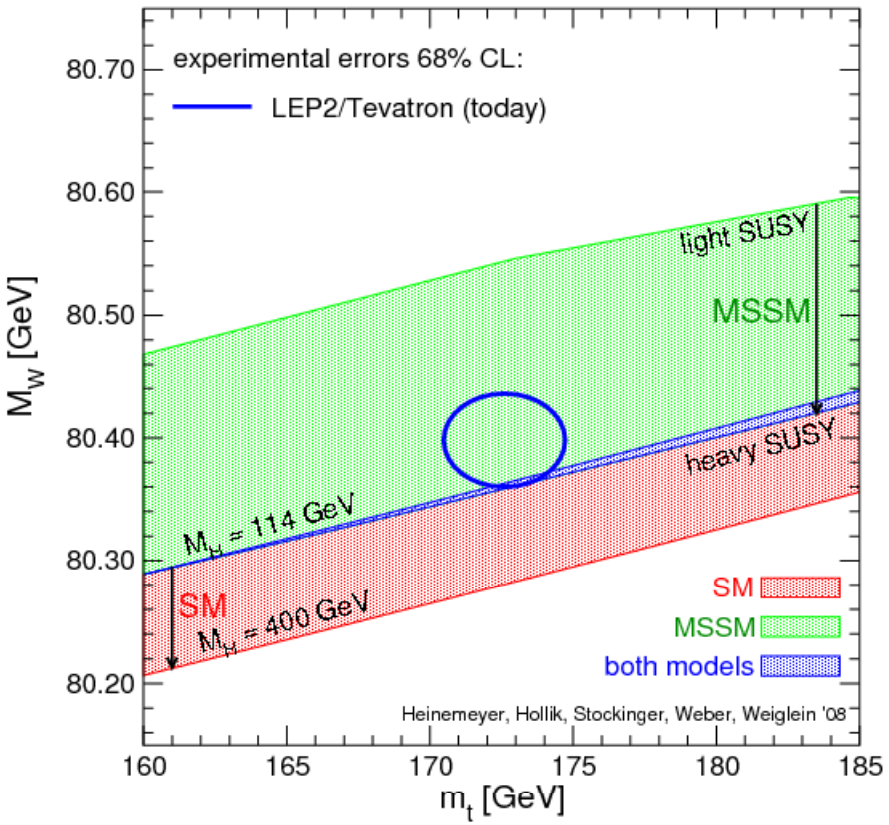
SM Constraints on the Higgs



$$m_H = 87 \pm^{36}_{27} \; GeV$$

$$m_H < 160 \; GeV \; @ 95\% C.L.$$

$$m_H > 114 \; GeV (direct)$$

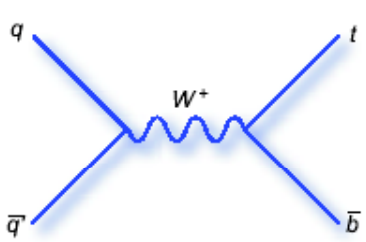


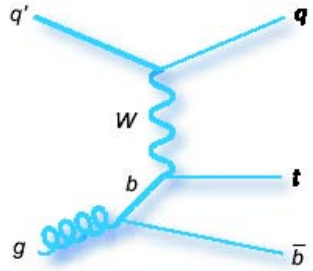
Light Higgs preferred by the SM with latest top and W mass

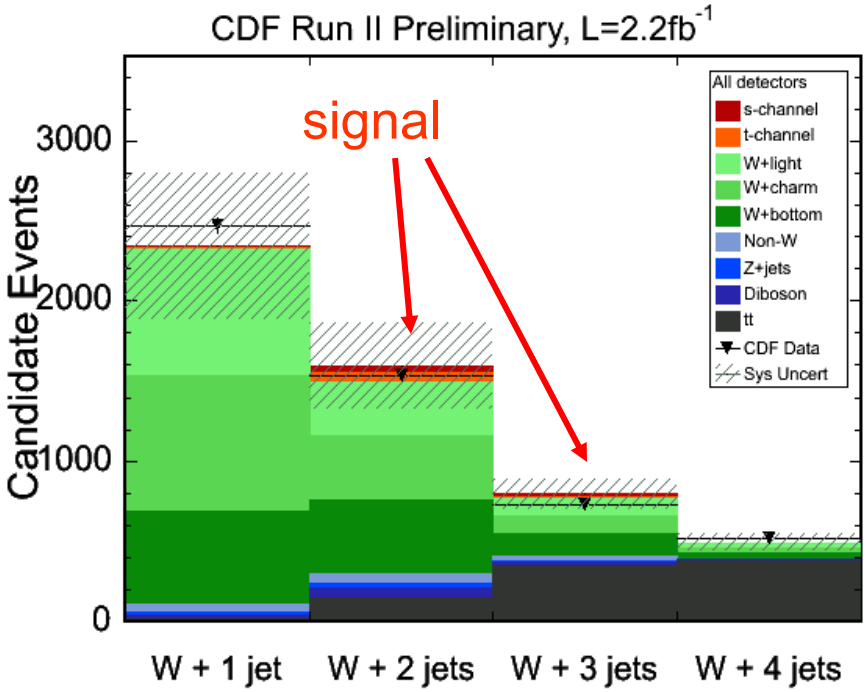
Plots from LEP/TEV EW working group

Single Top Production

- Experimentally challenging due to large W+jets background in lower jet multiplicities than pair production







