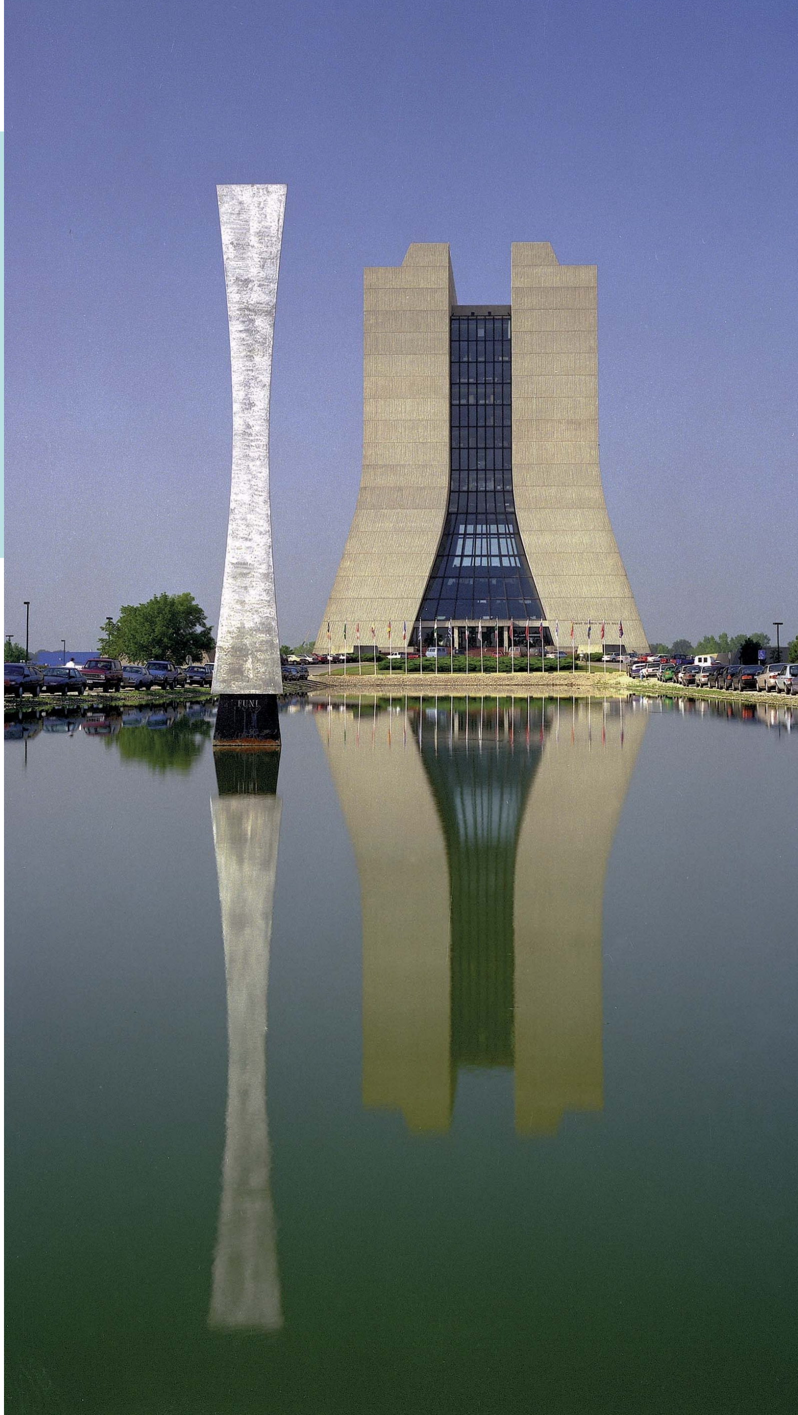
The Tevatron's Search for Low Mass Higgs Bosons

Wade Fisher

Michigan State University

On behalf of the CDF & DØ Collaborations



Fermilab

March 7th 2010

Outline

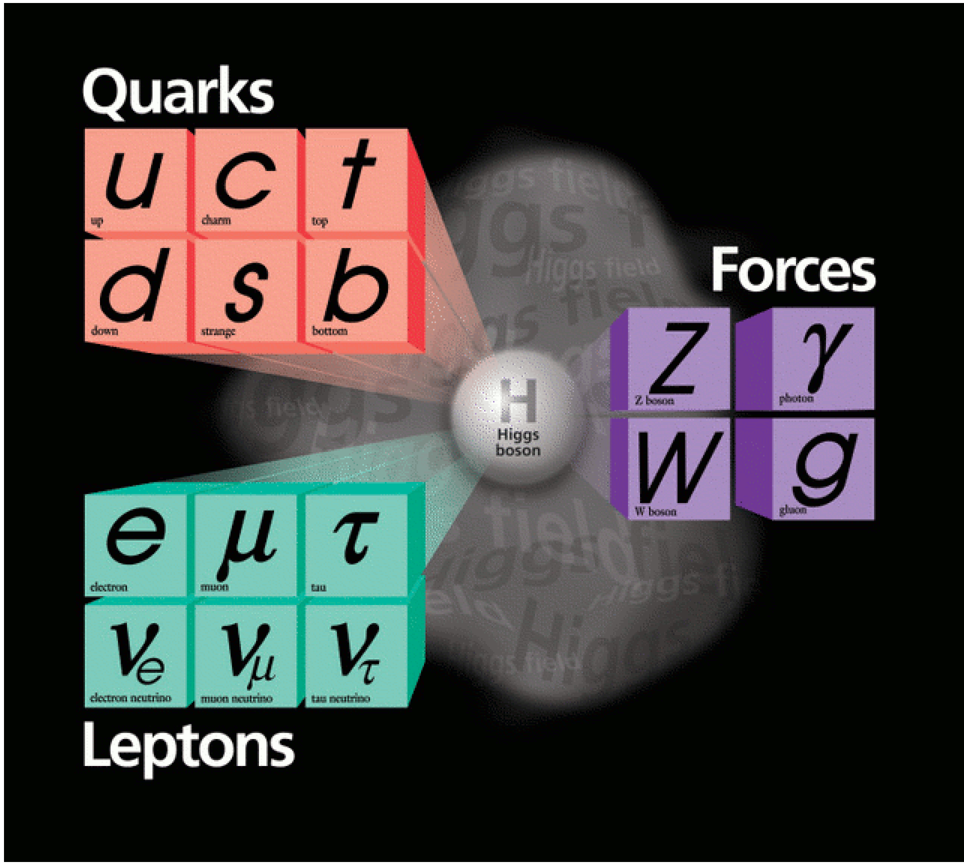
- ✗ Low Mass Higgs Bosons at the Tevatron
  - *(ie, H→bb searches)*
  - Theory & existing evidence
  - Higgs production & decay at the Tevatron
  - Low mass Higgs search strategies
  - Upper limits on Higgs production rates

- ✗ Outlook & Conclusions
  - Prospects for the future

The Case for the Higgs

The Standard Model of particle physics

- Describes known particles & interactions
- Does ***not*** describe mass generation
- The BEGHHK* mechanism may be a solution



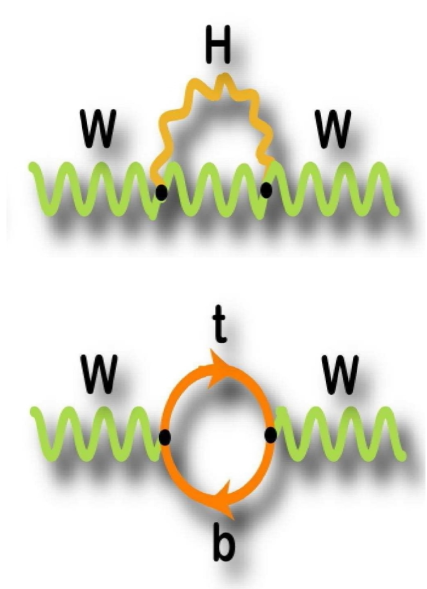
The theory predicts a new particle, but not its mass

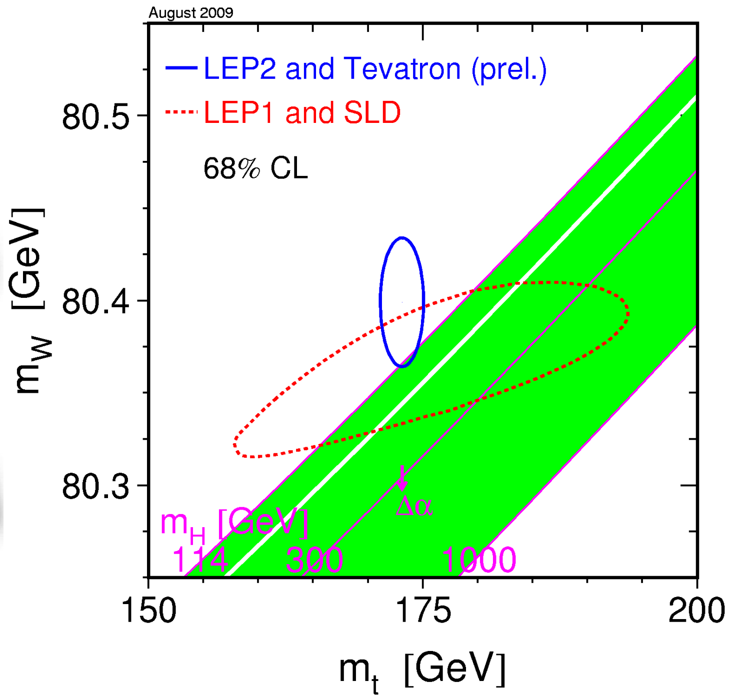
- If it exists, the mass must be determined experimentally

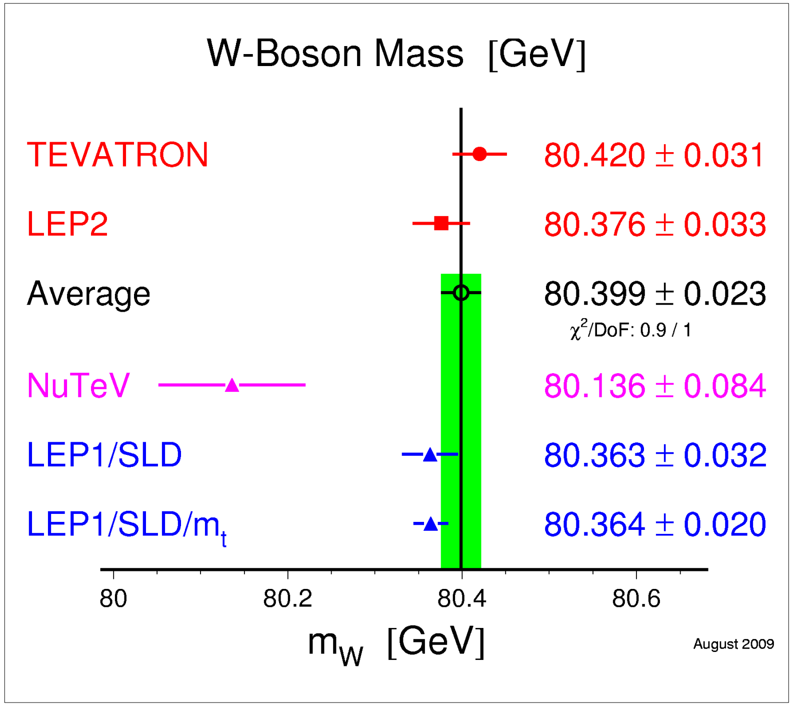
* F. Englert and R. Brout, Phys. Rev. Lett. 13: 321-323 (1964);
P.W. Higgs, Phys. Rev. Lett. 13: 508-509 (1964);
G.S. Guralnik, C.R. Hagen, and T.W.B. Kibble, Phys. Rev. Lett. 13: 585-587 (1964).

