Standard Model Higgs Limits at DØ

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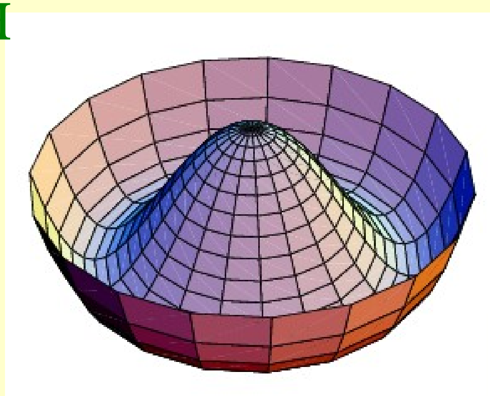
Probing EW Symmetry Breaking

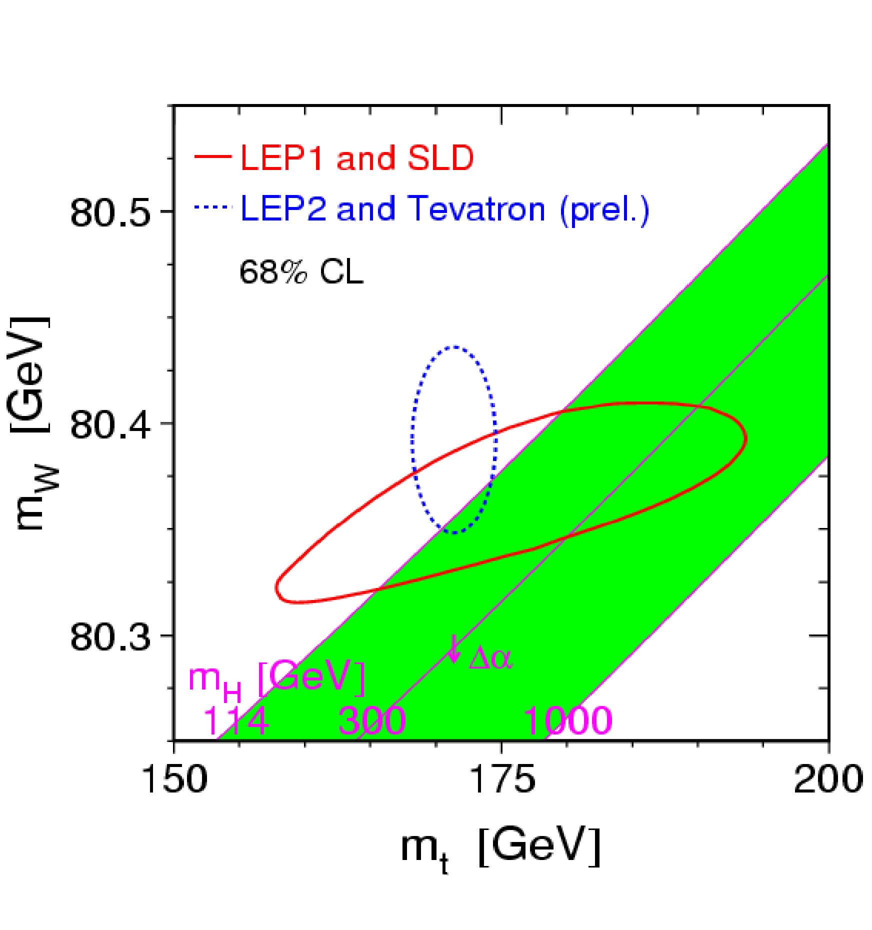
- $SU(2)_L \times U(1)_Y$ is well tested in collider experiments
  - But it is not a symmetry of our vacuum – otherwise quarks, leptons, and gauge bosons would all be massless
- Simplest model – one complex doublet of scalar fields in a Φ^4 potential, resulting in a non-zero VEV

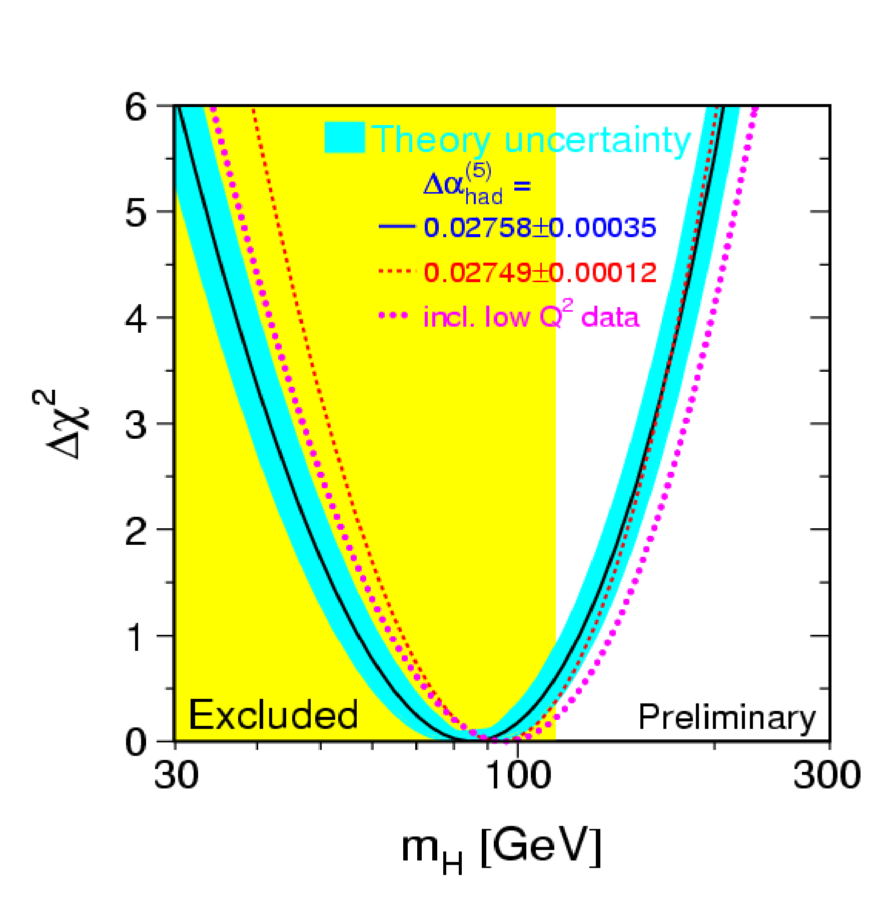
$$L_{Higgs} = \left| (\partial_\mu - i g W^\alpha_\mu T^\alpha - \frac{i}{2} k B_\mu)\phi \right|^2 - \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

  - Transverse polarizations of $W^{+/-}$ and Z take three of the four dof, remaining one becomes a fundamental scalar H
- This is not the only possibility!
  - SUSY Higgs, General 2HDM
  - Little Higgs, Technicolor



