SM Higgs Results from the Tevatron

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LPNHE Paris
On behalf of CDF and DZero

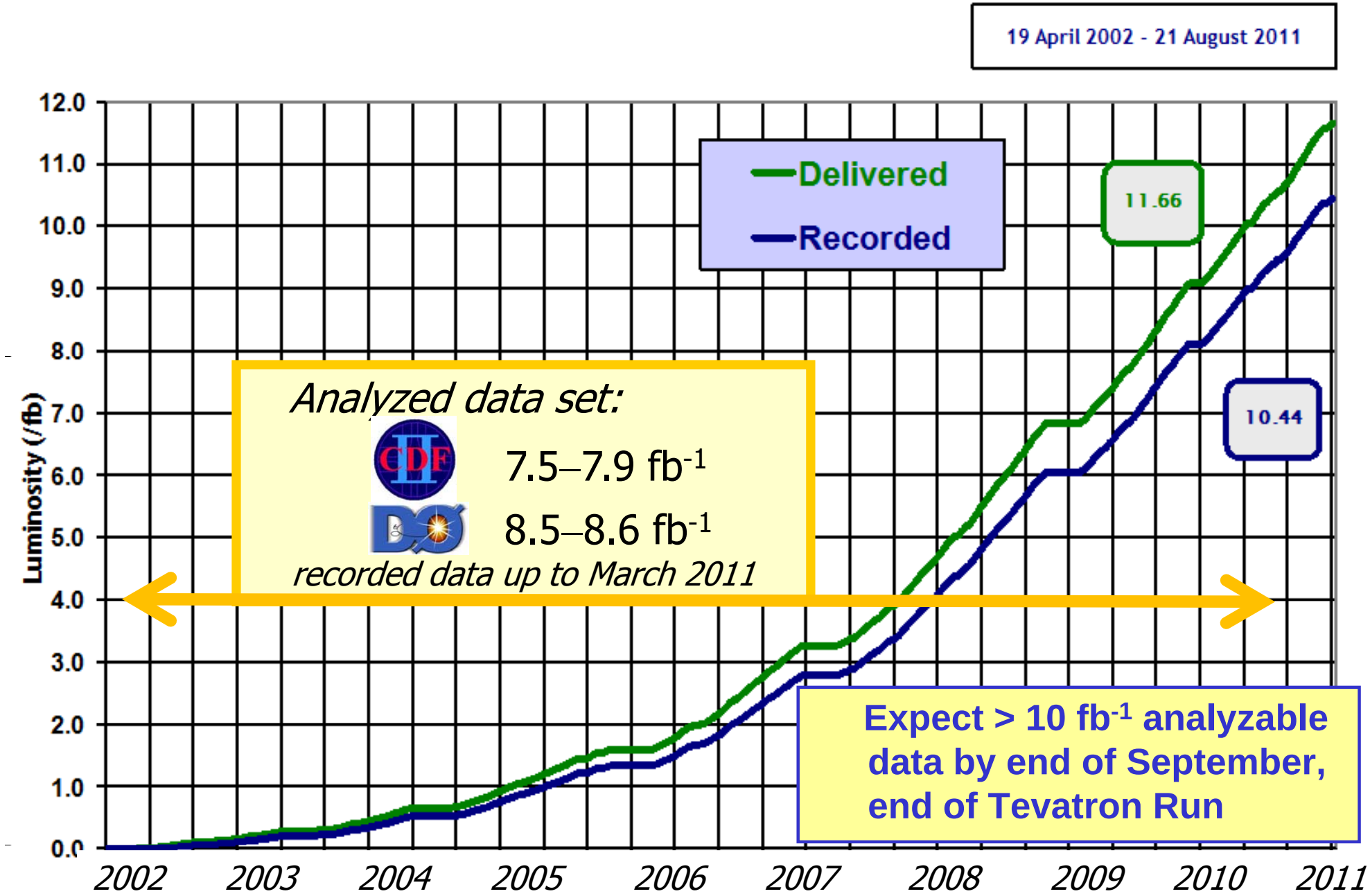
August 29th 2011

Thanks to all CDF & DZero colleagues

Outline

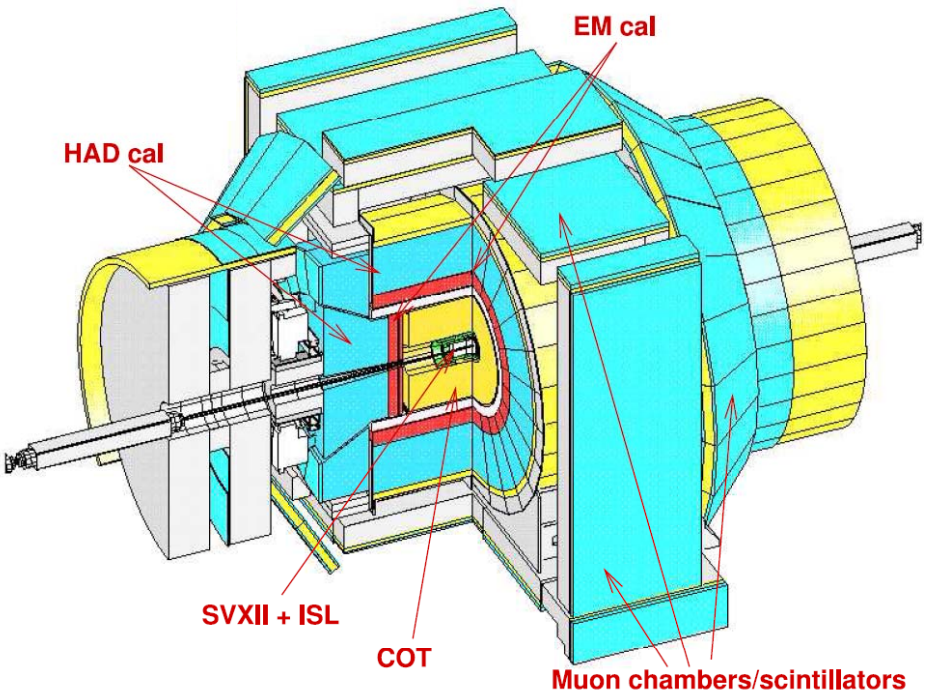
- The Tevatron, status and performance
- Searching for the Higgs @ Tevatron
- High mass Higgs exclusions
- Low mass Higgs searches
- Combinations of Standard Model searches
- Prospects