Experimental Constraints

- ✗ Existing experimental results can point us in the right direction
  - Direct search at LEPII resulted in lower mass bound: M_H>114.4 GeV
  - Refinements of top-quark and W-boson masses can indicate Higgs mass
  - **Top Mass: CDF+DØ: 173.1 ± 0.6 *(stat)* ± 1.1 *(syst)* GeV**
  - **W Mass: Tevatron measurements on track to dominate world average**



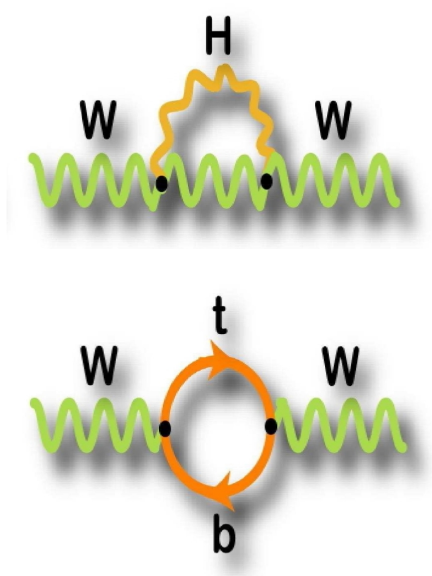


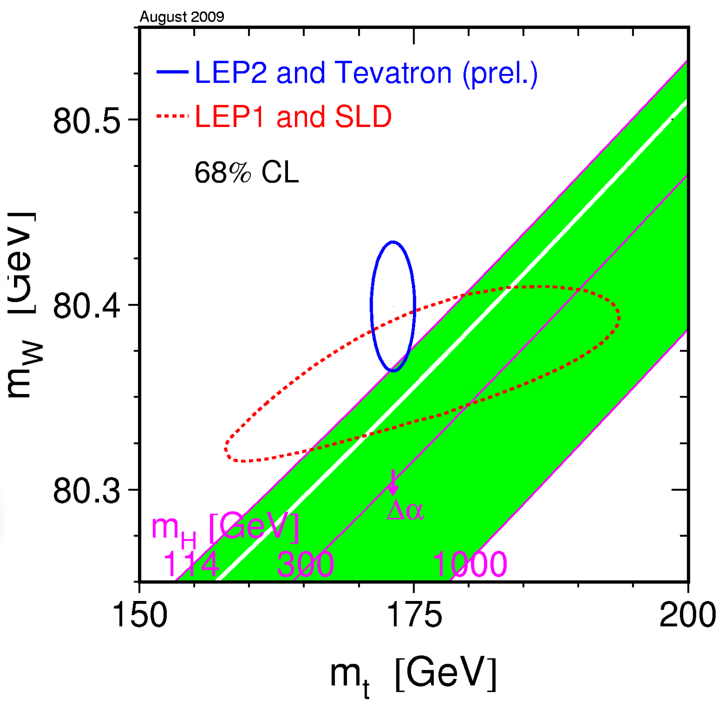


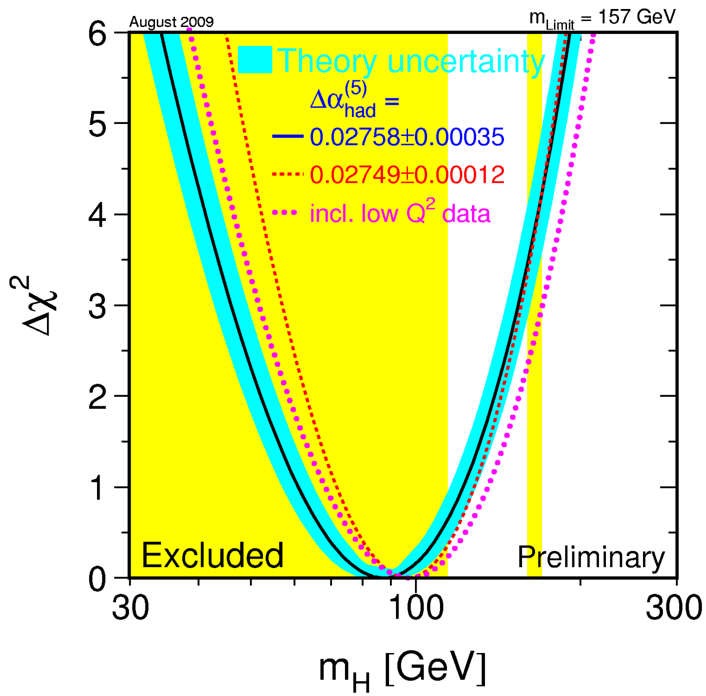
Indirect Experimental Evidence

- Existing experimental results can point us in the right direction
  - Direct search at LEPII resulted in lower mass bound: M_H>114.4 GeV
  - Refinements of top-quark and W-boson masses can indicate Higgs mass
  - **A fit of precision electroweak data yields: M_H < 186 GeV at 95% C.L.**

(M_H < 157 GeV not including the LEP II limit)







Indirect Experimental Evidence

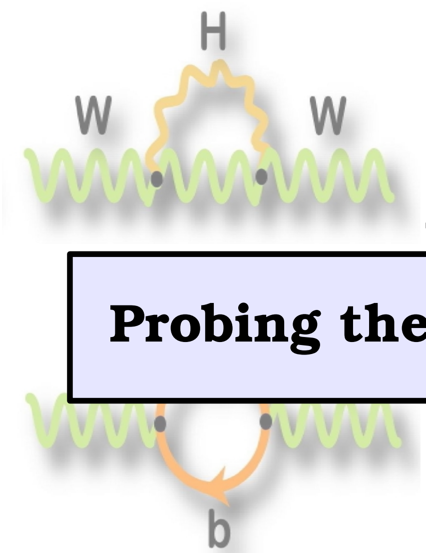
✗ The interactions between SM particles and the Higgs give indirect evidence

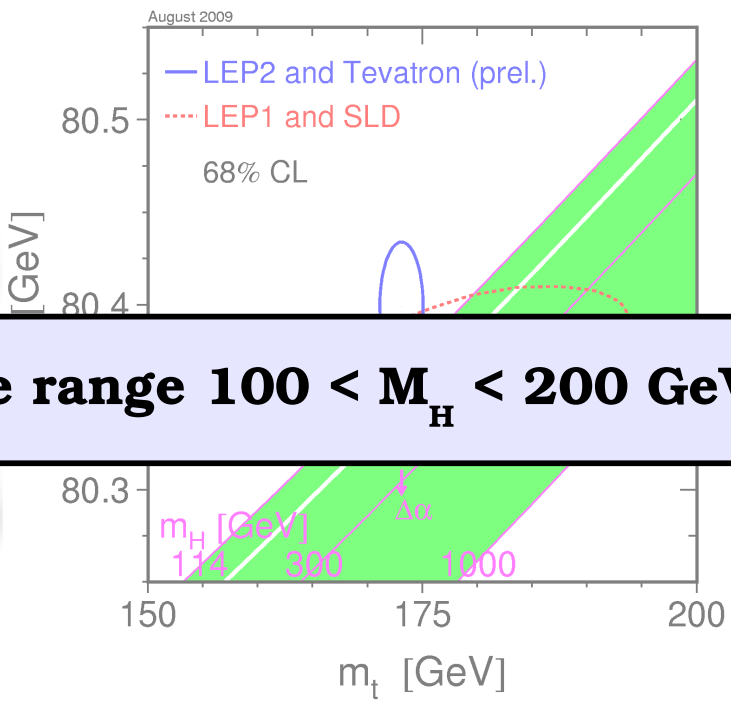
Direct search at LEPII resulted in lower mass bound: M_H>114.4 GeV

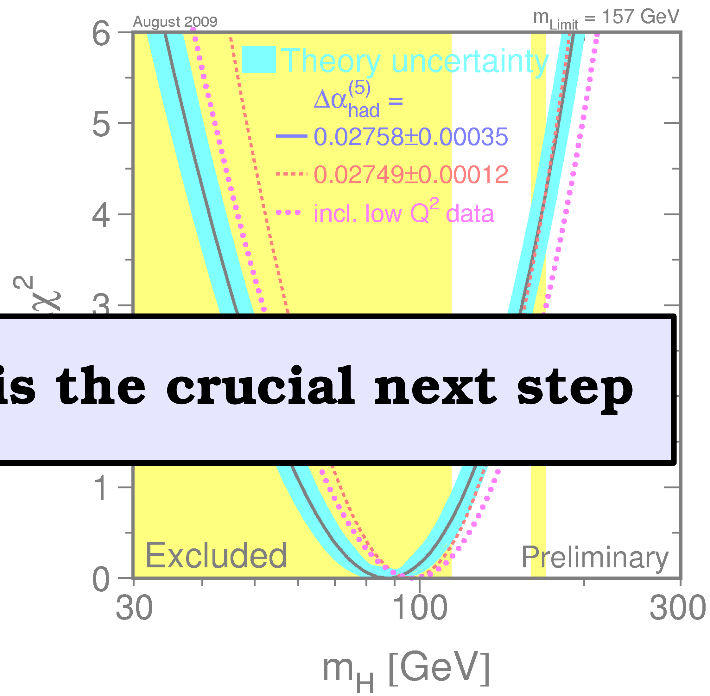
Refinements of top-quark and W-boson masses can indicate Higgs mass

A fit of precision electroweak data yields: M_H < 186 GeV at 95% C.L.