Experimental Constraints

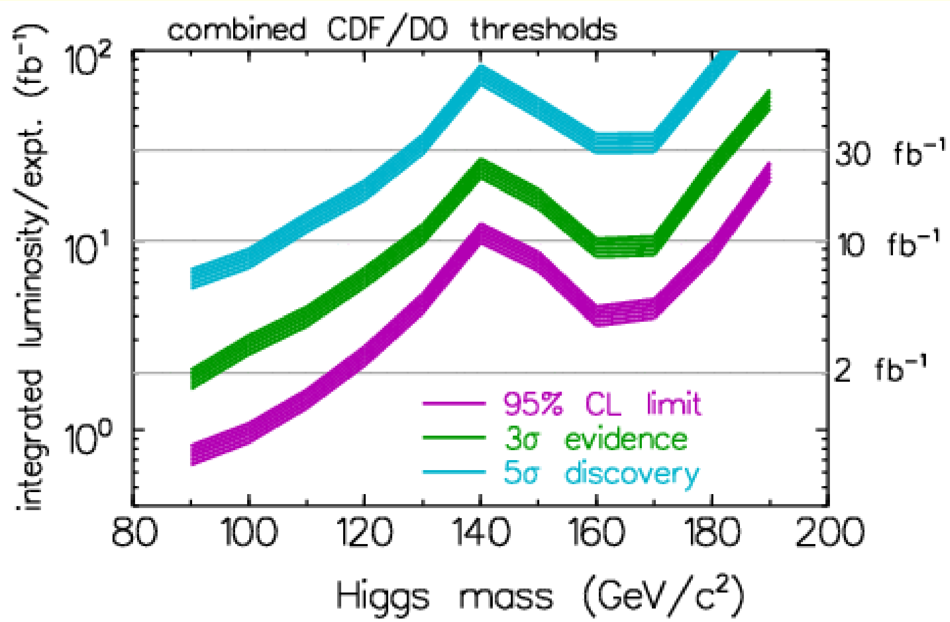




Direct searches at LEP2:
mH>114.4 GeV @ 95% CL

Precision EW fits:
mH<166 GeV @ 95% CL
mH<199 GeV with LEPII Limit

Previous Tevatron Studies

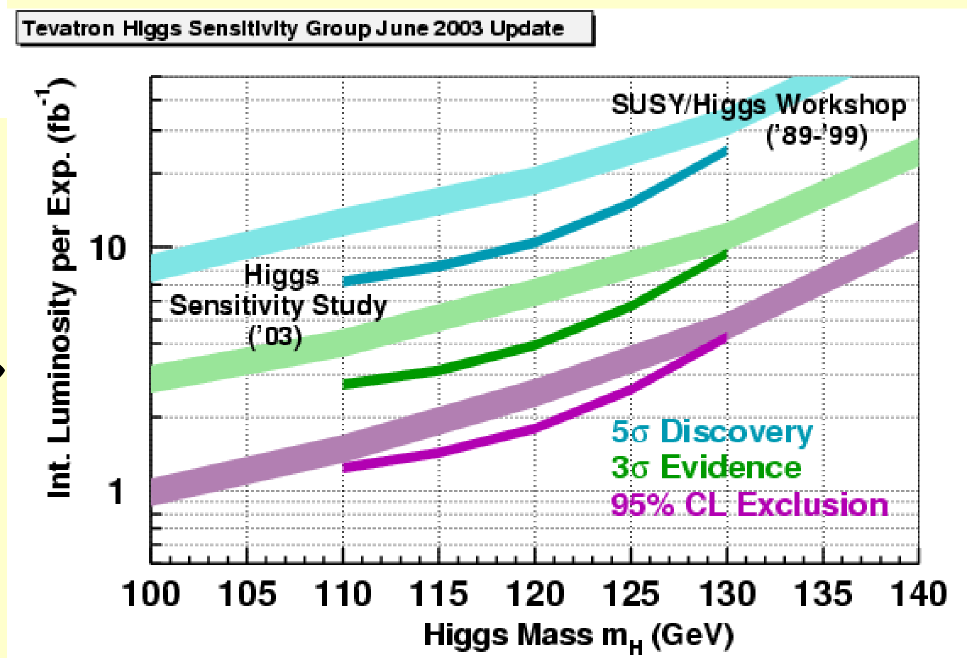


⇐

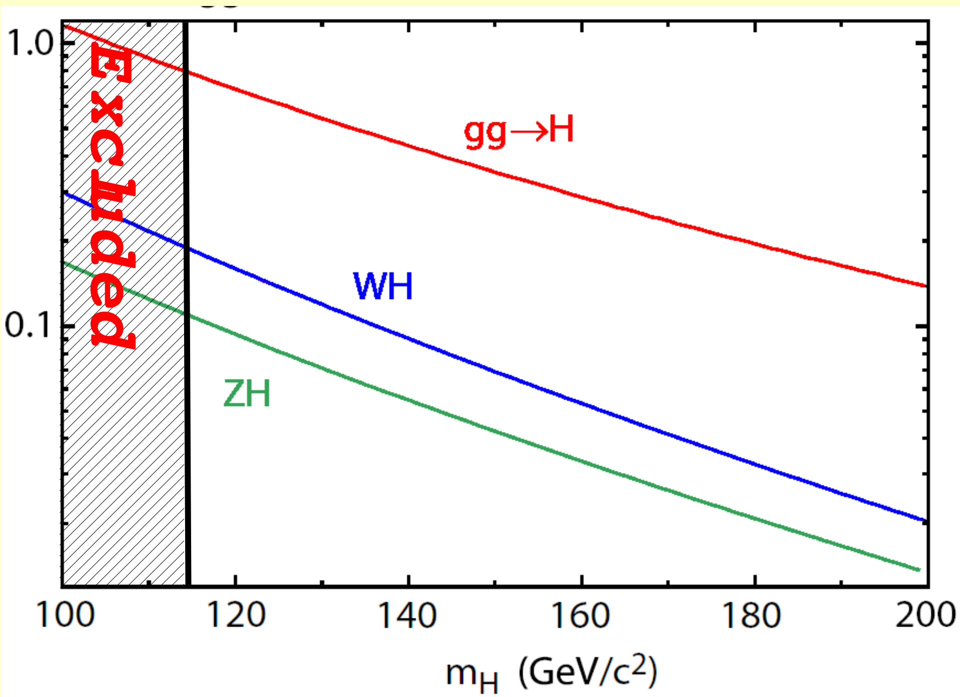
- ✗ SUSY-Higgs Working Group (10/2000)
- ✗ Based on parameterized simulation of an *average* FNAL detector
  - ✗ Systematics "estimated"

- ✗ Higgs Sensitivity Group (6/2003)
- ✗ Based on fully simulated detectors
  - ✗ MC-based, but data used for QCD estimation
  - ✗ No systematics included