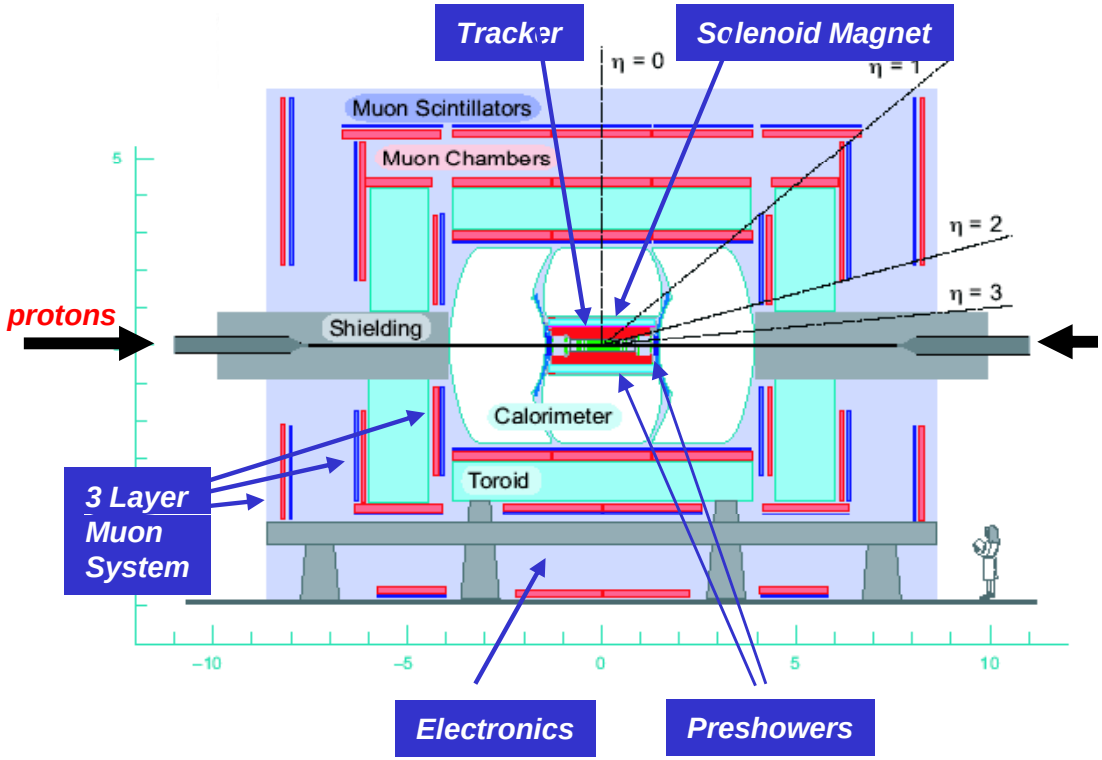
Tevatron Luminosity



Thanks to the Tevatron Accelerator Group for such a performance!

CDF and DØ Detectors





- General purpose detectors
- Good hermeticity
- Mature algorithms
- Well understood under all pile-up conditions

	Rapidity coverage	
	CDF	Dzero
Track	2.0	2.5
Calorimeter	3.6	4.2
Muon	1.0	2.0
B-field	1.4 T	2.0 T

Can we Test the Hypothesis of Spontaneous EW Symmetry Breaking ?

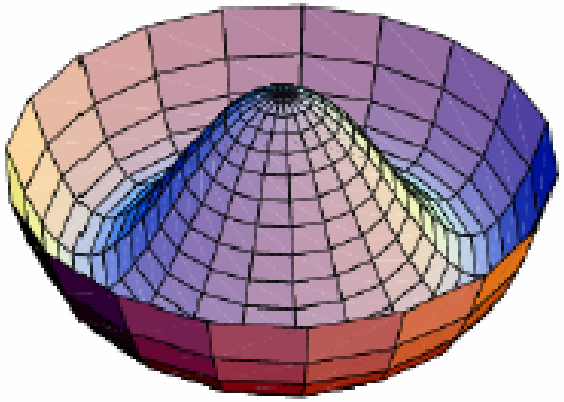
- $SU(2)_L \times U(1)_Y$ is very well tested in collider experiments

- But it is not a symmetry of our vacuum – otherwise quarks, leptons, and gauge bosons would all be massless

➔ $$L_{EM} = (\partial_\mu - ieA_\mu)\phi^*(\partial_\mu + ieA_\mu)\phi - [\mu^2\phi^*\phi - \lambda(\phi^*\phi)^2] - \frac{1}{4}F_{\mu\nu}F_{\mu\nu}$$

- Simplest model – one complex doublet of scalar fields in a ϕ^4 potential resulting in a non-zero "Vacuum Expectation Value"
  W^+, W^- and **Z** get three of the four ***d.o.f*** ➔ ***become massive,***
  one ***d.o.f*** left over → fundamental scalar particle H_{SM}

- Not the only possibility
  - Supersymmetric Higgs
  - General 2HDM
  - Higgs Triplets
  - Little Higgs
  - Technicolor



How do we determine the Higgs Boson Mass?