(M_H < 157 GeV not including the LEP II limit)







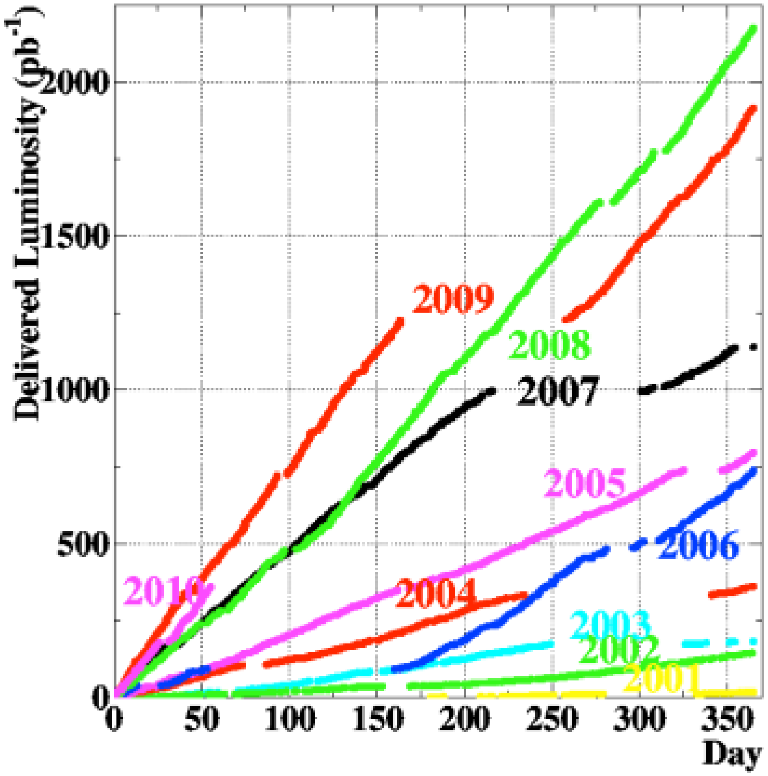
Probing the range 100 < M_H < 200 GeV is the crucial next step

The Continued Higgs Search

- ✗ Generations of physicists are eagerly awaiting the next chapter
  - The Tevatron collider provides an excellent hunting ground
  - Both experiments (CDF & DØ) have been delivered **>8 fb^{-1}** as of March 2010
  - One more year of running planned beyond 2010

Tevatron Accelerator Complex

Luminosity Delivered per Calendar Year (*CDF Exp*)

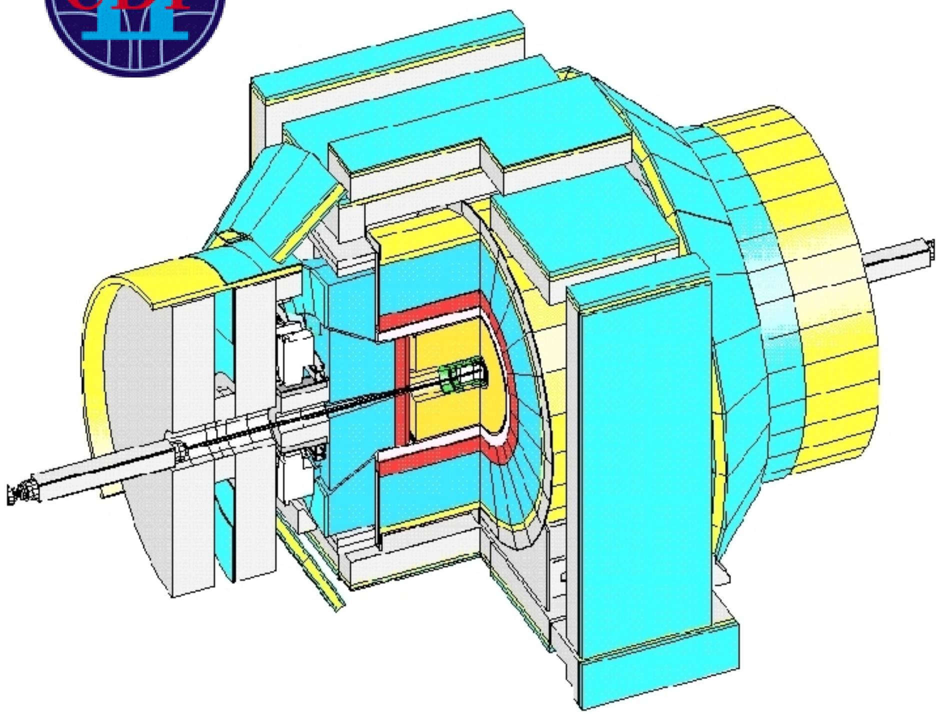


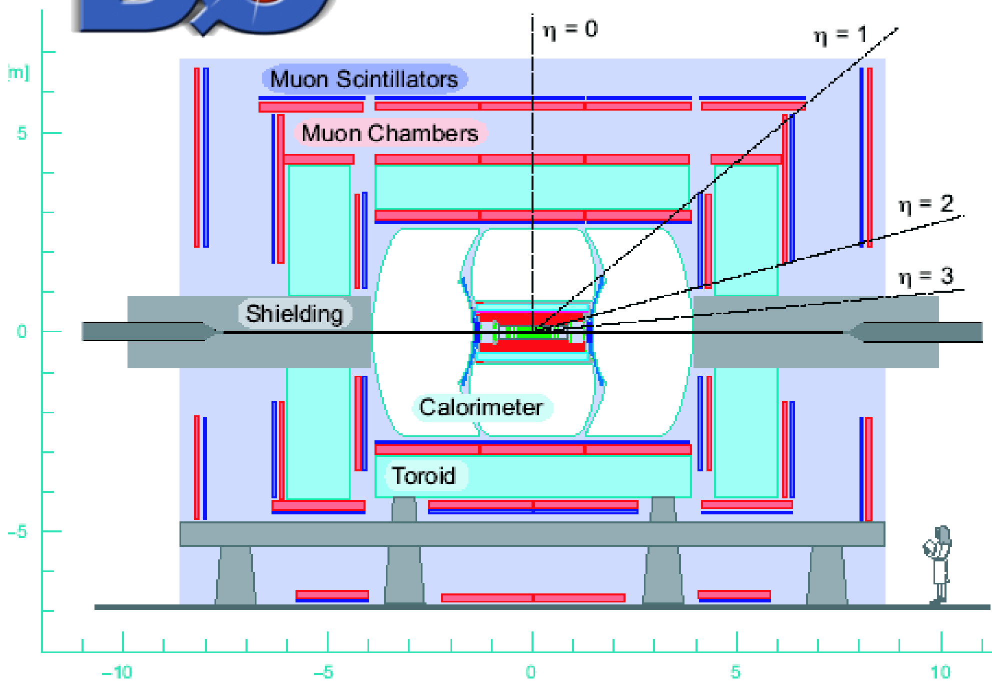
Tevatron Experiments

✗ <u>Tevatron experiments:</u> multipurpose detectors with broad particle-ID capability

Stable detectors and trigger. No further upgrades planned.