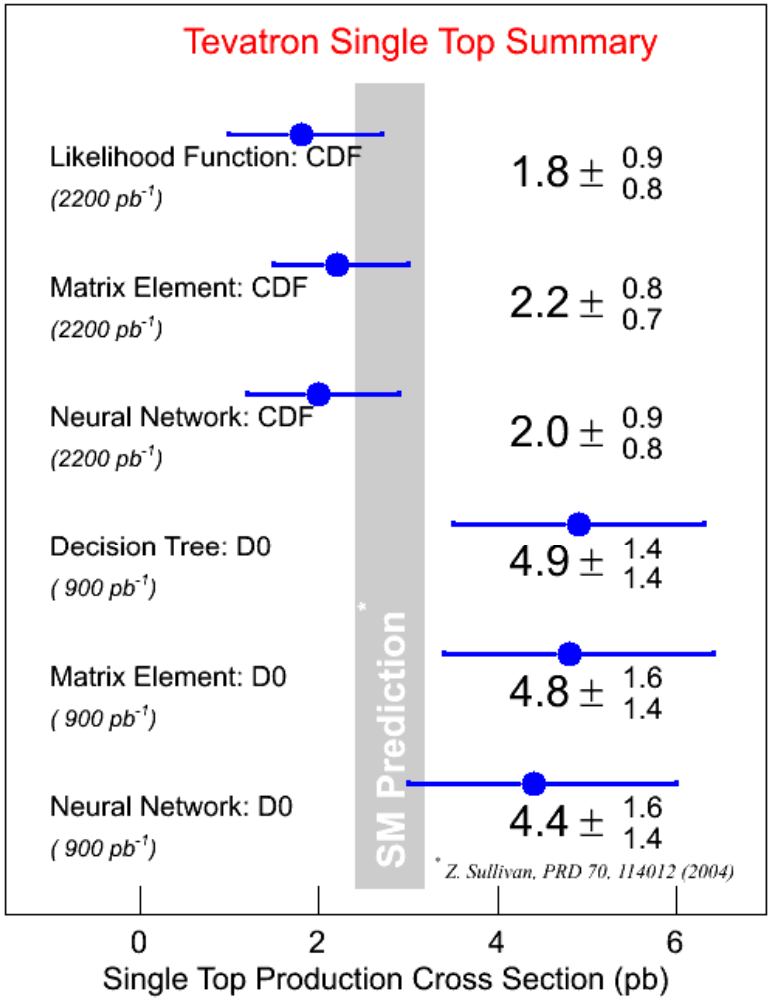
***s*-channel**	***t*-channel**
σ = 0.88 ± 0.11 pb	σ = 1.98 ± 0.25 pb

- Simple counting experiment cannot extract the signal from the overwhelming background
  - Need advanced techniques
  - Multiple methods per experiment (3 each)
    - Serve as cross check
    - Combination adds power

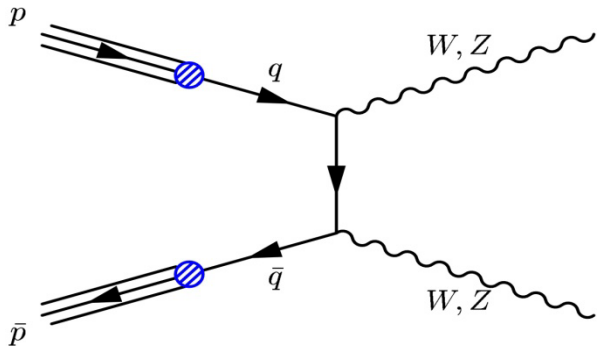
Evidence for single top production

Signal Significance		Cross Section
Expected	Observed	Measured
DØ (0.9 fb^{-1}) PRL 98, 181802 (2007)		
2.3σ	3.6σ	4.7±1.3 pb
|Vtb| = 1.31 + 0.25 - 0.21		
CDF (2.2 fb^{-1})		
5.1σ	3.7σ	2.2 ± 0.7 pb
|Vtb| = 0.88 ± 0.14 ± 0.07		

