QCD, Electroweak, and Higgs Boson Physics at the Tevatron

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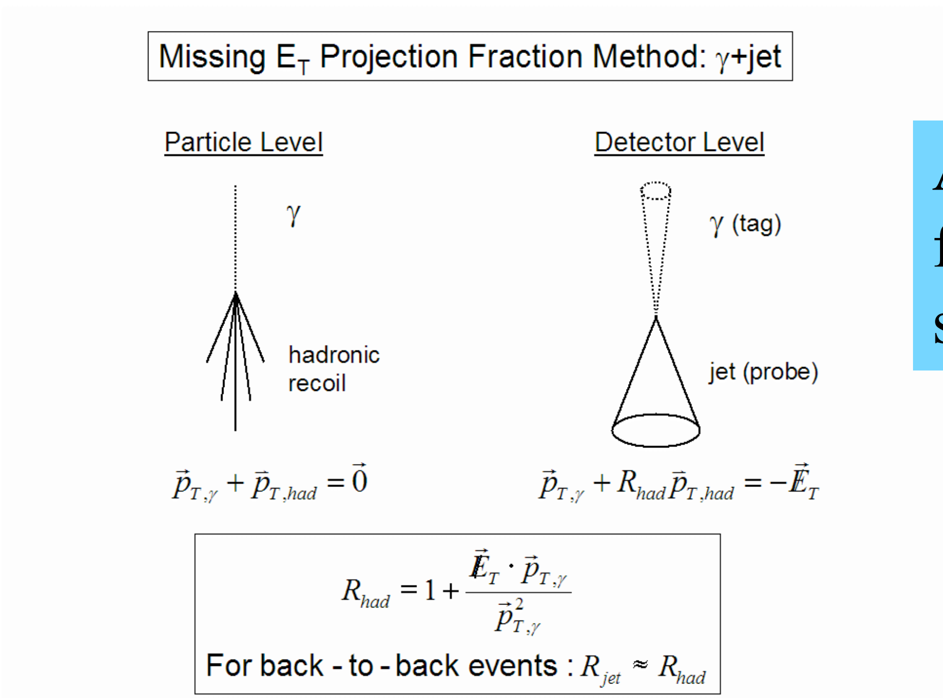
Introduction

- Fermilab is the best place in the world to perform precision tests of electroweak and QCD physics
- Lots of results coming out from both CDF and DØ
  - So I'll only give a brief overview of some of the highlights
- QCD physics:
  - Inclusive jet cross section
  - Z + jets cross section
  - Photon + jets cross section
- Electroweak physics:
  - W mass, width, and charge asymmetry
  - Diboson final states (also a Higgs decay channel…)
  - Searches for SM Higgs boson