Efficient data taking through the highest instantaneous luminosities





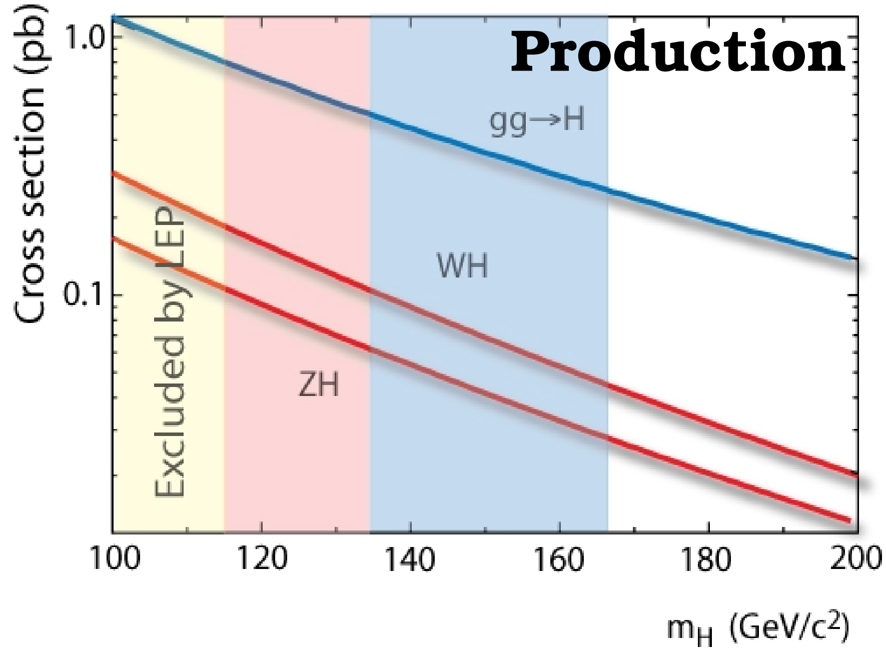
Tevatron Higgs Search Strategy

Higgs production via gluon fusion dominates at the Tevatron

- Large multijet background makes fully hadronic searches difficult

Next largest rate is associated production of W/Z bosons + Higgs

- Leptonic decays of W/Z bosons provide a tag for triggering and analysis

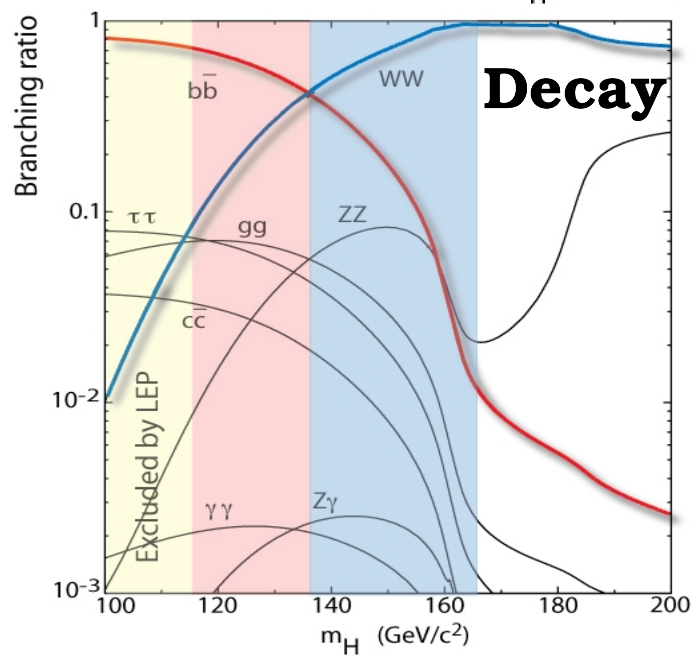


A low-mass Higgs (M_H<135 GeV) prefers to decay to bottom-quark pairs

- Need efficient identification of bottom quarks to reduce backgrounds

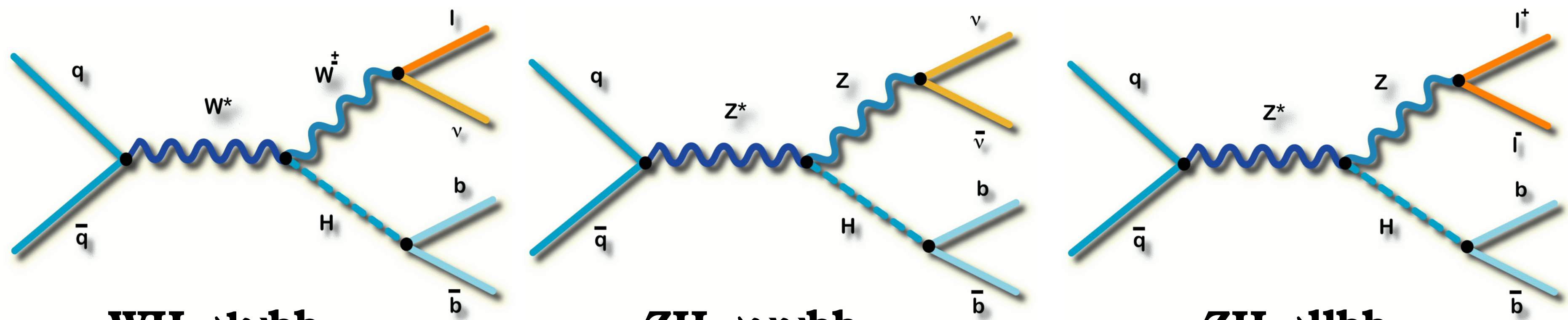
At high mass (M_H>135 GeV), search for $H \rightarrow WW^*$

- Potential for an off-shell W boson allows non-resonant production



Higgs Search Channels

Associated Production: Low mass only, 3 dominant final states

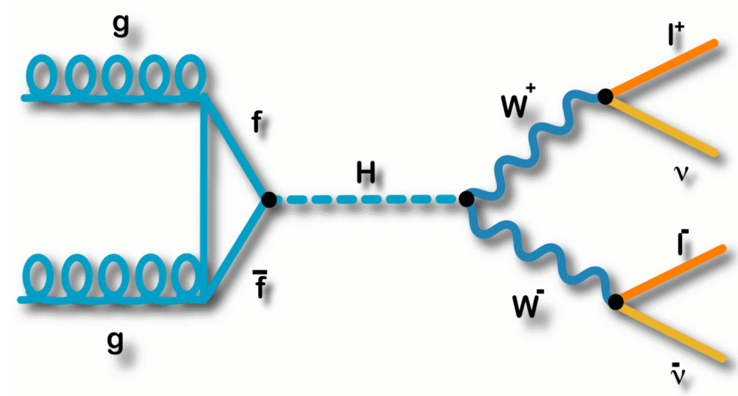


WH→lνbb **ZH→ννbb** **ZH→llbb**

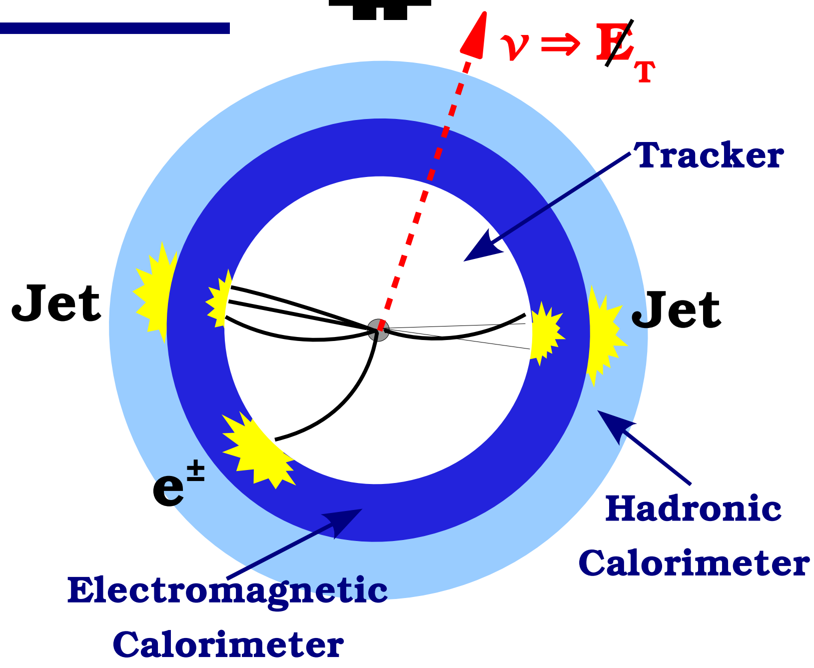
Gluon Fusion Production:

Maximum sensitivity at high mass, also useful at low mass

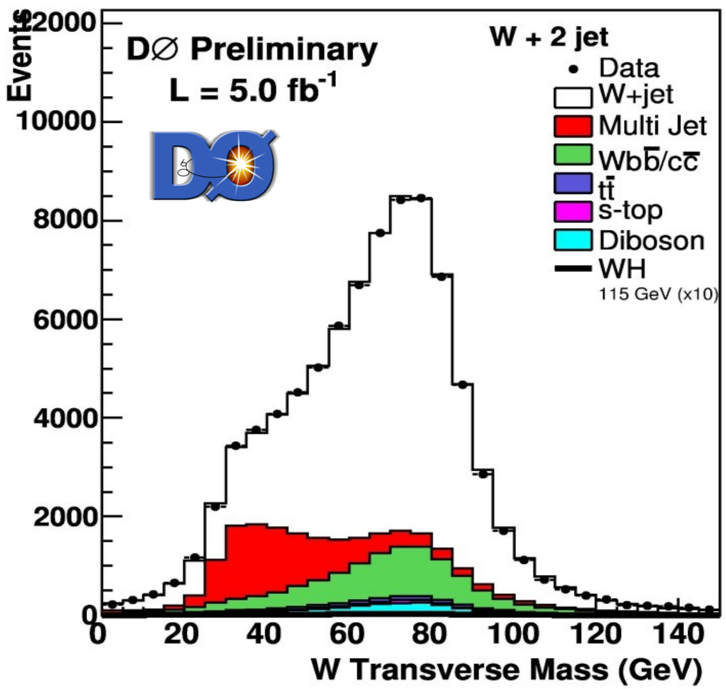
Discussed in the next talk

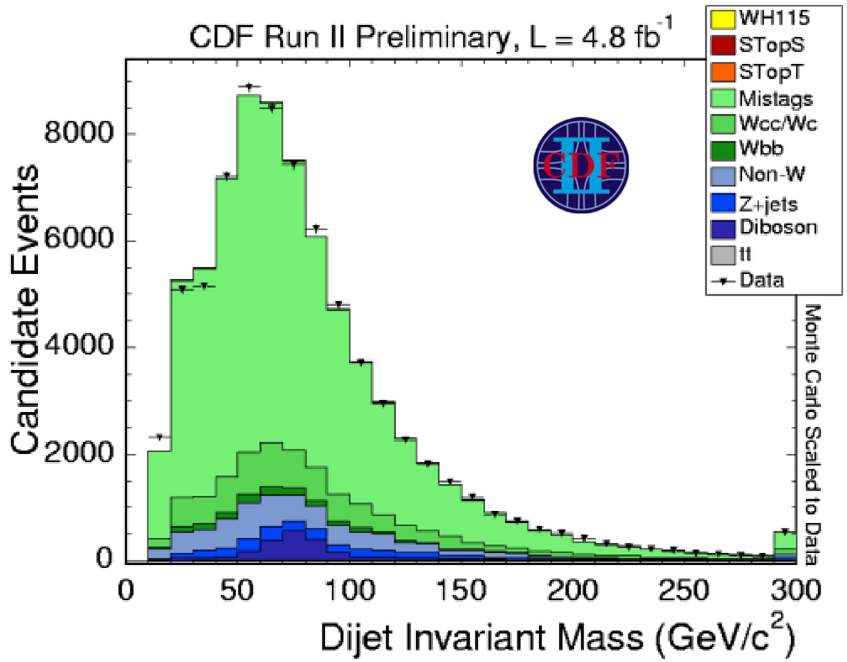


$WH \rightarrow l\nu bb$



- ✗ Identify events consistent with W decays
  - Trigger on **electrons** or **muons**
  - Select significant missing transverse energy (MET) as a signature for neutrinos
- ✗ Select events with 2 or 3 jets
  - Modeling of dijet invariant mass is crucial for detection of H→bb mass resonance





$ZH \rightarrow llbb$

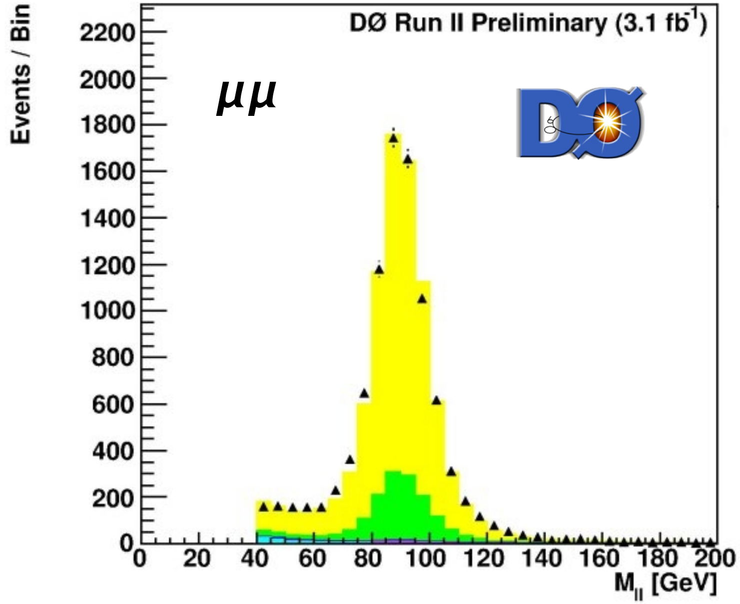
- Di-lepton Z boson decays make this channel:

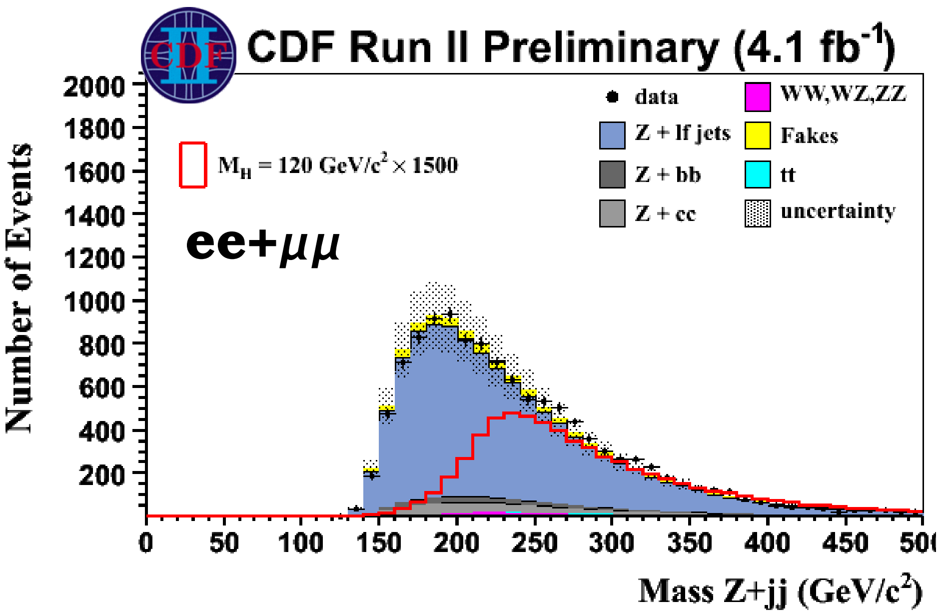
  Easier: More efficient trigger, smaller multi-jet background, reconstructed Z mass provides reliable handle on event.