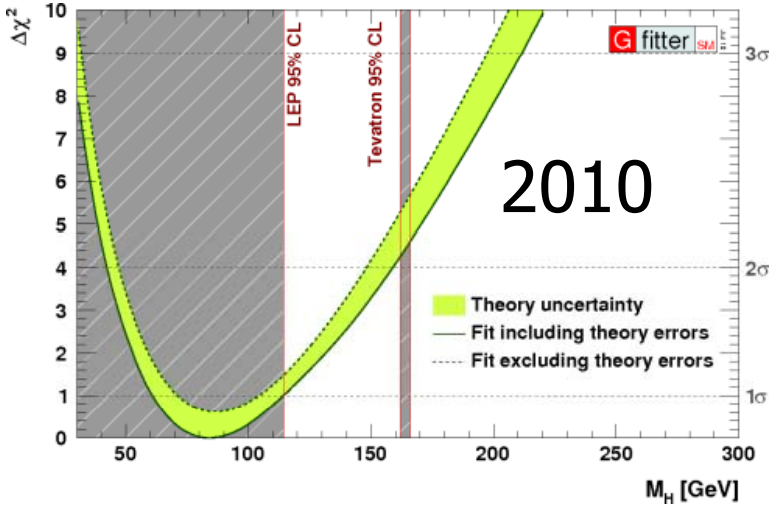
The **Higgs mass is not known** from theory but we can set experimental constraints

- ***Indirect limits***:

Electroweak precision measurements

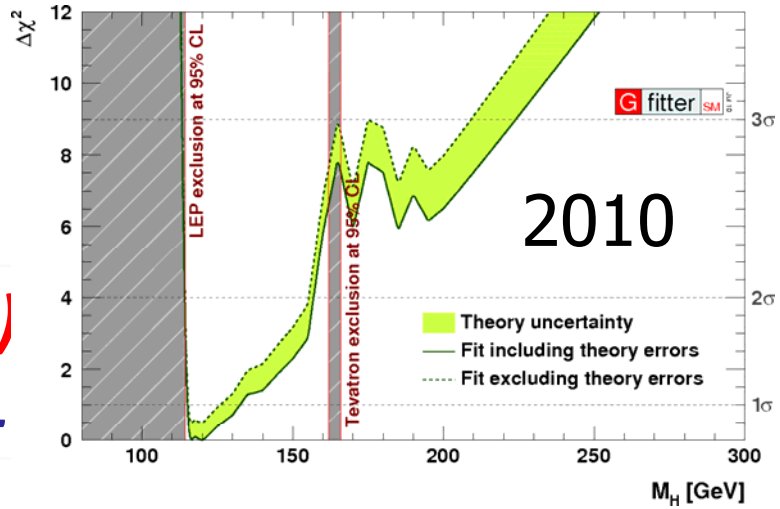
Constraints from top quark mass, W boson mass

Precision EW fit:
m_H = [47,159] GeV@95%CL



- ***Direct limits***:

LEP: m_{Higgs} > 114 GeV @ 95% CL
TEV: $m_{Higgs} \neq$ [158;173] GeV @ 95% CL (3/2011)