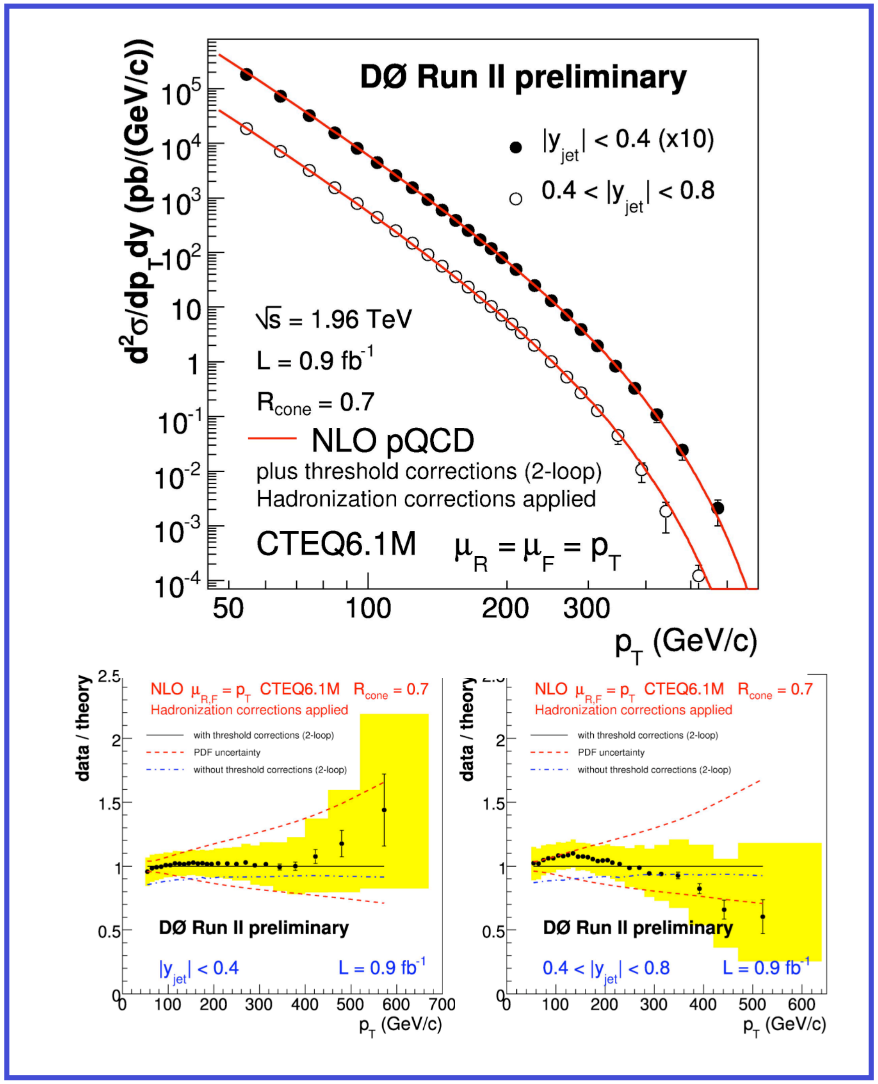
Inclusive Jet Cross Section

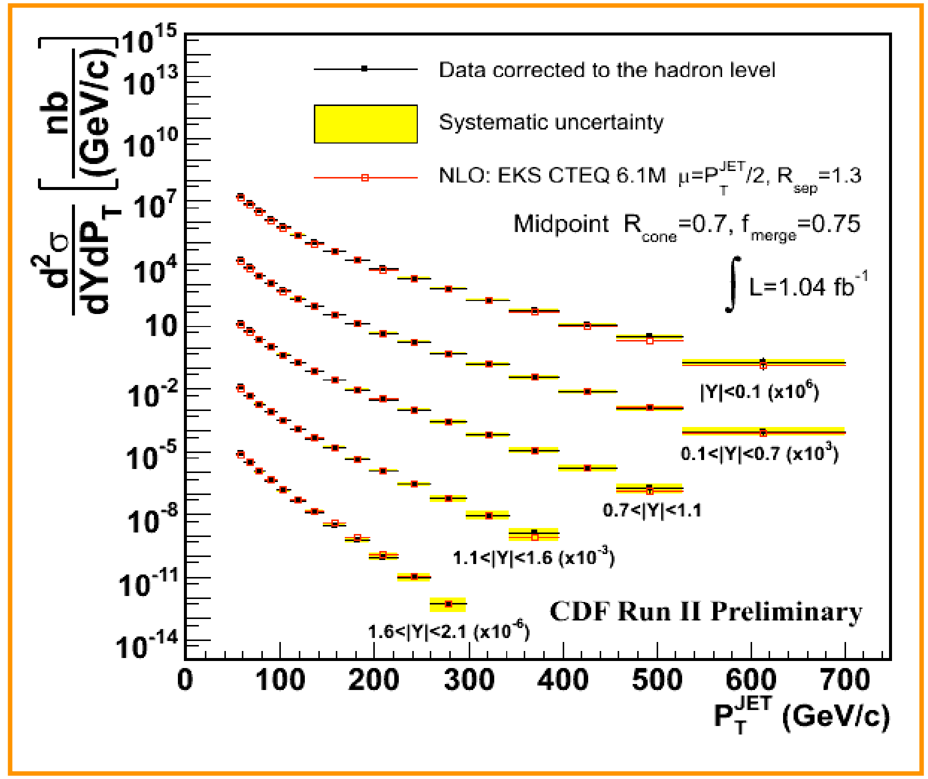
- Test of pQCD over ~8 orders of magnitude
  - constrains PDF's (especially gluons at high *x*)
  - sensitive to new physics (quark substructure)
- Primary experimental challenge:
  - translating observed hadronic energy to energy of initial parton



Also need corrections for underlying event, showering out of cone,…

Inclusive Jet Cross Section Results



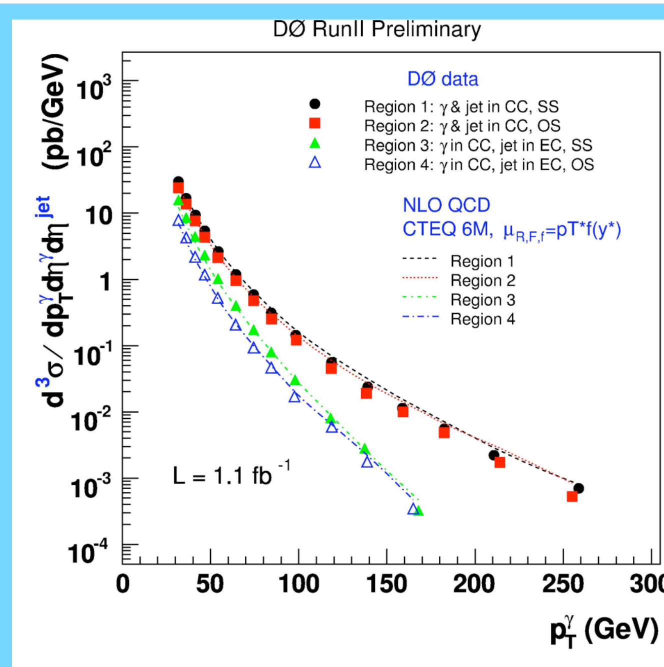


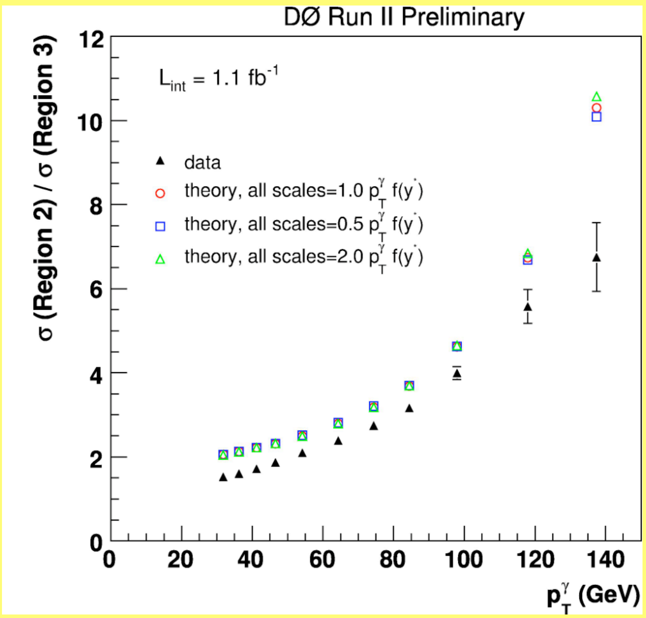
Consistent with pQCD across entire range

Photon + Jet Cross Section

- Another probe of QCD, and the high-*x* gluon PDF

Shape of cross section vs. photon p_T in broad agreement with theory in four photon/jet η regions…

