Many figures come from slides for "Higgs Boson Searches at CDF" by Craig Group at LLWI 09.

27 April 2009
Y. Horii

Search for a Higgs Boson Decaying to Two W Bosons at CDF

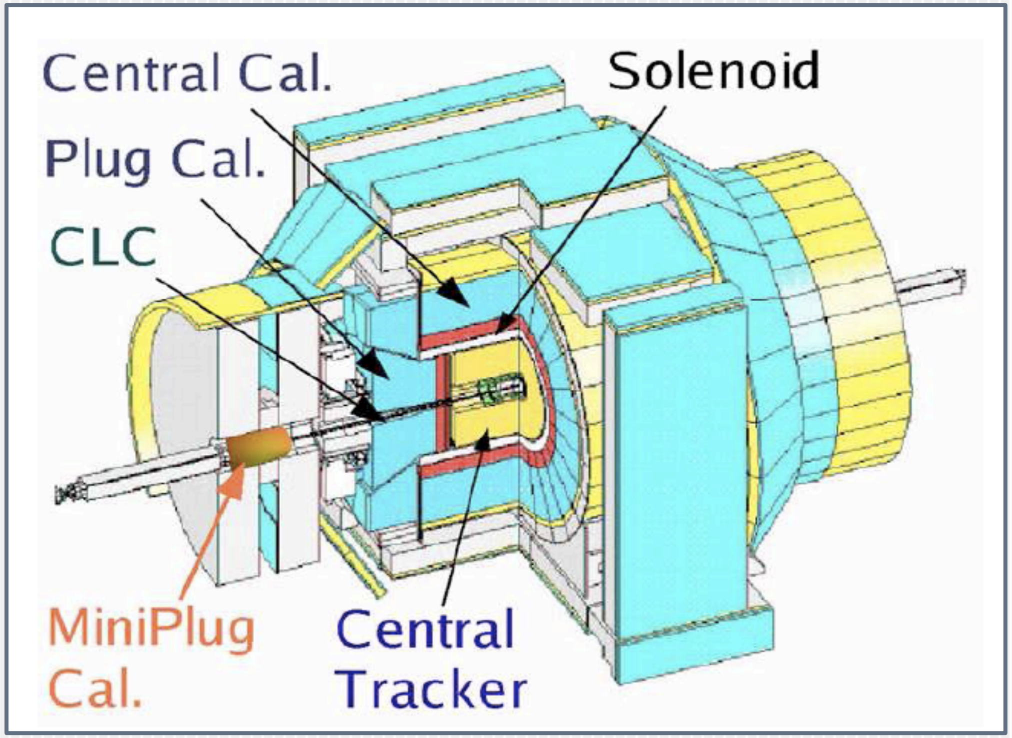
published in PRL 102, 021802 (2009)

FNAL (Fermi National Accelerator Lab)

- Tevatron: the highest energy proton-antiproton collider.
- Two experiments, CDF and Do, are operated.

The CDF Experiment

- About 5 fb^{-1} of integrated luminosity recorded by CDF.
- The results use up to 3 fb^{-1}.

