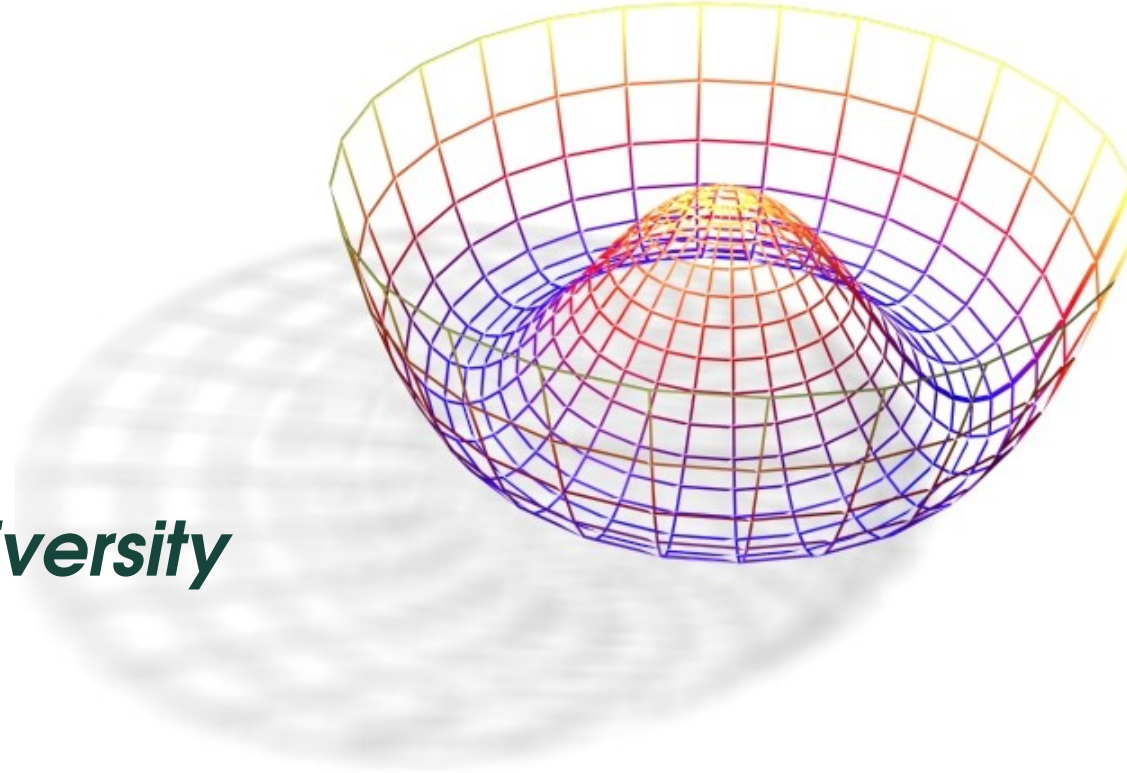
Seeking the Origin of Mass

Searches for Higgs Bosons at the DØ experiment



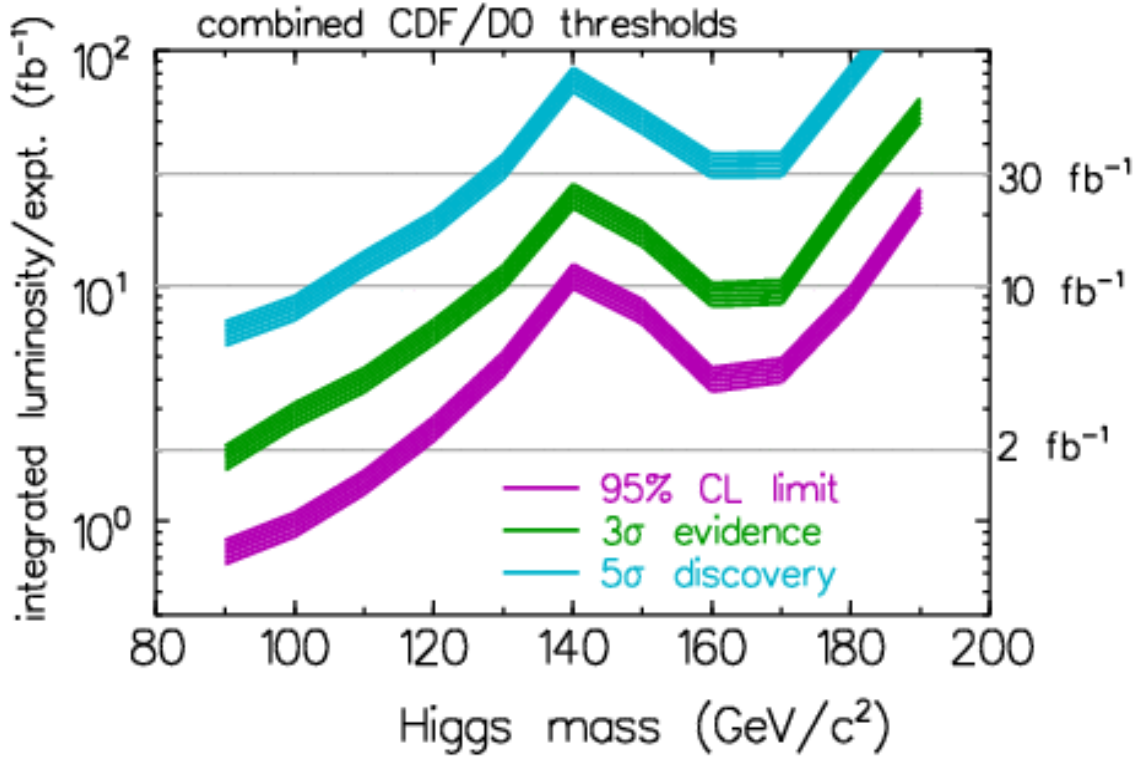
Wade Fisher

Michigan State University

For the Higgs Group
and the DØ collaboration

How we got into this mess...

- → SUSY/Higgs Working Group report from ~2000
- → SHWG covered most of the Higgs production and decay channels
- → Used parameterized simulations for an *average* FNAL detector performance
- → Very complete study using the resources available



With a few assumptions (eg, H→bb mass resolution) we can do a great job in Higgs searches.

How we got into this mess...

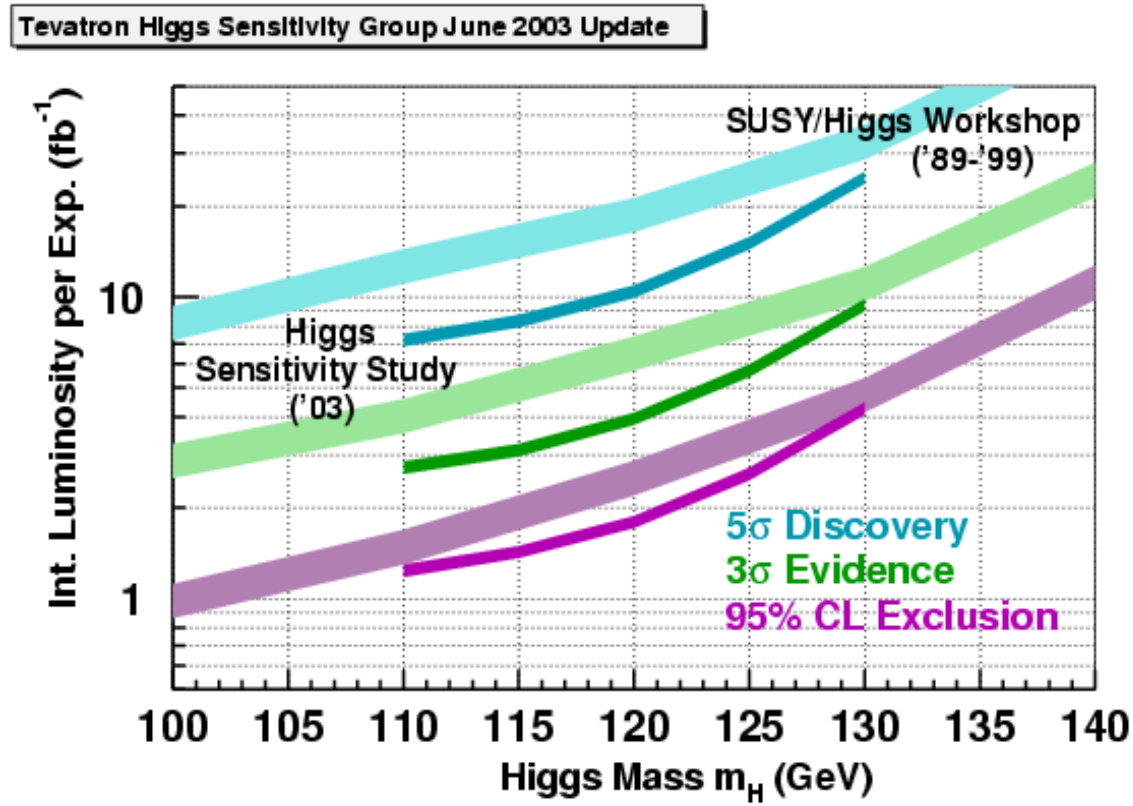
→ Higgs Sensitivity Study Group report from ~2003

→ Focus on H→bb decays only

→ Based on real simulations and included studies of potential systematic effects

Systematics not included in calculations

→ Similar conclusions, potentially even more supportive of a strong Tevatron push for the HIggs



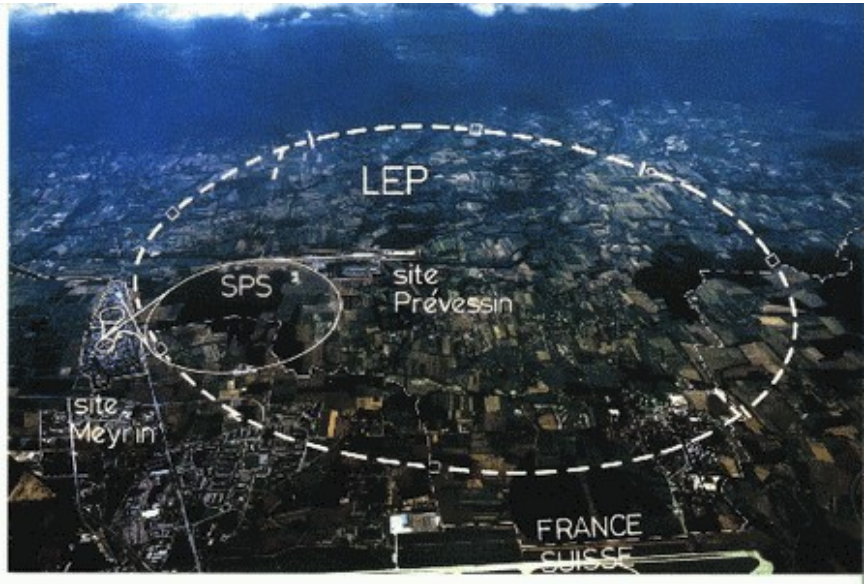
We were trying to sell a silicon upgrade at the time, but the motivation really was pure of heart.

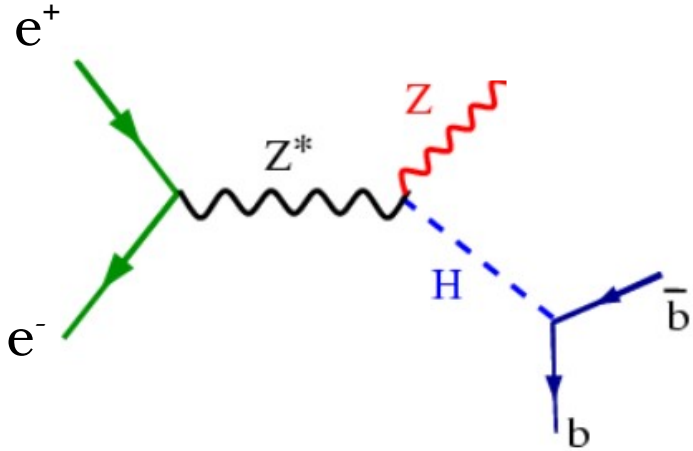
The Status before RunII

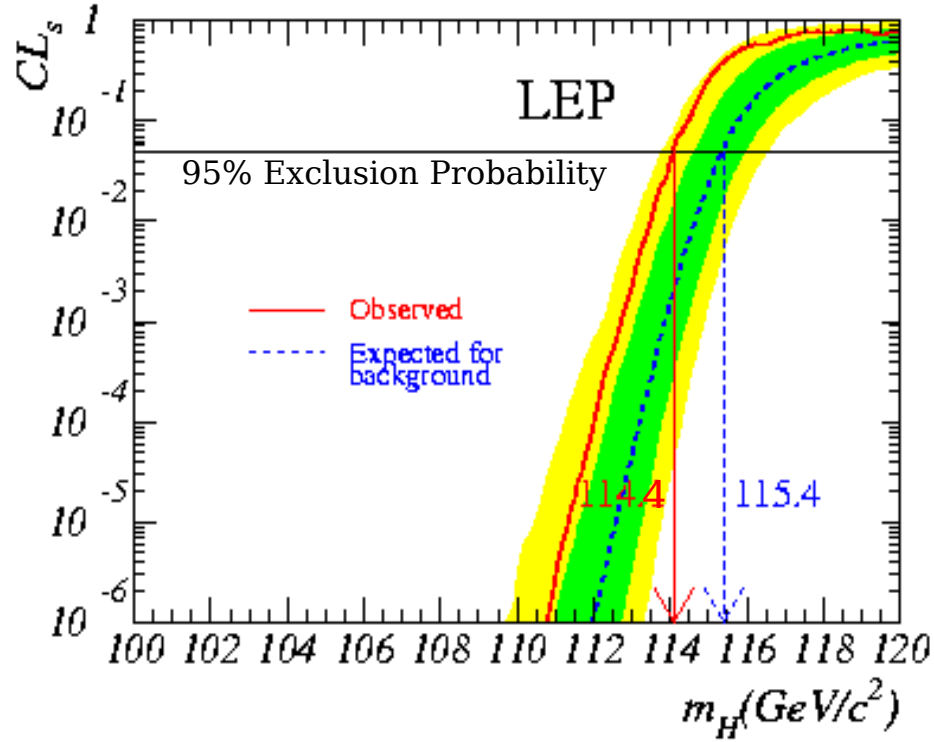
Wade Fisher
DØ 2011

Direct searches have limited the potential places the Higgs can hide

LEP II direct search: M_H >114.4 GeV at the 95% Confidence Level (C.L.)







Indirect Experimental Evidence

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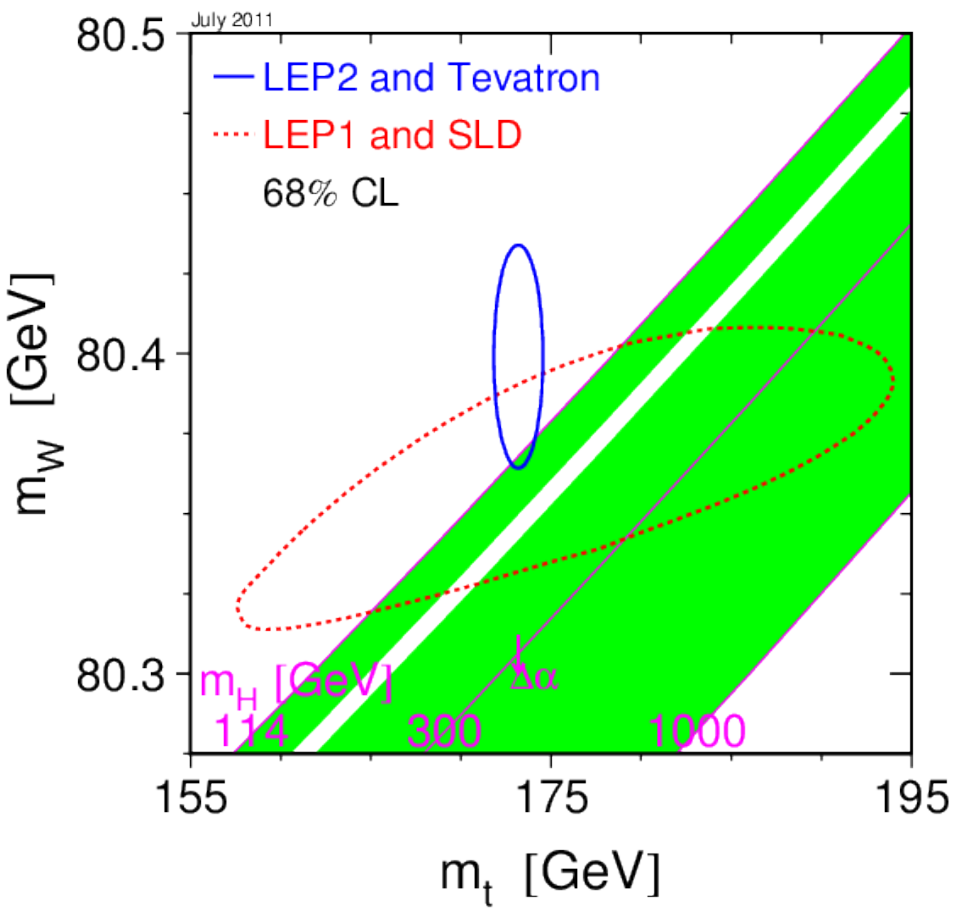
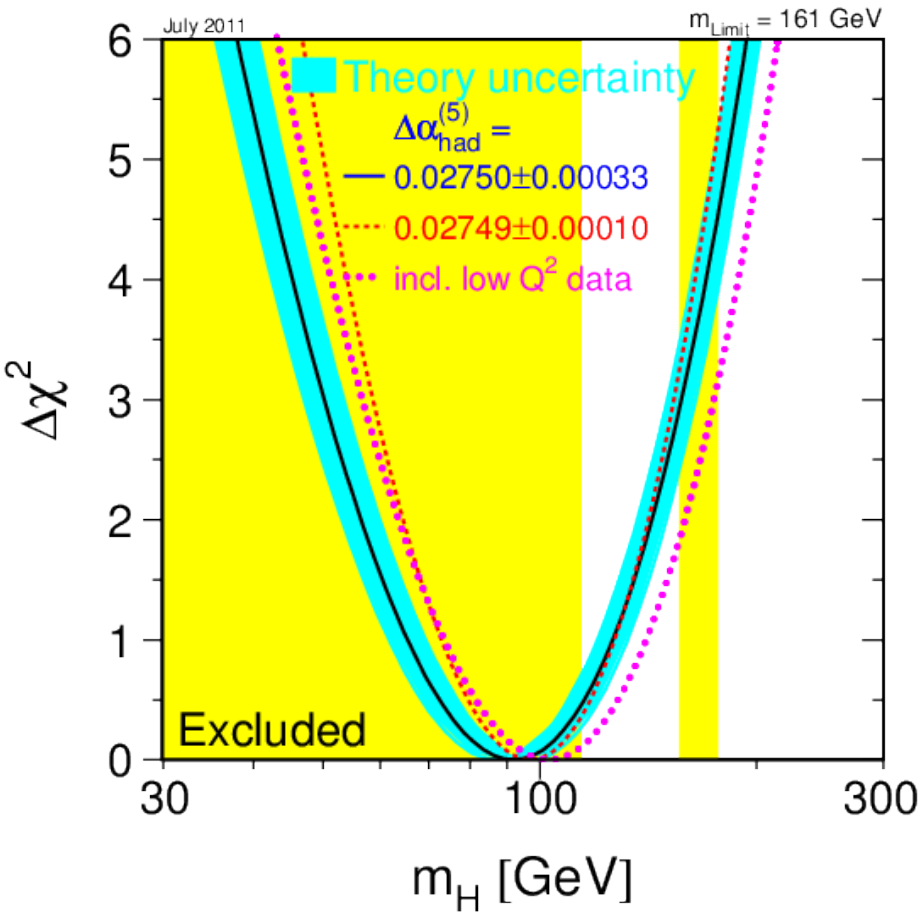
The interactions between SM particles and the Higgs provide indirect evidence through radiative corrections to particle masses