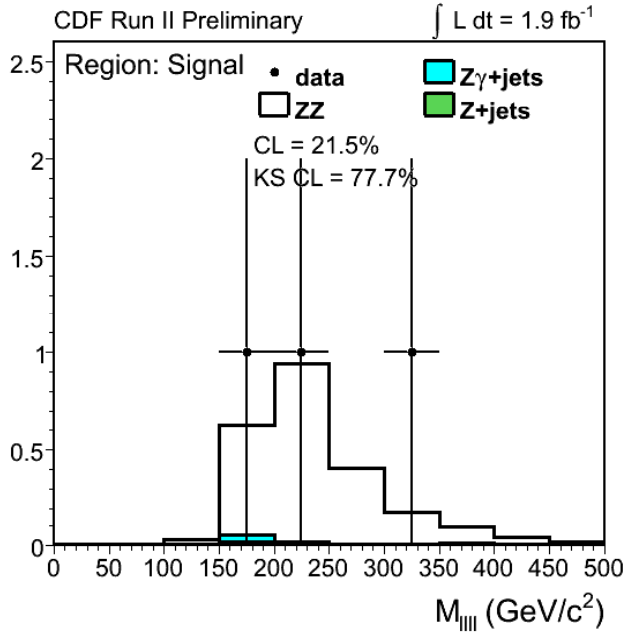
Same final state as WH



smallest measured x-sec: ZZ



$$\sigma(ZZ) = 1.6 \pm 0.1 \text{ pb (SM)}$$



CDF combines events with 4 charged leptons (e,μ), and 2 charged leptons and 2 neutrinos. Based on 3 $\ell\ell\ell\ell$ and 5 $\ell\ell\nu\nu$ candidates:

$$\sigma(ZZ) = 1.4^{+0.7}_{-0.6}(stat + syst)\,pb$$

4.4σ observed significance

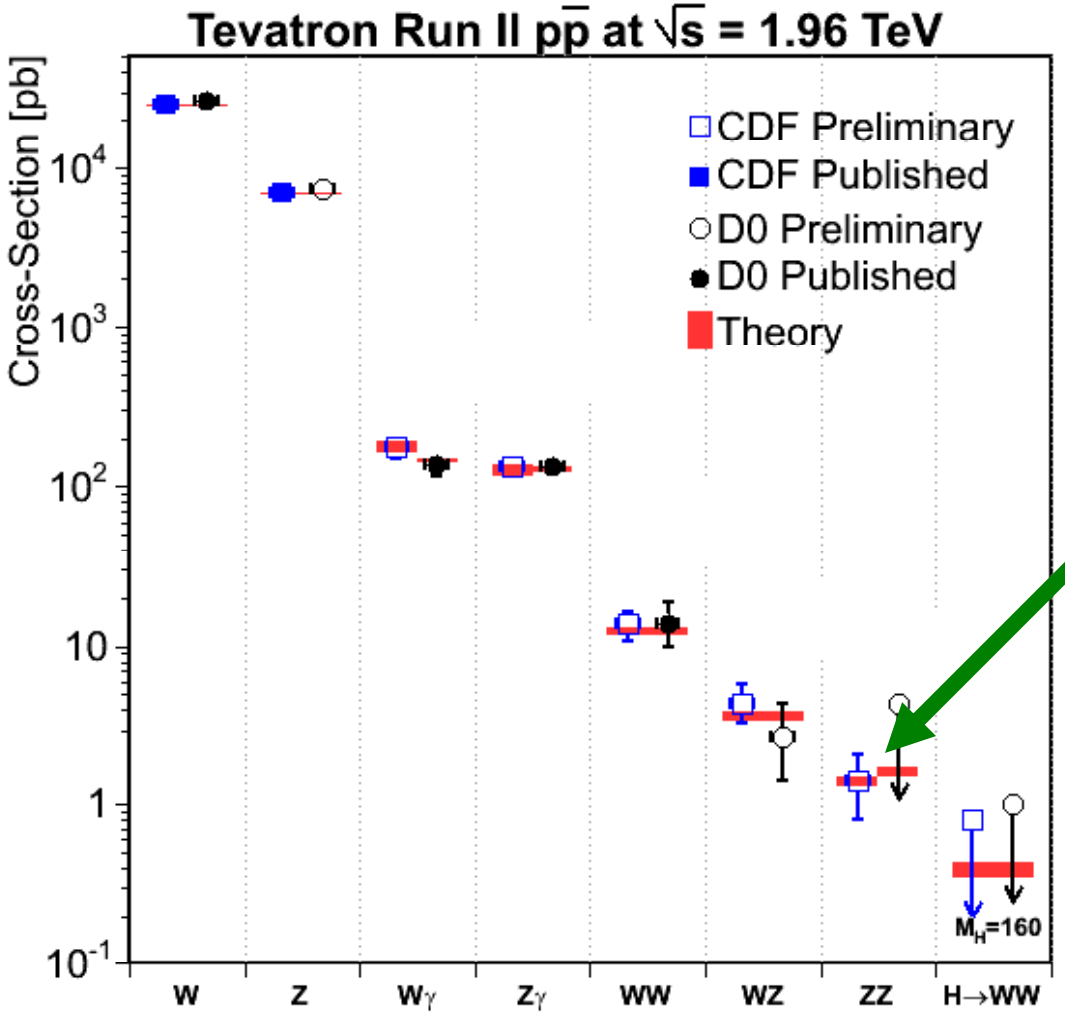
http://arxiv.org/abs/0801.4806v1

D0 uses events with 2 charged leptons and 2 neutrinos (2.2 fb-1)