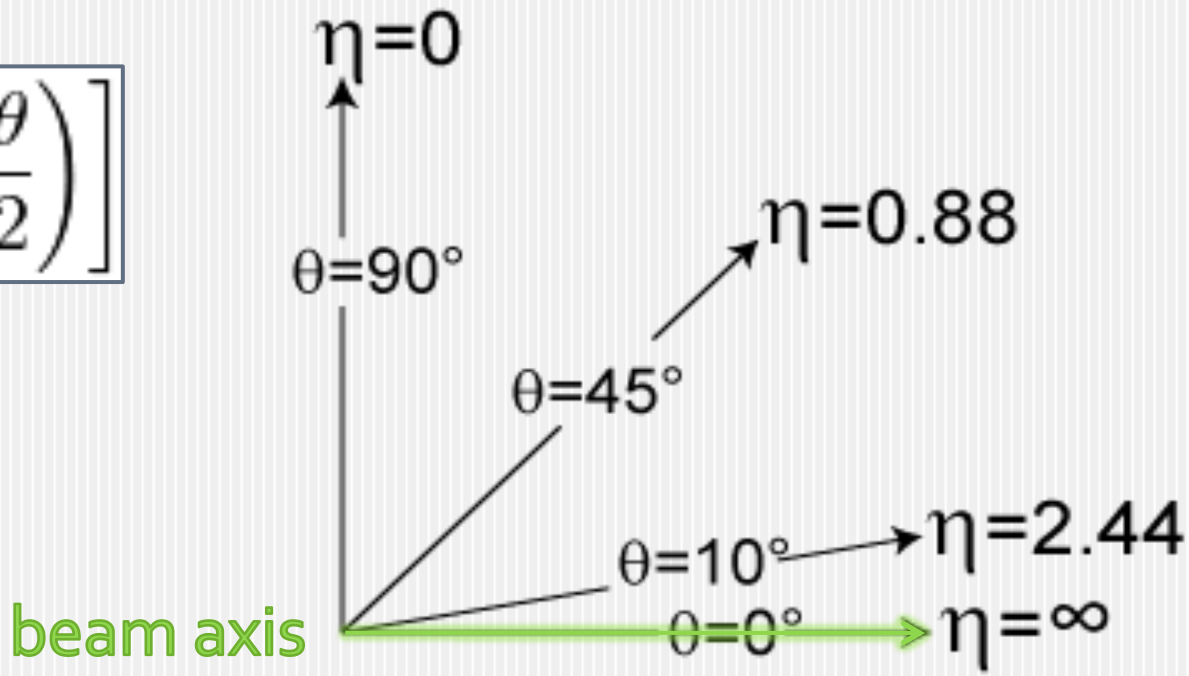


General-purpose detector

- Luminosity measurement
- Silicon vertex detector
- Central tracking chamber
- EM Calorimeters: Jets, e, γ
- Hadronic Calorimeters: Jets
- Muon chambers

Pseudorapidity

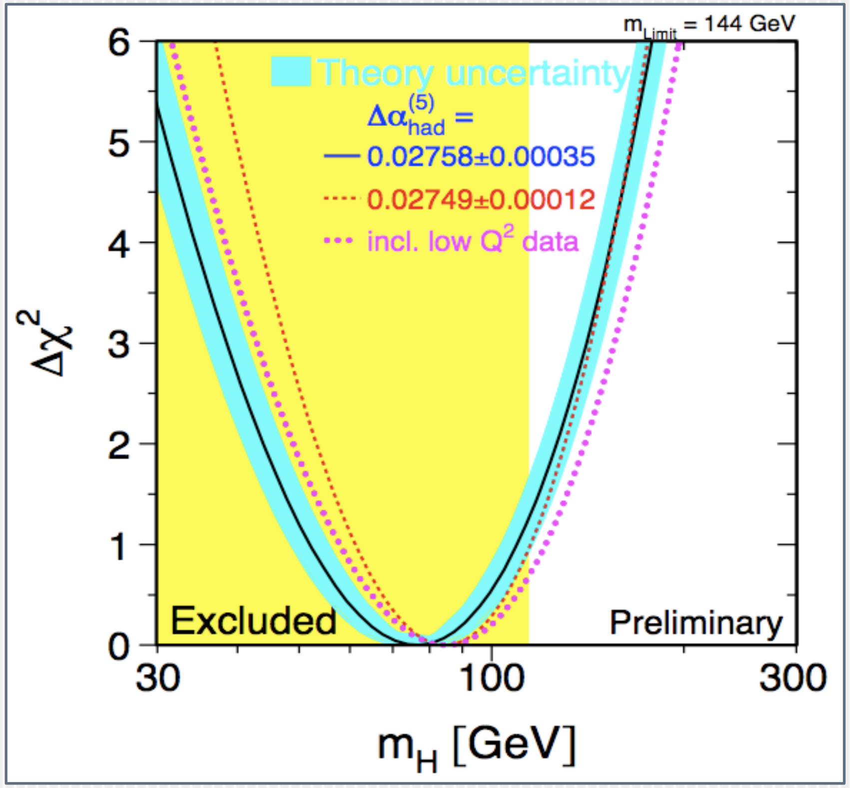
$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



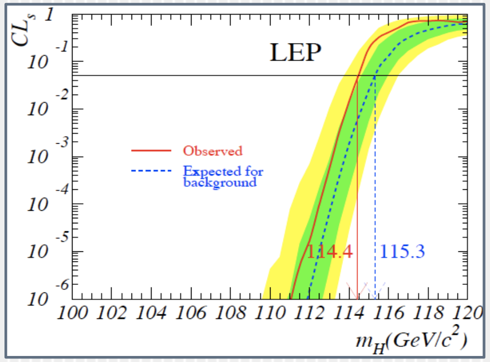
- The (pseudo-)rapidity is preferred over the polar angle θ, because, loosely speaking, particle production is constant as a function of rapidity.

Standard Model Higgs

- EW symmetry breaking introduced via the Higgs mechanism.
  - Allow for fermion and boson mass terms in SM.
  - Predict a massive particle: the Higgs boson.