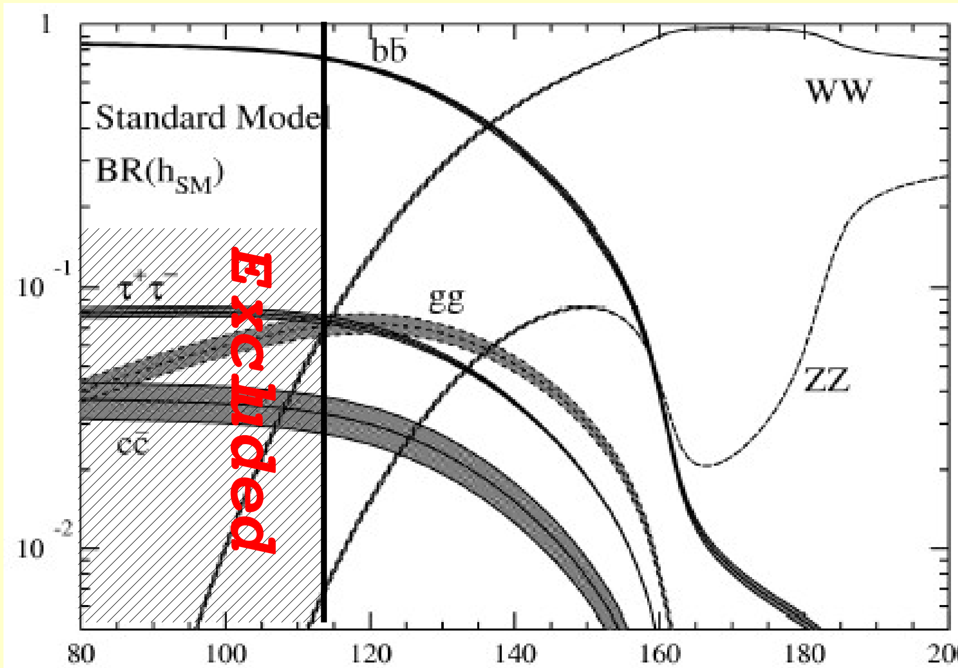
⇒



SM Higgs Production and Decay



- ✗ Production dominated by gluon fusion and associated production
  - ✗ 0.8-0.2 pb for gg→H
  - ✗ 0.2-0.03 pb for WH



- ✗ H→bb is dominant for low mass
  - ✗ Hard to see in gg→H, but associated W/Z provides "tag"
- ✗ Above mH=135 GeV, H→WW is the largest rate

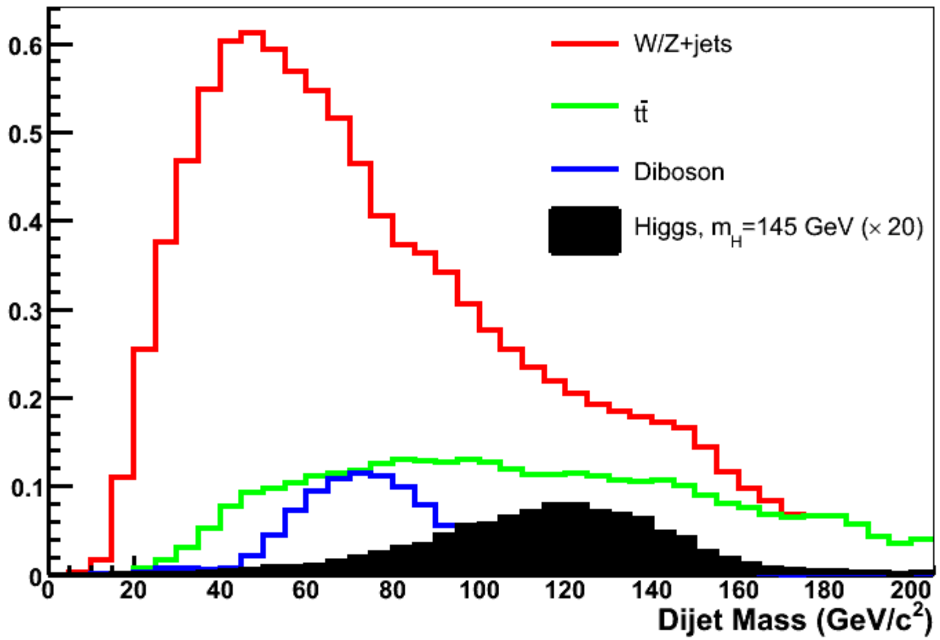
Search Channels

- Defined by production/decay signatures
  - H→bb separated into one & two b-Tag samples (ST & DT)
- **pp→WH→lνbb (*associated production*)**
  - WH→eνbb (ST+DT) 371 pb^{-1}
  - WH→$\mu\nu$bb (ST+DT) 385 pb^{-1}
  - WH→$\not{l}\nu$bb (ST+DT) 261 pb^{-1}
  - WH→WWW 363-384 pb^{-1}
- **pp→ZH→llbb (*associated production*)**
  - ZH→$\nu\nu$bb (ST+DT) 261 pb^{-1}
  - ZH→eebb (DT) 389 pb^{-1}
  - ZH→$\mu\mu$bb (DT) 320 pb^{-1}
- **pp→H→WW (*gluon fusion*)**
  - H→WW→ee + eμ + $\mu\mu$ 930-950 pb^{-1}

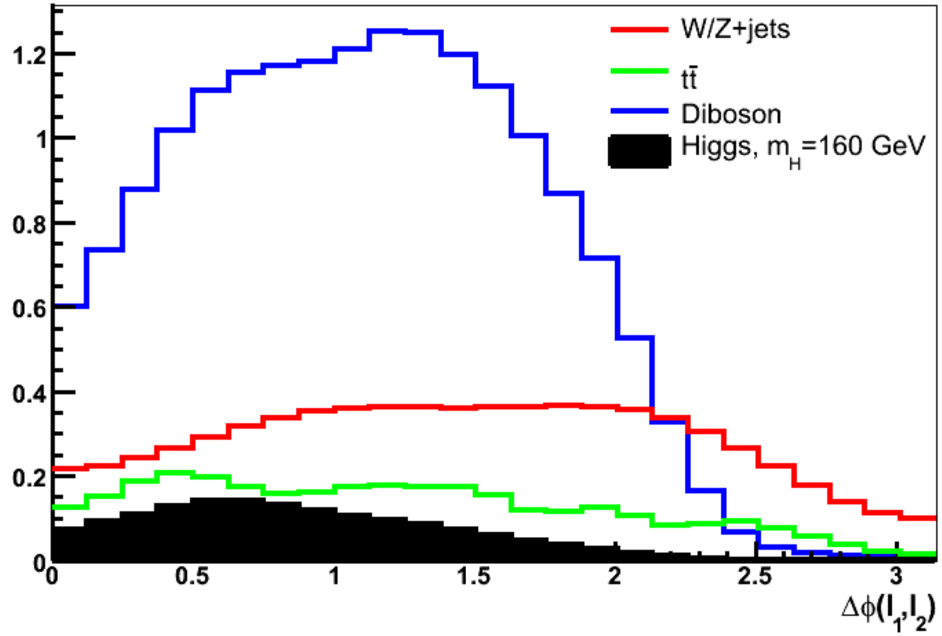
Search Channels

- Final variable determines ultimate signal/background separation
  - H→bb uses dijet invariant mass. W/Z+jets is largest background
  - H→WW uses $\Delta\Phi$ between leptons. Diboson production is largest background
- Next step is to combine the FV distributions of all channels to evaluate a combined limit