$$\sigma(ZZ) = 2.1 \pm 1.1(stat) \pm 0.4(syst)\,pb$$

2.4σ observed significance

On to the Higgs…



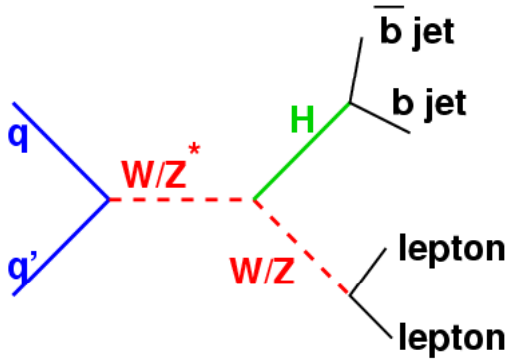
We are here!

SM Higgs search at the Tevatron

Low mass (m_H <~135 GeV):
dominant decay:

$$H \to b\bar{b}$$

Use associated production modes to get better signal/background



$$q\bar{q}' \to WH \to \ell\nu b\bar{b}$$

$$q\bar{q} \to ZH \to \ell^+\ell^- b\bar{b}$$

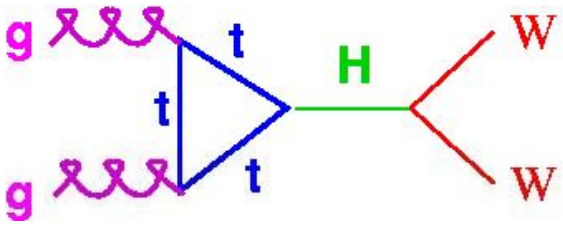
$$q\bar{q} \to ZH \to \nu\bar{\nu} b\bar{b}$$

Intermediate mass:

$$q\bar{q} \to WH \to WWW^{(*)}$$

High mass
dominant decay:

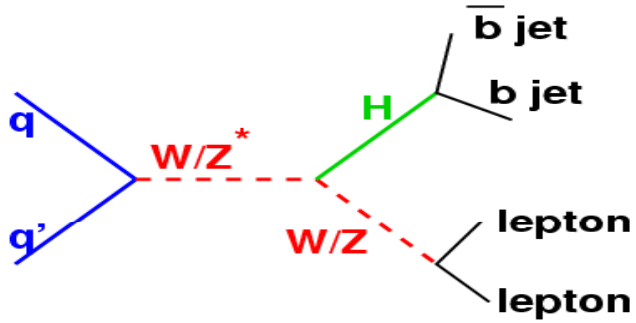
$$H \to WW^{(*)}$$



$$gg \to H \to WW \to \ell\nu\ell'\nu'$$

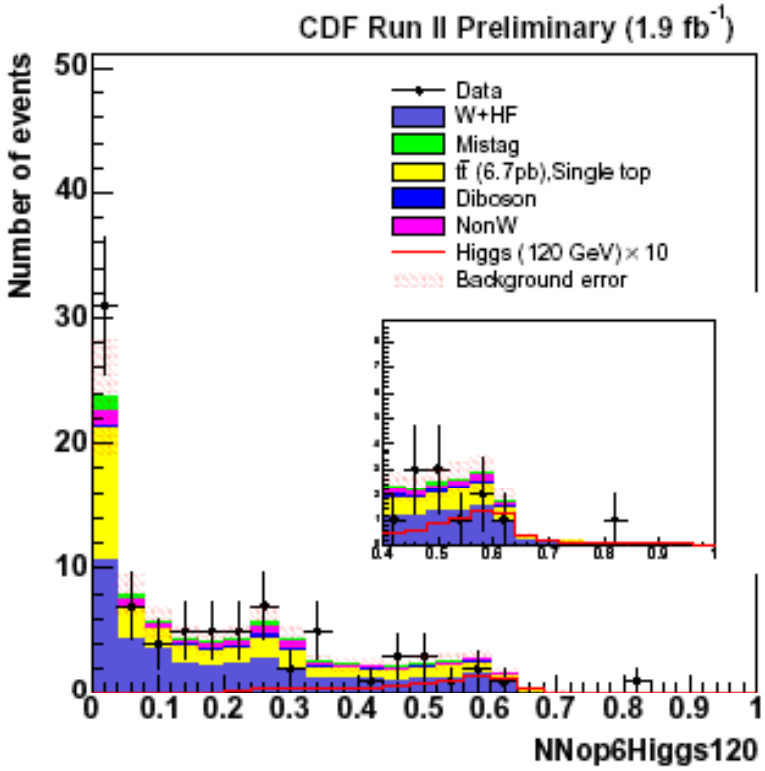
Higgs Searches examples: low mass

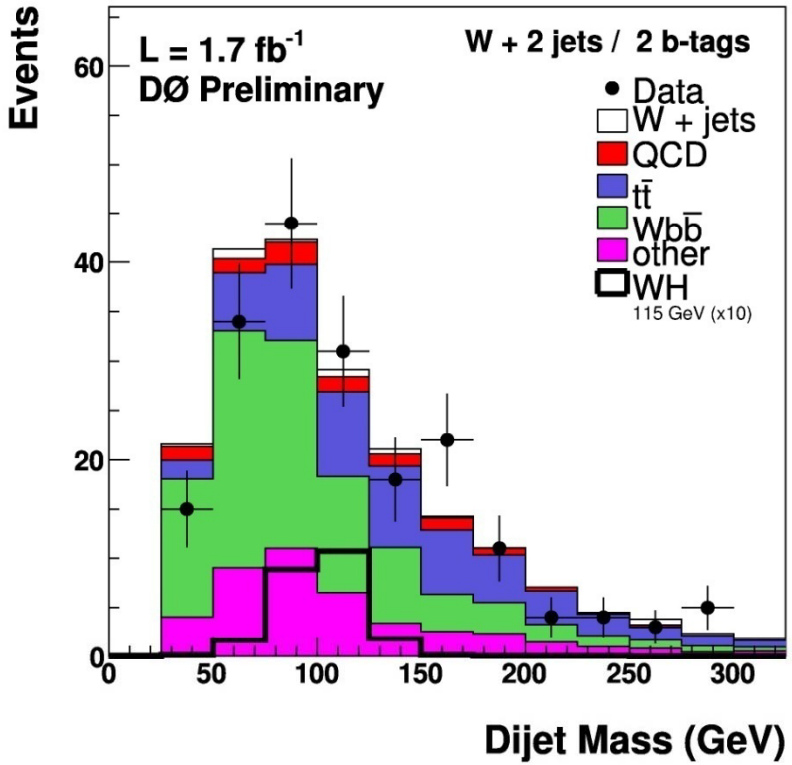
$WH \rightarrow \ell\nu bb$



e or μ + MET
2 jets
1 or 2 b- tags
NN discriminant

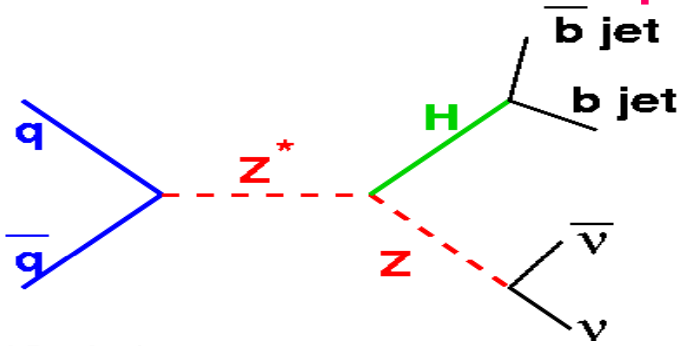
Best sensitivity @ 115 GeV



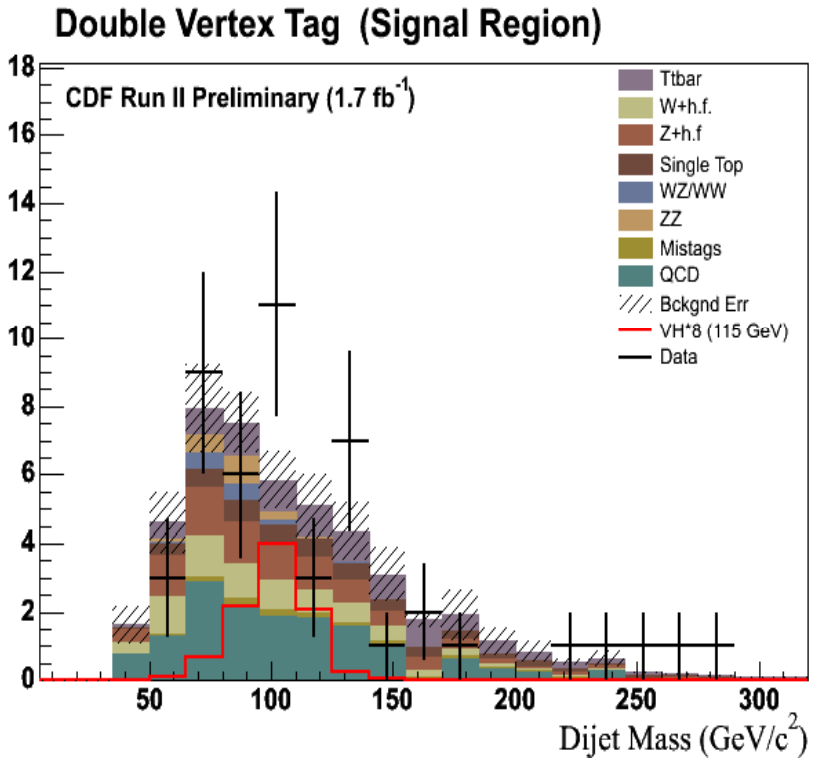