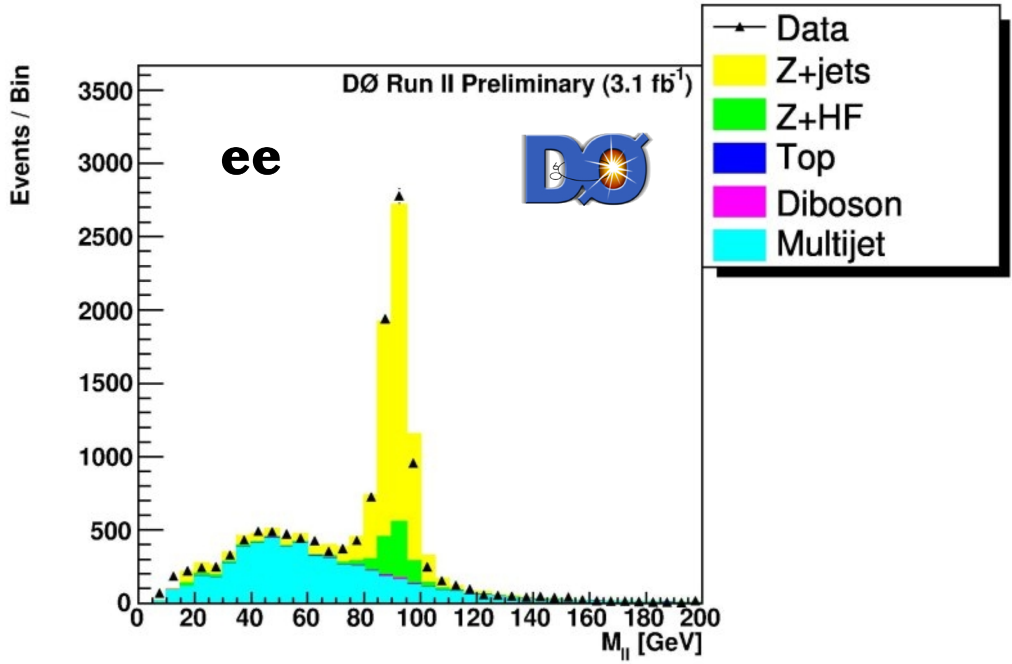
  Harder: Very small signal rate, more sensitive to lepton ID efficiency loss.

- Select two leptons & at least two jets

  Low MET final state enables the use of kinematic fitting to improve dijet mass resolution.

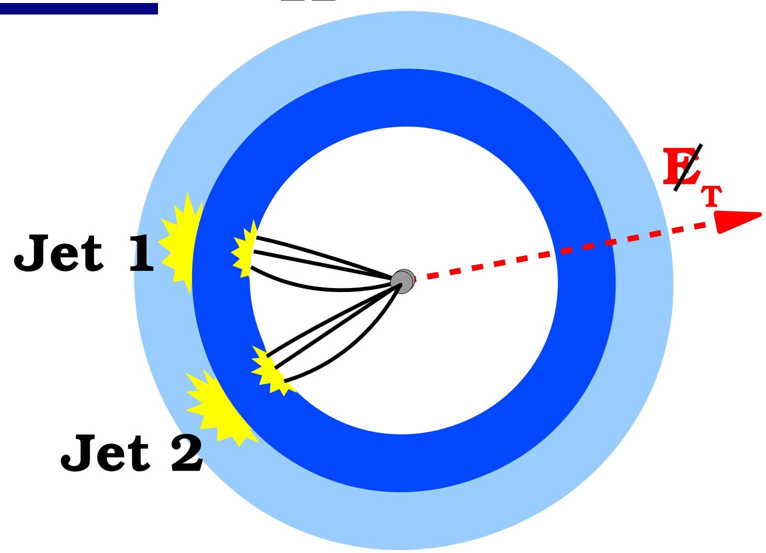




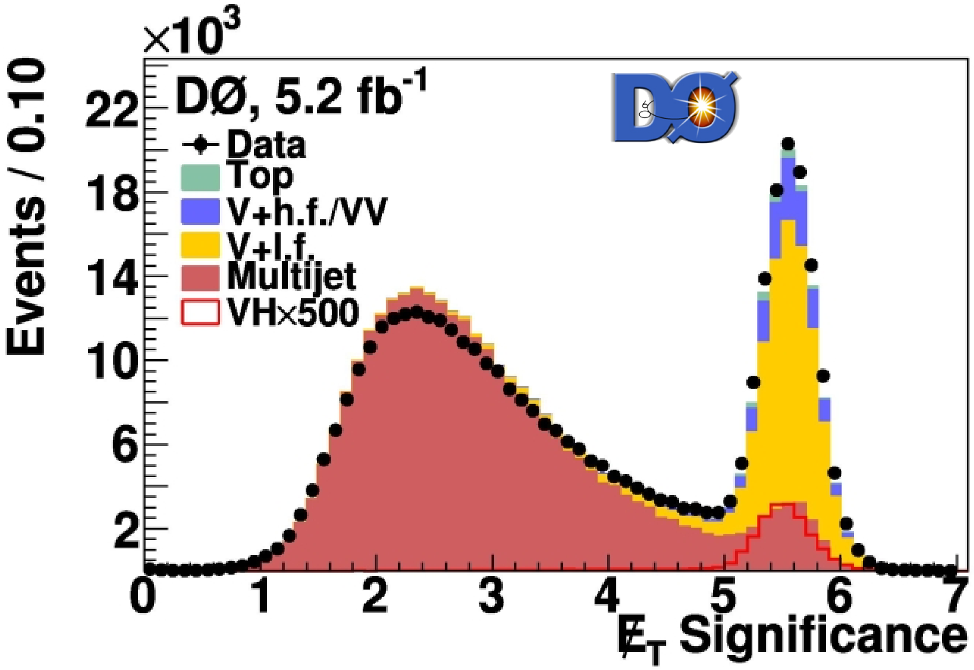


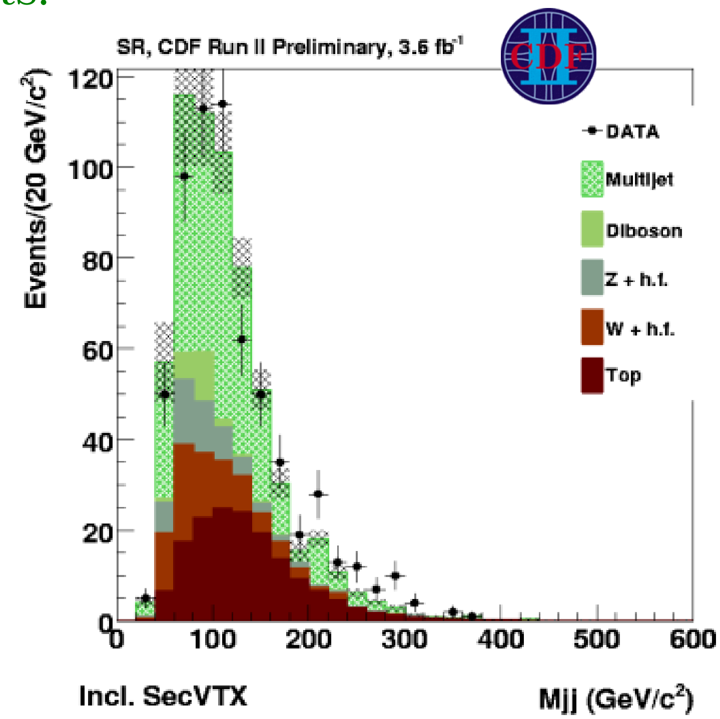
$ZH \rightarrow \nu\nu bb$

- For ZH→ννbb the search is more difficult: no charged leptons!
  - Rely on large MET (neutrinos!)
  - Backgrounds:
  - "Physics": Z+jets, W+jets, top-pair, ZZ, WZ
  - "Instrumental": Multijets with mis-measured jets

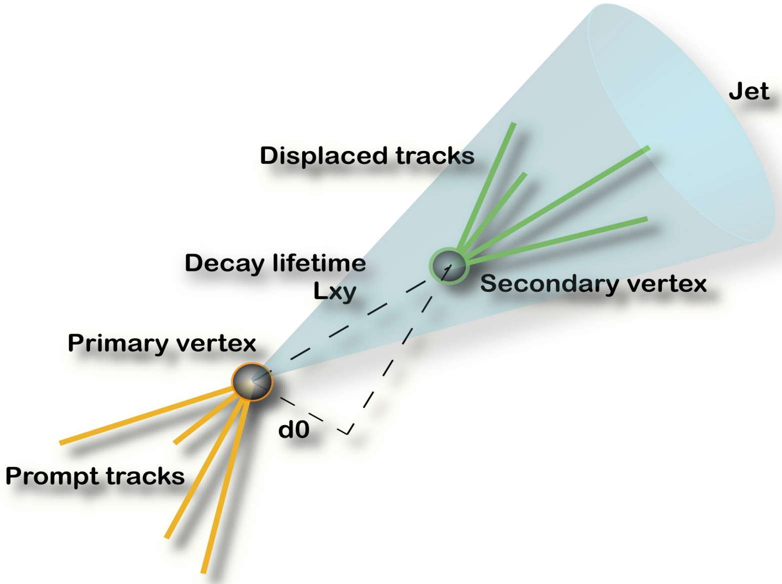


- Trigger on large MET + 2 jets, veto on leptons, improve multijet prediction by refining MET measurements.