H→bb Final Variable



H→WW Final Variable



Statistical Treatment

- DØ has chosen to use the CLs approach, which is a semi-Frequentist statistical treatment
  - The test statistic (or estimator) used is the Poisson likelihood ratio between the signal+background and background-only hypotheses

$$Q(\vec{s},\vec{b},\vec{d}) = \prod_{i=0}^{N_C} \prod_{j=0}^{N_{bins}} \frac{(s+b)_{ij}^{d_{ij}} e^{(s+b)_{ij}}}{d_{ij}!} / \frac{b_{ij}^{d_{ij}} e^{b_{ij}}}{d_{ij}!}$$

  - The **L**og **L**ikelihood **R**atio (LLR) is used to ensure a distribution monotonic in an increasing number of observed events.

$$\Gamma = -2\ln(Q) = -2\sum_{i=0}^{N_C}\sum_{j=0}^{N_{bins}}\left(s_{ij} - d_{ij}\ln\left(1+\frac{s_{ij}}{b_{ij}}\right)\right)$$

The CL_s Approach

- Using our statistical estimator (LLR), the Poisson-distributed outcomes of many repeated experiments are used to populate a PDF for each hypothesis.
  - We can then define a confidence level for each hypothesis (signal+bkgd or bkgd-only):

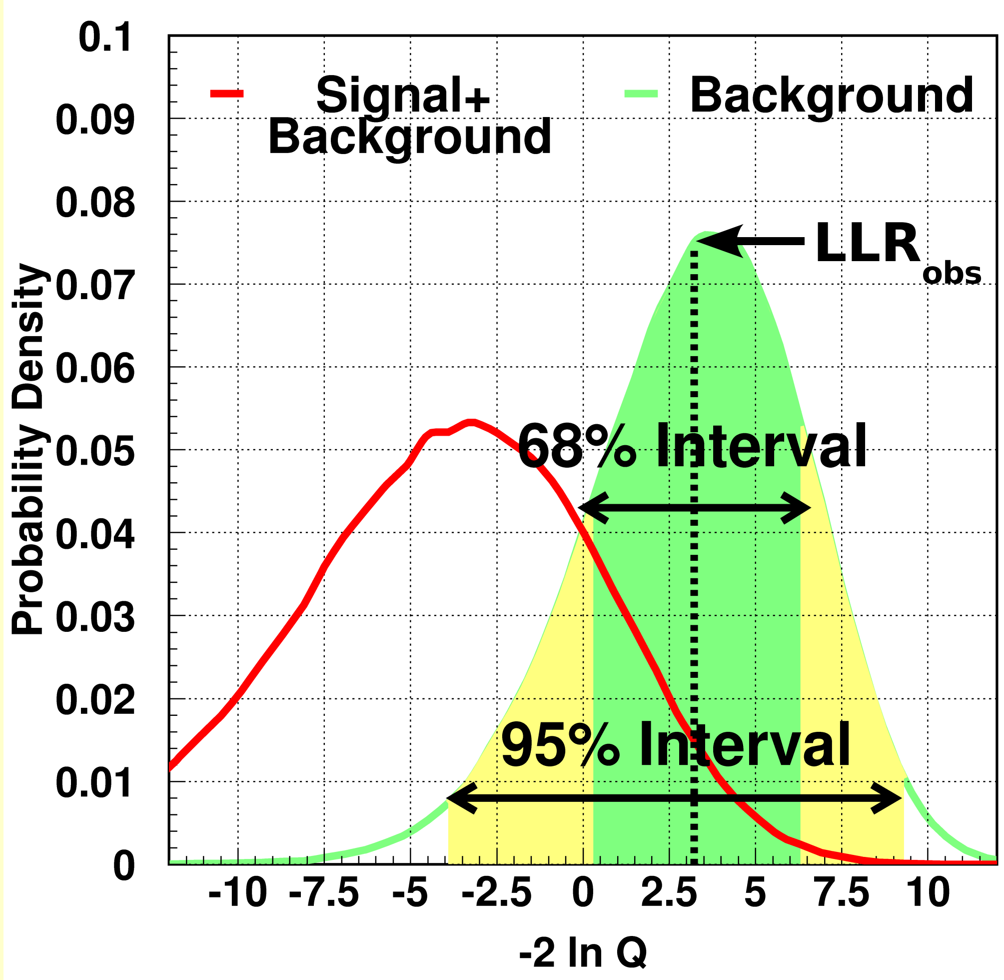
$$CL_n = \int_{\Gamma_{obs}}^{\infty} \frac{\partial P_n}{\partial \Gamma} d\Gamma$$

- By construction: $CL_s \equiv CL_{s+b} / CL_b$
  - The signal+background hypothesis is considered to be excluded at a confidence level of **X** when 1-CLs ≤ **X**% (e.g., X=95%)
  - This formulation provides for an estimate of the “goodness” of the background prediction

CLs in Pictures

- ✗ **Black dashed line: Observed LLR value (LLR_{obs})**
- ✗ **Green: Bkgd-only hypothesis**
  - ✗ **CL_b is region to right of LLR_{obs}**
  - ✗ **Equals ~50% for good bkgd/data agreement**
- ✗ **Red: Signal+bkgd hypothesis**
  - ✗ **CL_{s+b} is region to right of LLR_{obs}**