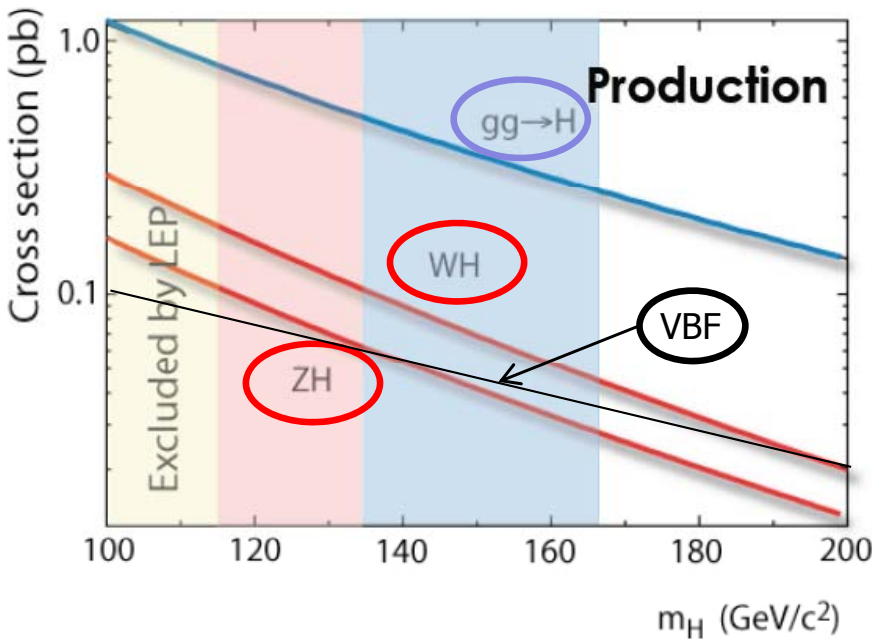


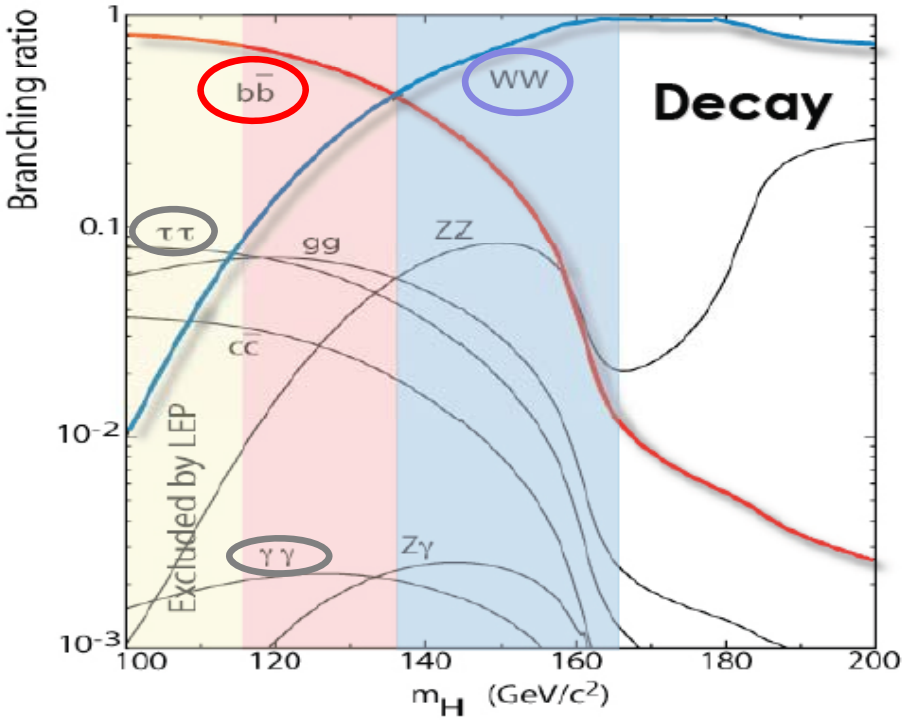
- ***Combining Direct and Indirect Limits (2010)***

GFITTER : m_{Higgs} = [114, 157] GeV @ 95 % CL

Data from LHC start to confirm that if there is a SM Higgs, it has a rather low mass (<~ 145 GeV)

Higgs Production and Decay at the Tevatron

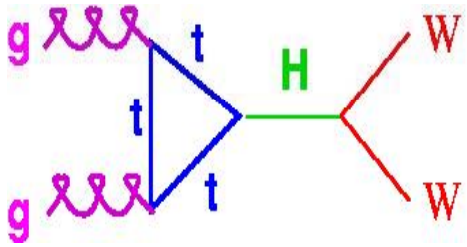




"High" mass (m_H > 135 GeV) dominant decay:

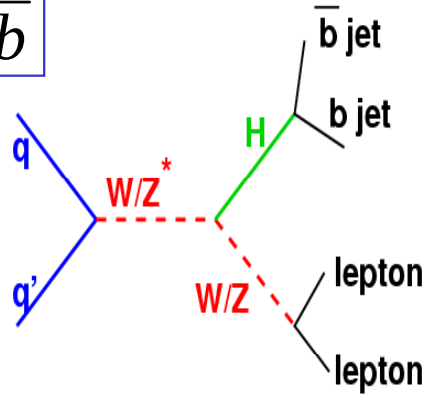
$$H \rightarrow WW^{(*)}$$

$$WW \rightarrow \ell \nu \ell' \nu'$$



Low mass (m_H < 135 GeV) dominant decay:

$$H \rightarrow b\bar{b}$$



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

$$ZH \rightarrow \ell^+ \ell^- b\bar{b}$$

$$ZH \rightarrow \nu \bar{\nu} b\bar{b}$$

use associated production modes to get better S/B

These are the main search channels, but there is an extensive program of measurement in other channels to extend the SM (and BSM) sensitivities.

What did we learn so far on SM Higgs?

Tevatron has already shown that the "high mass" part of the electroweak-favored range is excluded ➔ SM Higgs is between ~115 and ~150 GeV.

This summer, LHC has confirmed and extended these limits: it is also starting to confirm directly that higher masses (> 180 GeV) are not possible for SM Higgs (work to be completed with more LHC luminosity).

➔ Higgs has a low mass and is in a region where its Branching Ratios vary rapidly as a function of its mass

Challenge: we need to combine all decay modes to find it, but we also need individual measurements to identify it as the SM Higgs boson!

➔ Remind Tevatron strategy, starting from the high mass channels, then moving to the H→bb search, where Tevatron has unique capabilities

Higgs Search Strategy @ Tevatron

Optimize all channels individually, based on production and decay properties.

Select inclusive candidate samples maximizing acceptance to potential Higgs signals (different masses probed)

Separate further these channels into multiple analysis sub-channels of different S/B, to improve the sensitivity.

Model all backgrounds using simulation and data, with detailed verifications on independent control regions in data

Use advanced multivariate analysis tools to separate signal from background based on the full event kinematics

Derive systematic uncertainties from independent measurements, both in normalization and on the shape of their distributions.

Use standard statistical approaches and constrain the systematic uncertainties to the data, to obtain the best search results.