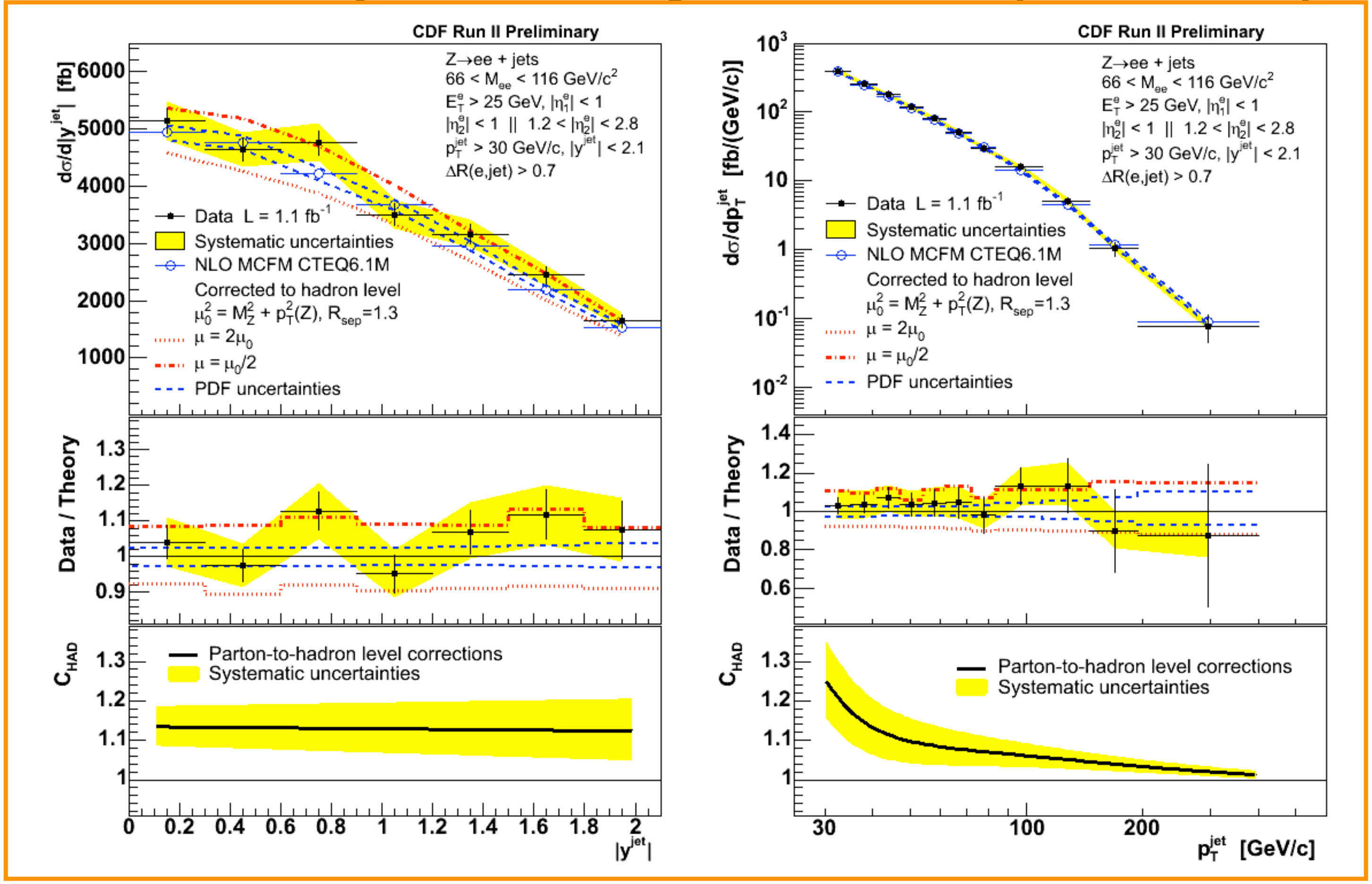




…but ratios of cross sections in different regions show discrepancies

Z+jets Cross Section

- Precision test of pQCD
- Vector boson + jets are background in many other analyses



W Boson Mass Measurement

- Prime example of precision physics at Tevatron
  - aim for error of ~1 in 10^4
- Use $W \to \ell\nu$ decays
  - neutrino not measured → can't form invariant mass
  - transverse mass and lepton p_T distributions are sensitive to M_W
- But they're also sensitive to
  - lepton energy/momentum scale and resolution
  - recoil energy scale and resolution
  - W p_T distribution
  - …
- Understanding all of these systematics is the challenge of this measurement

W + top quark mass constrains Higgs mass

Systematics

- From CDF's measurement using m_T:

Systematic (MeV)	Electrons	Muons	Common
Lepton Energy Scale	30	17	17
Lepton Energy Resolution	9	3	0
Recoil Energy Scale	9	9	9
Recoil Energy Resolution	7	7	7
$u_{\|\|}$ Efficiency	3	1	0
Lepton Removal	8	5	5
Backgrounds	8	9	0
$p_T(W)$ Model	3	3	3
Parton Distributions	11	11	11
QED Radiation	11	12	11
Total	39	27	26

Determined from

$$\left.\begin{matrix} J/\psi \\ \Upsilon(1S) \\ Z \end{matrix}\right\} \to \mu\mu,$$

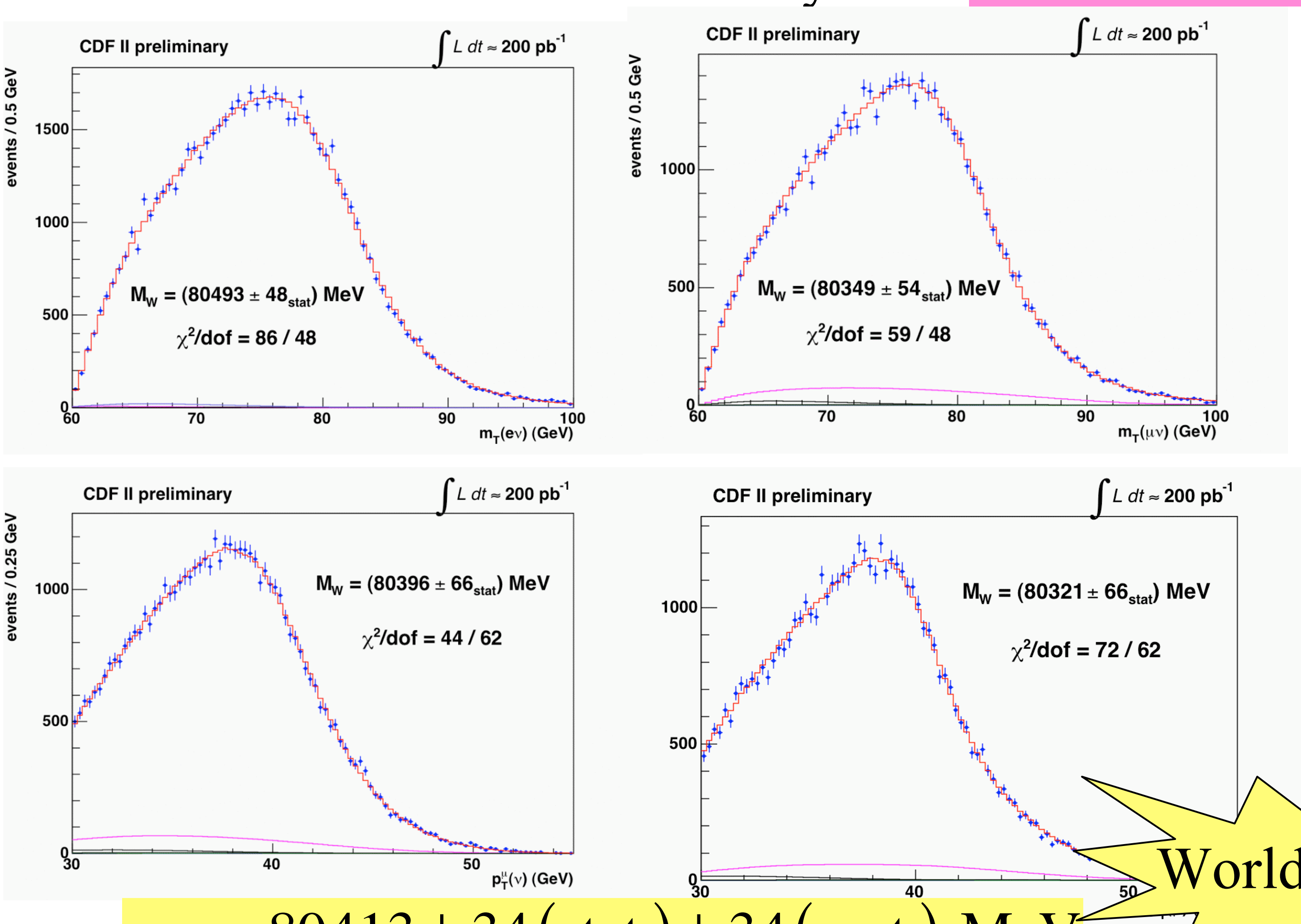
E/p in $W \to e\nu$,

$Z \to ee$

First RunII Result (CDF)