Example LLR Distributions

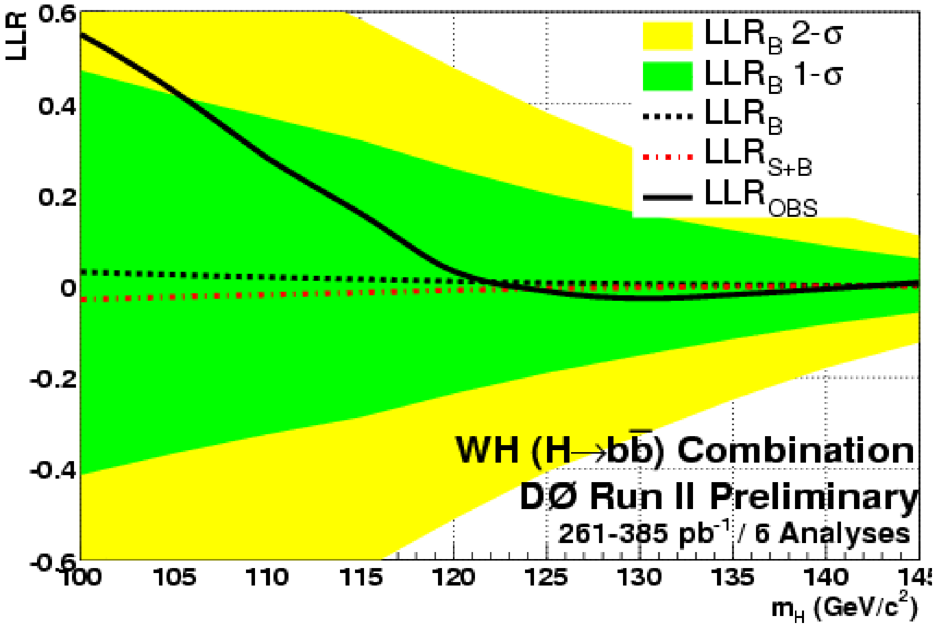


Systematic Uncertainties

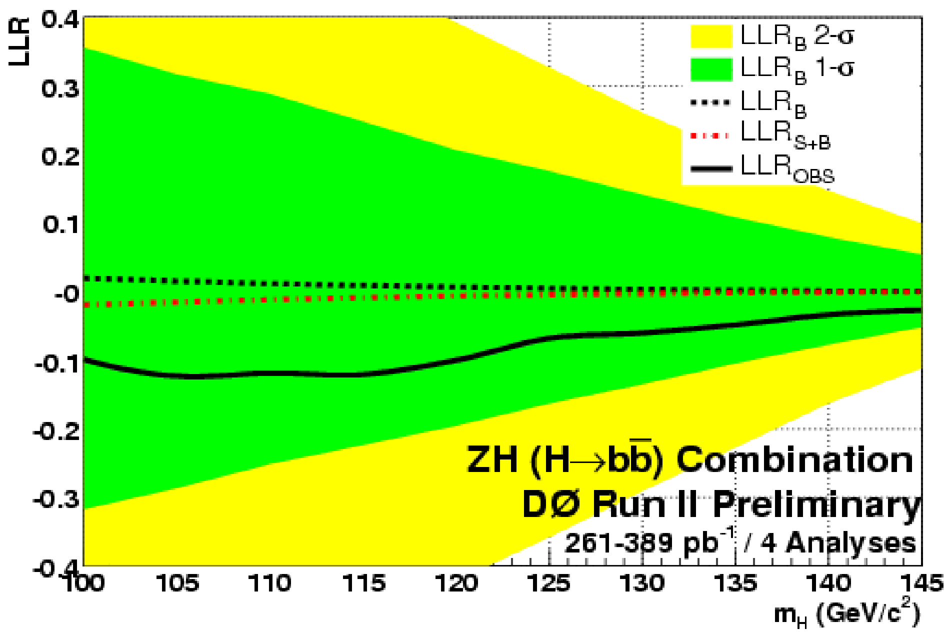
- Systematics are folded into the signal and background outcomes of the Poisson MC trials via Gaussian distribution.
  - Essentially broadens each PDF according to the size of the uncertainty
  - Correlations are carried through amongst bkgds and between signal and bkgd
- Average size of total uncertainty
  - 10-20% for signals, 10-25% for backgrounds

Source	Relative Size (%)
Luminosity	6.5
b-Tagging (per jet)	5.0-12.0
JES	2.0-7.0
Lepton ID (per lepton)	2.0-7.0
Background Xsec	5.0-20.0

Combined Results



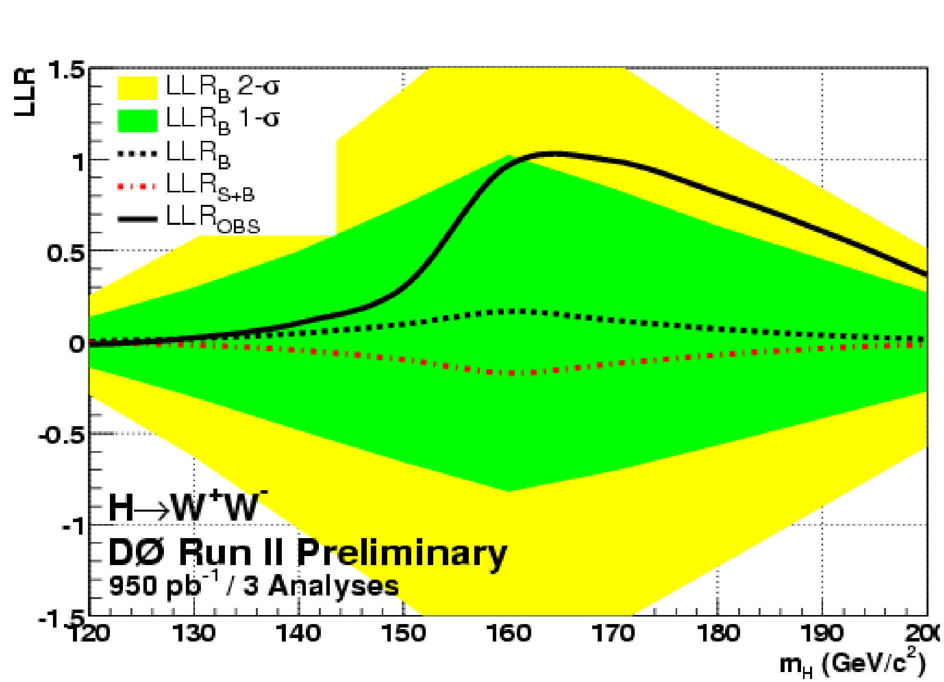
- ✗ **Top left:** LLR distributions for WH ($e\nu bb$, $\mu\nu bb$, & missing lepton) channels combined



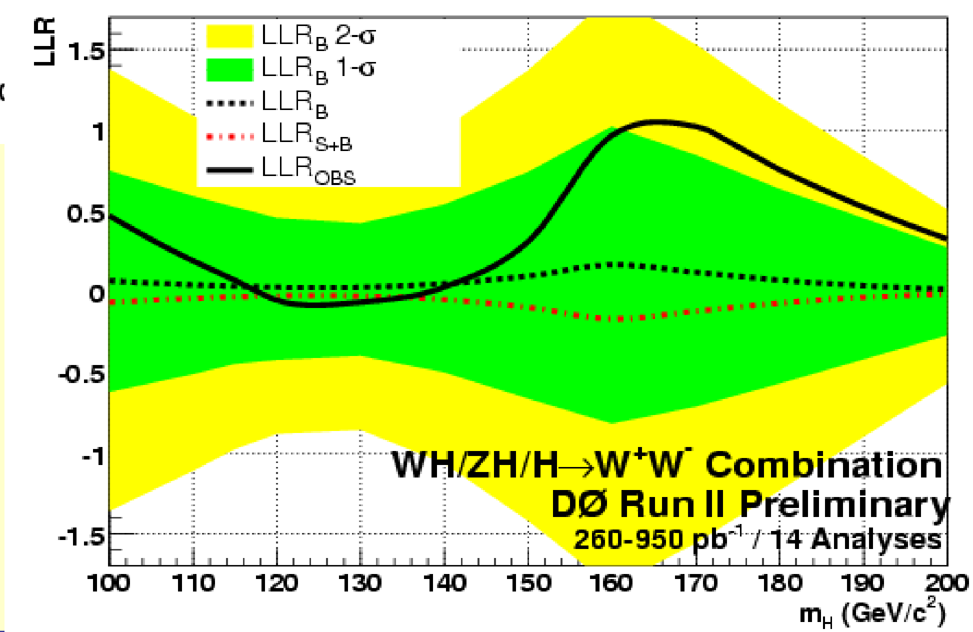
- ✗ **Bottom right:** LLR distributions for ZH (llbb and $\nu\nu bb$) channels combined

Combined Results

- **Top left:** LLR distributions for H→WW (ee, eμ, & $\mu\mu$) channels combined