A fit of precision electroweak data yields: M_H < 161 GeV at 95% CL

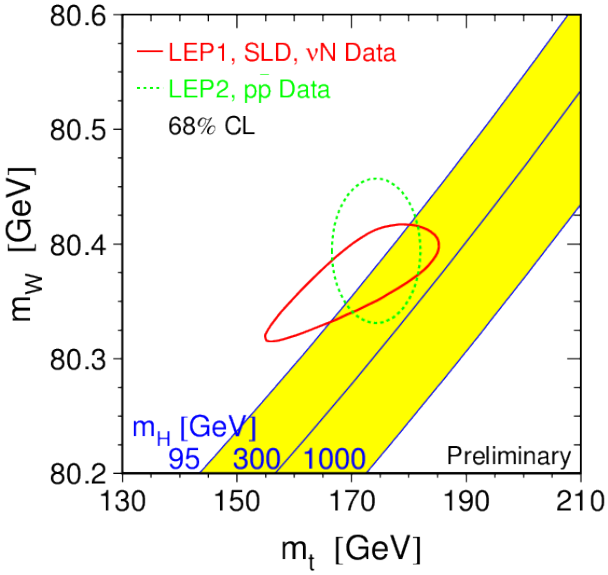
(M_H < 185 GeV including LEP II limit)



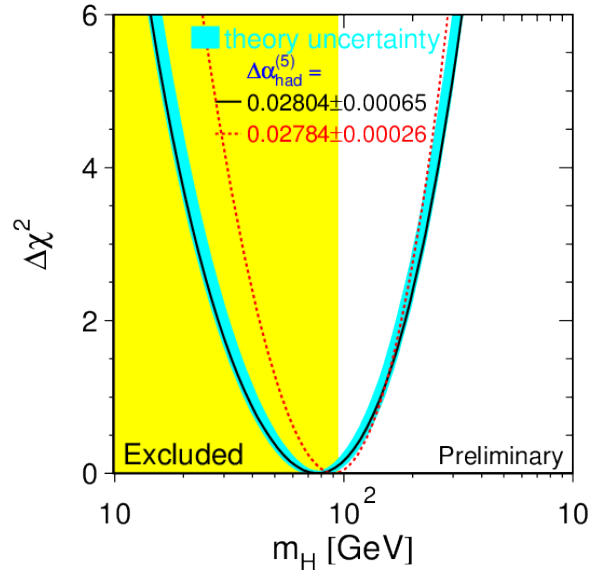


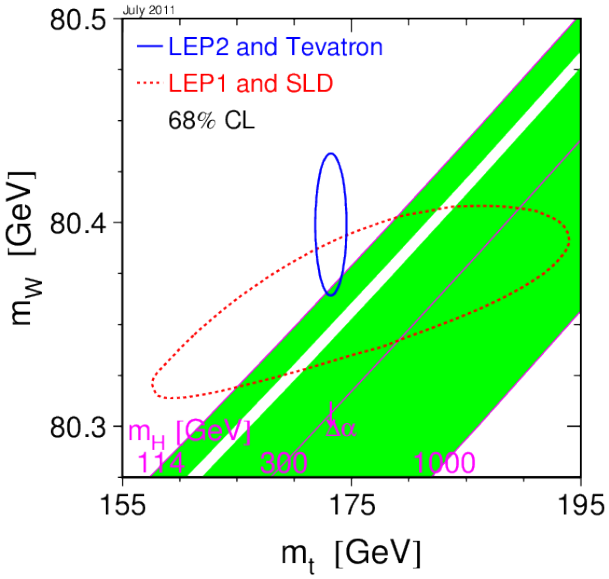
An Evolving Picture

Wade Fisher
DØ 2011

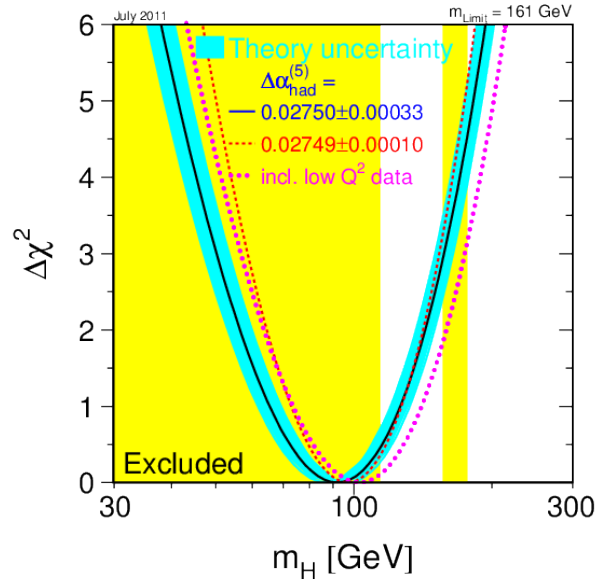


Results from ~2000





Results from 2011

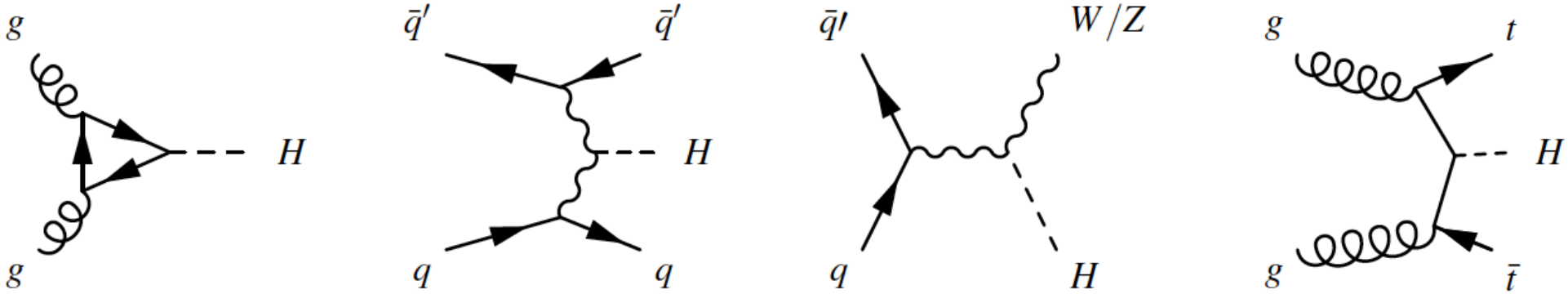


Standard Model

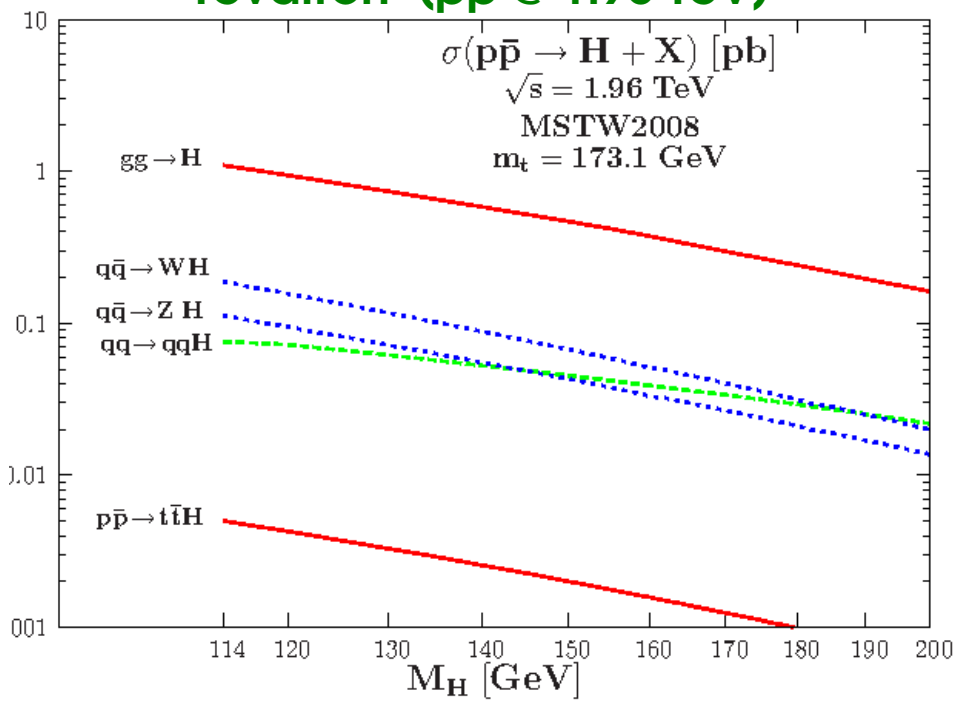
Higgs Searches

Higgs Production

Wade Fisher
DØ 2011

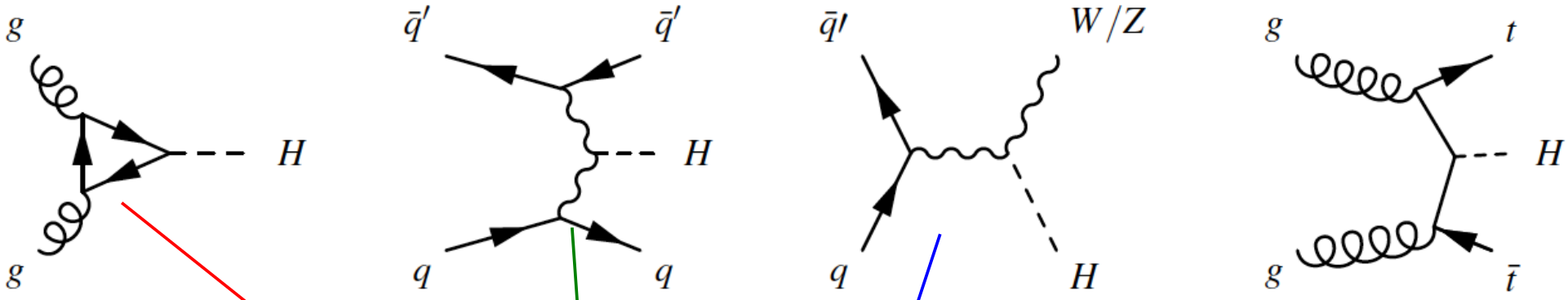


Tevatron ($p\bar{p}$ @ 1.96 TeV)

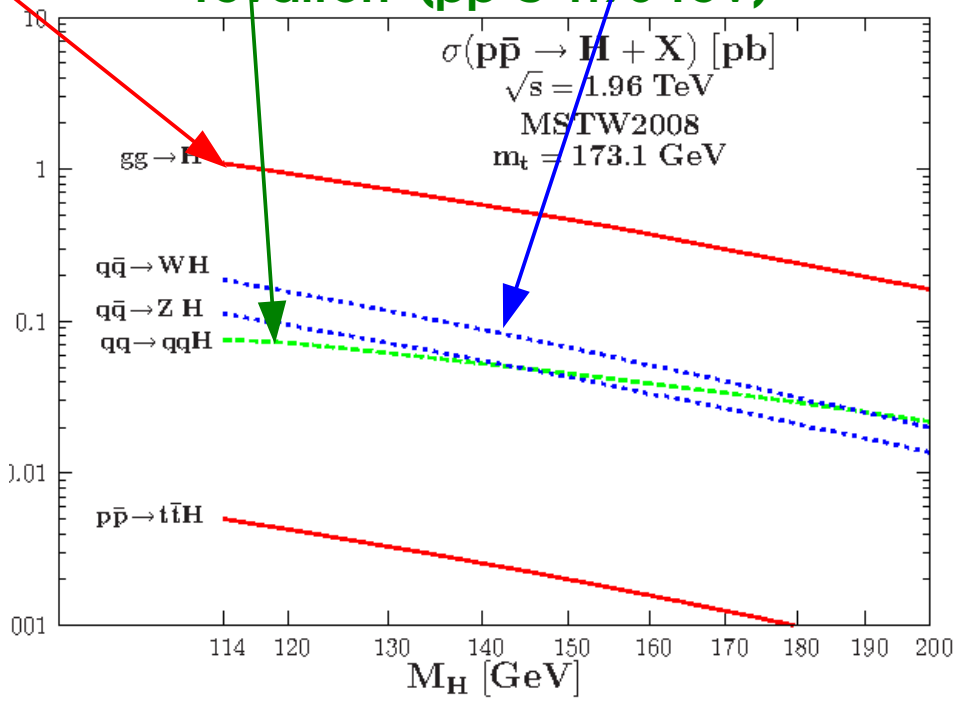


Higgs Production

Wade Fisher
DØ 2011



Tevatron ($p\bar{p}$ @ 1.96 TeV)



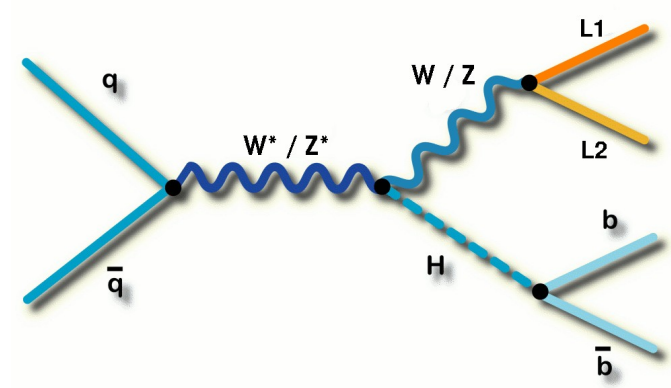
Higgs Decay Modes

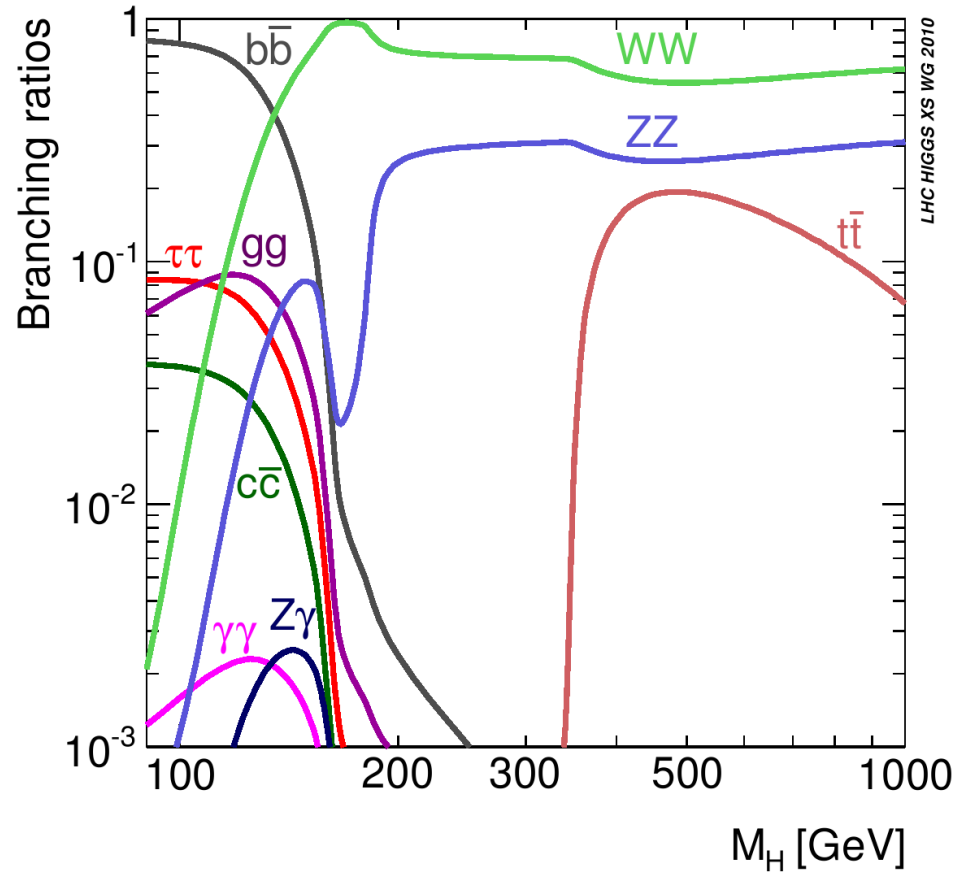
The Higgs decay determines what we see in the detector

- Strong coupling to mass selects out most massive particles for each possible mass
- Hadron colliders are quark/gluon factories: leptons/photons provide important handles for background reduction

- At low mass (M_H<135 GeV), the dominant Higgs decay is H→bb
  - Hard to distinguish H→bb from huge jet background, easier when paired with associated particles (*W, Z, top*)