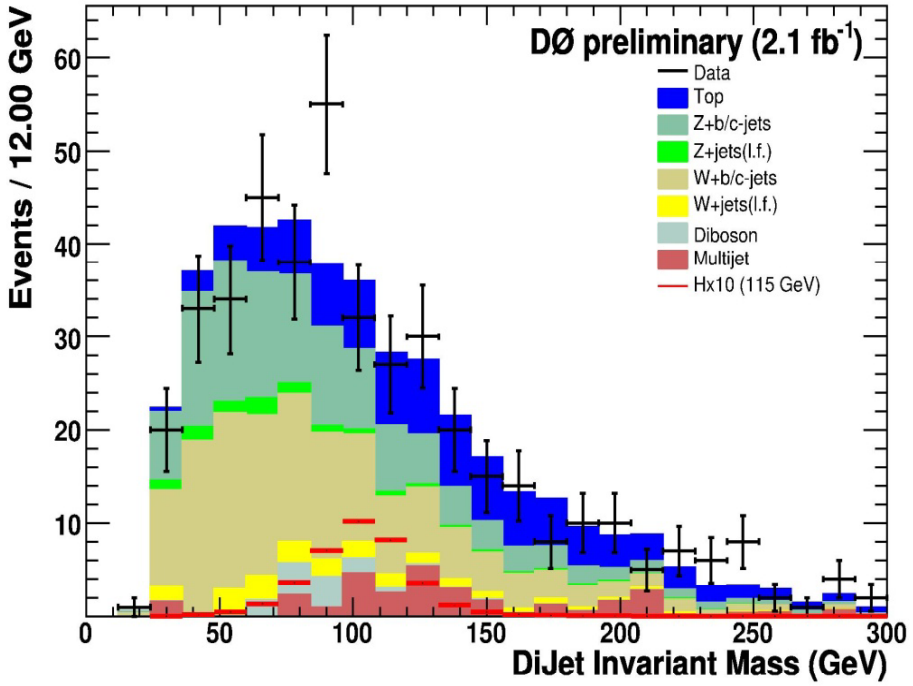
Higgs Searches examples: low mass

$ZH \rightarrow \nu\nu bb$



2 jets + MET
1 or 2 b- tags
NN (CDF)
BDT (D0)

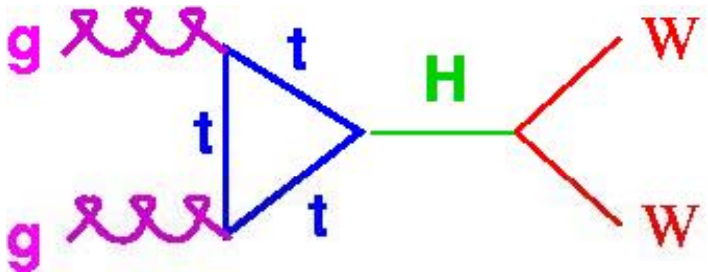




Also analyzed $ZH \rightarrow \ell\ell bb$

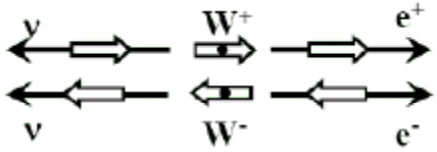
Higgs Searches examples: high mass

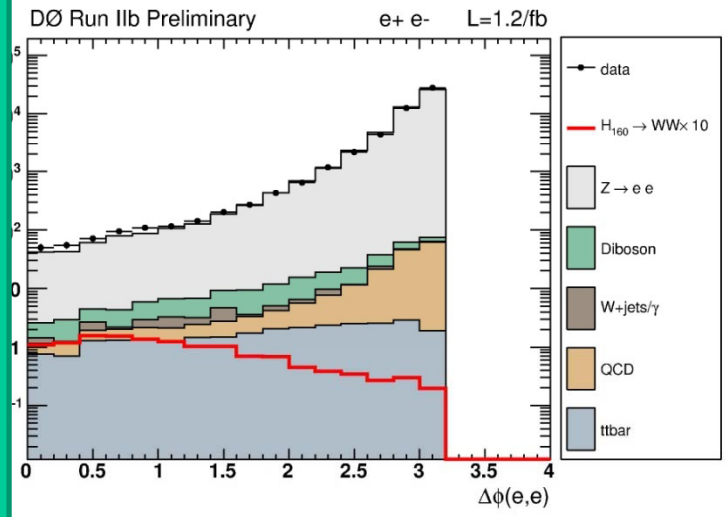
$H \rightarrow WW$
$\rightarrow \ell\,\ell\,\nu\nu$