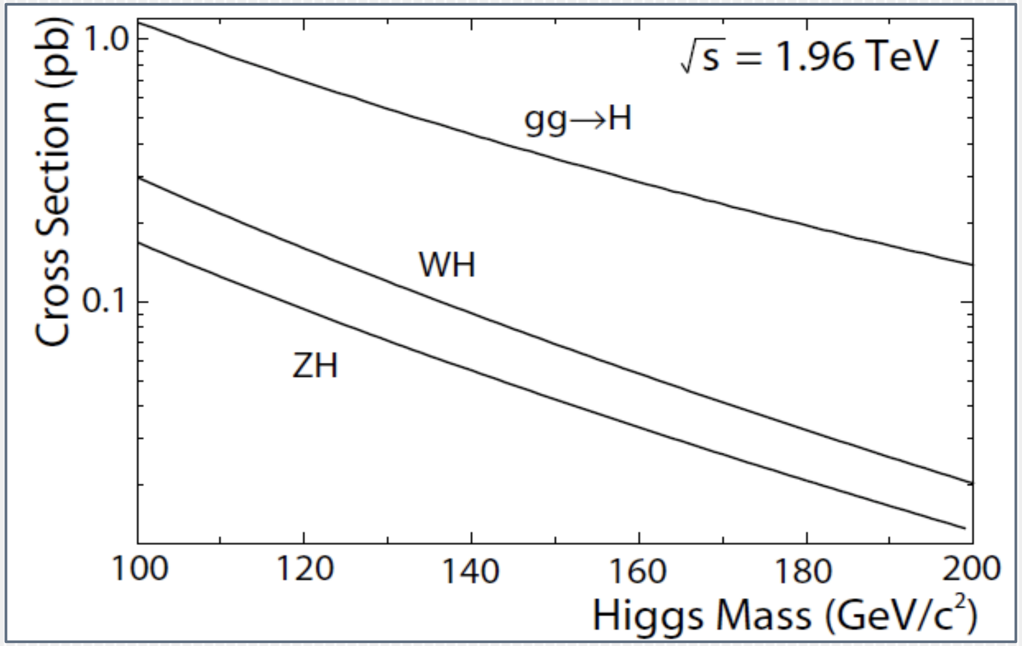


- Indirect EW constraints:
  $m_H < 144$ GeV (163 GeV in 2009)
  (assuming no significant contributions to the radiative corrections due to as-yet unobserved processes.)
- LEP direct searches:
  $m_H > 114$ GeV