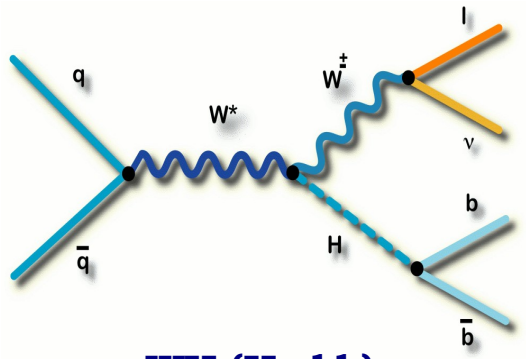
- At higher masses H→WW and H→ZZ decays dominate
  - Efficient and accurate reconstruction of lepton momenta gives reasonable Higgs mass resolution



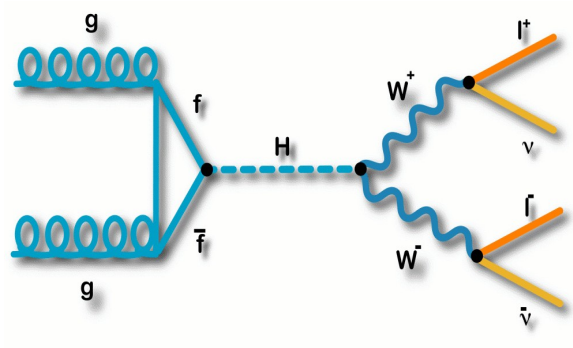


Backgrounds & Rates

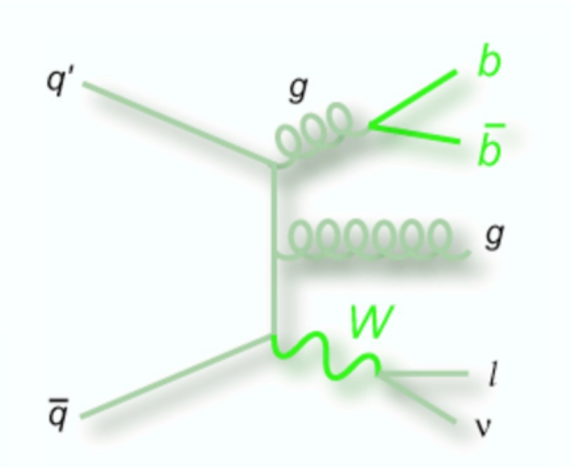
Wade Fisher
DØ 2011



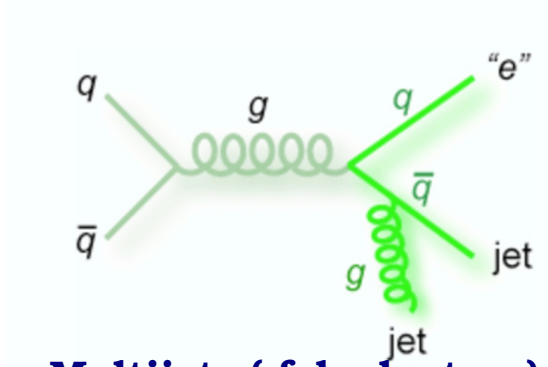
WH (H→bb)
σ×BR = 40 fb @ M_H=115



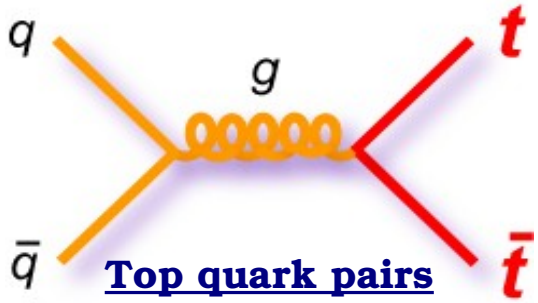
gg→H→WW
σ×BR = 34 fb @ M_H=165



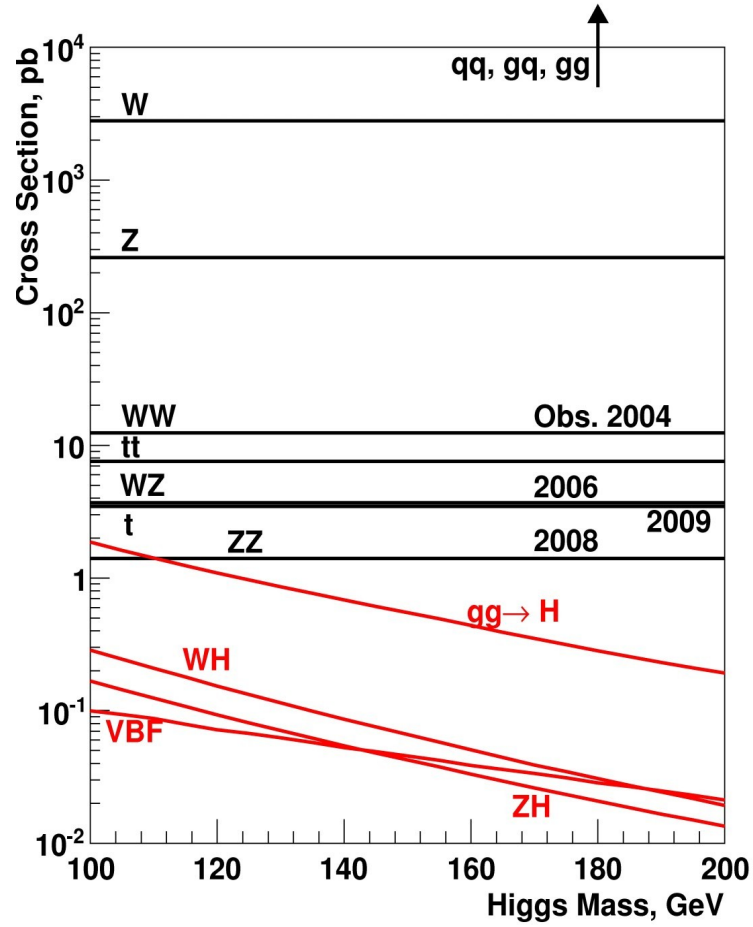
W/Z+jets or "Gluon Splitting"
σ×BR > 1,000,000 fb



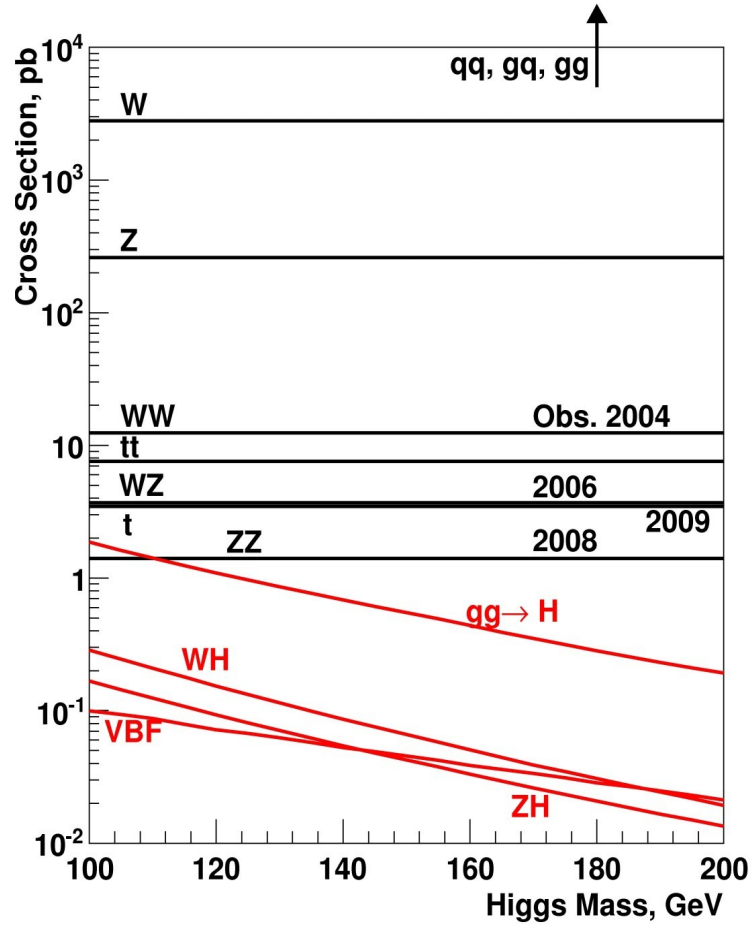
Multijets (fake lepton)
Measured in data



Top quark pairs
σ×BR = 7,800 fb



Backgrounds & Rates



Searching for H→bb

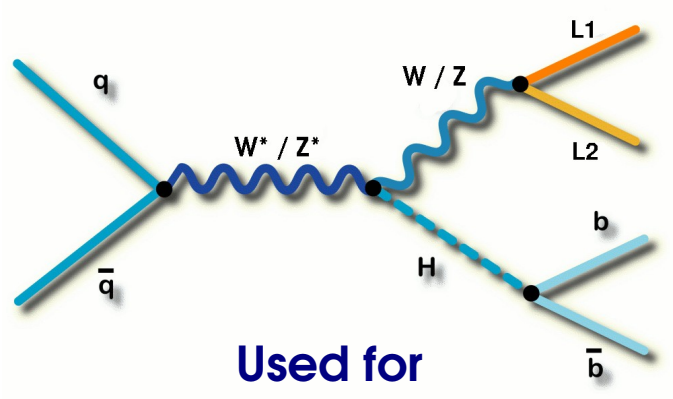
Wade Fisher
DØ 2011

Start with events consistent with W/Z decays

- W→lν & Z→ll: Select events with **electrons** or **muons**
- Z→νν: Select neutrino signature (*large missing transverse energy*) and 2 jets signature

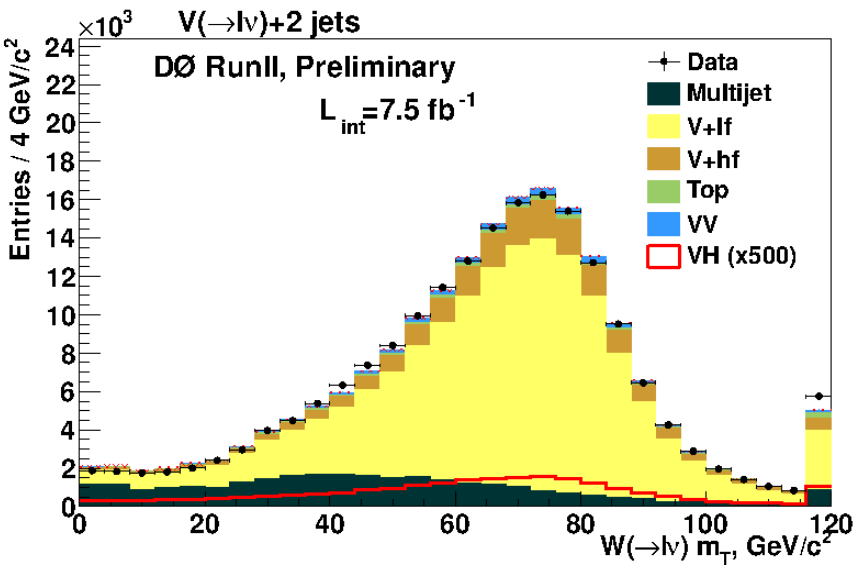
Each final state poses a unique challenge

- W→lν: Invisible neutrino limits degree of constraint
- Z→ll: Despite full kinematic constraint, limited by small branching fraction
- Z→νν: Multijet background difficult to model/control

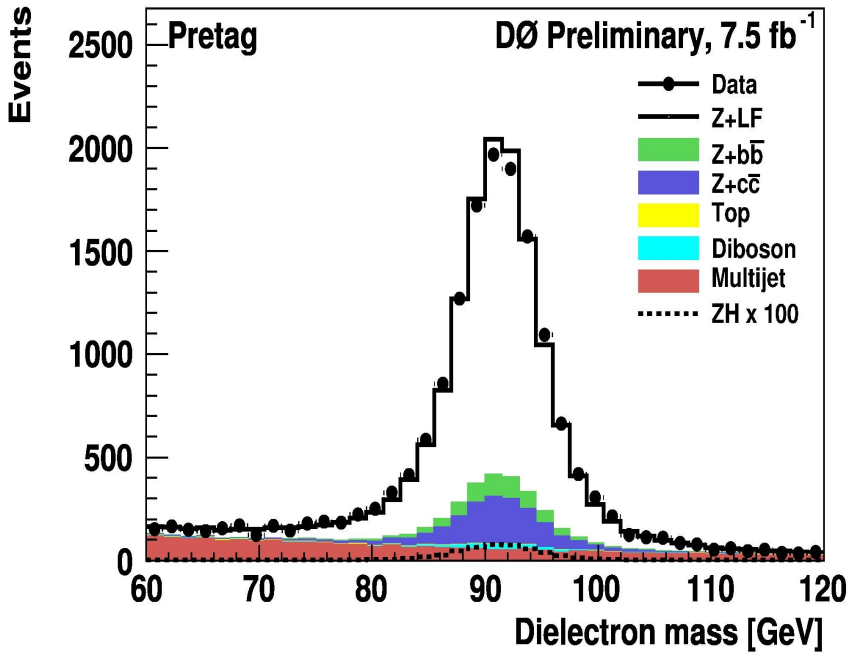


Used for M_H < 150 GeV

W→lν Transverse Mass



Z→ll Mass



Searching for H→bb

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DØ 2011

Start with events consistent with W/Z decays

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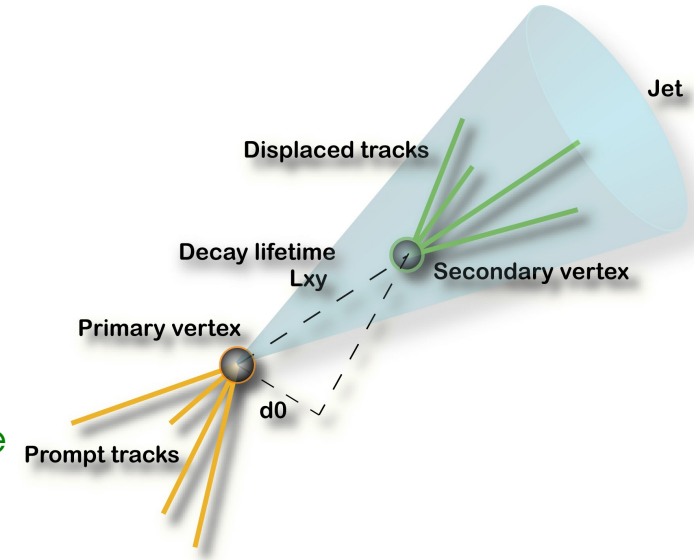
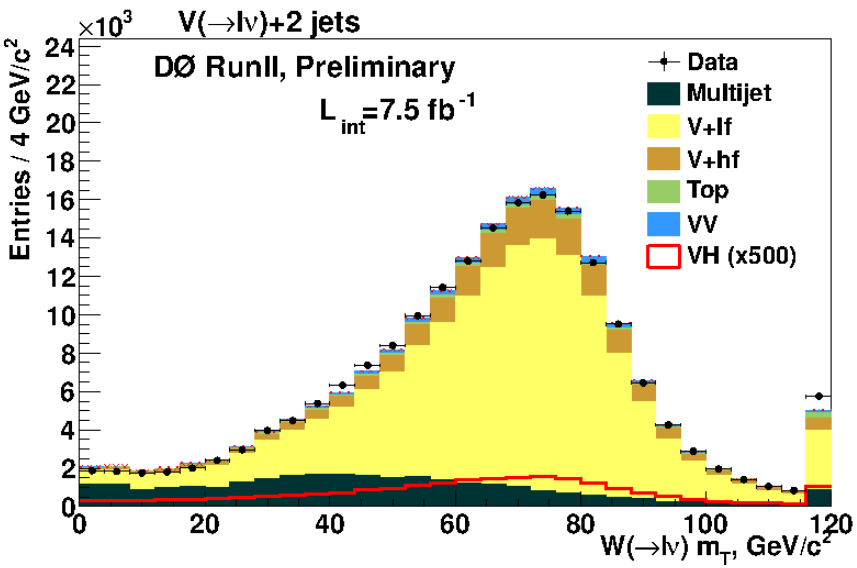
Identification of b-quark jets very powerful background rejection tool

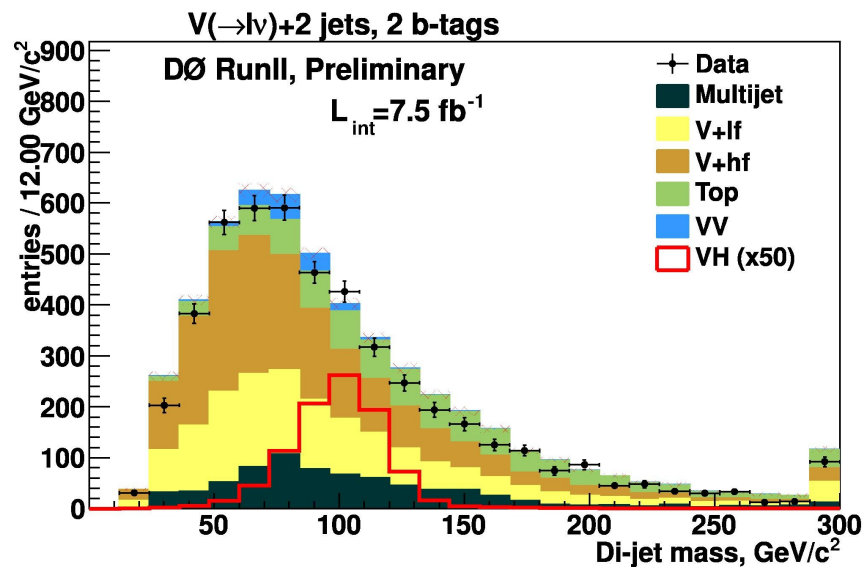
- We have moved to using rather loose taggers which have efficiencies around 70%
- Counteract percent-level fake rates by using residual information in B-ID multivariable analysis distributions