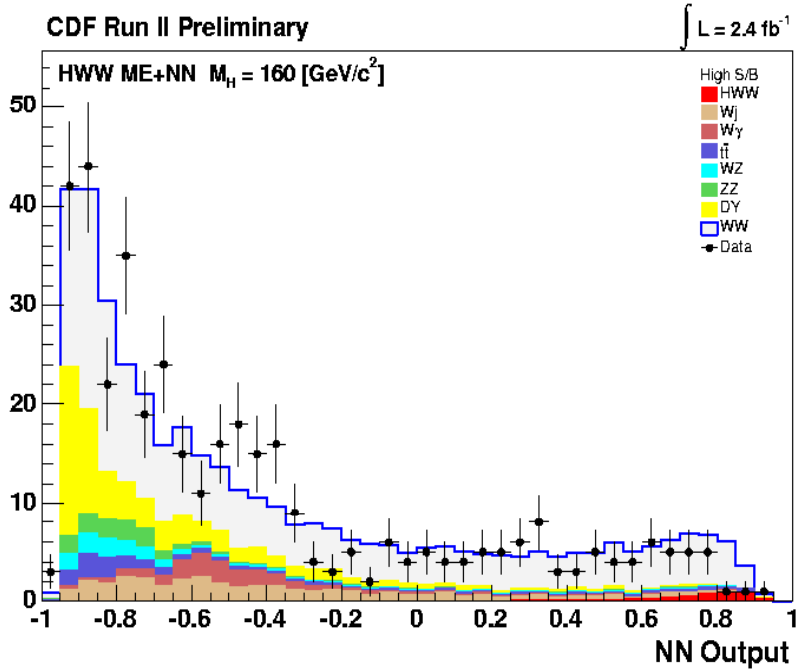


dilepton + MET
ME + NN

Best sensitivity @ 160GeV



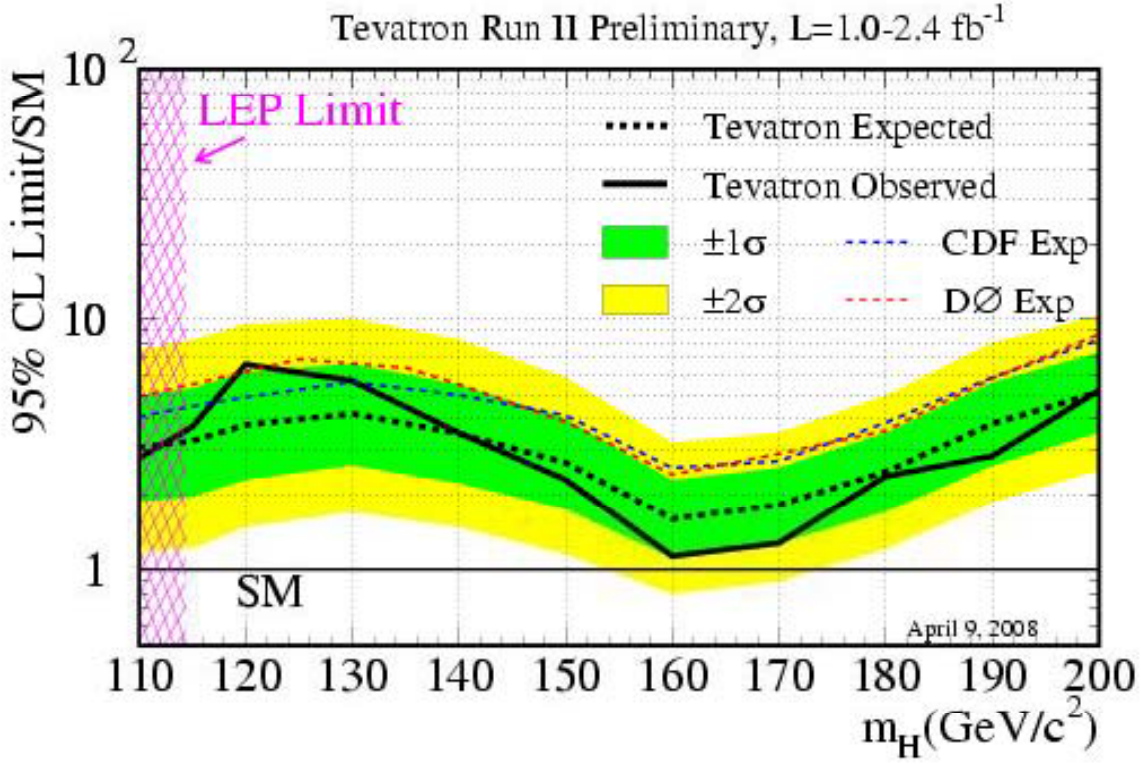




Leptons from H decay are parallel $\rightarrow \Delta\Phi(\ell\,\ell)$ discriminates against WW background.

Tevatron Combination

Combination (April 2008) includes 29 mutually exclusive final states!!



Black lines: Expected and Observed 95% C.L. ratios to SM x-section.