- **Bottom right:** LLR distributions for all search channels combined



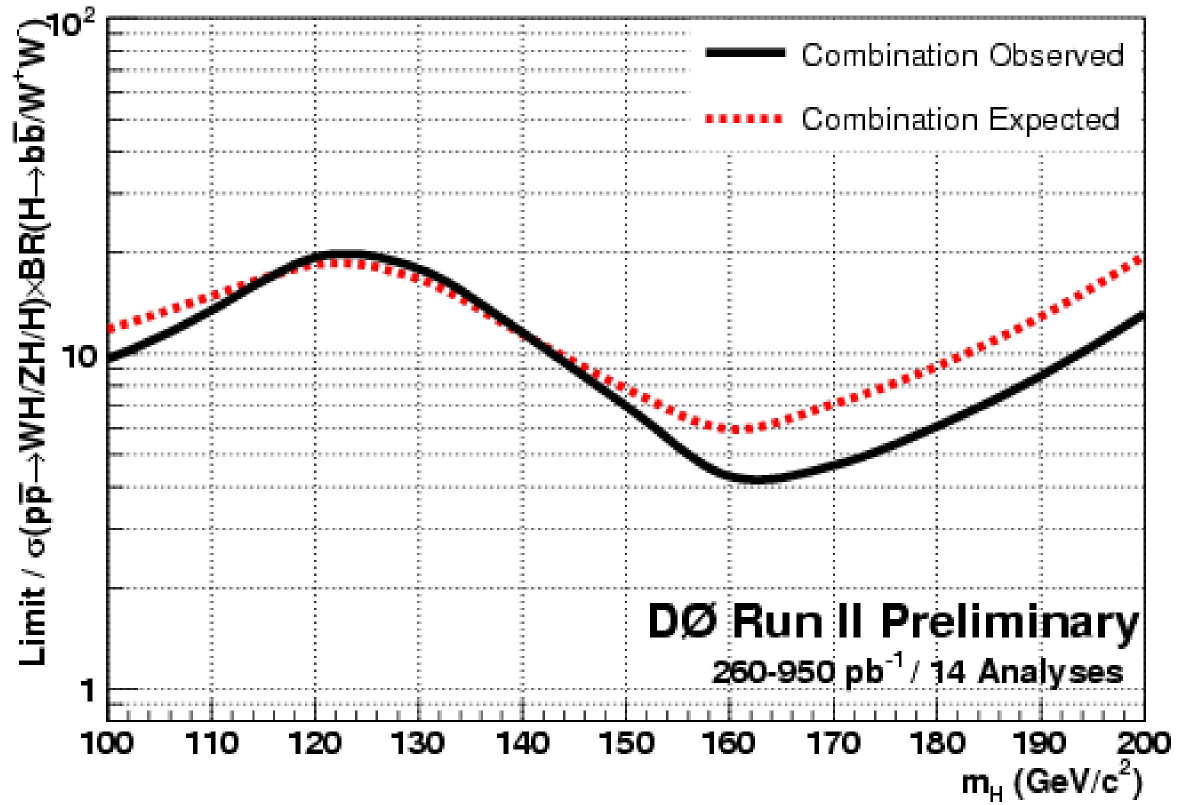
DØ SM Higgs Limits

- We present limits in terms of R = 95% CL limit / σ_{SM}

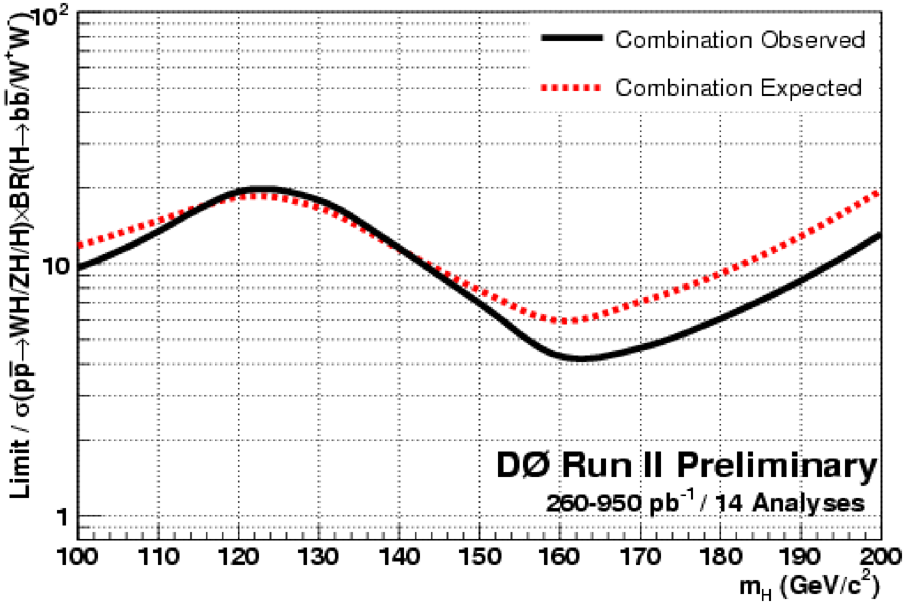
- R<=1 indicates model exclusion

- $\mathbf{R_{obs}}$: 16.3 at m_H=115
  4.3 at m_H=160

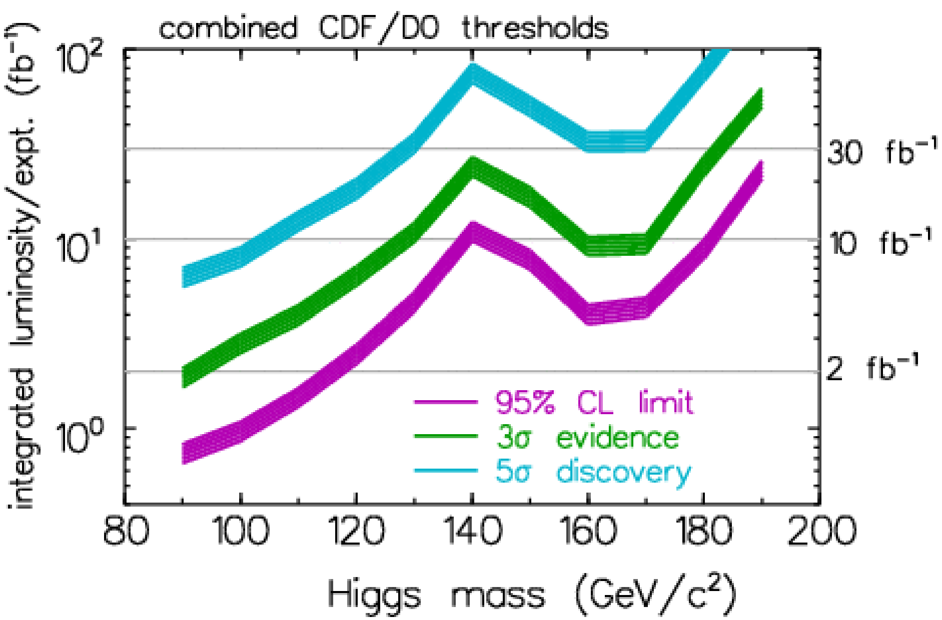
- $\mathbf{R_{exp}}$: 16.7 at m_H=115
  5.9 at m_H=160