Identifying b Quarks



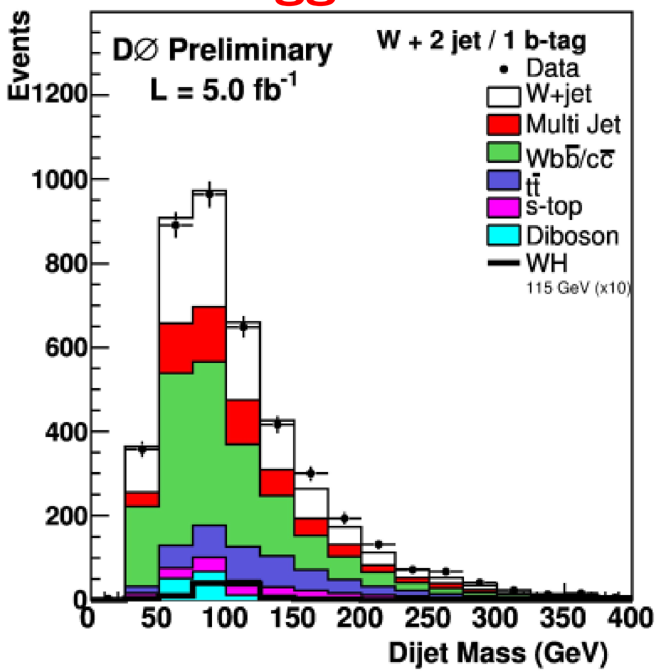
Background reduction via the identification of displaced jet decay vertices (b-Tagging)

Typical tag efficiency:

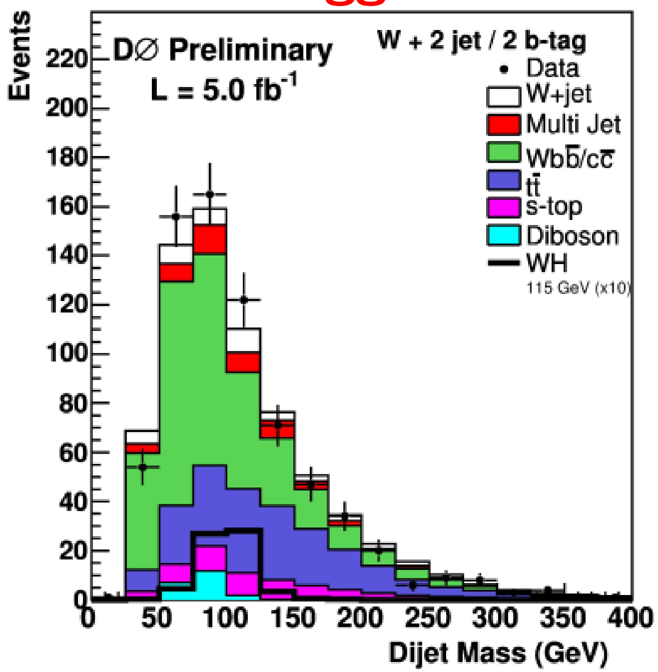
50-70% real b quarks

0.5-5% light quarks

1 Tagged Jet



2 Tagged Jets



Categorize events based on number and quality of b-tagged jets. Select orthogonal samples of:

- ✗ Two b-tagged jets
- ✗ Exactly one b-tagged jet

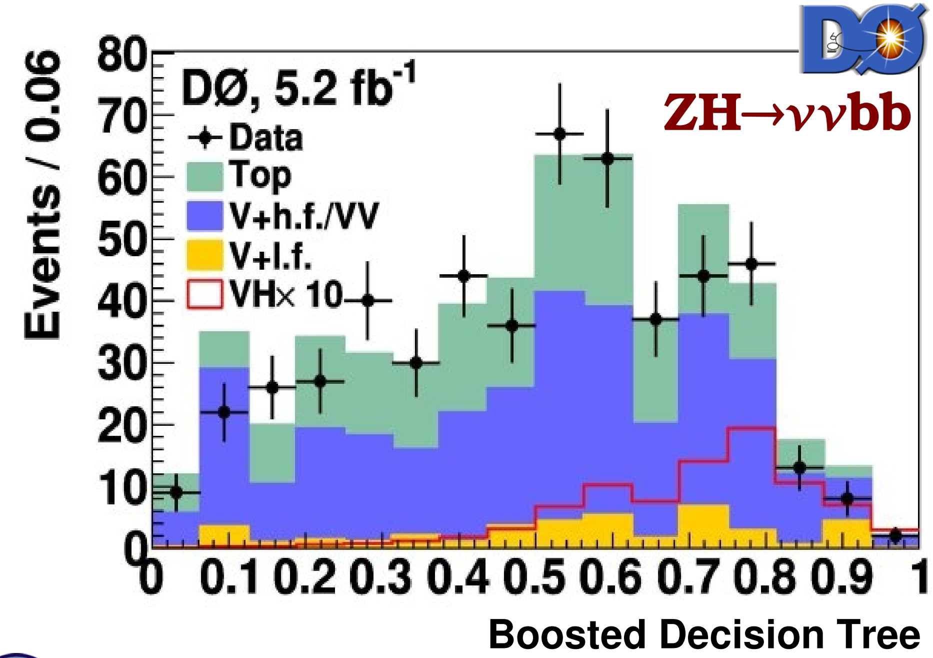
Multivariate Analysis

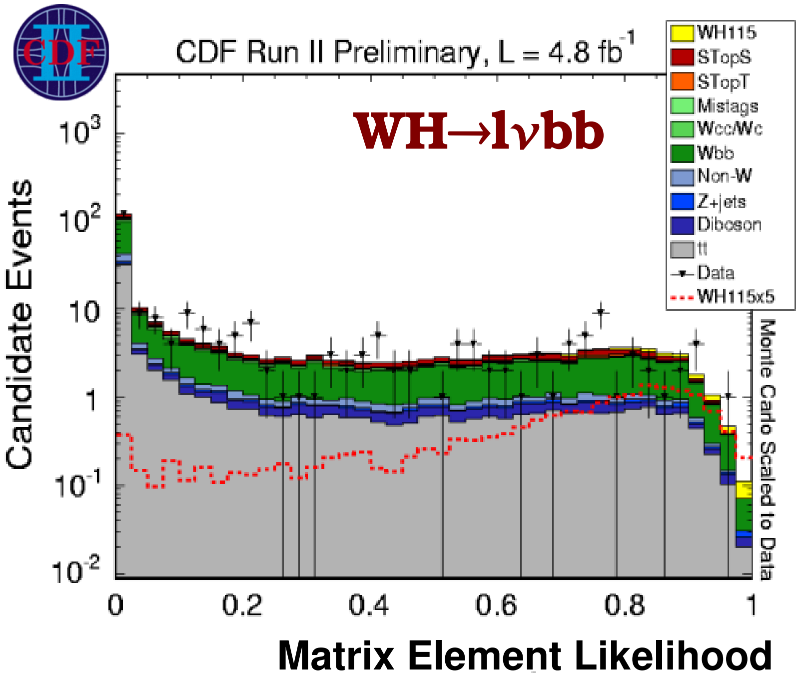
Multivariate techniques are used to improve signal to background ratios

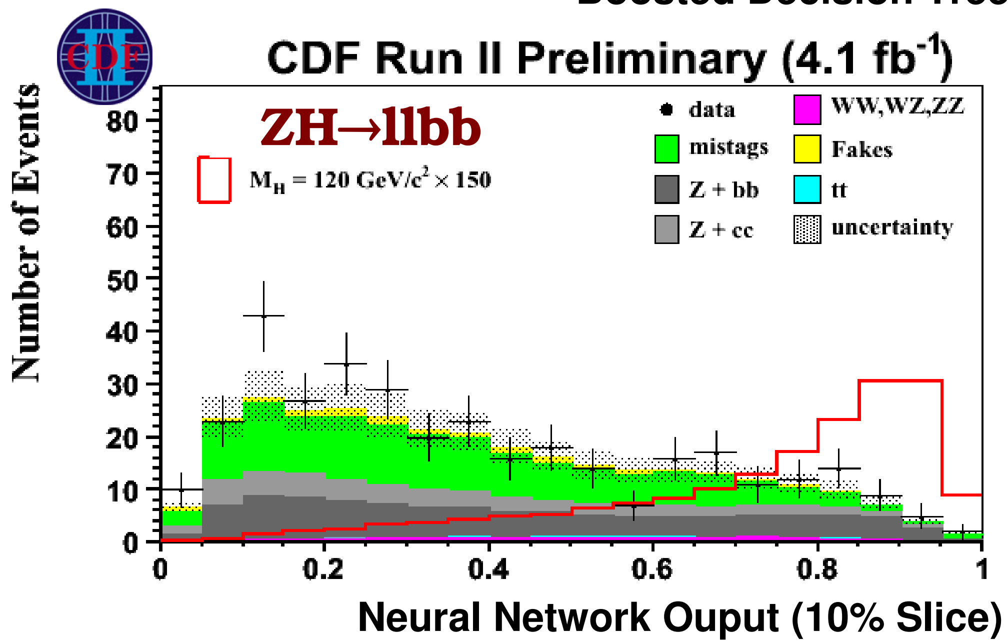
- Boosted decision trees
- Neural Networks
- Matrix Element Discriminants