Higgs Event Yield expectation

Expected number of events available for selection to CDF + DZero at the end of Tevatron running (10 fb^{-1})

Higgs Mass	WH→lνbb	ZH→ννbb	ZH→llbb	H→WW→lνlν
120 GeV	~500	~240	~80	~260
135 GeV	~200	~100	~40	~520
150 GeV	~60	~40	~20	~640

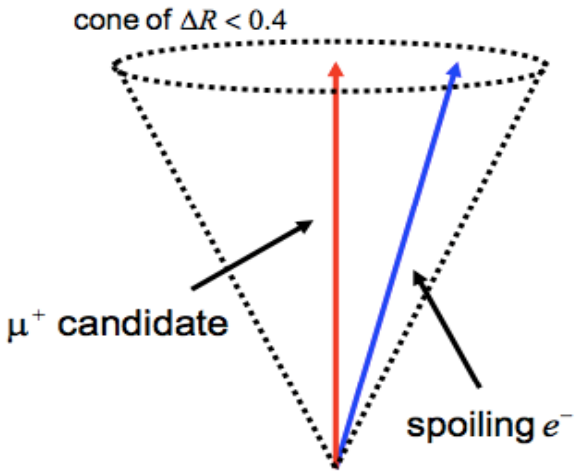
But: reconstruction/selection/tagging efficiencies is
~ 10% in H→bb channels
~ 25% in H→WW channels

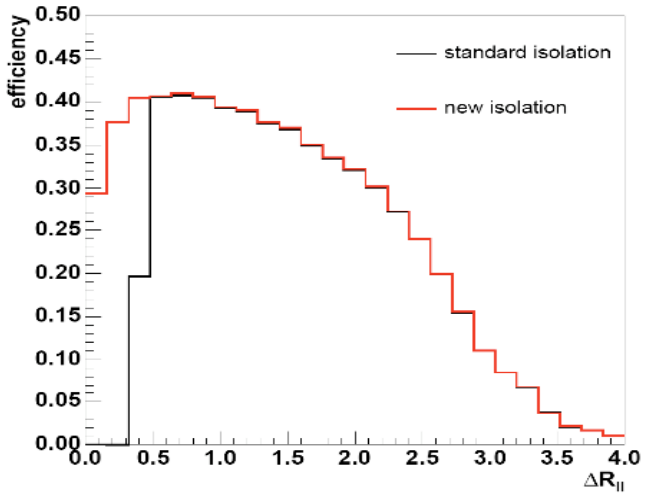
(N.B.: lνbb can appear as "ννbb" events in the experimental final states)

H→WW→lνlν Higgs Search

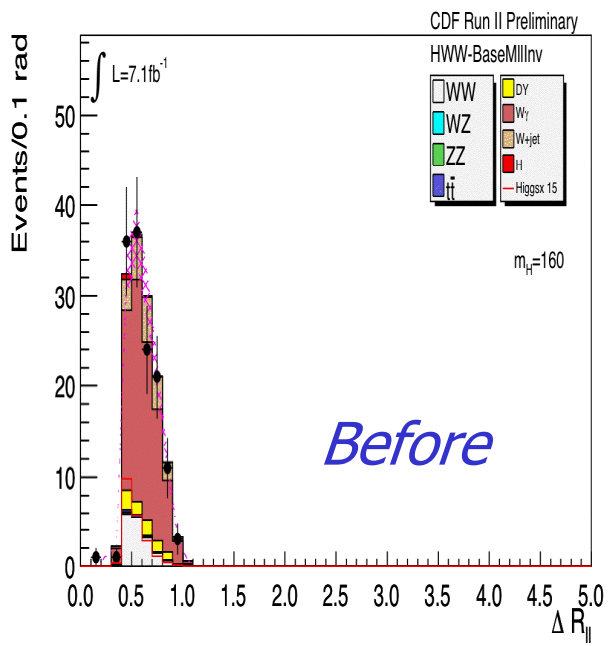
Event selection : two high p_T leptons and large missing E_T

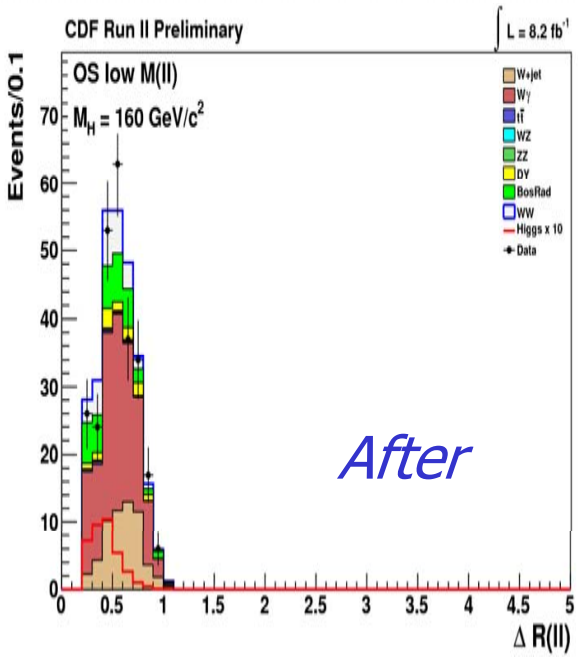
- Maximizing detector lepton acceptance is critical
- **New:** CDF modified its isolation algorithms to prevent self-spoiling of nearby lepton pairs





- The recovered events lie in the highest S/B region
- Expected limits in CDF low-M_{ll} channel improved by more than a factor of three!