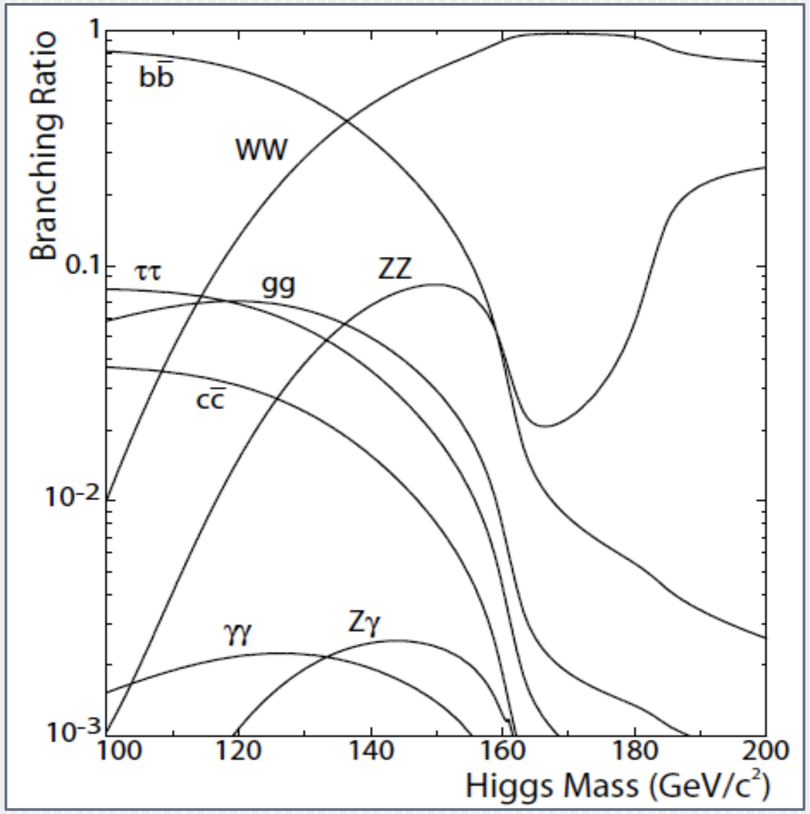


Production and Decay of SM Higgs

Production

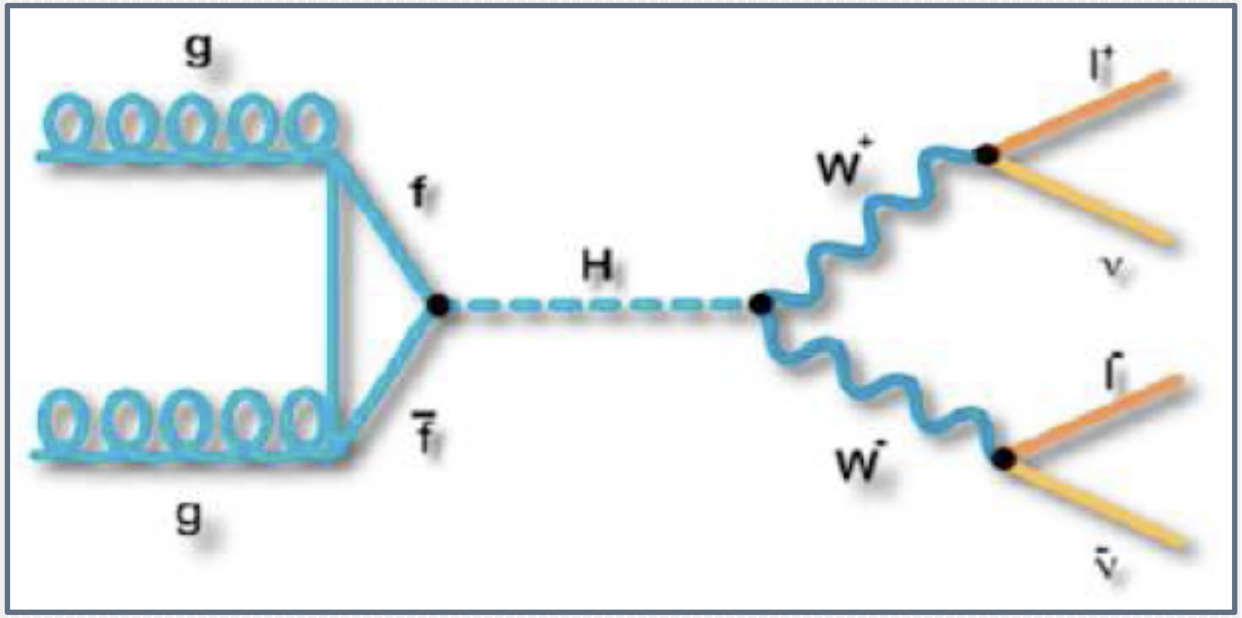


Decay



- *gg→H→bb* : overwhelmed by background.
  (Search for associated *W/Z* production for low mass Higgs.)
- *gg→H→WW* : most sensitive Higgs search at Tevatron.

$gg \rightarrow H \rightarrow W^+W^-$



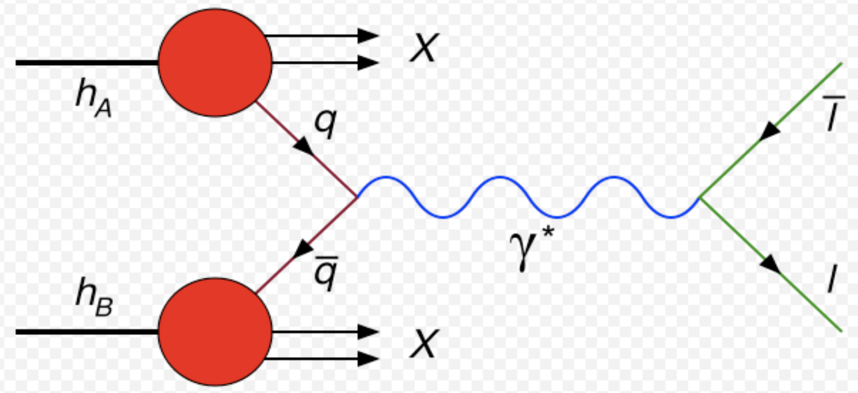
- f : dominated by top quark contribution.
- One of the final state W bosons is virtual (W^*) for m_H below two times the W mass.
- $l = e, \mu, \tau\ (\tau \rightarrow e\nu\nu, \mu\nu\nu)$.

Method of the Analysis

- Triggers
  - Four selections including high p_T leptons and missing E_T.
  - Efficiencies are measured using leptonic *W* and *Z* data samples.
- Leptons
  - Lepton ID (to reject *W*+jets and $W+\gamma$): optimized on large *W*/*Z* samples for six mutually exclusive categories.
  - Requirements to be isolated (E_T and p_T in a cone of ΔR).
- Higgs
  - Selected from events with exactly two lepton candidates.
  - One lepton matching trigger: E_T (p_T) > 20 GeV for *e* (μ).
  - The other lepton: 10 GeV.
  - m_{ll} > 16 GeV to suppress misidentified multijet events.

SM Backgrounds and suppression

- Drell-Yan (DY), *tt*, *WW*, *WZ*, *ZZ*, *W*+jets, and *W*+γ.
  - Drell-Yan process: a quark of a hadron and an antiquark of another (anti-)hadron annihilate, creating a virtual photon or Z boson which then decays into a pair of oppositely-charged *l*.



- DY suppression: sufficiently large missing E_T.
- *tt* (*t*→*W*+jet) suppression: fewer than two jets with $E_T > 15$ GeV and $|\eta| < 2.5$.

Acceptances

- Generator
  - MC@NLO: *WW* (BG)
  - PYTHIA: $WW^{(*)}$ (signal), DY, *WZ*, *ZZ*, *tt*
  - Another generator: $W\gamma$
- Detector simulation: GEANT-4-based.
  - Efficiency corrections for leptons by $Z \rightarrow l^+l^-$ events.
  - Additional correction on the suppression of $W\gamma$ by data.
- *W*+jets contribution: estimated from data.
  - Extrapolate from a sample that contain a lepton and a jet.
  - Probability of the jet misidentification from a jet-based triggers.

After the selection,

- Expected background events: 768±91.
  - Check of the background estimation is performed using a similar method to the signal extraction for the events $qq \rightarrow WW$.

- Observed events: 779.
- To differentiate signal and background, two techniques are combined.
  - ME technique: use an event-by-event calculation of probability density for each process to produce the observed events.
  - NN (Neural Network): use the simulated data and W+jets model to improve approximation in the ME technique.