Typically achieve S/B of ~1/10-1/50

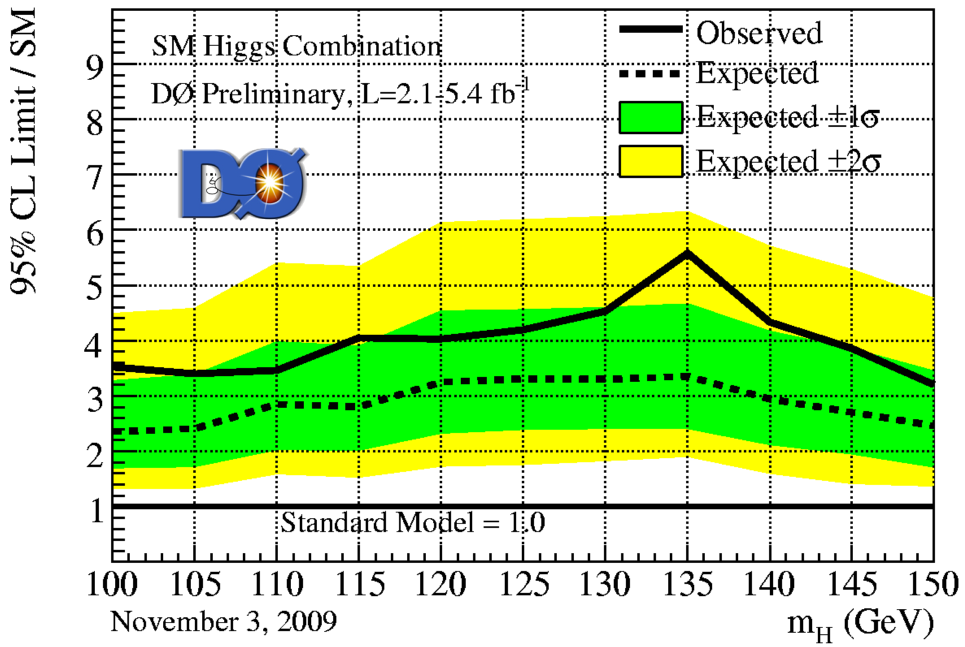
S/B ~1/100 for dijet mass alone

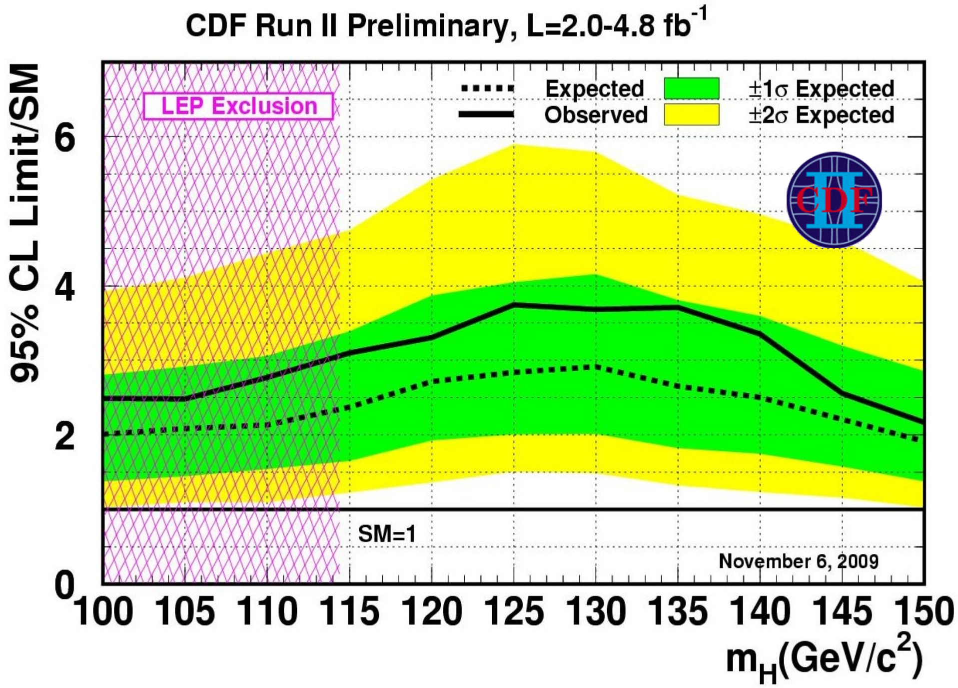






Limits on Higgs Production





Each experiment constructs 25-30 orthogonal H→bb searches

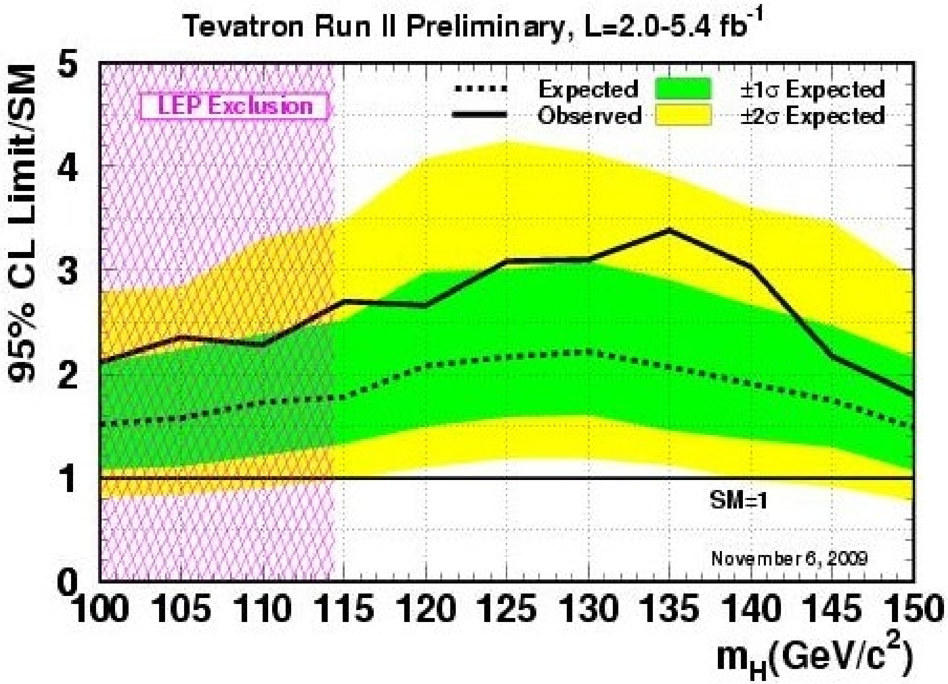
Combined results for all Higgs search channels for each experiment

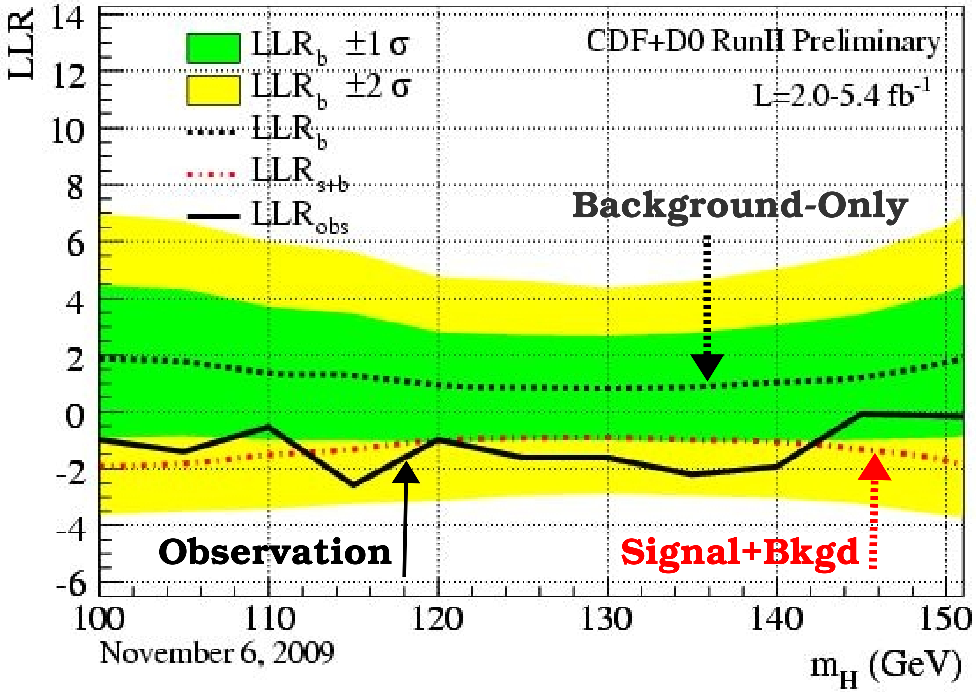
Both experiments find expected limits near **~2.5×SM at M_H = 115 GeV.**

M_H=115 GeV: DØ 4.0 (2.8) observed (expected)

M_H=115 GeV: CDF 3.1 (2.4) observed (expected)

Limits on Higgs Production

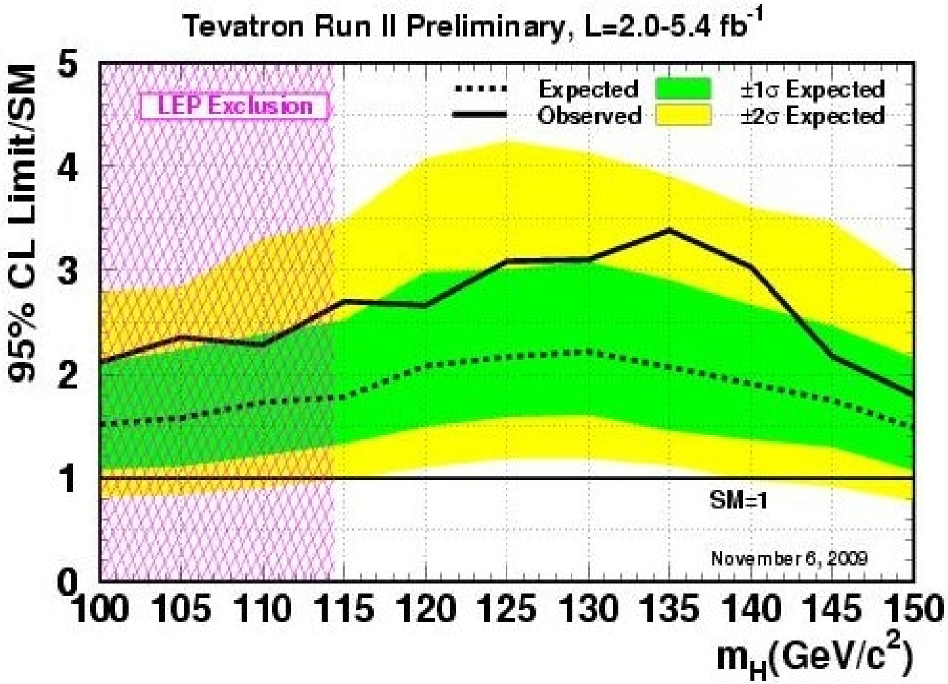


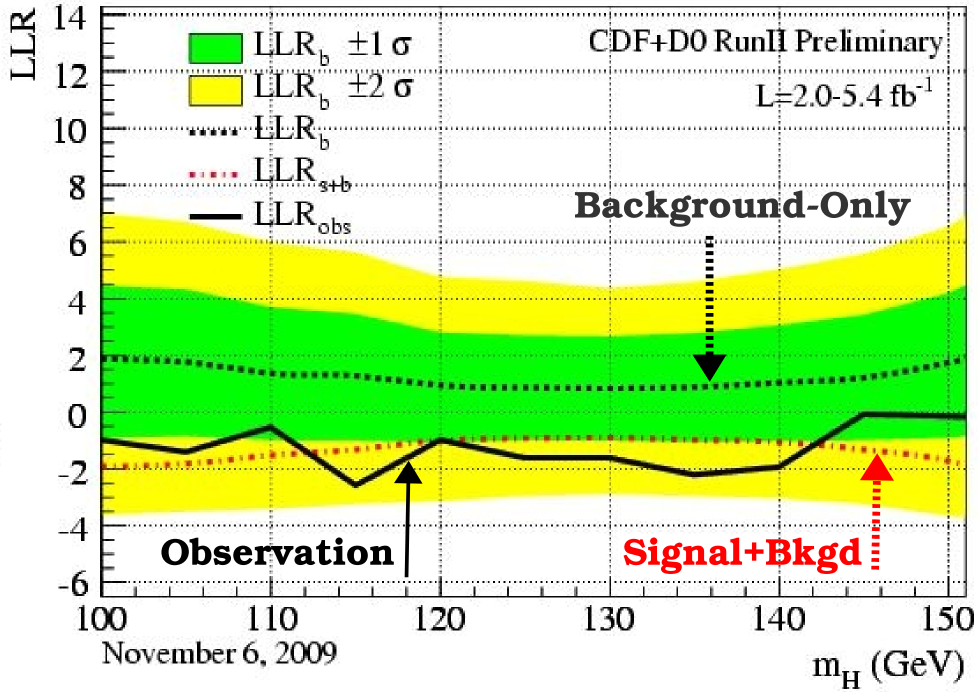


Combined CDF+DØ results in 2.0-5.4 fb^{-1}

M_H=115 GeV: 2.70 (1.78) observed (expected)