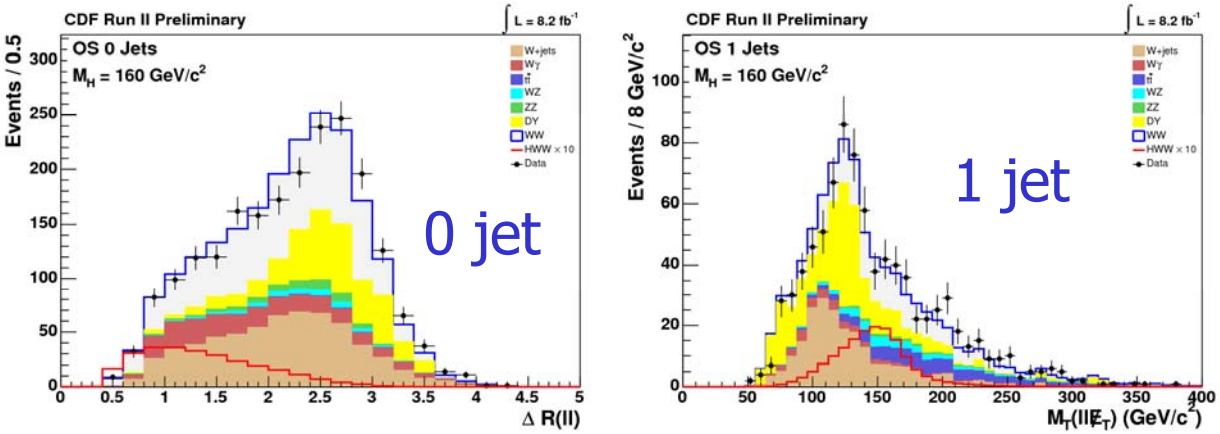


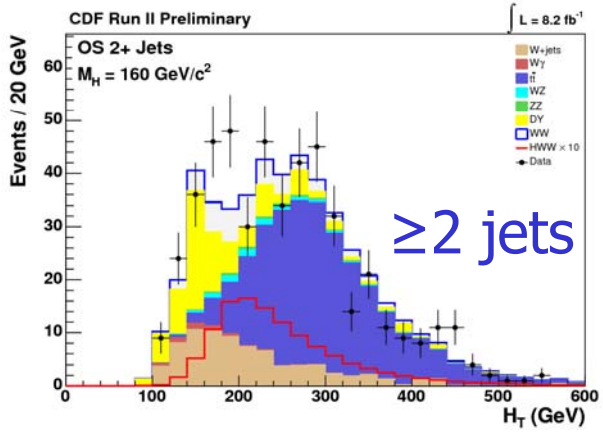
Maximizing Sensitivity

search sensitivity optimized by dividing events into multiple analysis channels

➔ use separate, optimized discriminants for each channel based on

- specific signal contributions
- specific background contributions
- specific event kinematics



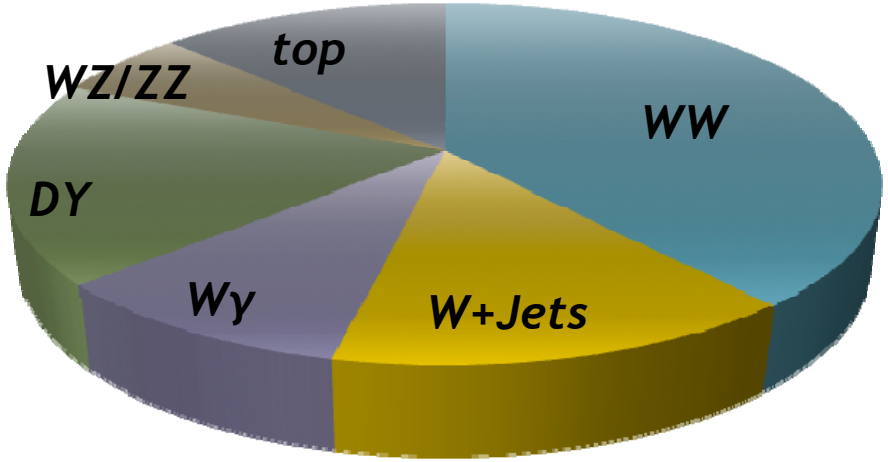


Collect as many Higgs events as possible:

➔ both CDF and D0 include events with same-sign leptons, events with hadronic tau candidates, W hadronic decay modes (D0)

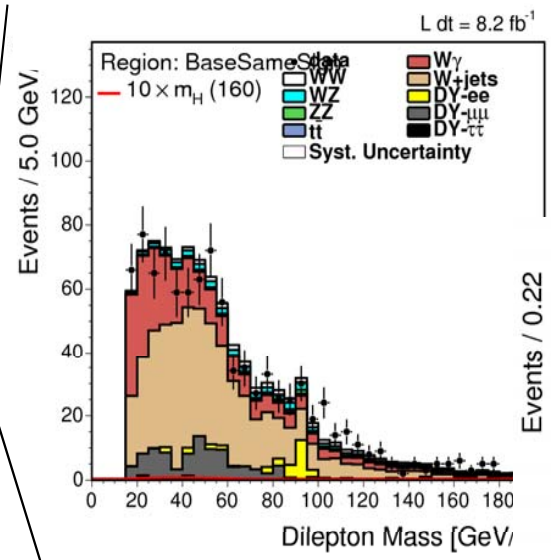
SM Backgrounds to H→WW

- Need to separate small potential signal from large SM background contributions in our search channels
- After inclusive selection S/B ~ 0.02 in the most sensitive search channels

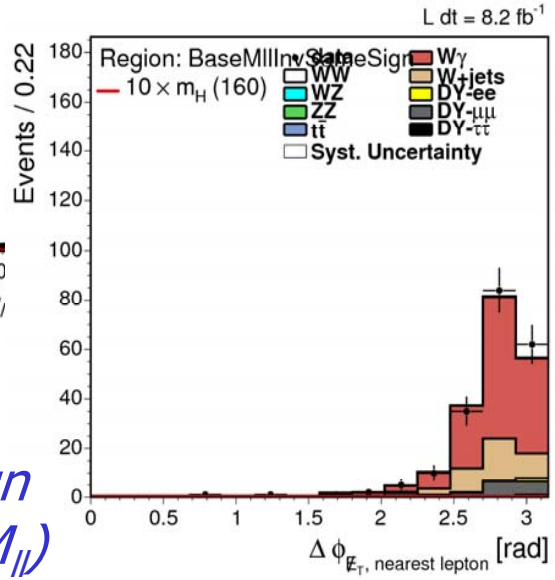


➔ Need to model well ALL backgrounds

- Define specific control regions to test modeling for each individual background (whenever possible)