Matrix Element

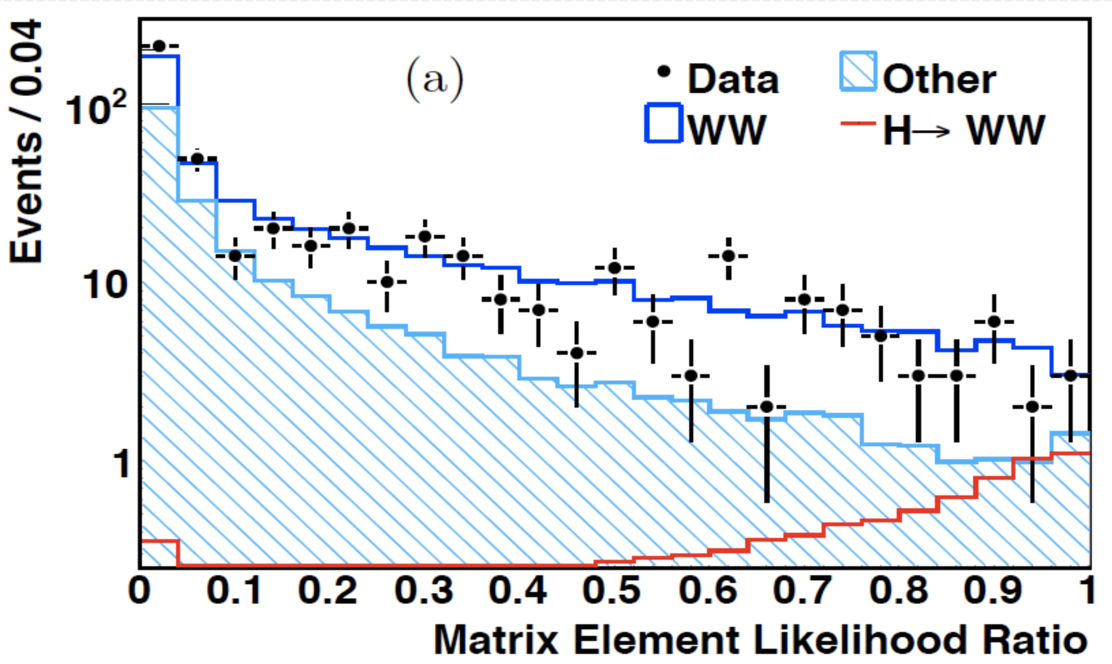
Parton level calculation

Efficiency

Transfer function

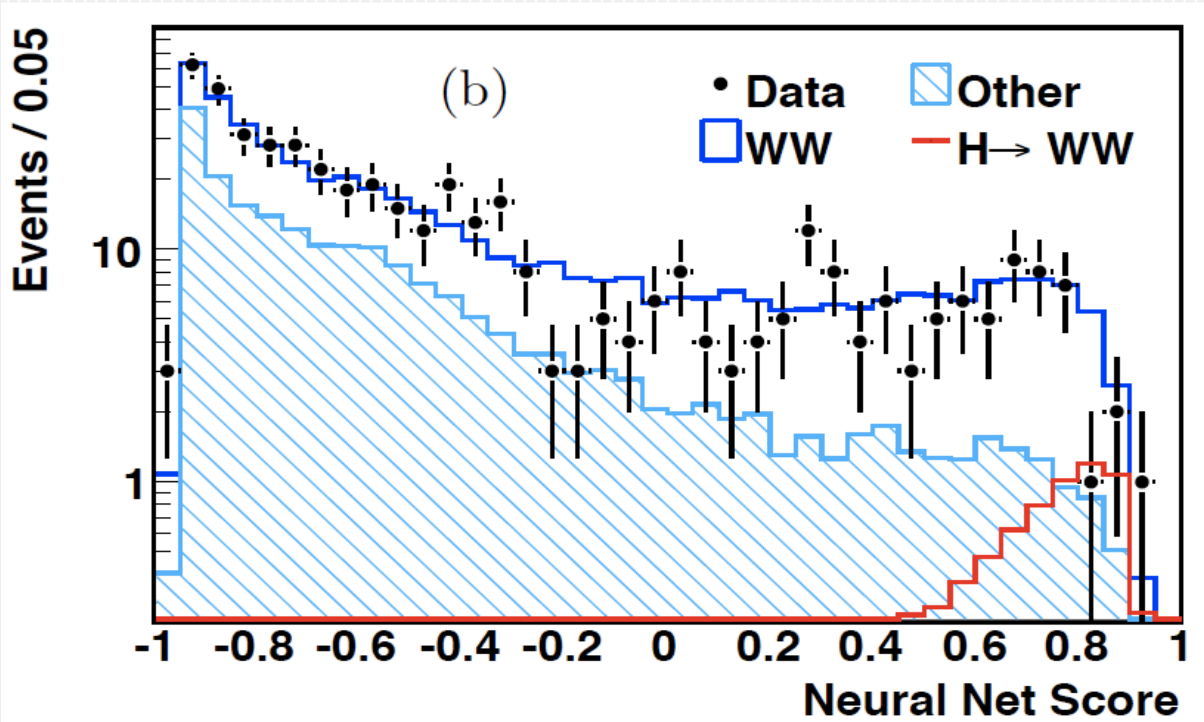
$$P(\vec{x}_{obs}) = \frac{1}{\langle\sigma\rangle}\int \frac{d\sigma_{LO}(\vec{y})}{d\vec{y}}\epsilon(\vec{y})G(\vec{x}_{obs},\vec{y})d\vec{y}$$

- Probability as a function of observed lepton momenta and missing E_T.
- The likelihood ratio is defined as the signal probability divided by the sum of signal and background probabilities.