Limits on Higgs Production





Combined CDF+DØ results in 2.0-5.4 fb^{-1}

M_H=115 GeV: 2.70 (1.78) observed (expected)

Averaged by channel sensitivity, this result corresponds to 4.4 fb^{-1} of analyzed luminosity per experiment

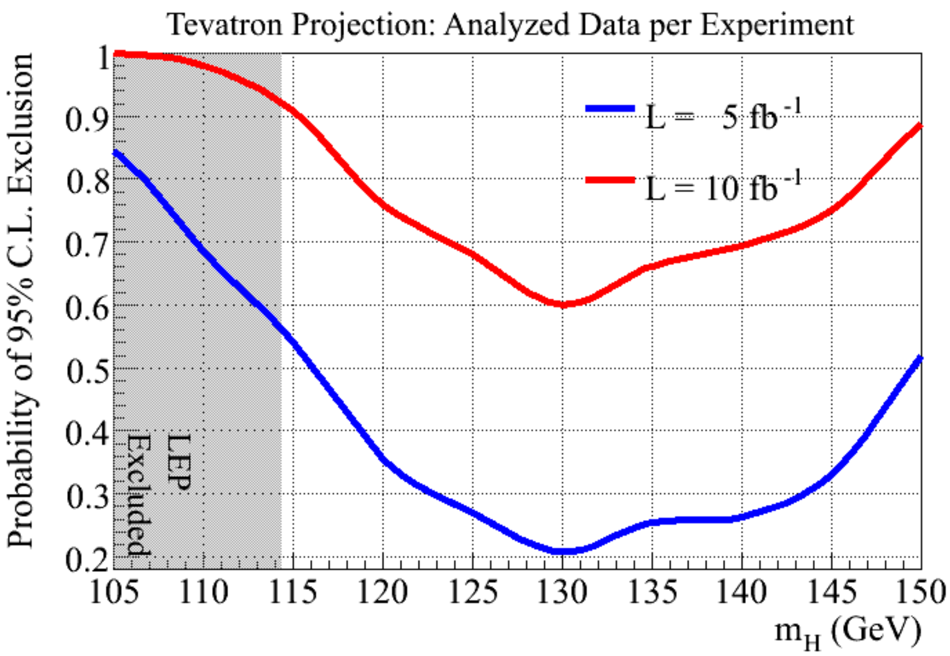
Higgs Sensitivity Projections

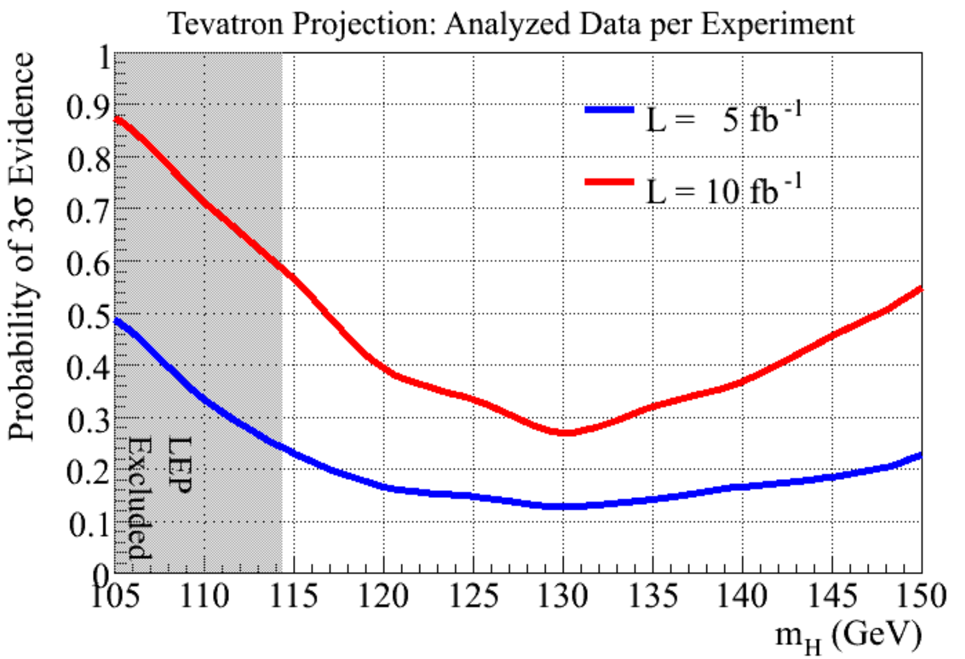
Can project sensitivity as a function of analyzed luminosity

- ~5 fb^{-1} available for analysis in 2009
- ~10 fb^{-1} available for analysis in 2011

Benchmark scenario:

- Assumes analysis design will remain similar to today's designs
- Assumes we achieve potential for known sources of improvement
- Expect to improve a range of analysis aspects: dijet mass resolution, b-tagging performance, detector acceptance, add missing search channels, and others

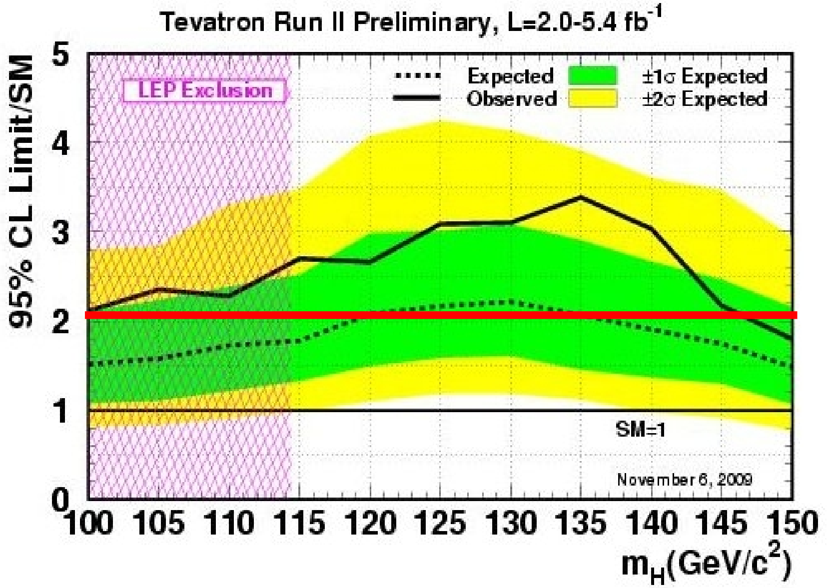




Conclusions

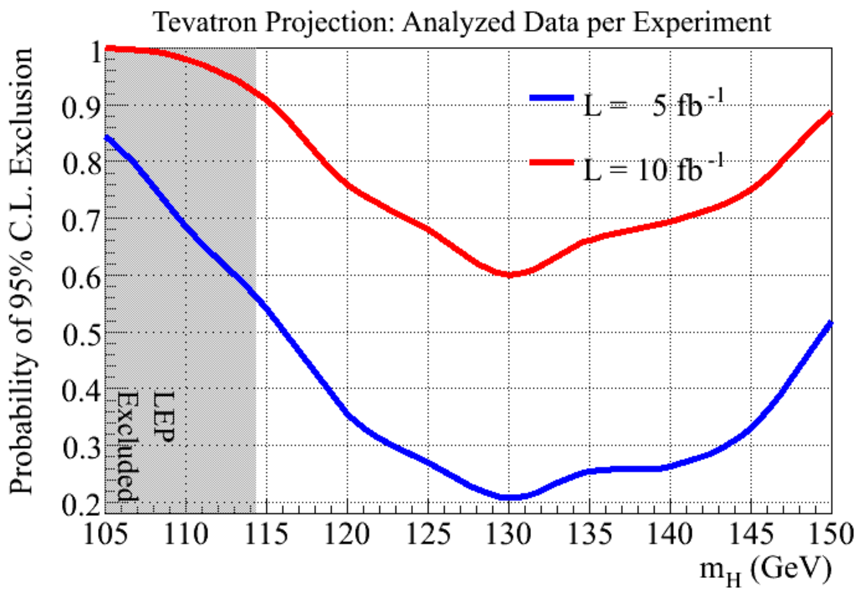
✗ We are working hard to find a Higgs boson

- Dedicated efforts at CDF & DØ are boosted by excellent Tevatron performance
- Low mass Higgs searches are mature and beginning to explore broad improvements to analysis technique
- Expected limits are within a factor of 2.2 of the Standard Model prediction for all masses



✗ It's an exciting time to be a Higgs hunter!

- We expect **>2.3x** more luminosity to analyze for M_H<135 GeV



Expect constant improvement for all mass ranges as our search matures

Extra Slides

Higgs Sensitivity Projections

A few active areas of analysis improvements (not a full list!):

- Demonstrated charm quark discrimination ability: ~30% equiv lumi gain
- Improved usage of b-Tagging information: ~20% equiv lumi gain
- Reduced dijet mass resolution: ~15% equiv lumi gain
  for every 1% absolute gain in σ_{Mbb} for up to ~50-60% possible
- Addition of lower yield final states ($H \to \tau\tau/\gamma\gamma/ZZ/l\nu jj$, etc): ~5-10% equiv lumi gain
- Improved lepton ID eff & reduced inst. lumi dependence: ~5-10% equiv lumi gain

These factors alone can buy us ~1.4× in the limit (~2× in effective luminosity)