W→lν Transverse Mass



Dijet Invariant Mass

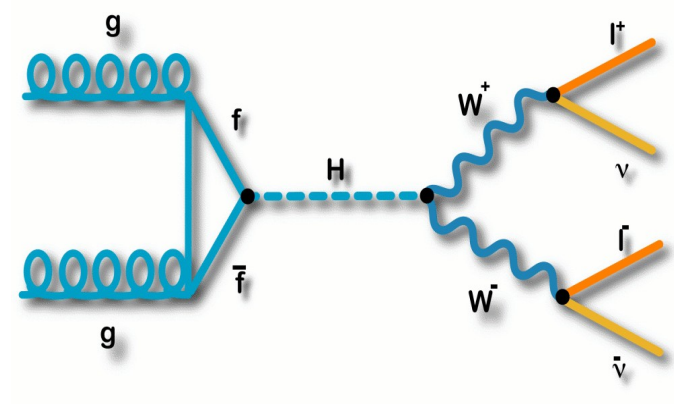


Searching for $H \rightarrow W^+W^-$

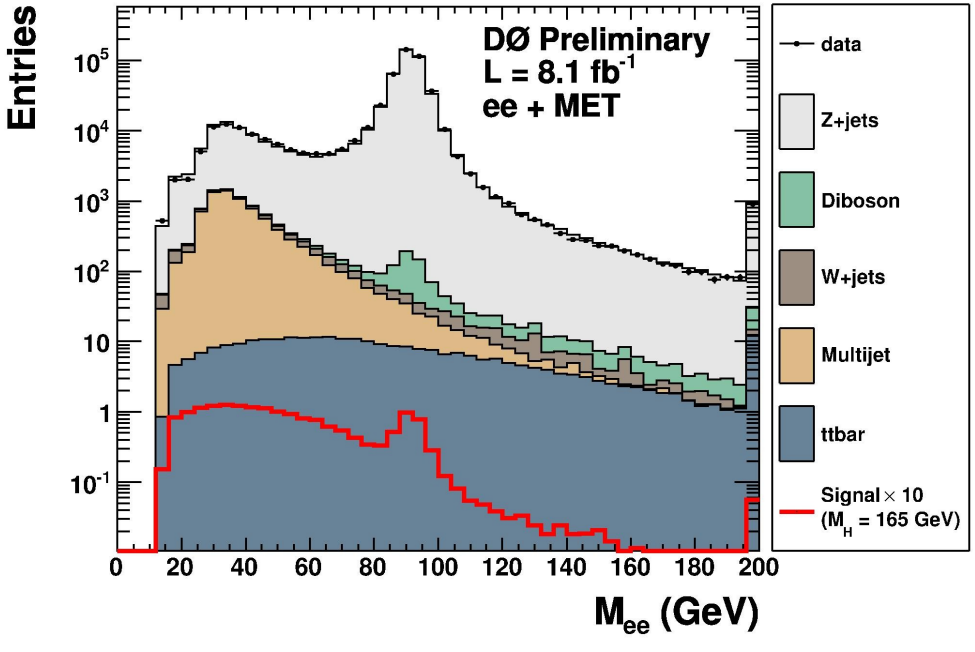
Wade Fisher
DØ 2011

Selecting leptonic W-boson decays to reduce the very large multijet backgrounds

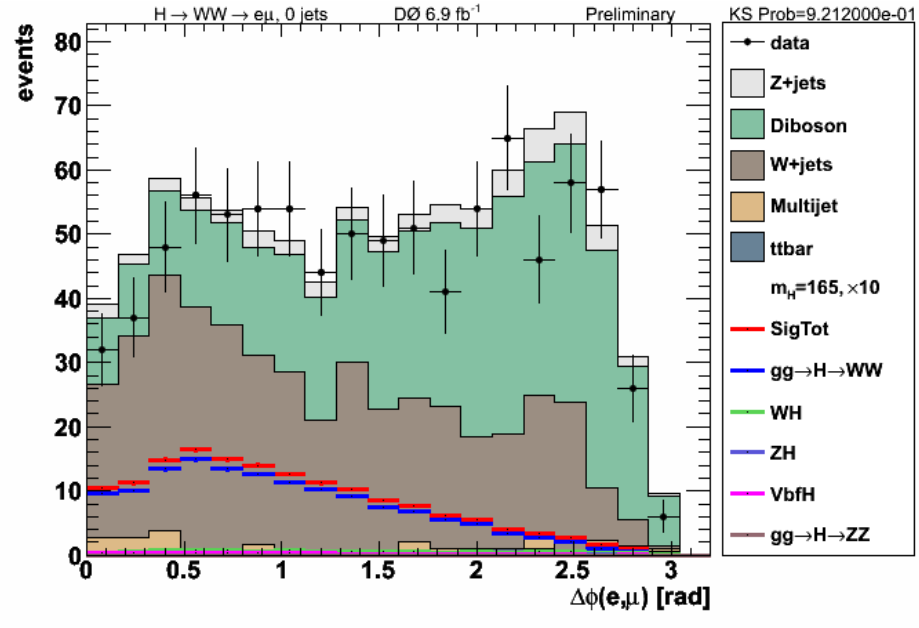
- Use Z mass for normalization, veto region near peak
- 2 neutrinos: missing E_T signature helps reject all but direct WW production
- Capitalize on spin correlations to discriminate WW background (*H = scalar, W/Z = vector*)



Di-lepton Invariant Mass



Di-lepton Angular Separation



Searching for $H \rightarrow W^+W^-$

Wade Fisher
DØ 2011

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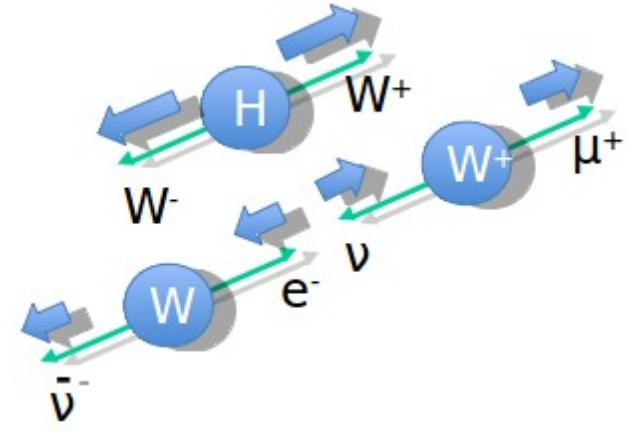
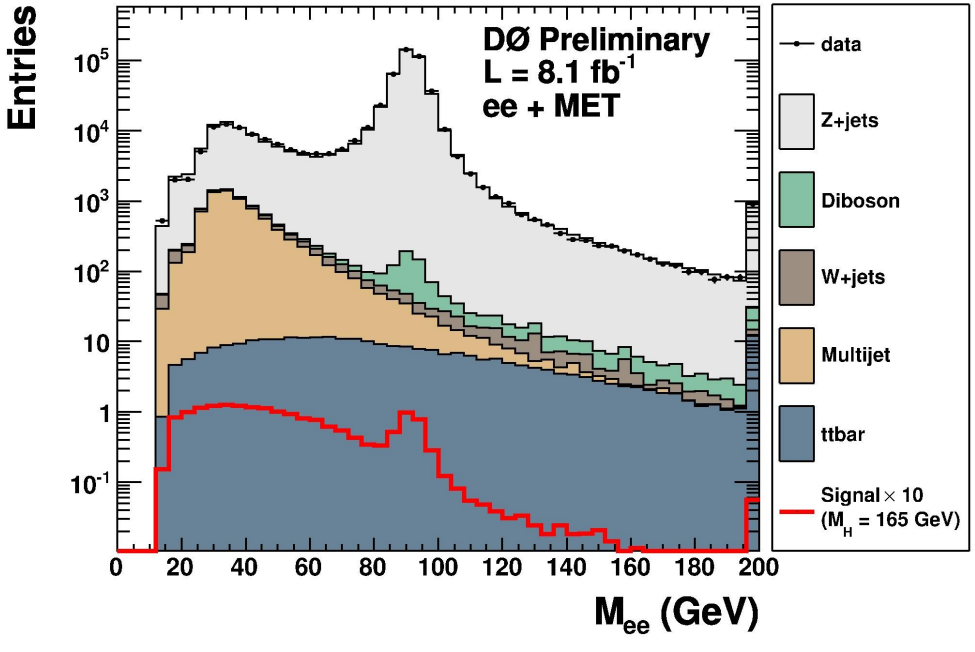
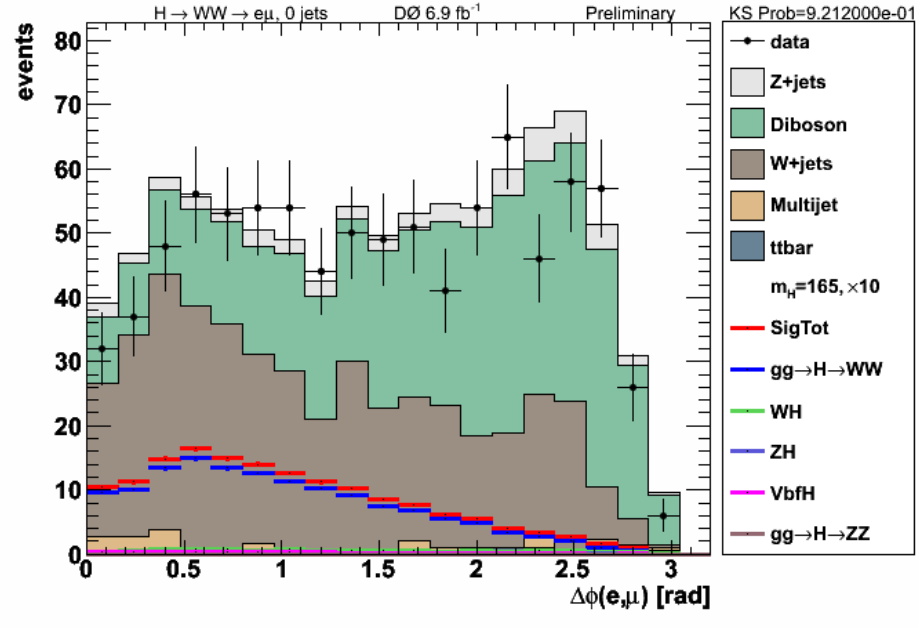


Particle spin (helicity) & momentum constrained to satisfy spin-0 Higgs decay

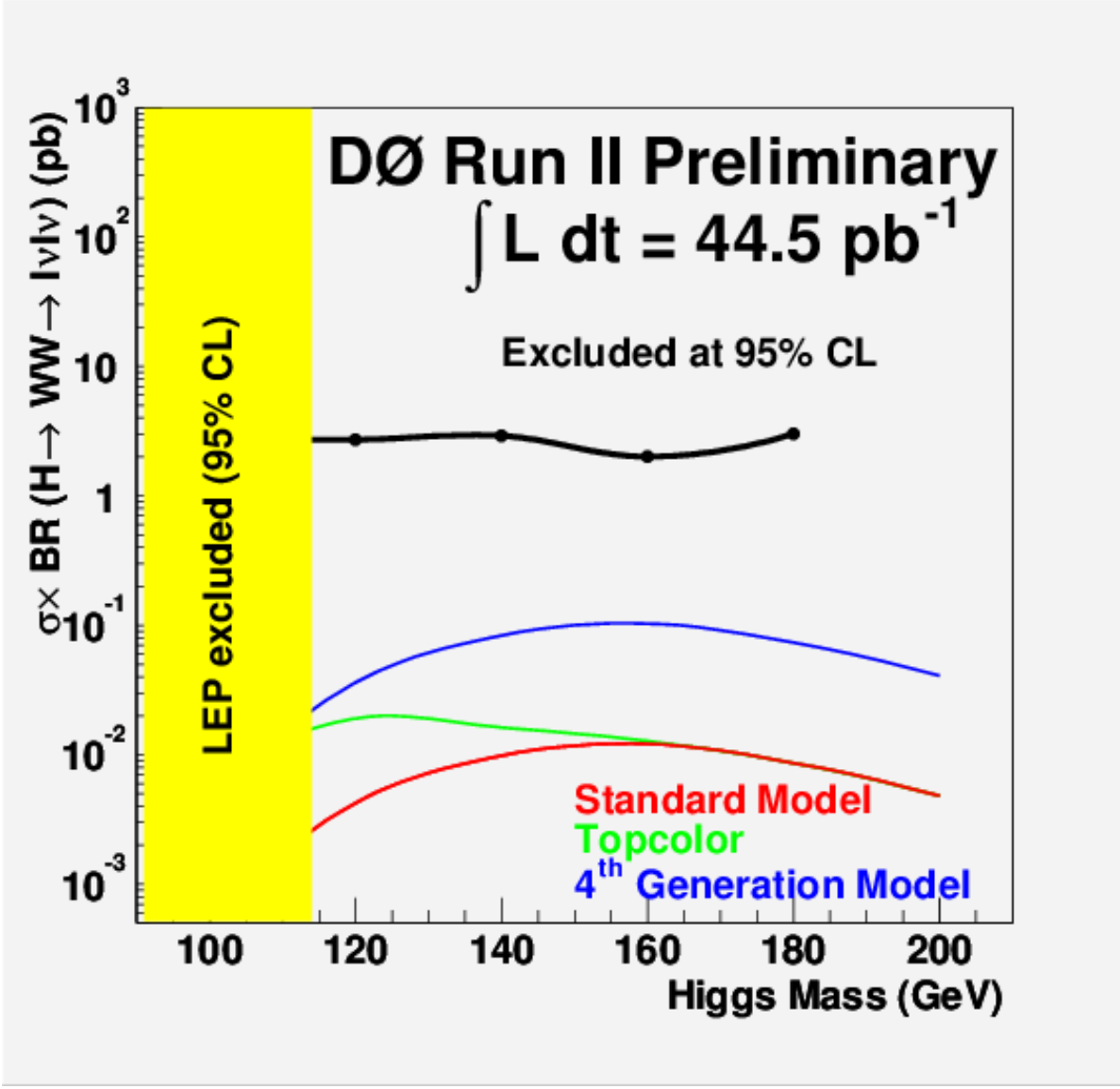
Di-lepton Invariant Mass



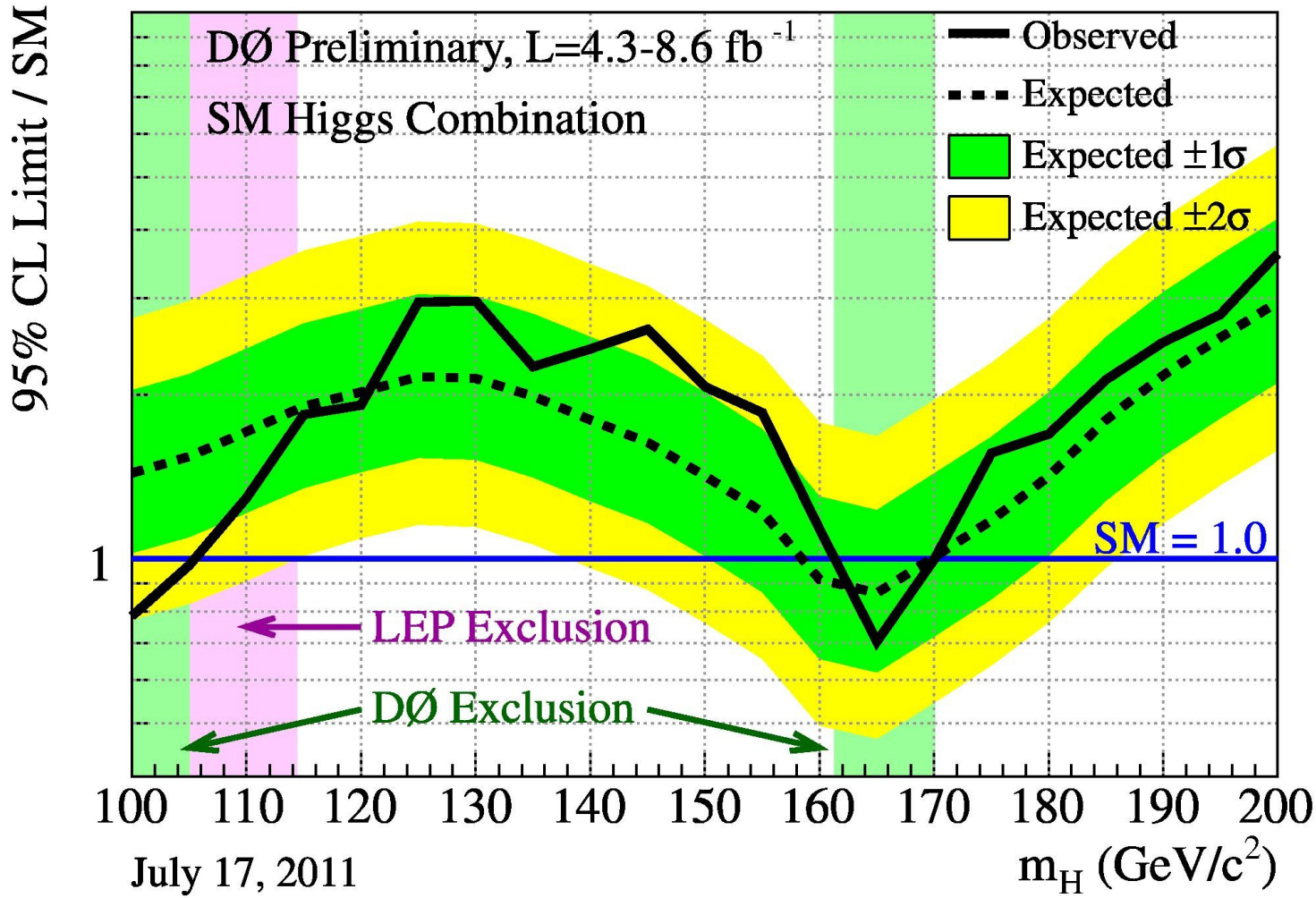
Di-lepton Angular Separation



Limits!