Preliminary, 200 pb^{-1}

- Uses both electron and muon decays

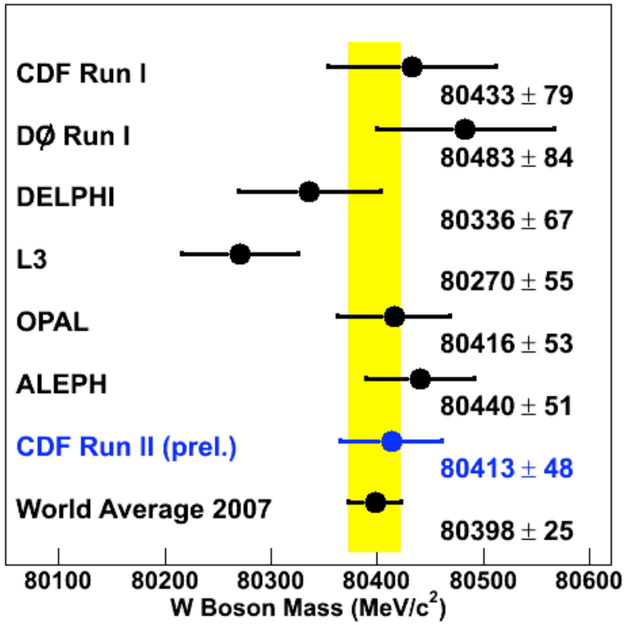


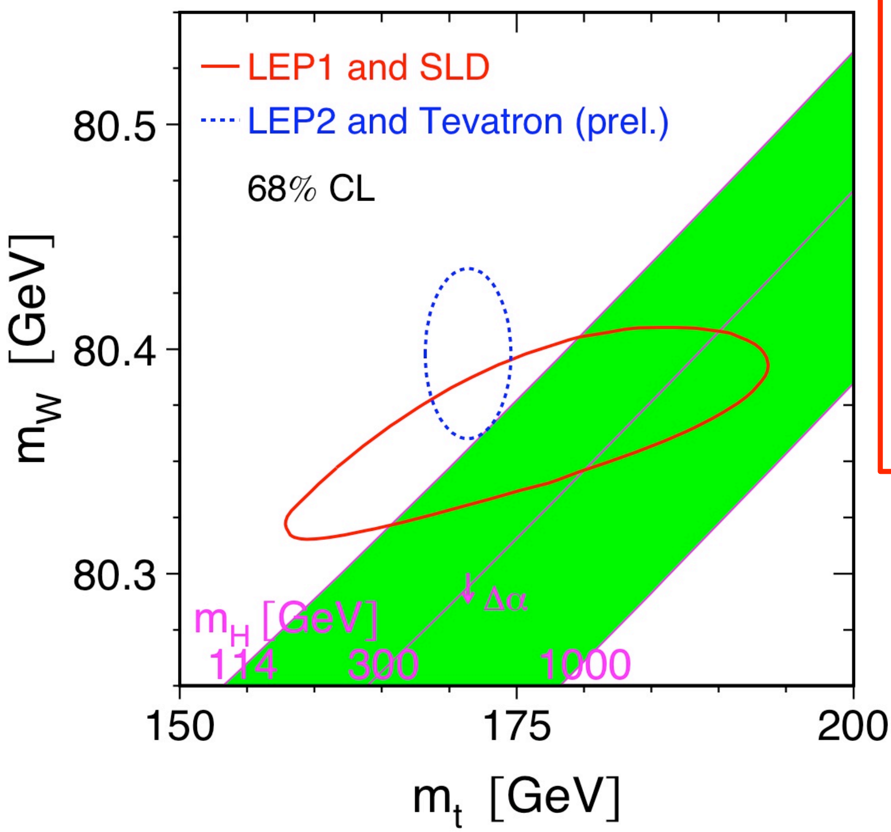
World's best

$$m_W = 80413 \pm 34(\text{stat.}) \pm 34(\text{syst.})\ \text{MeV}$$

Implications

- New result is consistent with world average



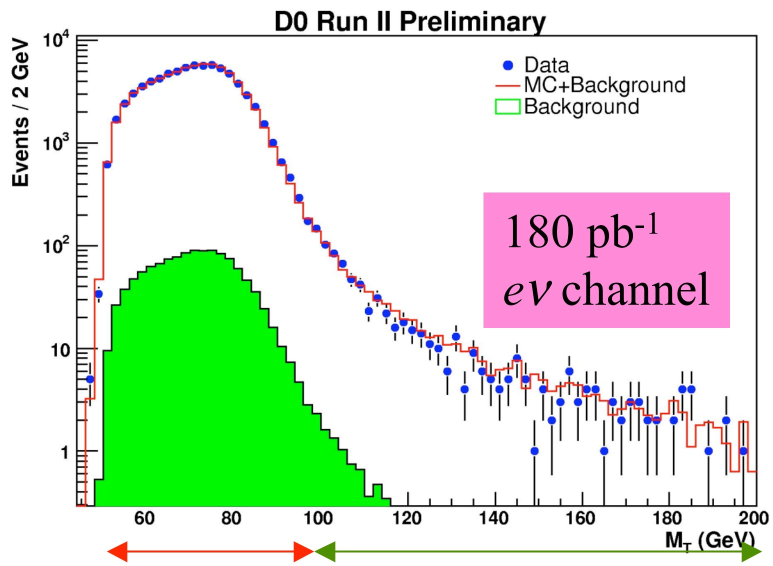


- And favors a light Higgs

$$M_H = 80^{+36}_{-26}\ \text{GeV}$$

W Boson Width

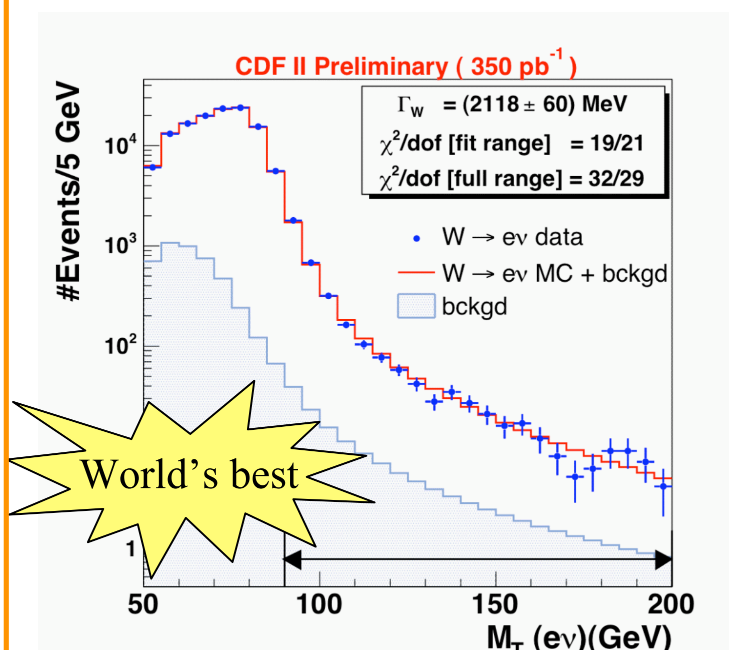
- Width predicted in SM: 2.090 ± 0.008 GeV
  - larger value indicates non-standard decay channels
- As with *W* mass, transverse mass is used for measurement
  - but now, the high tail, not the central distribution, is of interest