Neural Network

- NN discriminant using various kinematic variables as well as ME likelihood ratios: trained for each of m_H.
- Most discriminating variables: $LR_{H\rightarrow WW(*)}$, ΔR_{ll}, $E_{missing,T,rel}$.



Systematic uncertainties

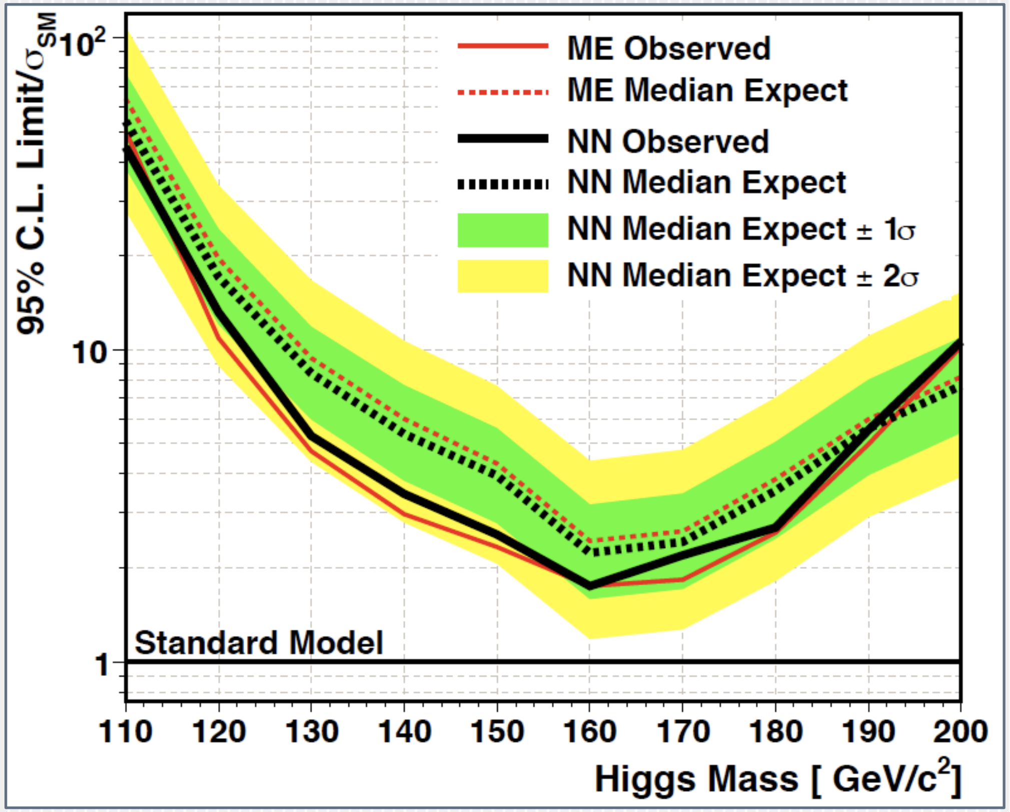
- (Uncertainties due to MC affect all components except for *W*+jets.)
- Lepton selection and trigger efficiency: 1.4-2.0% (Sig), 2.1-7.1% (BG).
- PDF uncertainties for acceptance estimation: 1.9-4.0%.
- Luminosity uncertainty: 6%.
- Cross section uncertainties: 10% (*WW*, *WZ*, *ZZ*, $W\gamma$), 15% (*tt*).
- Higher order QCD effects: 5.5% (*WW*), 10% (others with LO Simu.).
- Misidentification rate of jet: 24% (*W*+jets).
- Resolution modeling of the missing E_T: 20% (DY).
- Detector material description and γ-conversion veto efficiency: 20% ($W\gamma$).

95% C.L. limits

- A Bayesian credibility level (C.L.) is calculated.
- Median expect: for the background-only hypothesis (from many pseudoexperiments).