DØ Run II Preliminary
∫L dt = 44.5 pb-1
Excluded at 95% CL
LEP excluded (95% CL)
σ× BR (H→ WW→ lνlν) (pb)
10^3
10^2
10
1
10^-1
10^-2
10^-3
Standard Model
Topcolor
4th Generation Model
100
120
140
160
180
200
Higgs Mass (GeV)

Tevatron Results



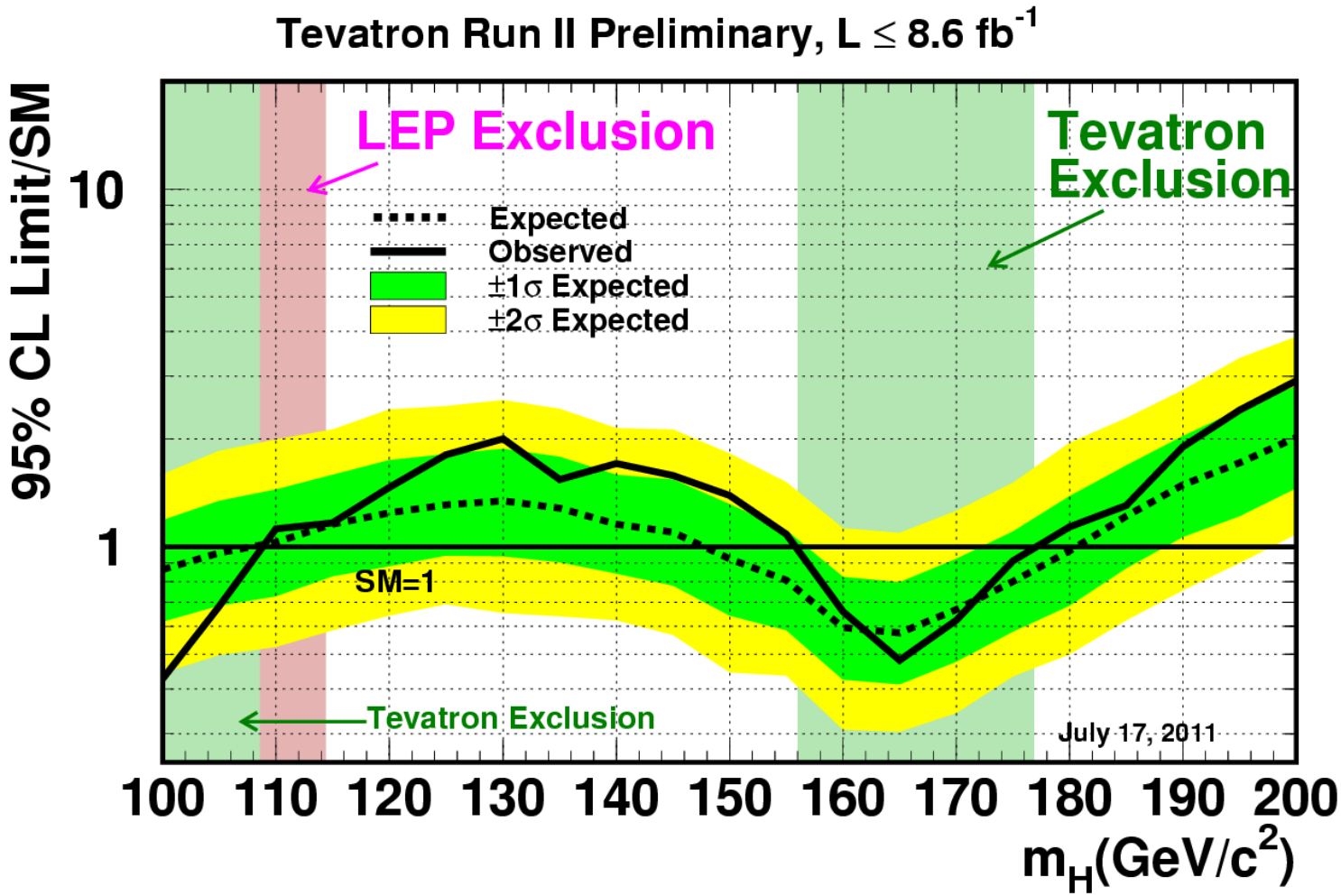
SM Higgs excluded at 95% C.L.

$M_H < 105$ GeV

$161 < M_H < 170$ GeV

Tevatron Results

Wade Fisher
DØ 2011



SM Higgs excluded at 95% C.L.

$M_H < 108$ GeV

$156 < M_H < 177$ GeV

Beyond the Standard Model

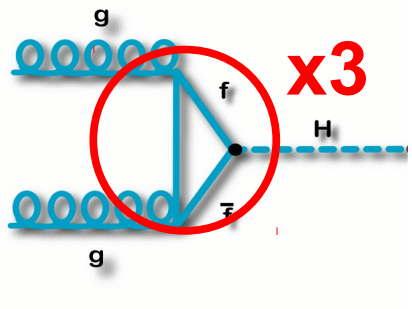
Higgs Searches

BSM Higgs

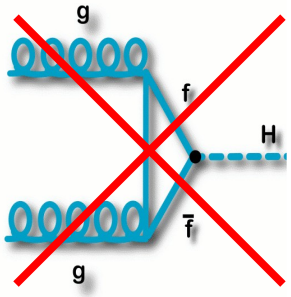
Wade Fisher
DØ 2011

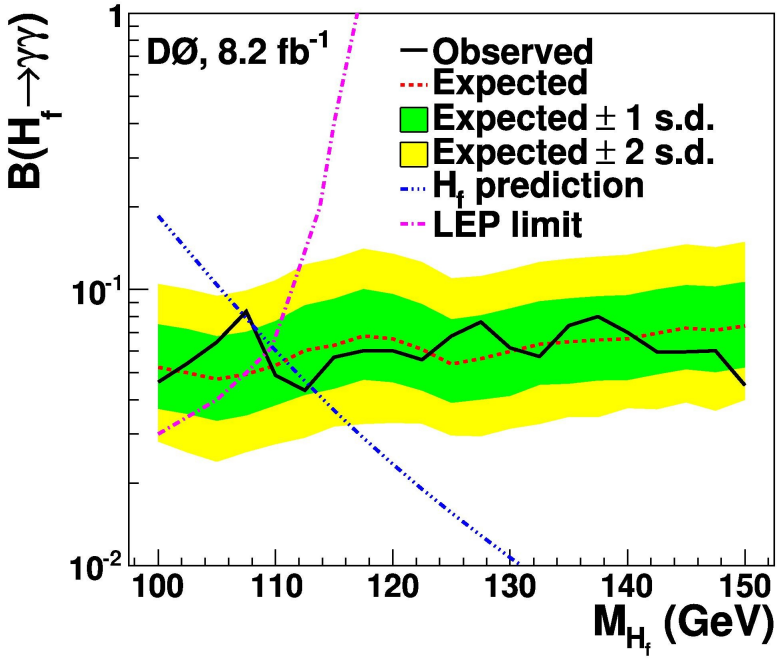
An additional generation of quarks/leptons could drastically alter the Higgs landscape

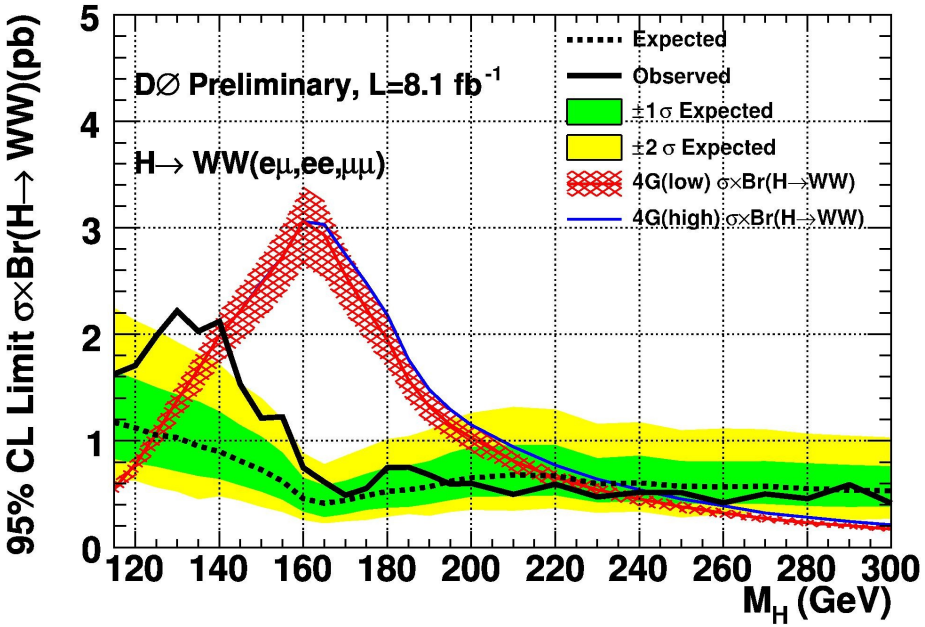
- 2 extra heavy quarks adds 2 more gg→H diagrams
  - An increase of ~9x in gg→H rate!
  - Essentially no change in VH, VBF, ttH rates



We can also construct models in which there are Higges which decay exclusively to bosons (Fermiophobic Higgs)







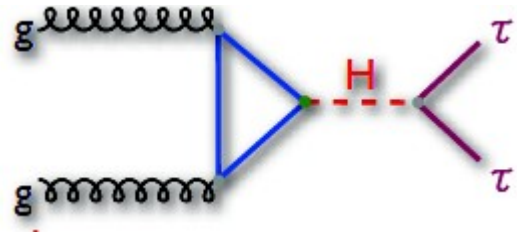
MSSM Higgs Searches

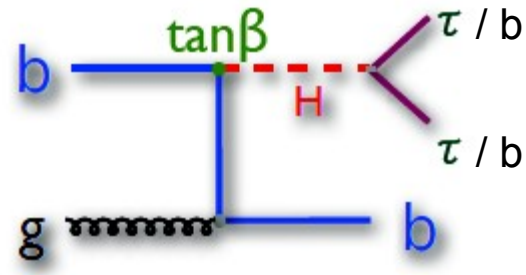
Challenging 3 b-quark final state only possible with very efficient b-tagging

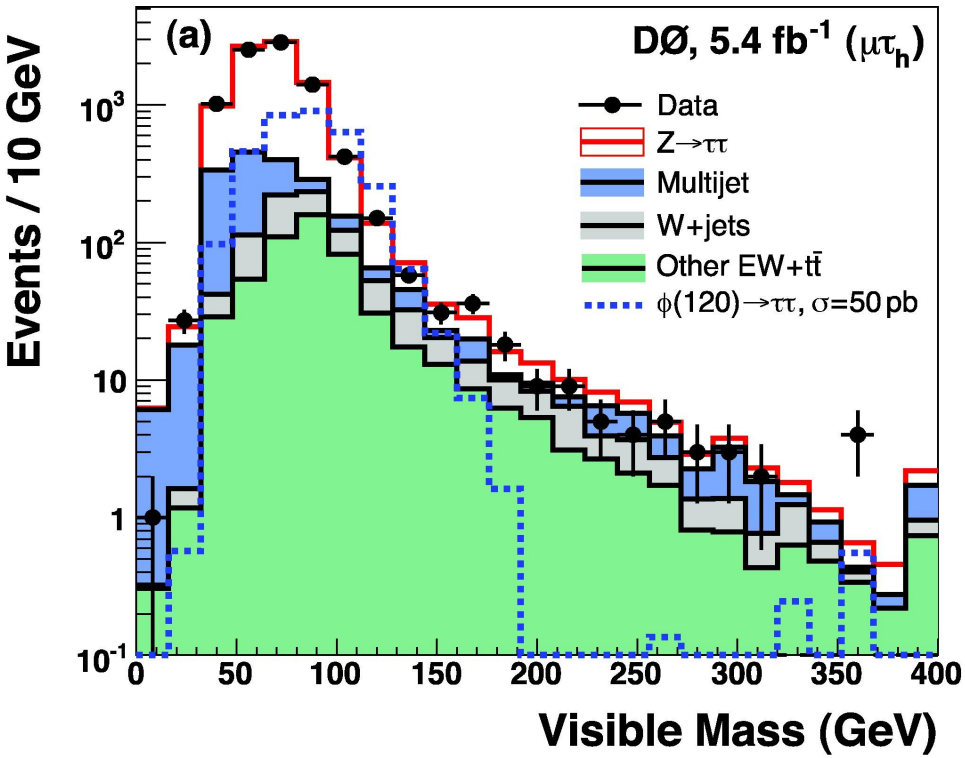
- Signal mass resolution ultimately limits high mass search potential

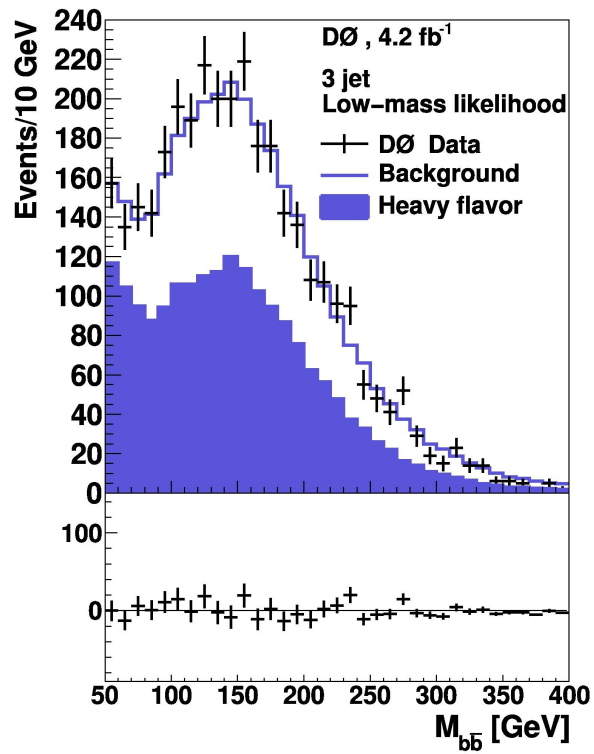
Di-tau searches contribute to both the MSSM and SM search efforts

- Di-tau "visible mass" is one of the most powerful search criteria







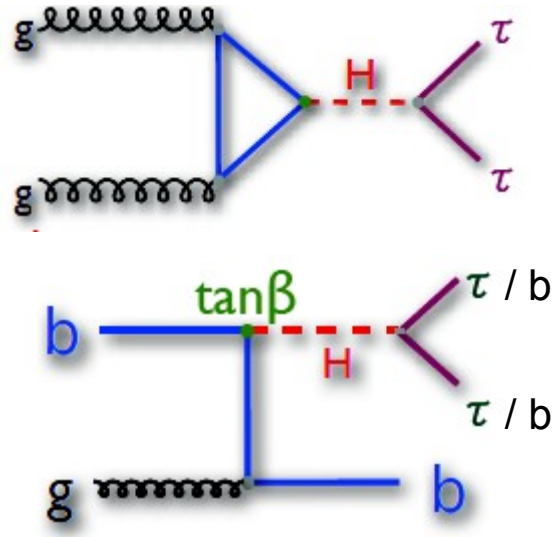


MSSM Combined Results

Upper limits on cross section can also be interpreted in MSSM parameter space.

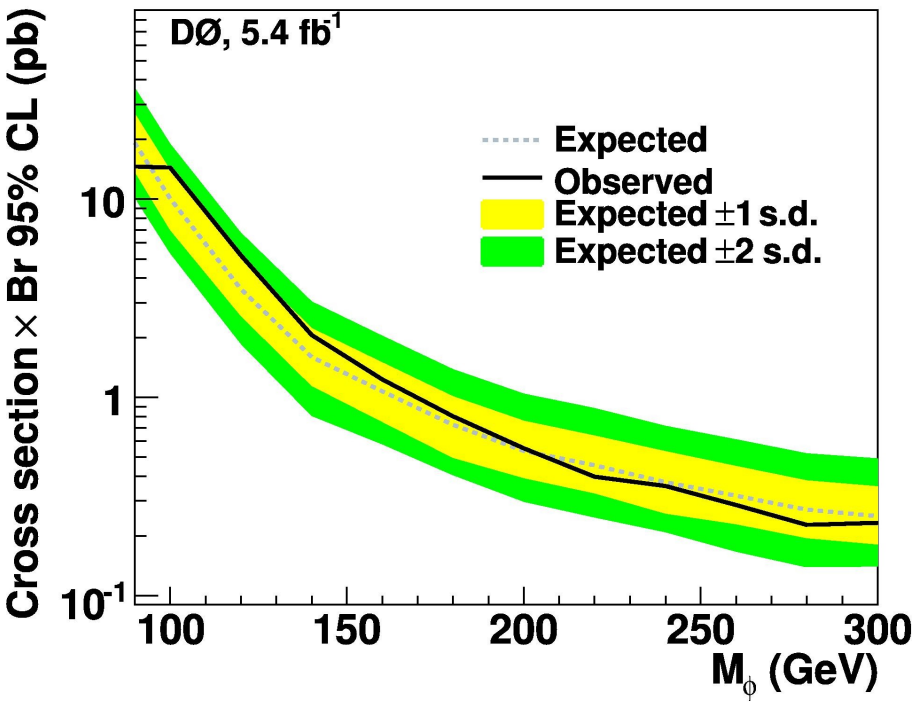
→ Limits now overlapping LEP limits for some parameter choices