Normalize *W* content

Determine Γ(*W*)

$$\Gamma(W) = 2.011 \pm 0.093(\text{stat.}) \pm 0.107(\text{syst.})\ \text{GeV}$$



$$\Gamma(W) = 2.032 \pm 0.071(\text{stat.} + \text{syst.})\ \text{GeV}$$

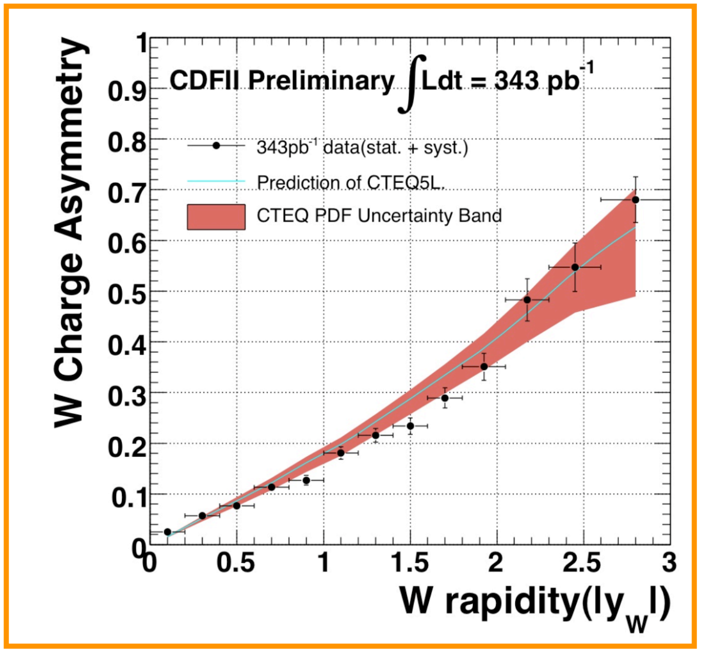
W Charge Asymmetry

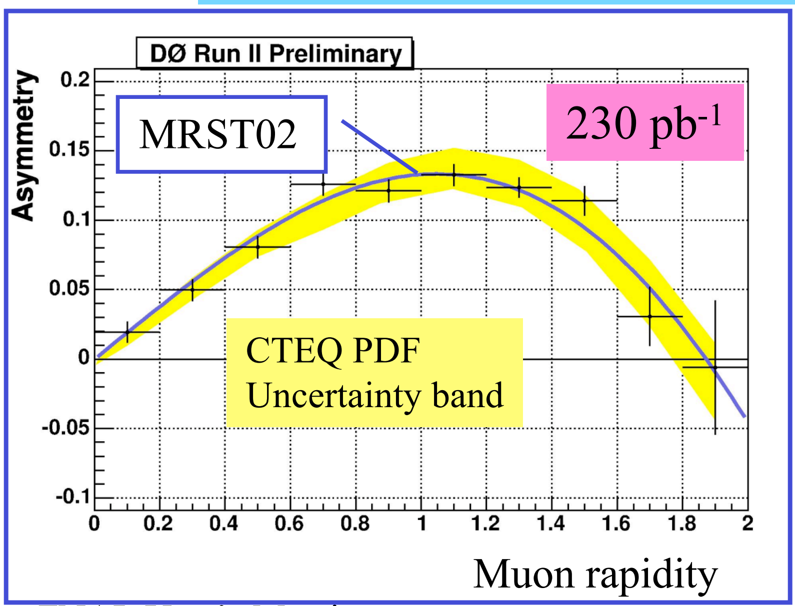
- Test of parton distribution functions
  - asymmetry doesn't exist at LHC!
- Asymmetry in charged lepton or W rapidity:

At high x:
0.005 - 0.3

$$A(y) = \frac{d\sigma/dy(\ell, W^+) - d\sigma/dy(\ell, W^-)}{d\sigma/dy(\ell, W^+) + d\sigma/dy(\ell, W^-)}$$

Requires precise understanding of charge mismeasurement rate



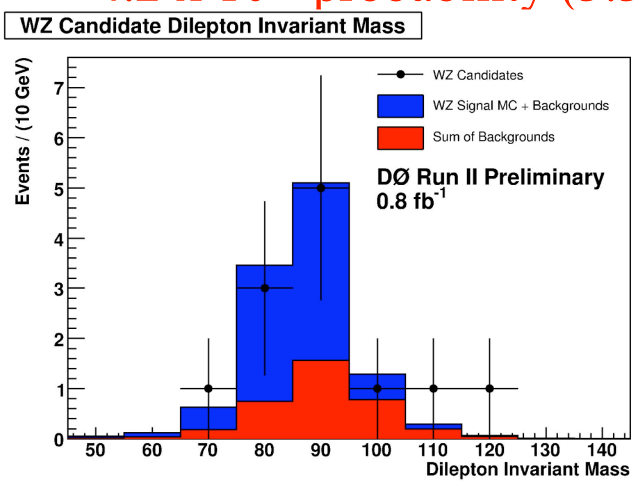


Diboson Cross Sections

- *WW*, *WZ*, *ZZ*, $W\gamma$ and $Z\gamma$ cross sections are sensitive to new physics
  - test structure, not parameters, of SM
- Look for leptonic boson decays
- *WZ* (SM cross section: 3.7 ± 0.3 pb at NLO)