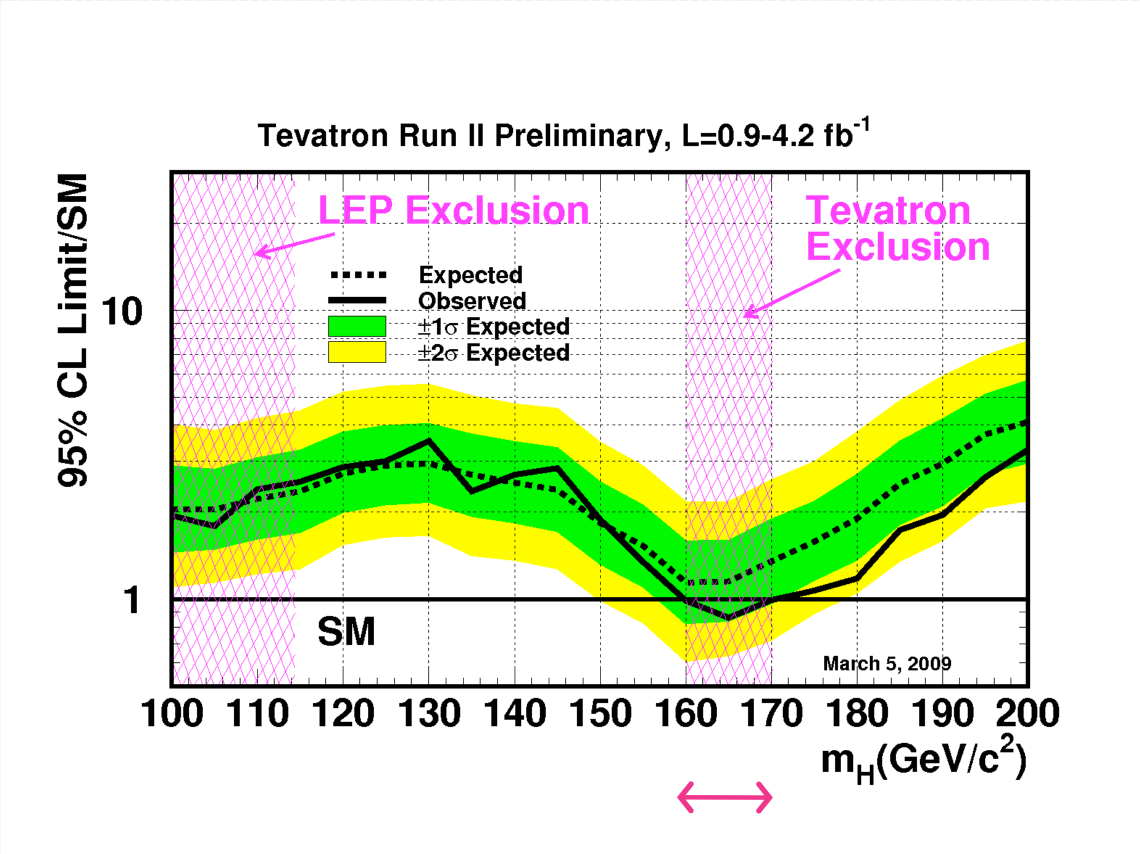
TABLE II: Expected and observed upper limits on $\sigma(gg \to H) \times \mathcal{B}(H \to WW^{(*)})$ and $\sigma(gg \to H) \times \mathcal{B}(H \to WW^{(*)})/\sigma_{\rm SM}(gg \to H) \times \mathcal{B}_{\mathcal{SM}}(H \to WW^{(*)})$ as a function of m_H.

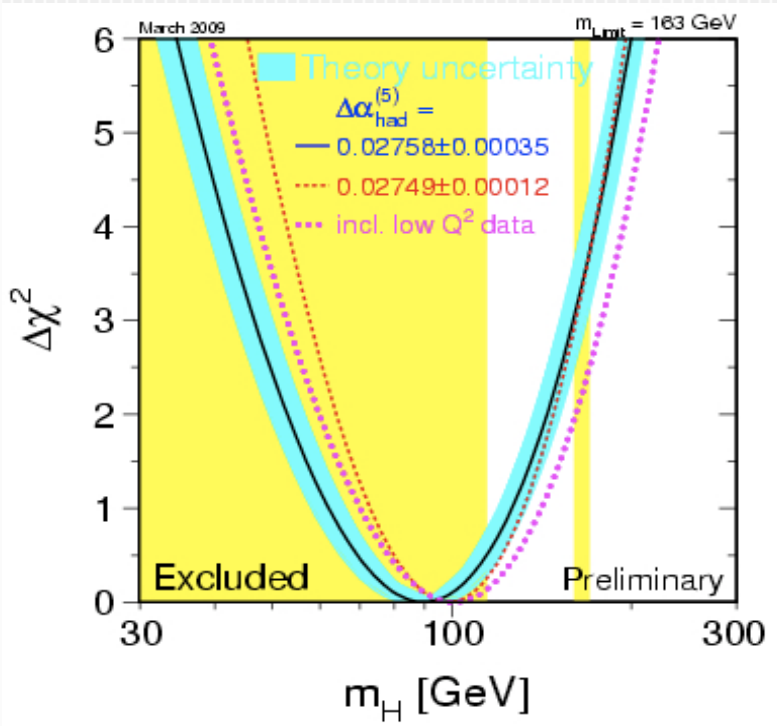
m_H (GeV/c^2)	110	120	130	140	150	160	170	180	190	200
Using Matrix Element Only										
Expected (pb)	3.6	2.6	2.2	1.9	1.5	0.9	0.9	1.1	1.2	1.3
Observed (pb)	2.8	1.5	1.1	0.9	0.8	0.7	0.6	0.7	1.0	1.5
Expected/SM	63.7	19.6	9.4	6.0	4.3	2.4	2.6	3.8	6.0	8.2
Observed/SM	50.3	10.9	4.7	3.0	2.3	1.7	1.8	2.6	5.0	10.3
Using Neural Net Discriminator										
Expected (pb)	3.0	2.3	1.9	1.7	1.4	0.9	0.8	1.0	1.1	1.2
Observed (pb)	2.5	1.7	1.2	1.1	0.9	0.7	0.7	0.7	1.0	1.6
Expected/SM	54.0	17.1	8.4	5.4	3.9	2.2	2.4	3.5	5.6	7.7
Observed/SM	44.6	13.2	5.3	3.5	2.6	1.7	2.2	2.7	5.5	10.6