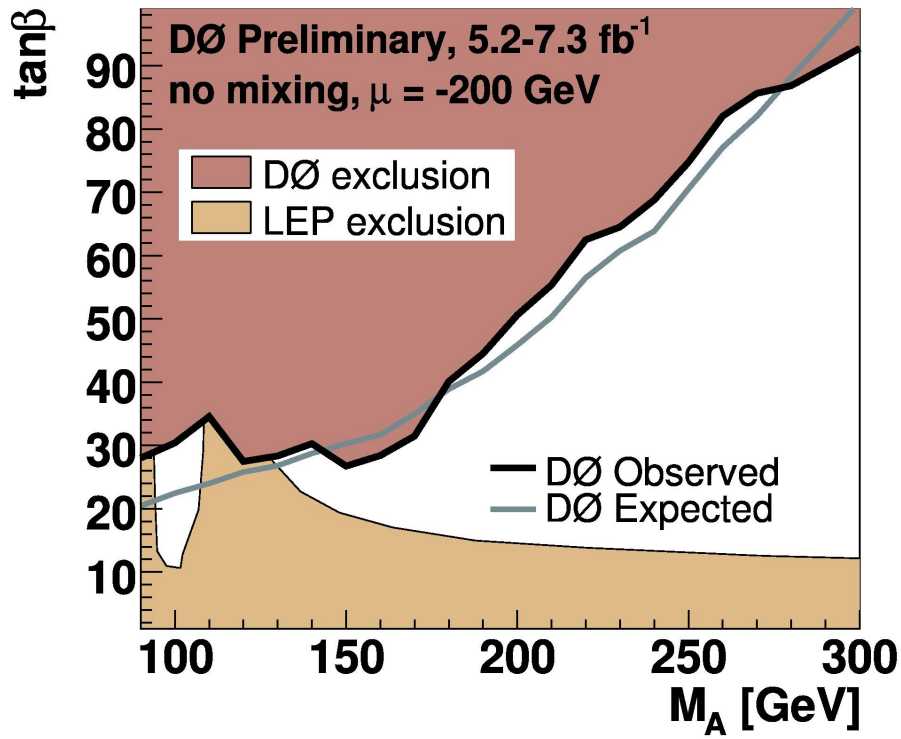
LHC experiments closing fast here



bH → bbb
bH → bττ

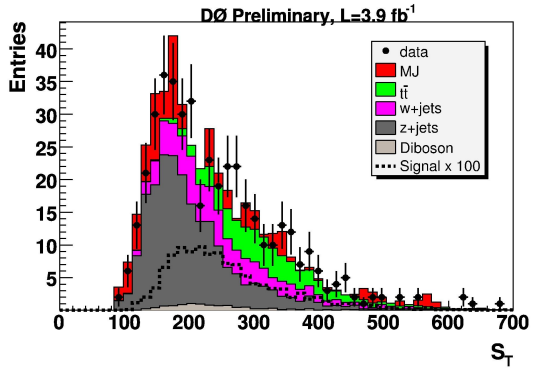
H → ττ

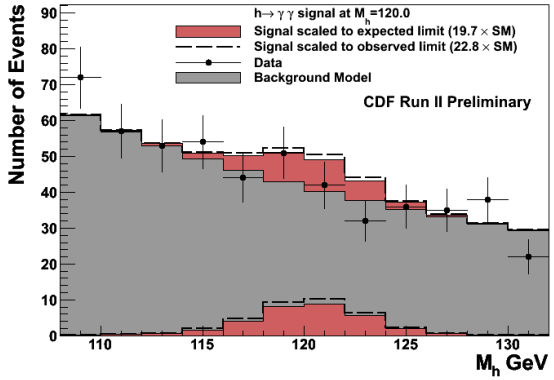


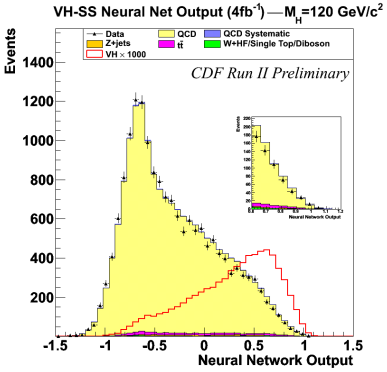


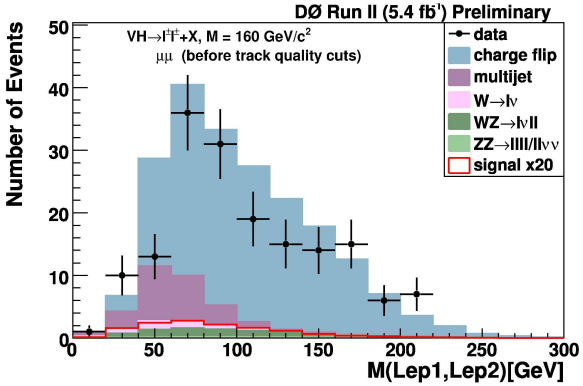
Many More Channels to Cover!

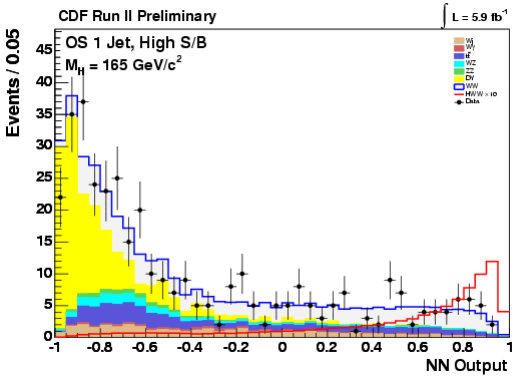
Wade Fisher
DØ 2011

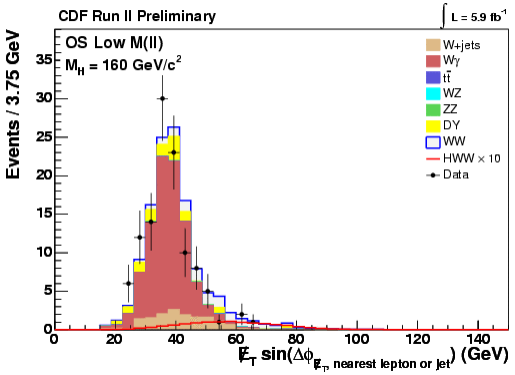


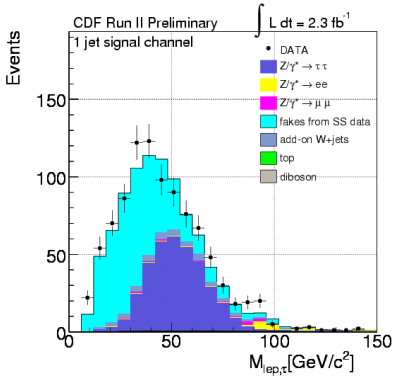


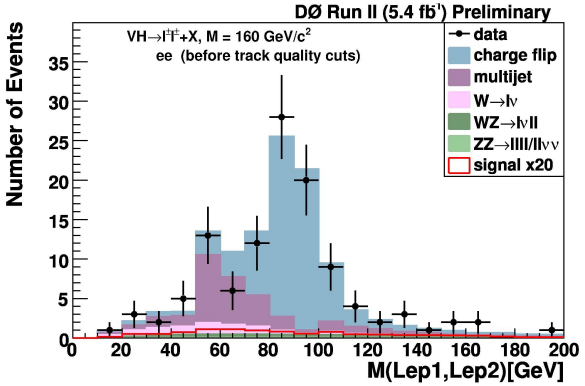


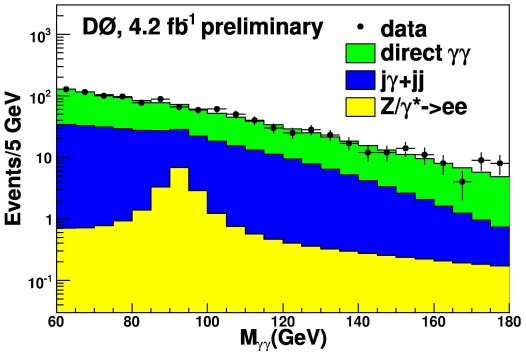












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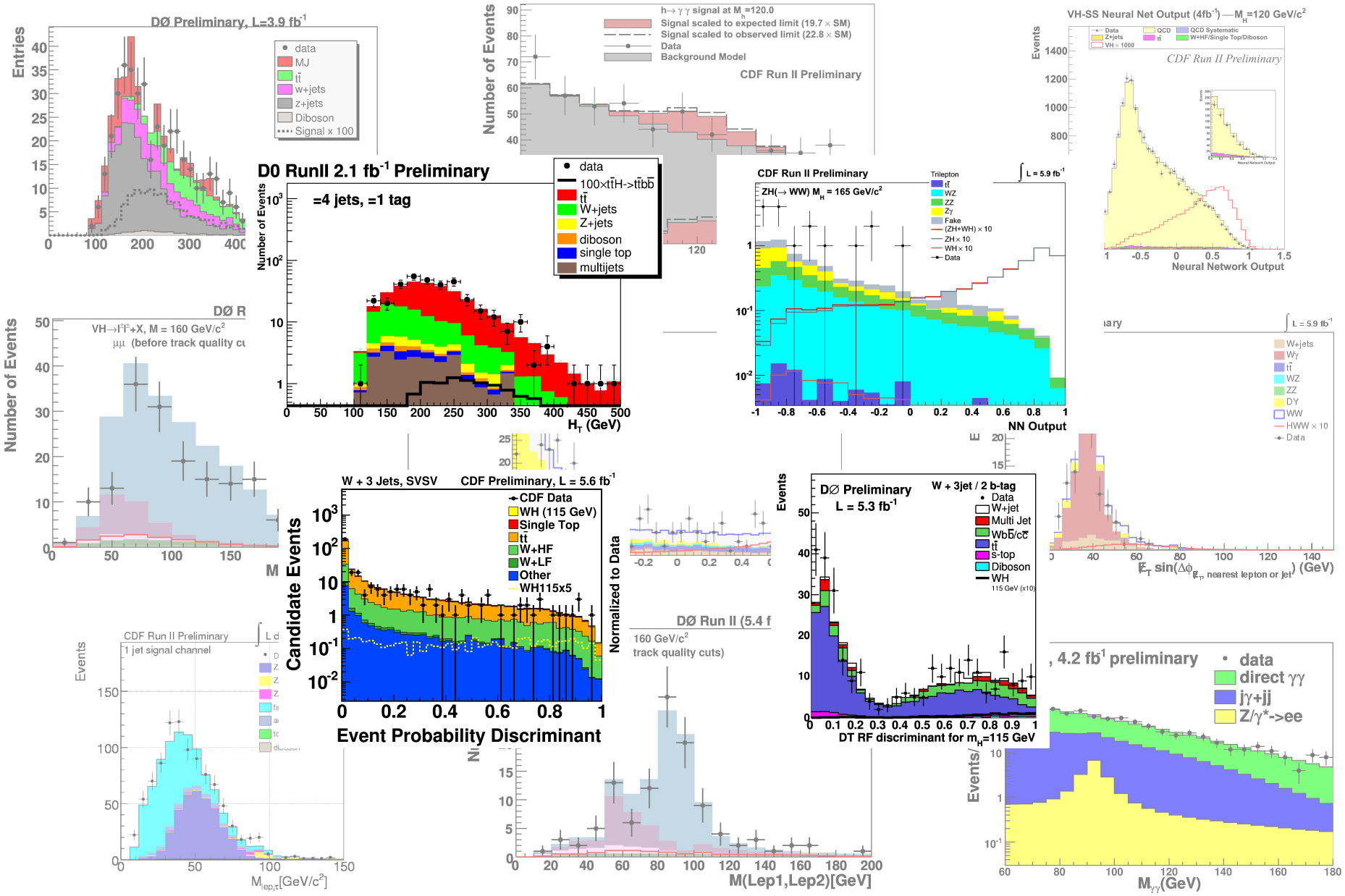
DØ 2011



Snapshot of our Efforts

High Mass Higgs

8.6 fb^{-1} $H \to WW \to l\nu l\nu$	⇒ For pub
7.3 fb^{-1} $H+X \to \mu\tau + \leq 1jet$	⇒ For pub
8.2 fb^{-1} $H \to \gamma\gamma$	⇒ **Published**
5.4 fb^{-1} $VH \to SS$ dileptons	⇒ **Submitted**
8.X fb^{-1} $VH \to SS$ emu	⇒ Preliminary
8.X fb^{-1} Trileptons	⇒ Preliminary

BSM Higgs

5.2 fb^{-1} $bH \to bbb$	⇒ **Published**
7.3 fb^{-1} $bH \to b\tau\tau \to b\mu\tau_{had}$	⇒ **Published**
5.4 fb^{-1} $H \to \tau\tau \to e\mu/\mu\tau_{had}$	⇒ **Submitted**
7.3 fb^{-1} $HX \to \mu + \tau_{had} jj$	⇒ For pub
4.3 fb^{-1} $HX \to e + \tau_{had} jj$	⇒ For pub
7.0 fb^{-1} $H^{++}H^{--} \to 2\tau 2\mu$, 4τ	⇒ **Submitted**

Low Mass Higgs

8.6 fb^{-1} $ZH \to llbb$	⇒ Preliminary
8.4 fb^{-1} $ZH \to \nu\nu bb$	⇒ Preliminary
8.5 fb^{-1} $WH \to l\nu bb$	⇒ Preliminary
5.4 fb^{-1} $H \to WW \to l\nu jj$	⇒ **Published**
4.2 fb^{-1} $H \to ZZ \to lljj$	⇒ In EB
4.3 fb^{-1} $WV \to l\nu jj/bb$	⇒ In EB
4.3 fb^{-1} W+2jet	⇒ **Published**
8.X fb^{-1} $VZ \to X + jj/bb$	⇒ Preliminary

Combinations

DØ SM Combination	⇒ Preliminary
Tevatron SM Combination	⇒ Preliminary
Tevatron MSSM	⇒ Next goal, pub
DØ MSSM	⇒ For publication
Tevatron & DØ 4th Generation	⇒ For publication
Tevatron & DØ Fermiophobic	⇒ For publication
Tevatron $VZ \to X + jj/bb$	⇒ Preliminary

Glimpses into a possible future of Higgs searches

Higgs Search Projections

Wade Fisher
DØ 2011

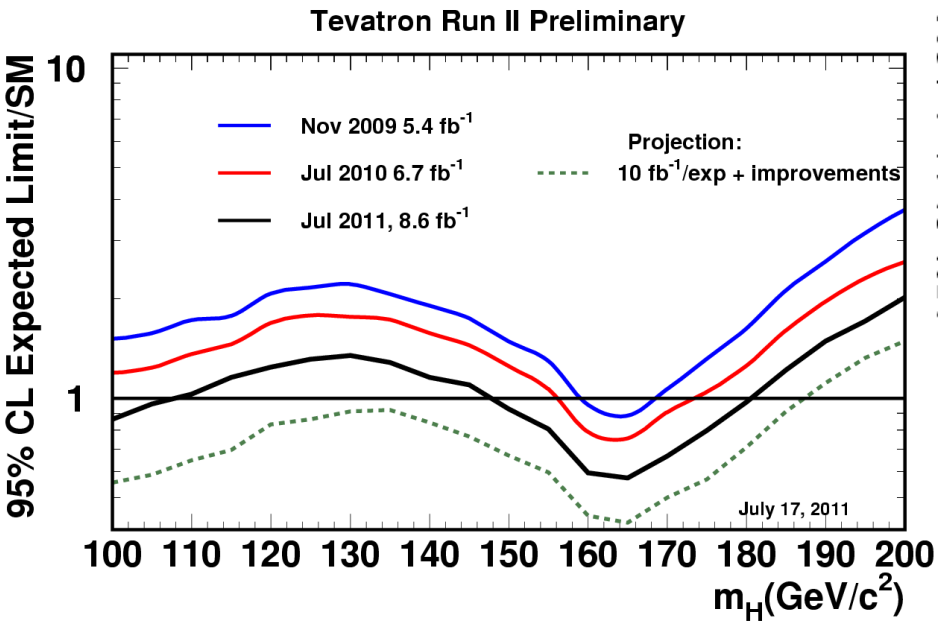
Today we collect our last events

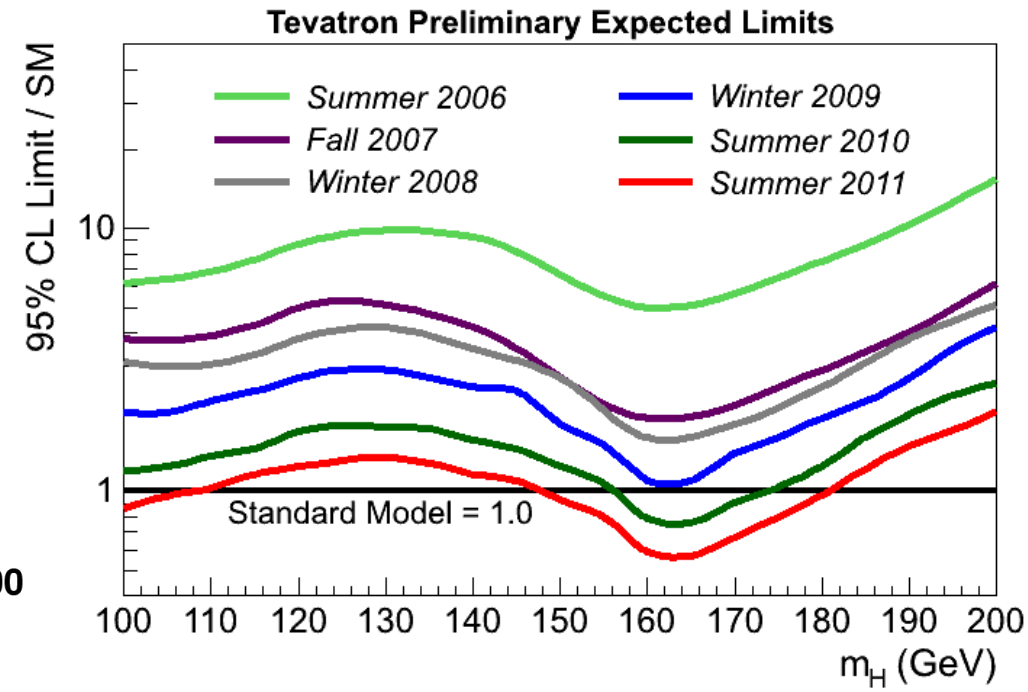
- Current results based on ~8.0 fb^{-1} on average, will have ≥10 fb^{-1} in the end.
- Including ongoing analysis improvements, could exclude M_H<190 GeV

Searches have shown steady progress over time

- Include both boon and bust, as we've had increases in expected signal rates from theory and with poorer-than-expected search aspects
- Now pushing very hard to finish up the last few analysis improvements