W+jets : same-sign dileptons

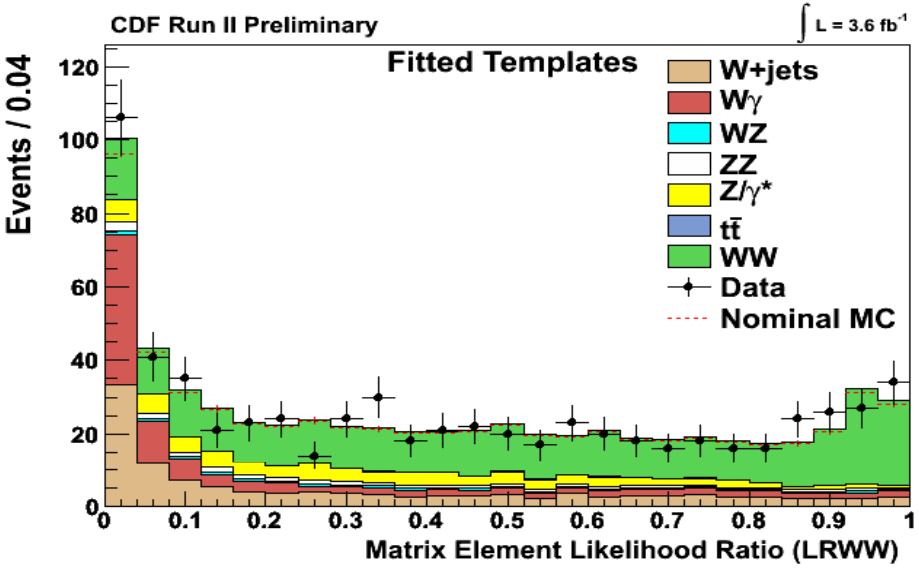


W+γ : same-sign dileptons (low M_{ll})

- In the case of dibosons (WW/Z, ZZ) there are no control regions so we measure them to check their modeling
- If the MC modeling is insufficient, we do additional tunings (based on data)

WW and ZZ measurements

Diboson cross section measurements are based on the same tools and data samples used for the $H \to WW \to l\nu l\nu$ search
➔ important cross check on background modeling and analysis techniques



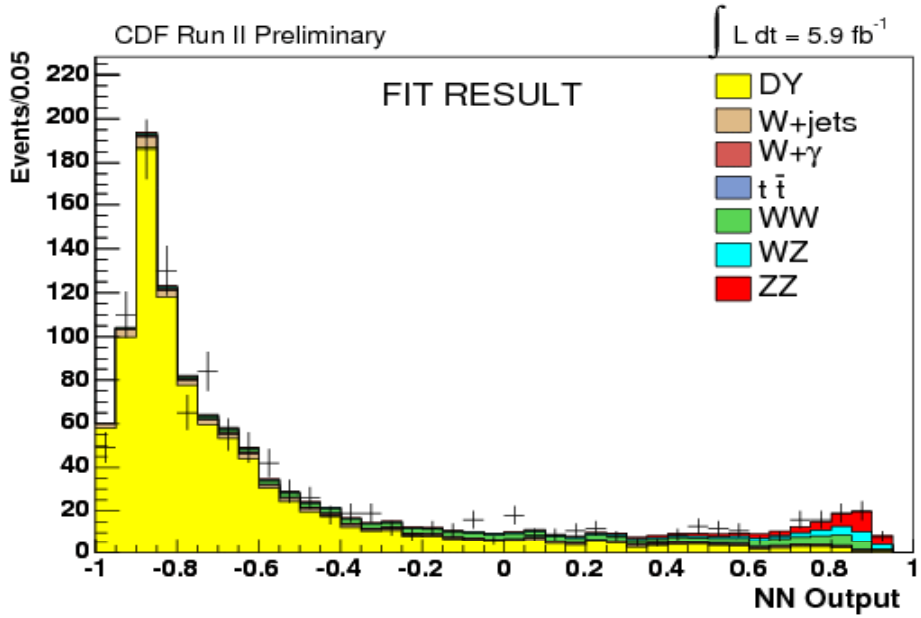
$WW \to l\nu l\nu$: $\sigma(WW) = 12.1^{+1.8}_{-1.7}$ pb