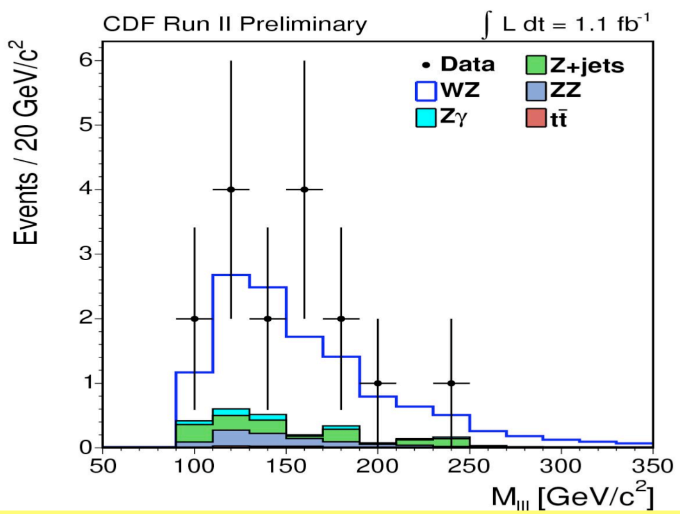
Probes physics beyond the Tevatron's direct energy reach

DØ: 12 events, 3.6 ± 0.2 bkg.
- 4.2×10^{-4} probability (3.3σ)



$$\sigma\left(p\bar{p} \rightarrow WZ\right) = 3.98^{+1.91}_{-1.53}\,\text{pb}$$

CDF: 16 events, 2.7 ± 0.4 bkg.
- 1.1×10^{-9} probability (6.0σ)



$$\sigma\left(p\bar{p} \rightarrow WZ\right) = 5.0^{+1.8}_{-1.4} \pm 0.4\,\text{pb}$$

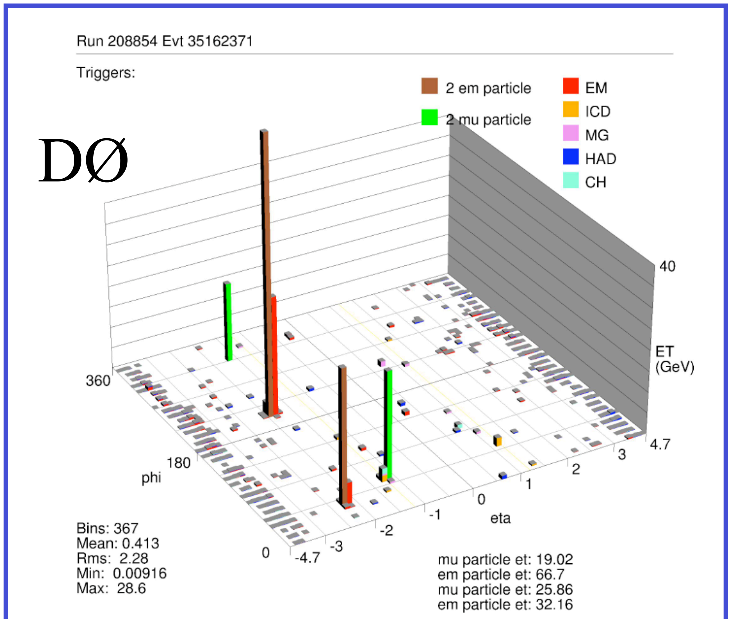
Evidence for *ZZ* Production

SM Cross Section: 1.4 ± 0.1 pb at NLO

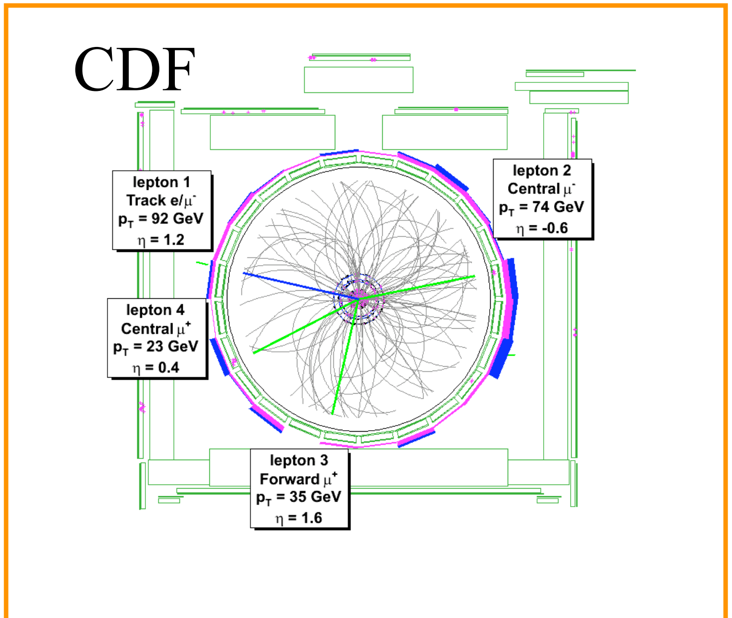
- Cleanest signatures have small $\sigma \times BR$:

$$ZZ \rightarrow \ell\ell\ell\ell: \quad 6 \text{ fb}$$
$$ZZ \rightarrow \ell\ell\nu\nu: \quad 36 \text{ fb}$$

- Each experiment finds one $\ell\ell\ell\ell$ candidate:



0.17 ± 0.04 bkg.

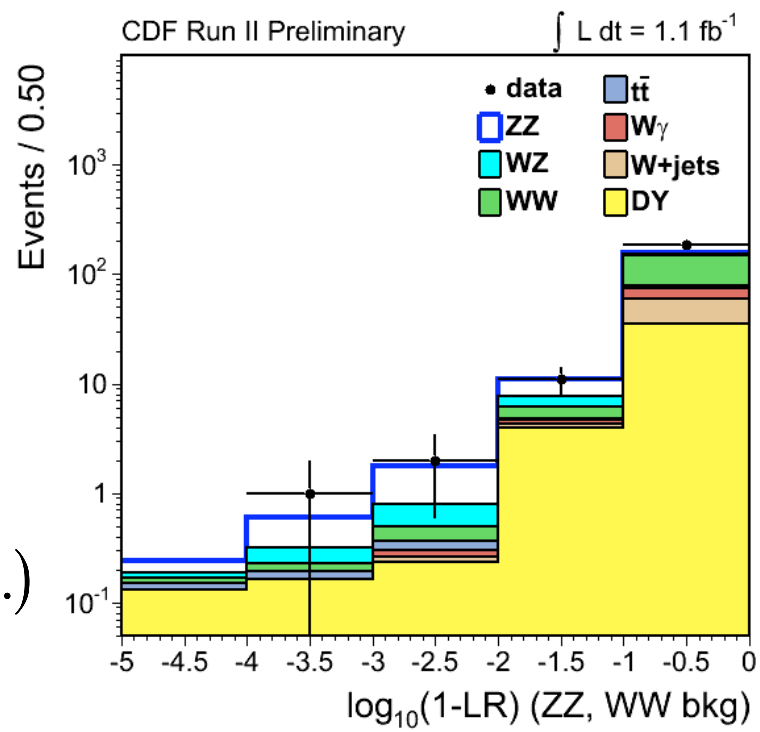


0.029 ± 0.021 bkg.