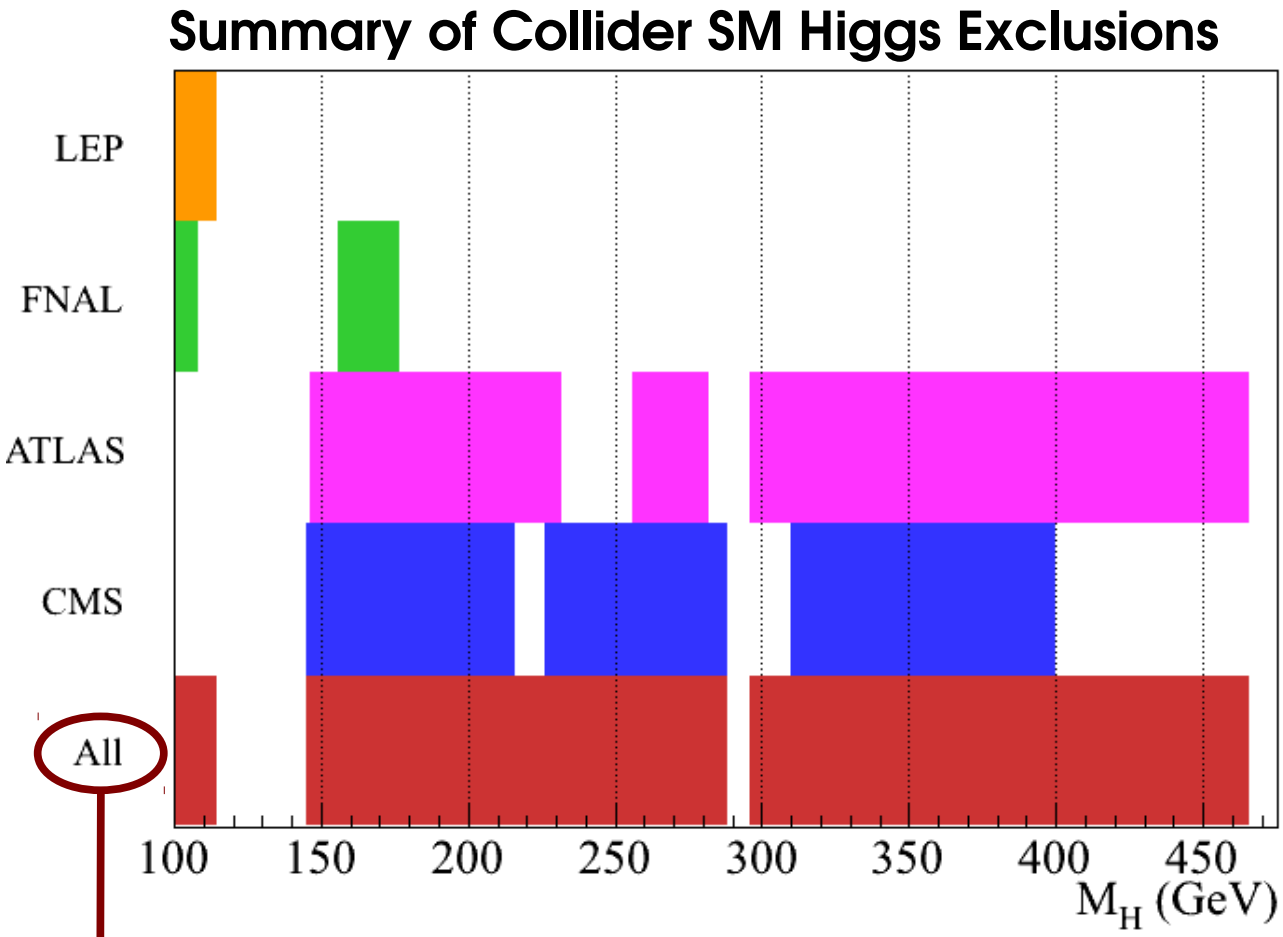
Tevatron Exclusion Prediction



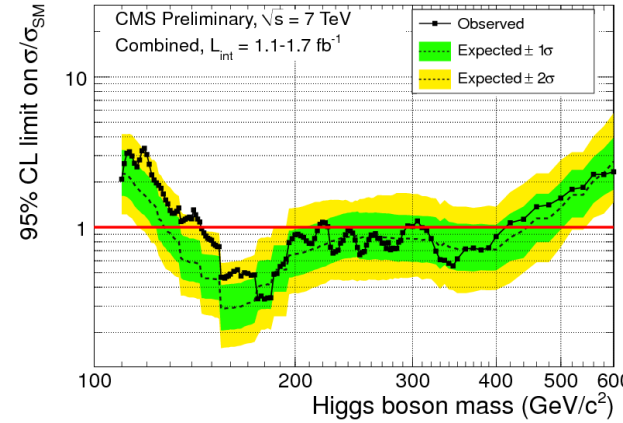


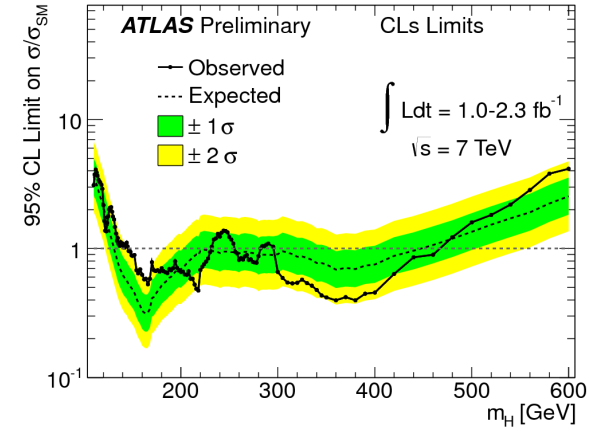
Limits on SM Higgs Production

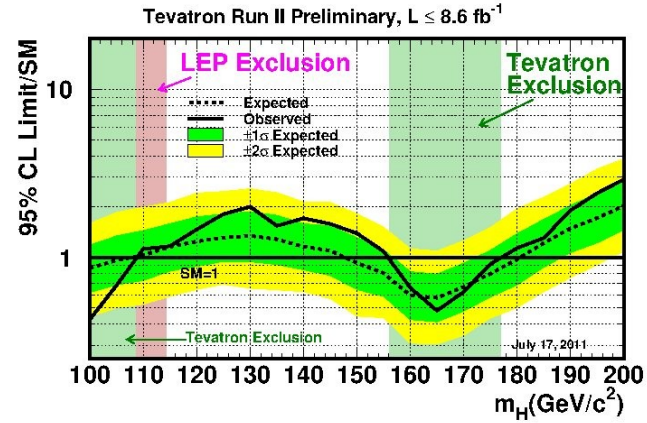
Wade Fisher
DØ 2011



Simple OR of exclusions







Limits on SM Higgs Production

Wade Fisher
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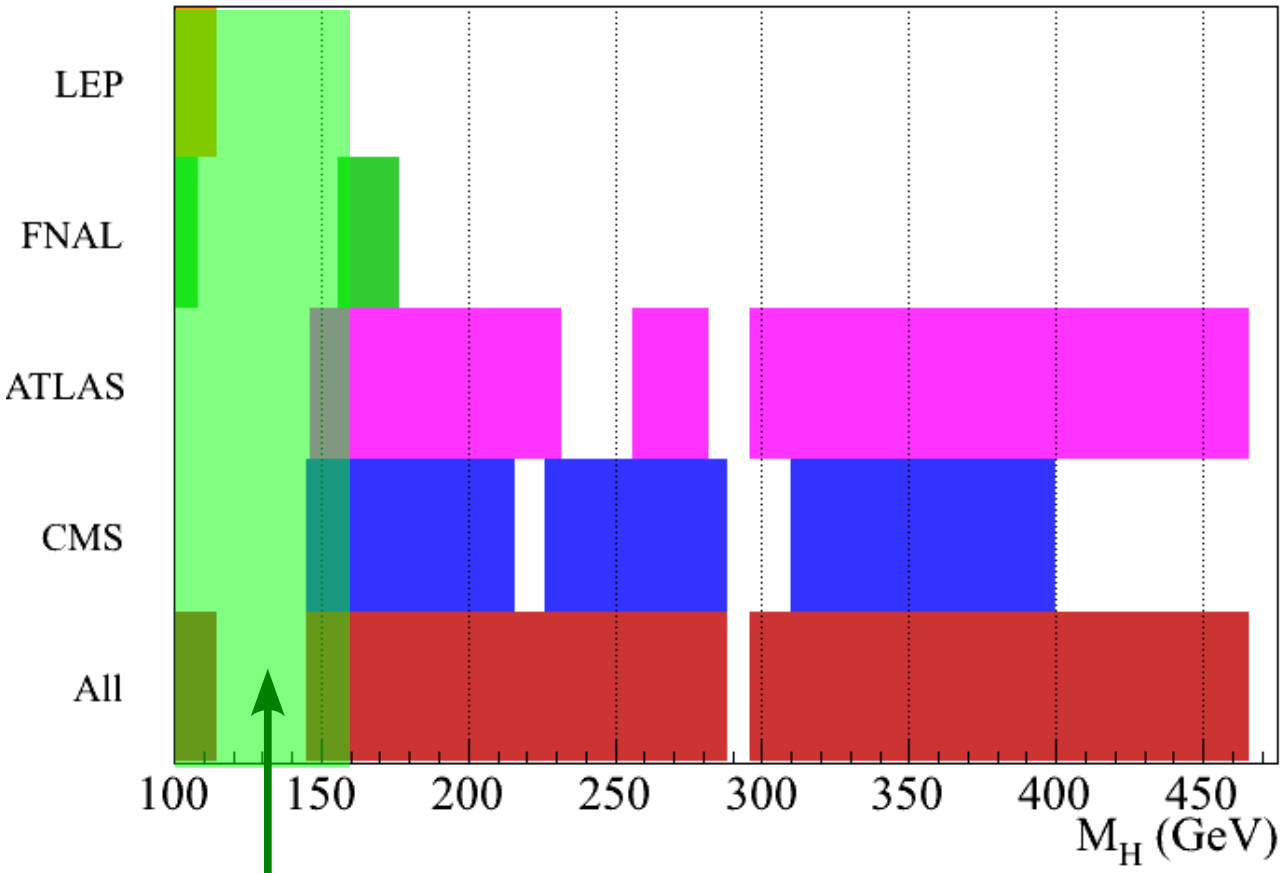
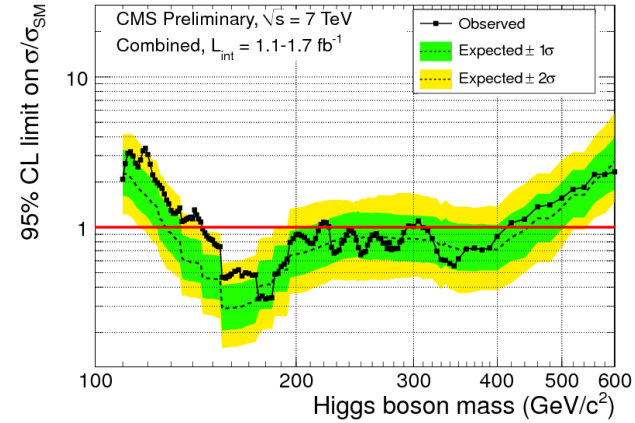
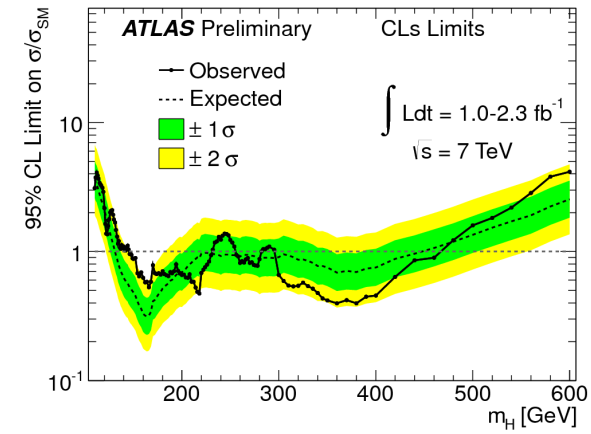
Summary of Collider SM Higgs Exclusions

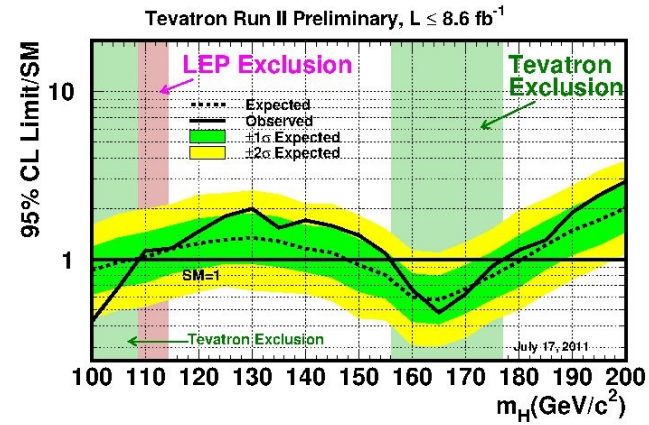


95% C.L. region preferred by fit to precision EW data

NOT EXCLUDED!







Higgs Search Projections

Wade Fisher
DØ 2011

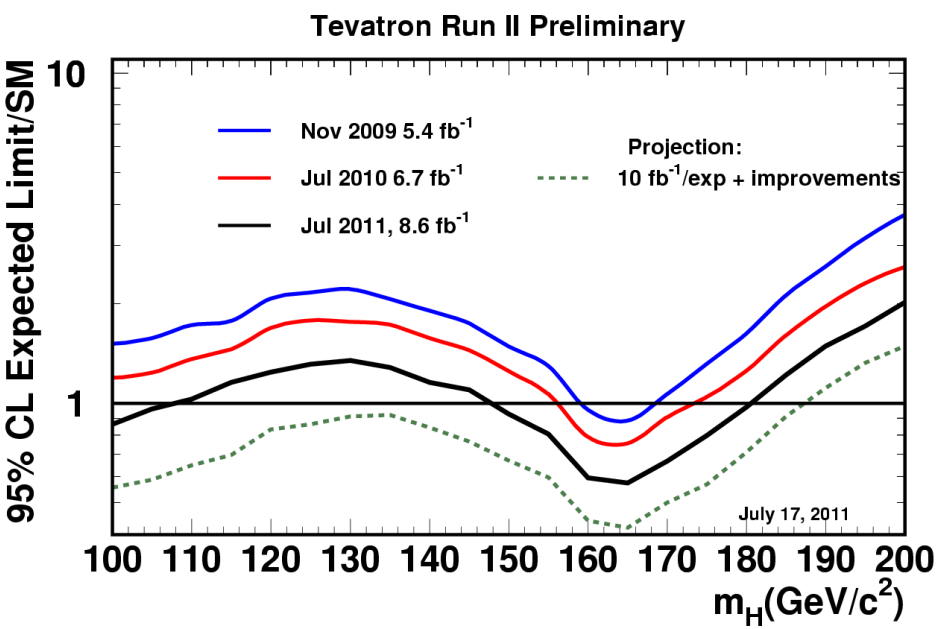
Today we collect our last events

- Current results based on ~8.0 fb^{-1} on average, will have ≥10 fb^{-1} in the end.
- Including ongoing analysis improvements, could exclude M_H<190 GeV

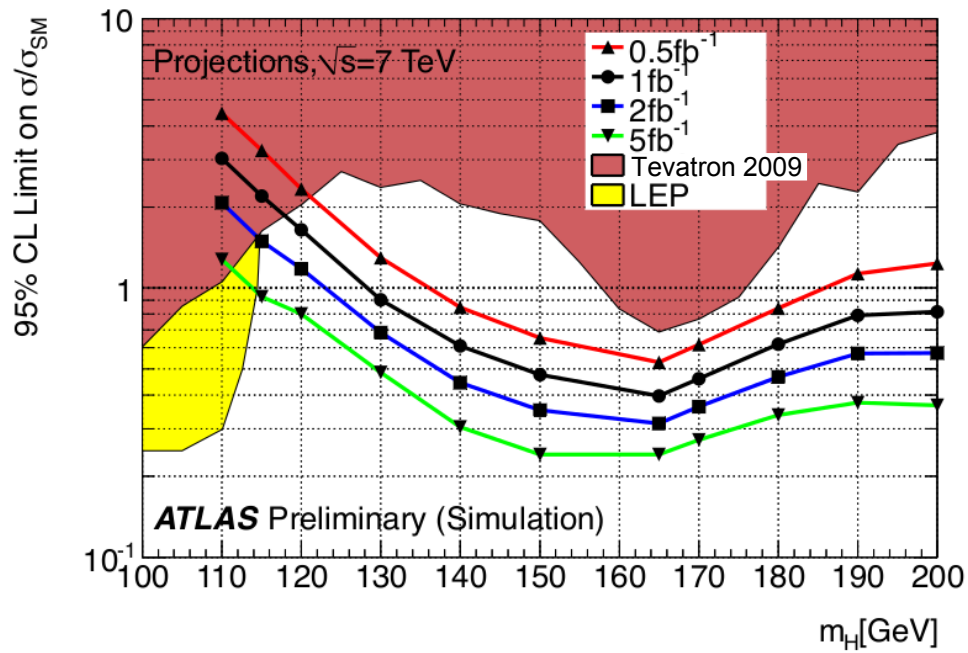
The LHC should have ~4 fb^{-1} on the timescale of Winter 2012

- Broad discovery potential for M_H>130 GeV
- More difficult for M_H<130, reliant largely upon $H\rightarrow\tau\tau$ and $H\rightarrow\gamma\gamma$

Tevatron Exclusion Prediction



ATLAS Exclusion Prediction



Conclusions

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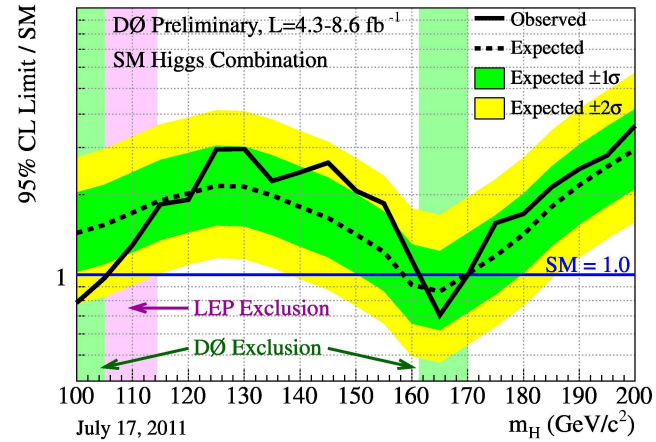
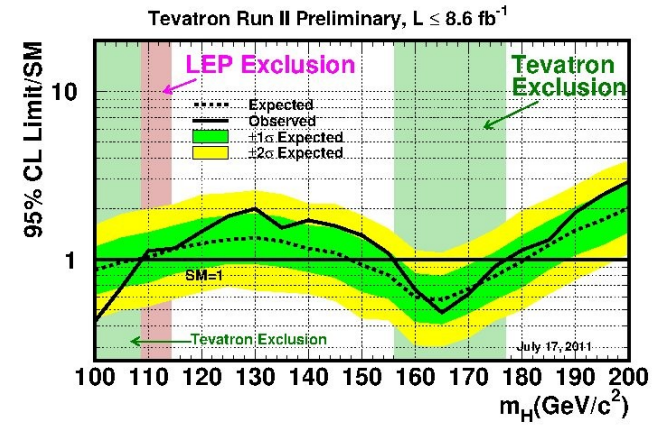
Beginning before RunII, we have cultivated a Higgs physics program to be proud of

- The Tevatron was never expected (or designed) to be able to perform a Higgs search
- We are already making great progress with less then our full potential

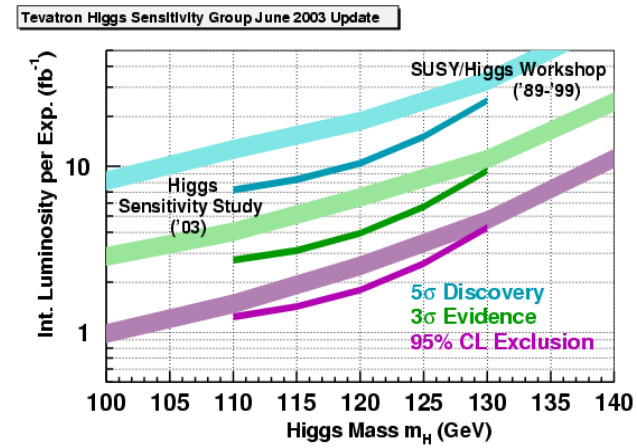


HEP collider programs have been very successful in assembling a Higgs search program

- With a strong showing across the relevant mass range, we will help the community understand electroweak symmetry breaking
- The LHC experiments are also doing well, and together we'll hopefully learn what nature is telling us about mass



With a broad search program ongoing, we hope real answers are close



Please stay tuned!