Combined Limits

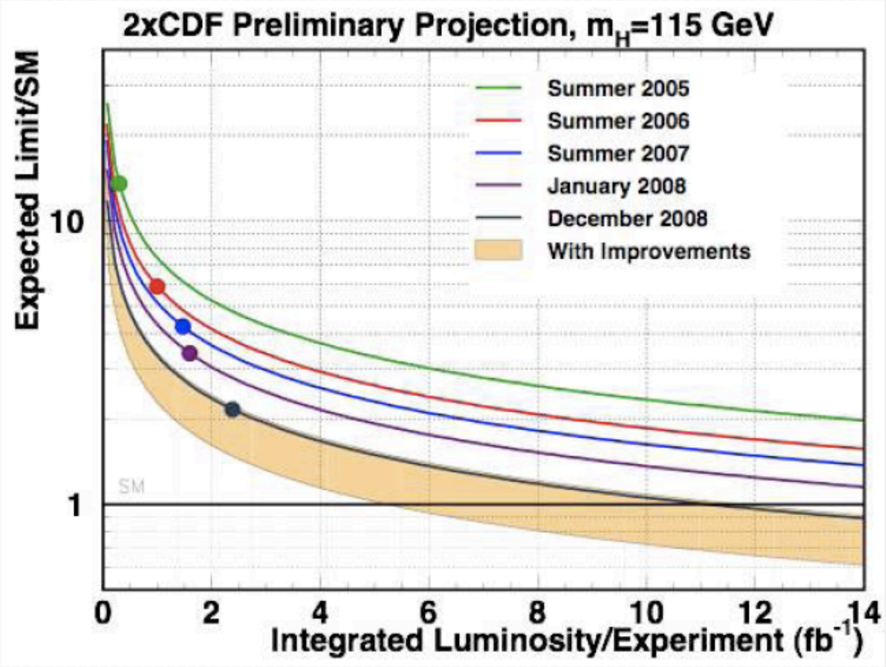
- The figures show the results combined with the ones for several modes (*ZH*, *WH*) and for CDF and Do experiments.
- Exclusion has begun!



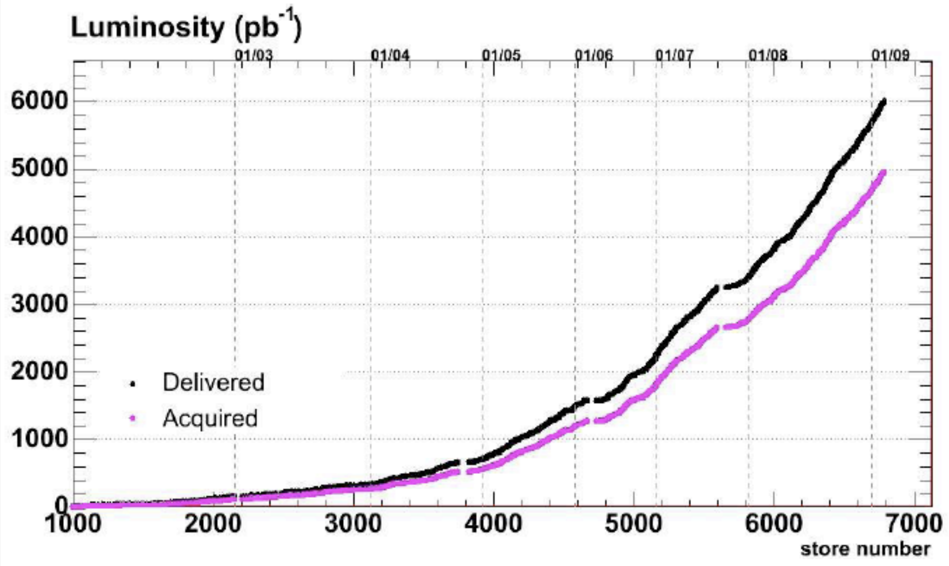


Prospects

- Tevatron exclude over the full mass range with 8-10/fb.



- Collected with more 1.5-2.5 years.



Summary

- Limits on $gg \to H \to WW$ are obtained using 3/fb data sample recorded by the CDF detector.
- ME+NN technique is used to discriminate signal from BG.
- At most sensitive value of m_H=160 GeV, the limit is only 1.7 times the SM prediction.
  - Combined result (CDF+D0) excludes m_H around 160 GeV.
- Will be better to stay tuned.