Evidence for *ZZ* Production

- CDF uses matrix-element likelihood ratio to separate *ZZ* from *WW* in $\ell\ell\nu\nu$ channel
- Combining both channels gives:

$$\sigma = 0.75^{+0.71}_{-0.54}\,(\text{stat.+syst.}) \pm 0.05\,(\text{lumi.})$$



First 3σ evidence

Measured diboson cross sections are all consistent with SM

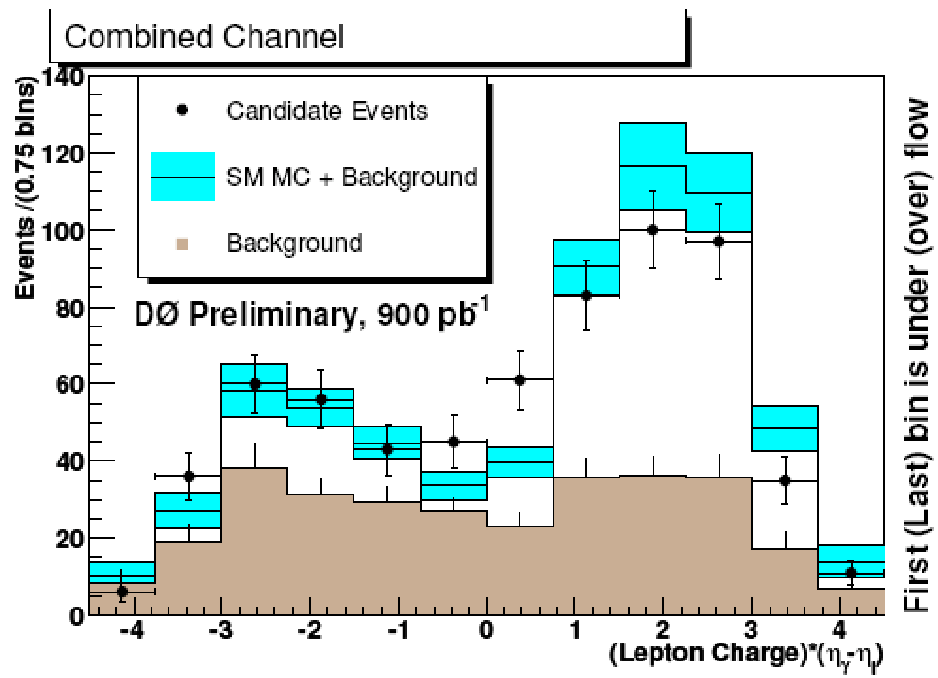
$W\gamma$ Charge-Signed Rapidity

- In SM, interference between production diagrams creates dip in distribution of

$$\text{Lepton charge} \times \big(y(\gamma) - y(\ell)\big)$$

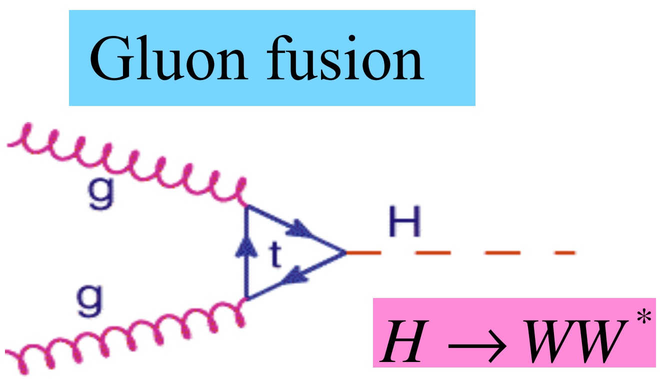
- Anomalous couplings would fill in the dip

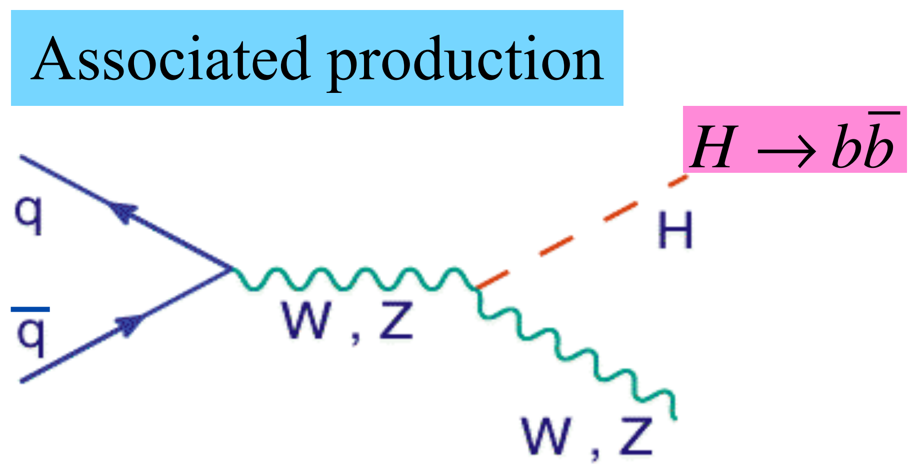
- DØ data consistent with expected dip



Searches for SM Higgs Boson

- Higgs Boson discovery was (and is) one of the primary motivations for Run II
  - But it's not easy: cross sections are modest, common $H \to b\bar{b}$ mode buried in background
- Best channels:





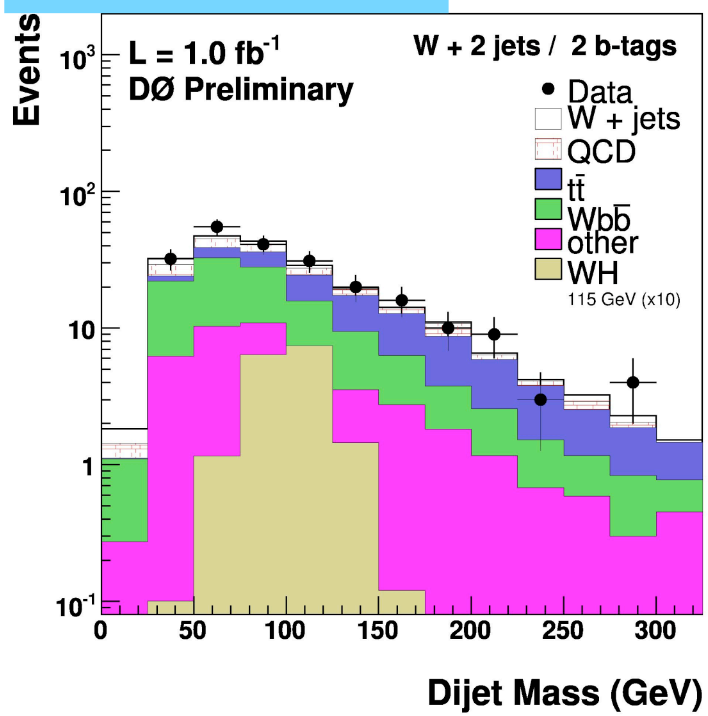
- Both experiments have performed searches in both channels (across many decay modes)
  - with highly sophisticated signal/background discrimination based on matrix element calculation