Getting our Bearings



- We're at ~300 pb^{-1} at low mass…and 1 fb^{-1} at high mass
  - Cannot compare directly

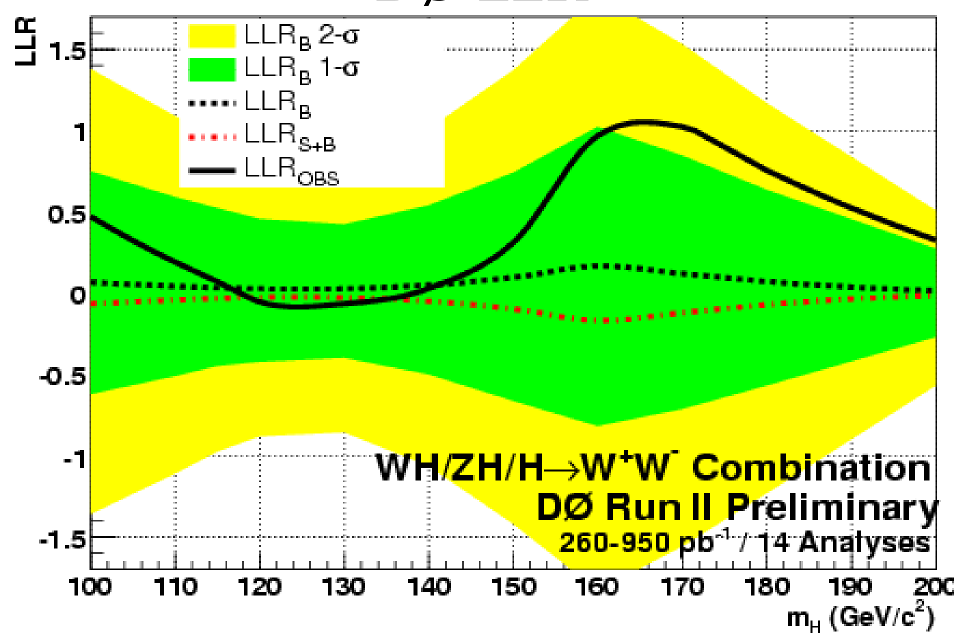


- And we still need to "double" our luminosity by combining with CDF…

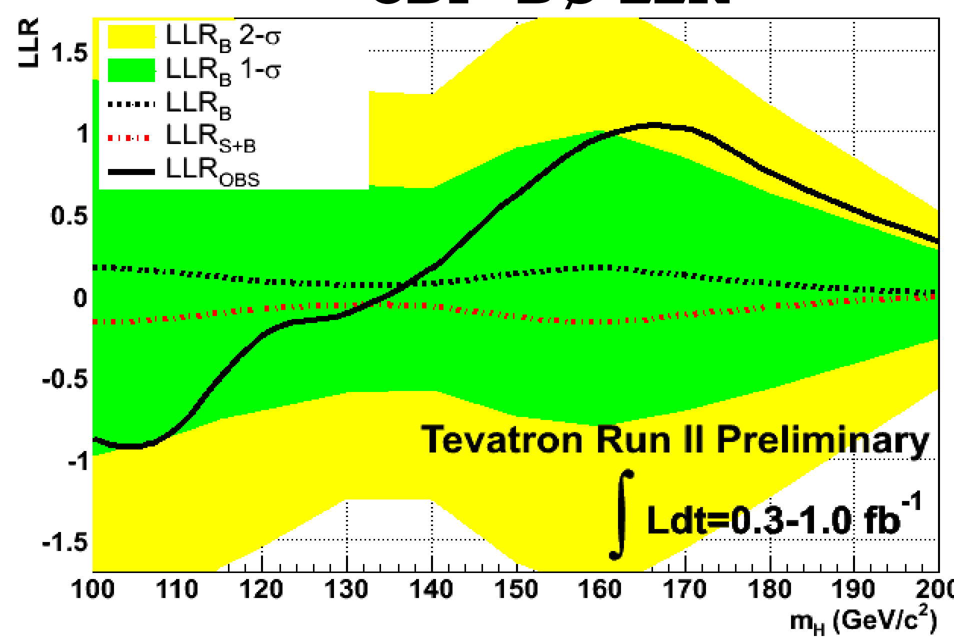
Adding CDF's Results

- At the time of this combination, CDF added:
  - WH→lνbb / ZH→ννbb / ZH→llbb at 1fb^{-1}
  - H→WW (ee, eμ, & μμ) at 360 pb^{-1}
  - Systematics very similar in size, most treated as uncorrelated between DØ and CDF