Extra Material

Results from the LHC

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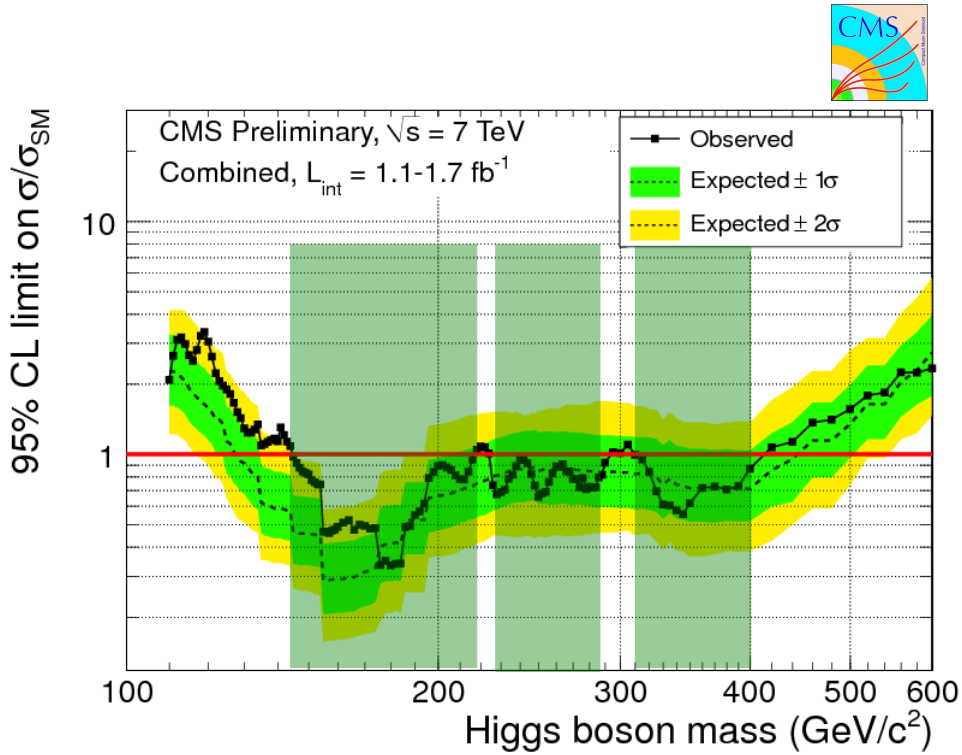
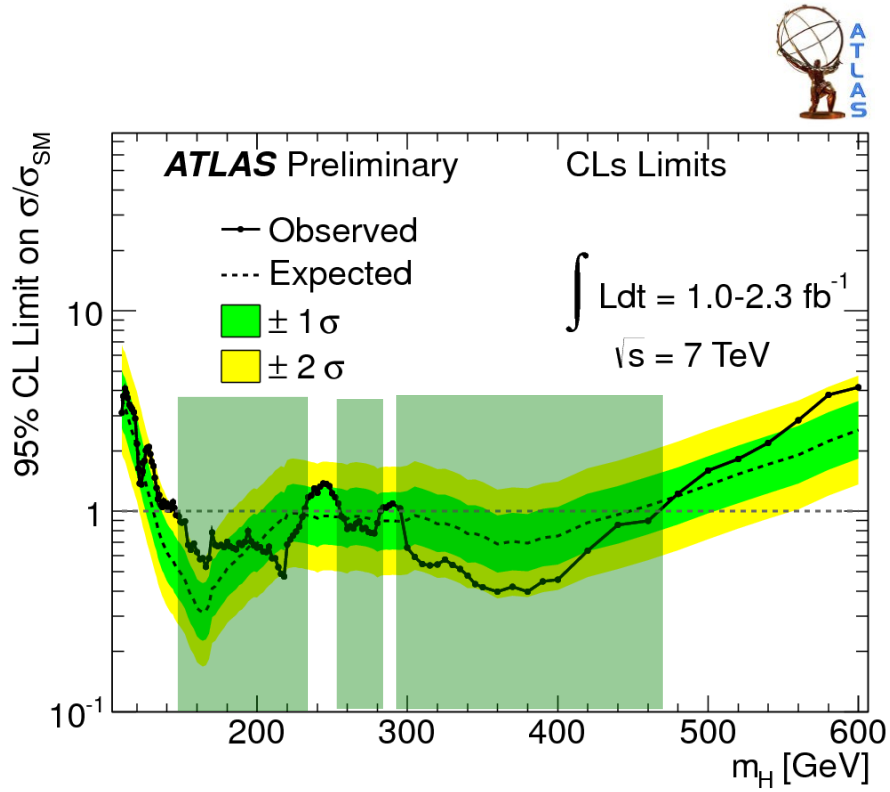




SM Higgs excluded at 95% C.L.

$145 < M_H < 216$ GeV

$226 < M_H < 288$ GeV

$310 < M_H < 400$ GeV

SM Higgs excluded at 95% C.L.

$146 < M_H < 232$ GeV

$256 < M_H < 282$ GeV

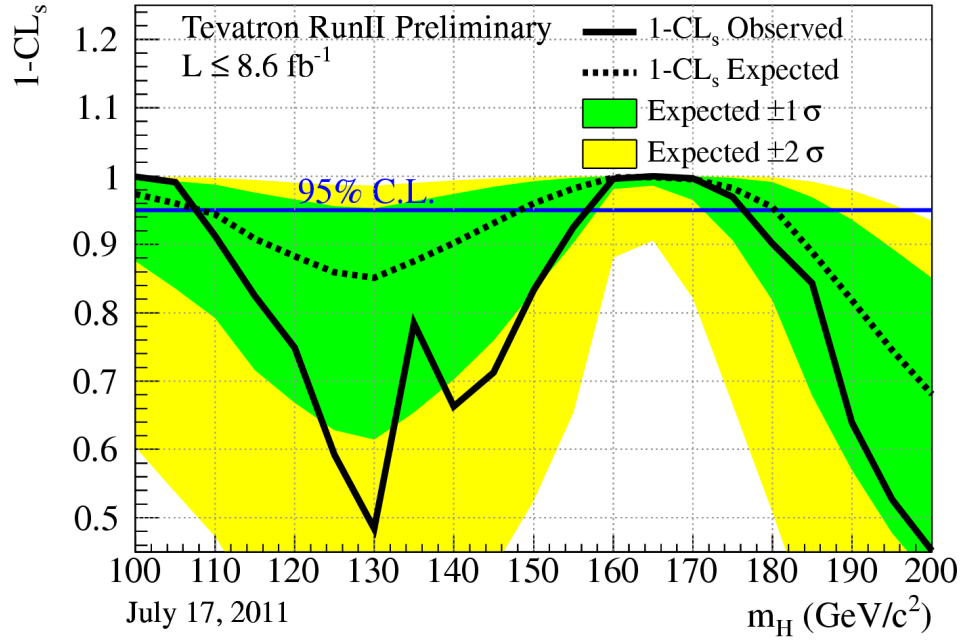
$296 < M_H < 466$ GeV

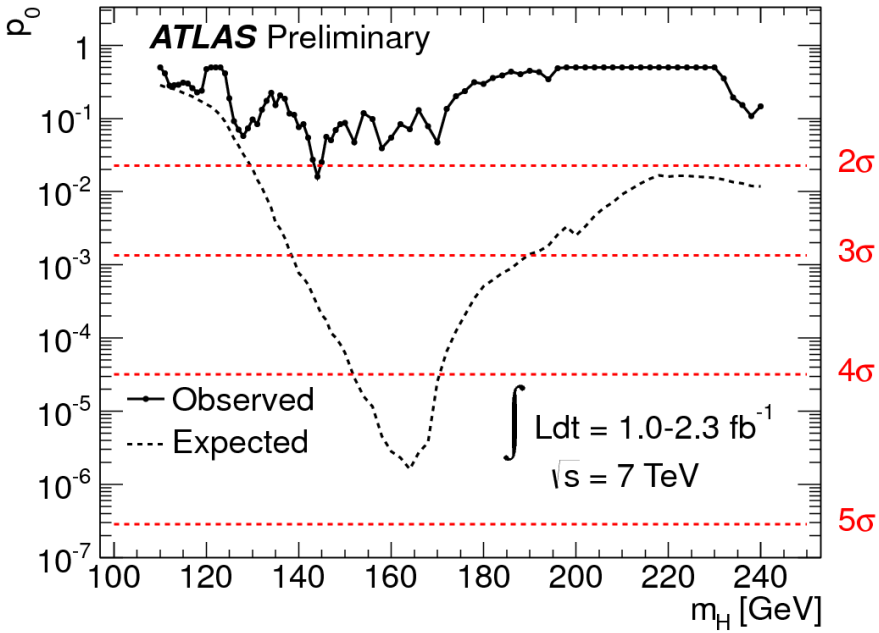
What do today's results tell us?

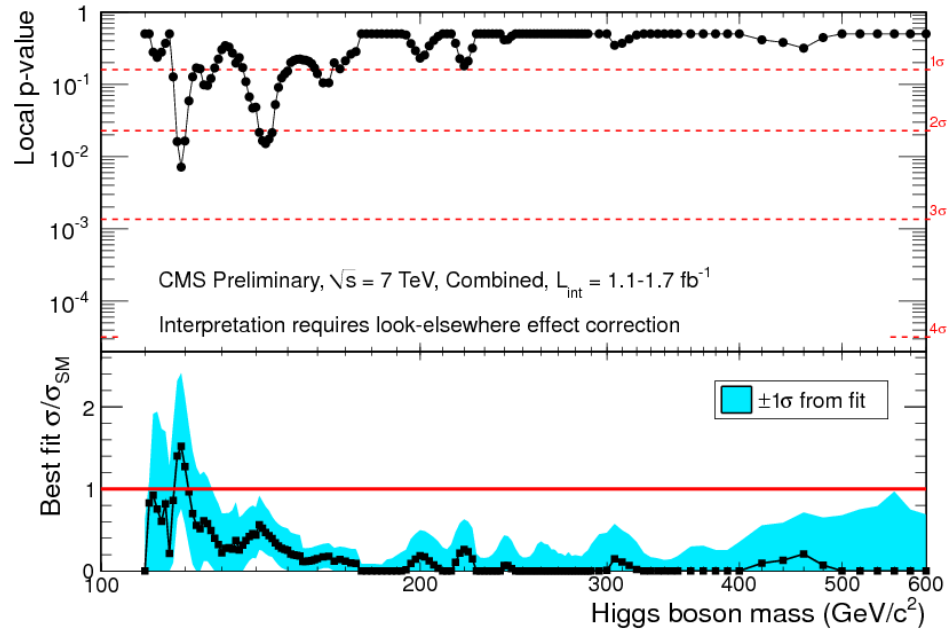
Wade Fisher
DØ 2011

Can we already learn something from today's results?

- All three sets of results have excesses in the M_H~120-150 GeV range
- We do expect a broad excess due to somewhat poor mass resolution (driven largely by H→WW→lνlν decays)
- At this point, there are no smoking guns, but this mass region remains very interesting.







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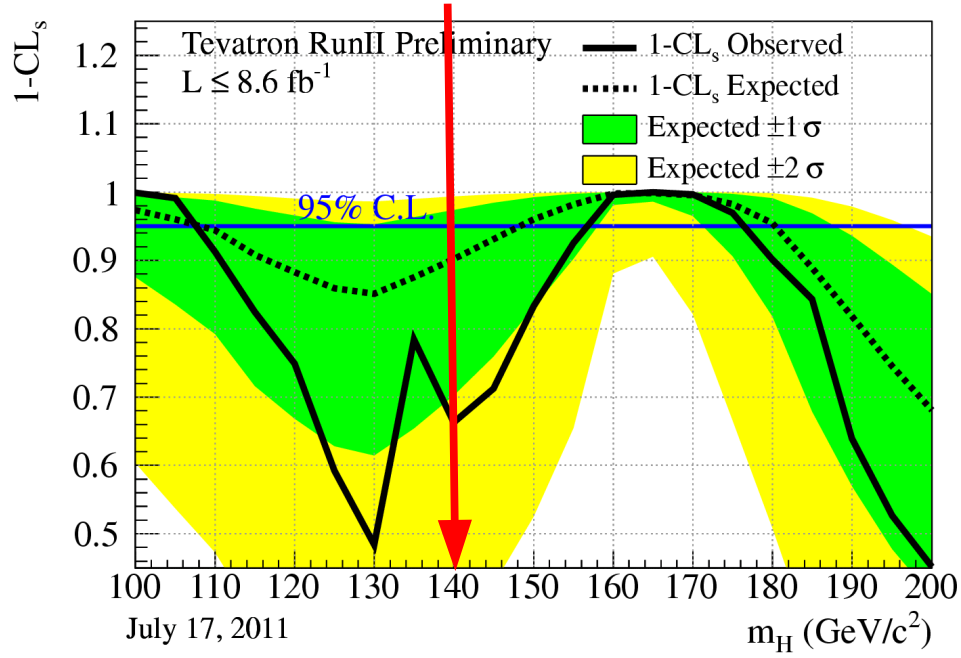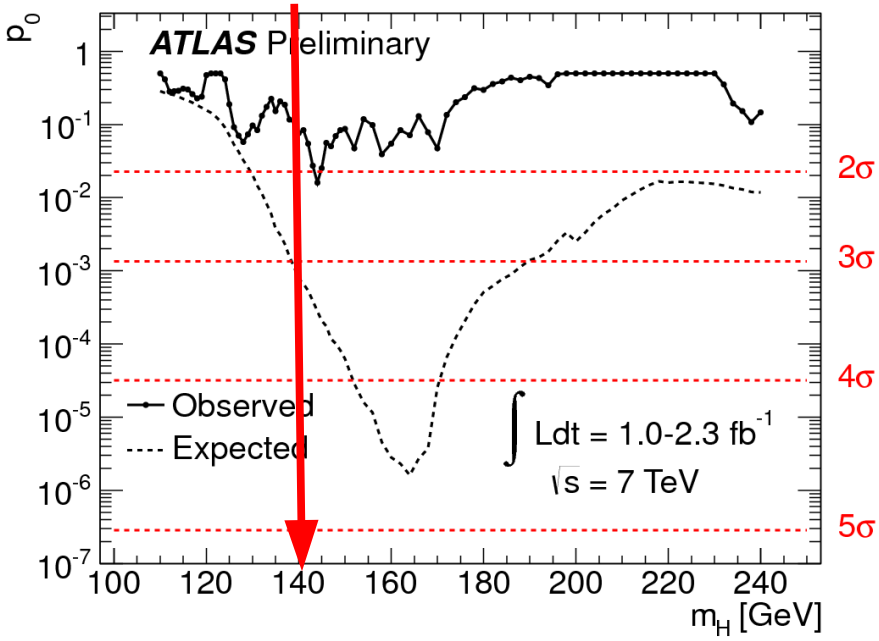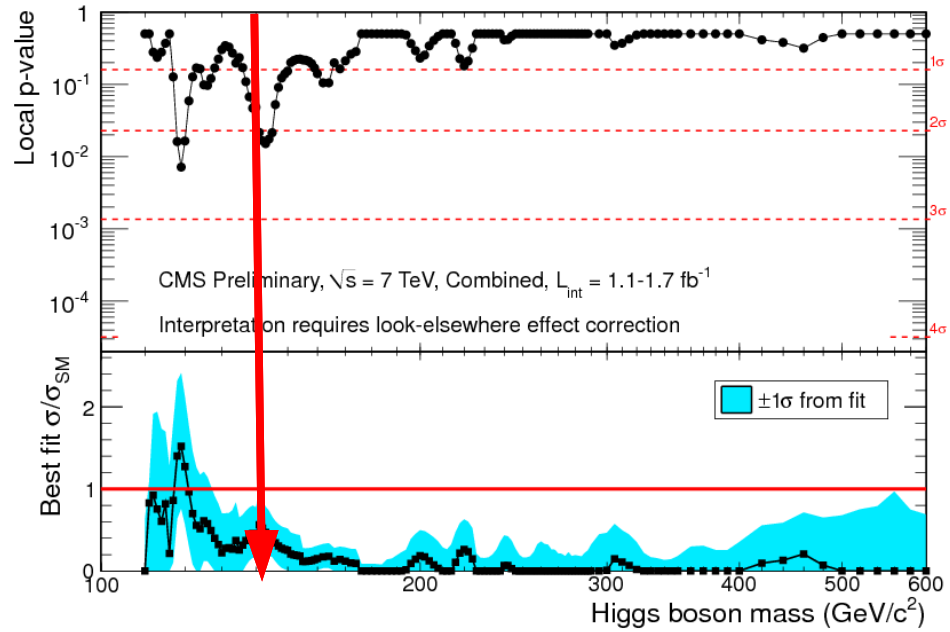
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