Examples of Higgs Searches

- Looking at low and high masses:

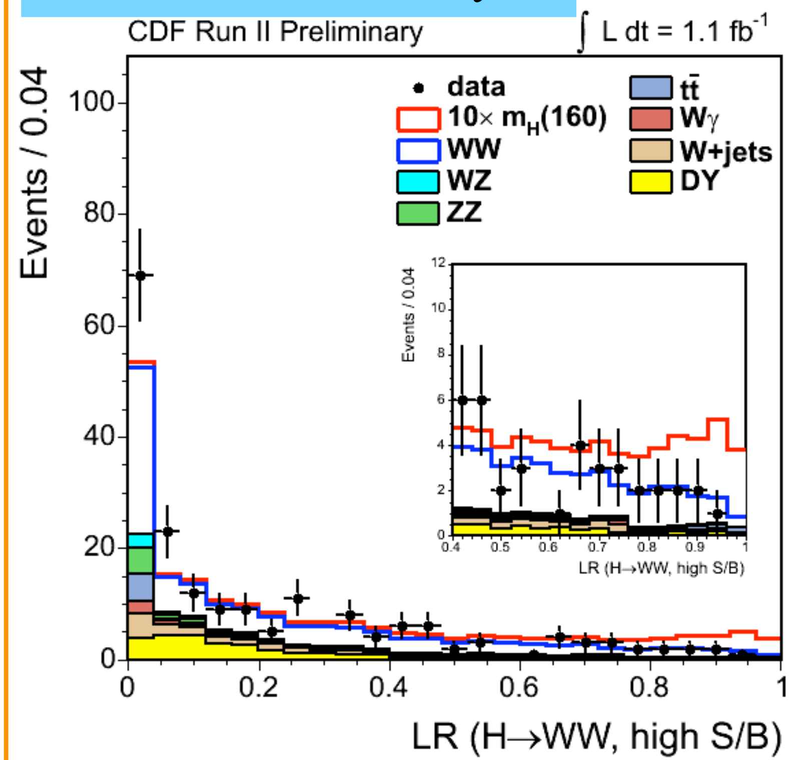
$WH \to \ell \nu b\bar{b}$

Cut-based analysis



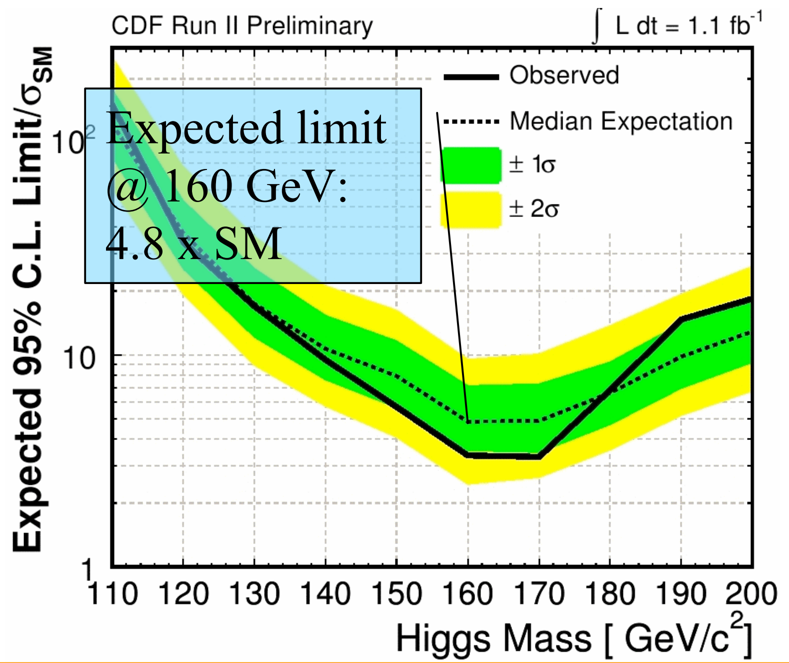
$H \to WW^*$

Matrix element analysis

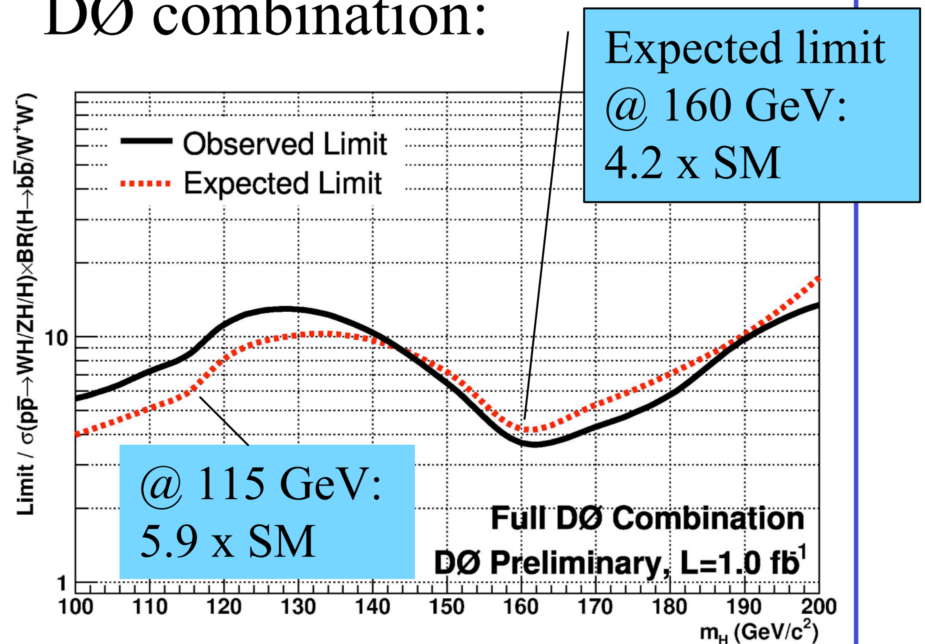


Cross Section Limits and Prospects

CDF's best: $H \rightarrow WW^*$



DØ combination:



- Approaching sensitivity to SM Higgs

With peak performance from Tevatron, CDF, and DØ, we will limit or see the Higgs before LHC

Summary

- Rich program of electroweak and QCD physics underway at the Tevatron
  - Sensitive tests of QCD and determination of PDFs
  - Diboson cross sections and angular distributions constrain non-SM couplings
  - *W* mass measurement constrains Higgs mass
  - And direct searches are nearing sensitivity to SM Higgs
- All of the above based on 1fb^{-1}
  - In the past few days we've reached 3fb^{-1} delivered to each experiment

Looking forward to a strong finish to the Tevatron program