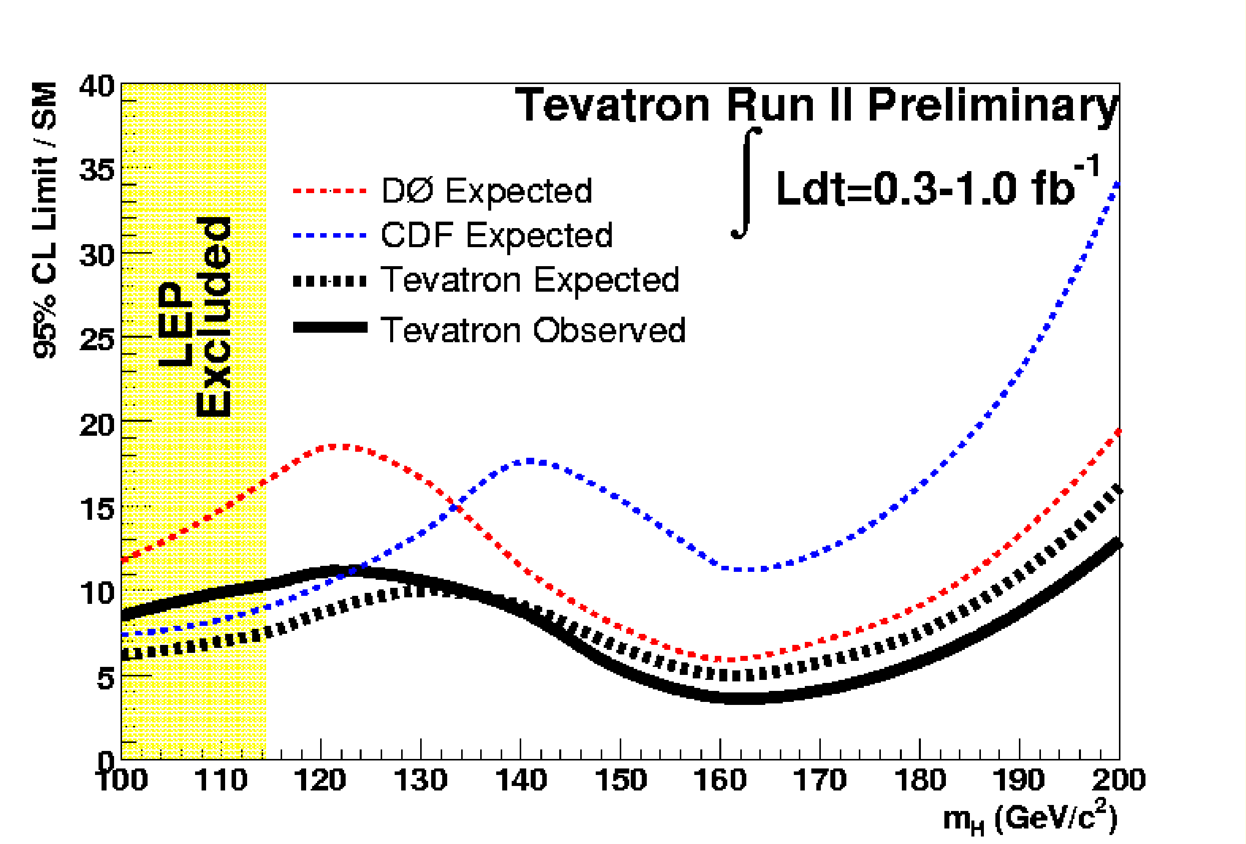
DØ LLR



CDF+DØ LLR

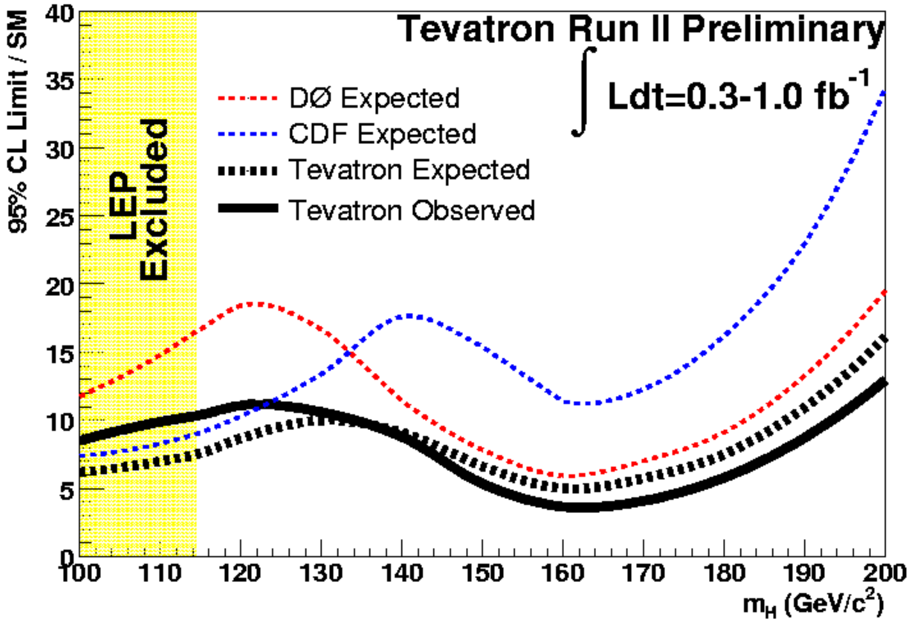


Combined Tevatron SM Higgs Limits

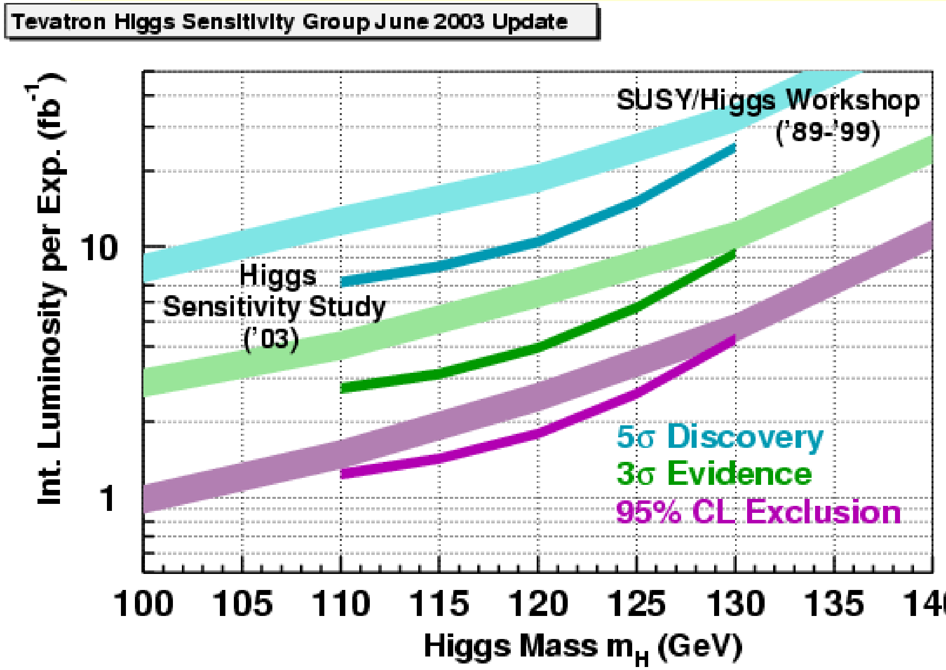


- **R_{obs}:** 10.4 at m_H=115 & 3.8 at m_H=160
- **R_{exp}:** 7.6 at m_H=115 & 5.0 at m_H=160

Another Map Check



✗ The HSG result indicates we should be able to exclude (R=1) at mH=115 with 1.5-2.0 fb^{-1}



✗ With asymmetric inputs, (0.3-1.0 fb^{-1}), we can extrapolate limits to 1fb^{-1}:

R_{exp}: 6.0 at m_H=115

& 4.0 at m_H=160

An Emerging Path...

- ✗ Though we're not quite there, we're missing pieces
  - ✗ Advanced analysis selections (NN,ME) provide factor of ~1.7 in equivalent luminosity
  - ✗ New channels (taus, H→ZZ) in the pipeline
  - ✗ Many systematics currently statistics limited

Ingredient (DØ)	Equiv Lumi Gain @ 115	Xsec Factor MH=115 GeV	Xsec Factor MH = 160 GeV
Today with $1fb^{-1}$	-	6.0	4.0
Lumi = 2 fb^{-1}	2	4.2	2.8
NN b-Tagging	3	2.4	2.8
NN Analyses	1.7	1.9	2.1
Improved mass resolution	1.5	1.5	2.1
New Channels	1.3	1.3	1.8
Reduced systematics	1.2	1.2	1.7

➔At 115 GeV need ~2.7 fb^{-1} **At 160 GeV need ~5.5 fb^{-1}**

Final Comments

- ✗ Current DØ SM Higgs analyses are very encouraging
  - ✗ Increasing dataset ➔ improving background description ➔ more advanced analyses
- ✗ First combination with CDF was very successful
  - ✗ We each learned a few things
  - ✗ Trying hard to keep up with aggressive predictions
- ✗ As pieces of the Tevatron Higgs search fall into place, we're getting closer to new knowledge of the Standard Model
  - ✗ New results are just on the horizon, expect updated DØ and Tevatron combinations soon