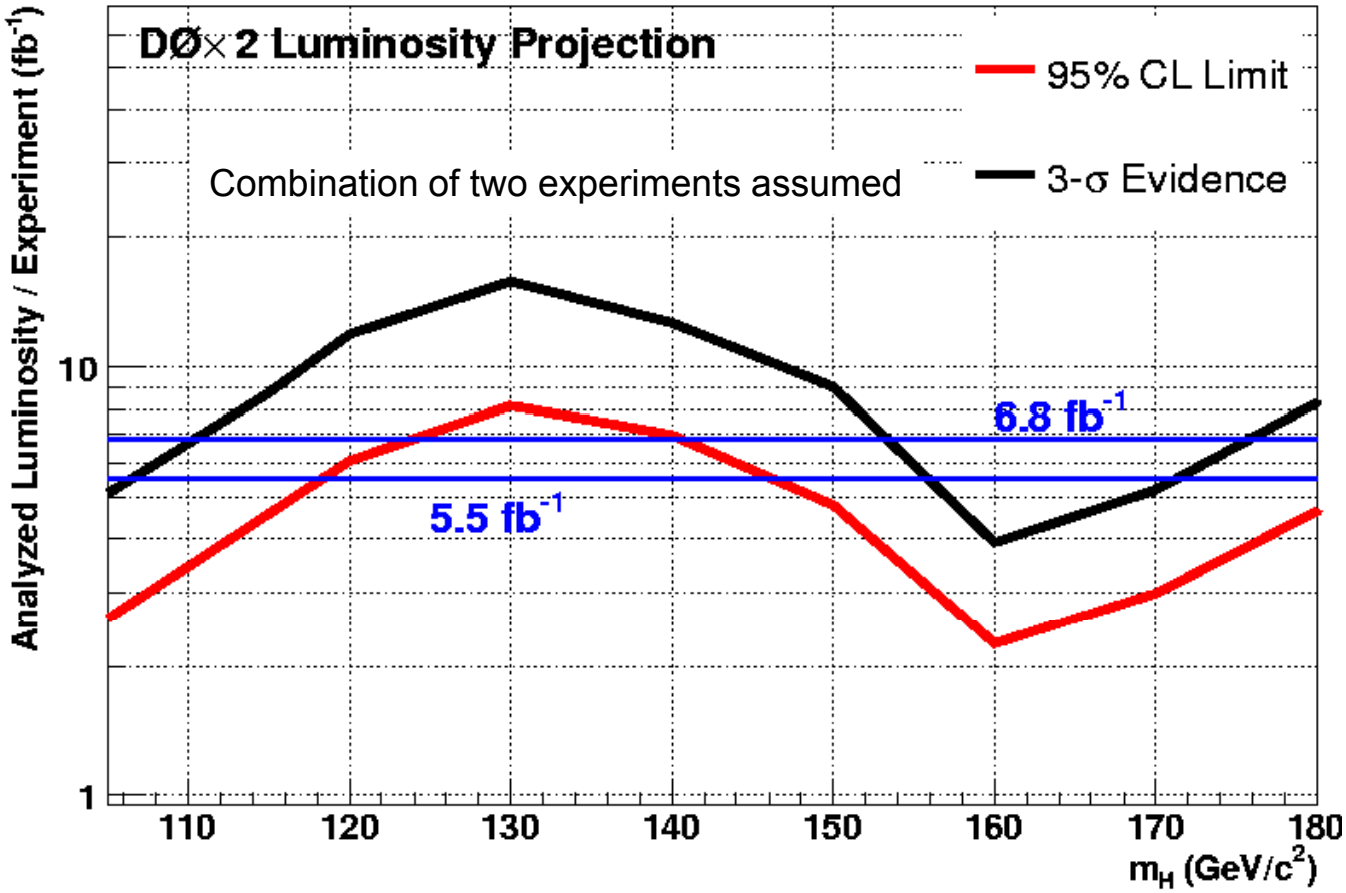
Bands: 1 and 2 σ fluctuations on expected limit, in background-only hypothesis.

Tau & γγ channels add sensitivity. Other channels were re-analized

For m_H=115, expected (observed) 95% CL relative to σ_{SM} = 3.3 (3.7)

For m_H=160, expected (observed) 95% CL relative to σ_{SM} = 1.6 (1.1)

Median expected Higgs sensitivity



2010
2009

With data accumulated by the end of 2010, we expect

- 95% exclusion possible over almost entire allowed mass range
- 3σ evidence possible at low and high ends of range

Conclusions

- DØ and CDF are running better than ever
  - Data taking efficiencies ~ 90%
  - Fast turn-around from data-taking to physics results
  - Rate of publications consistently growing
- Many exciting measurements and discoveries

CDF - http://www-cdf.fnal.gov/physics/W08CDFResults.html

DØ - http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

- Tevatron program is rich and promising
- We are enthusiastic about the physics through the end of the decade