NLO QCD : $\sigma(WW) = 12.4^{+0.8}_{-0.8}$ pb

$ZZ \to ll\nu\nu$: $\sigma(ZZ) = 1.5^{+0.6}_{-0.5}$ pb

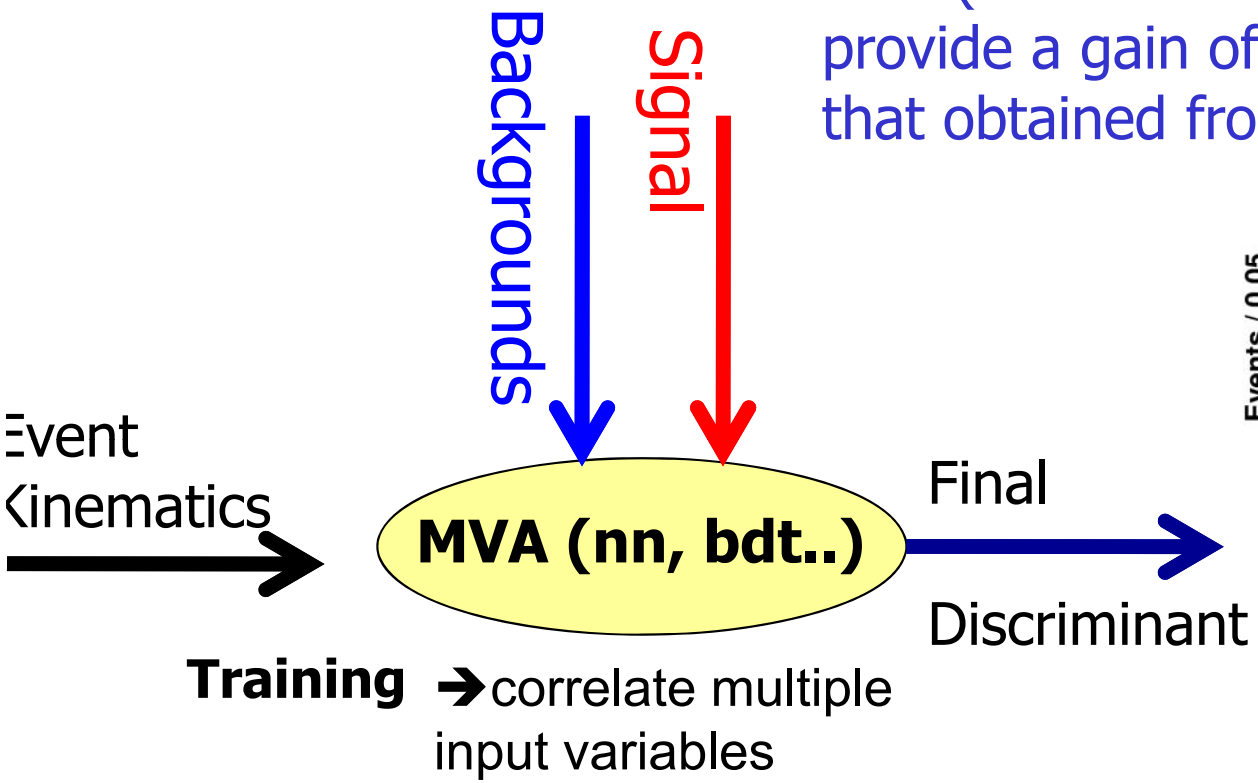
NLO QCD: $\sigma(ZZ) = 1.4^{+0.1}_{-0.1}$ pb

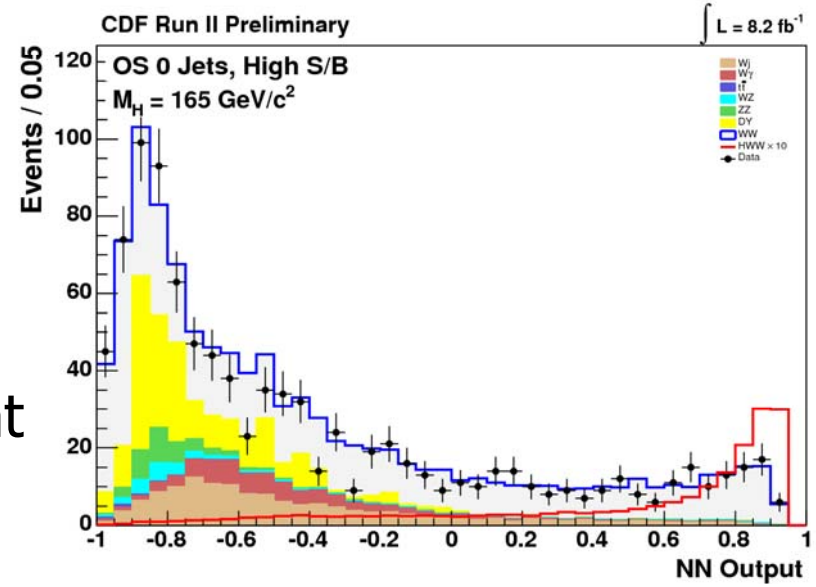
bb final states are analyzed separately



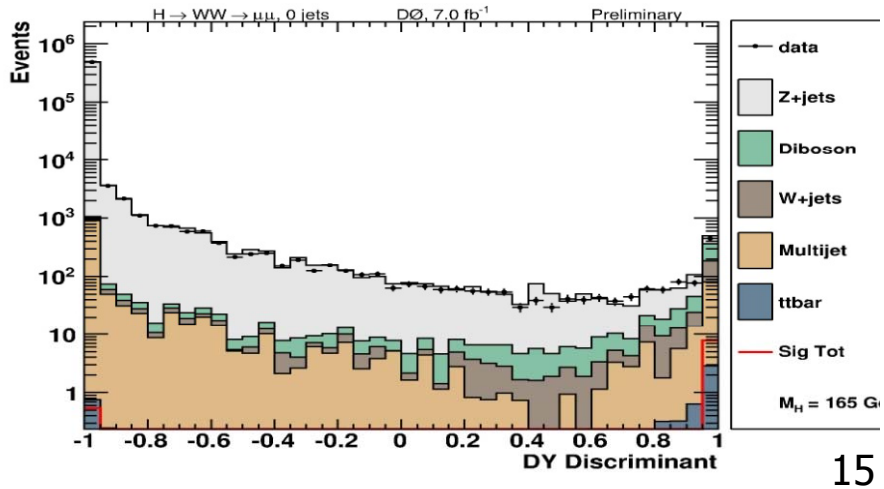
Final/Intermediate Discriminants

MVA (neural networks, boosted decision trees..) provide a gain of ~20% in sensitivity beyond that obtained from optimized, cut-based analysis





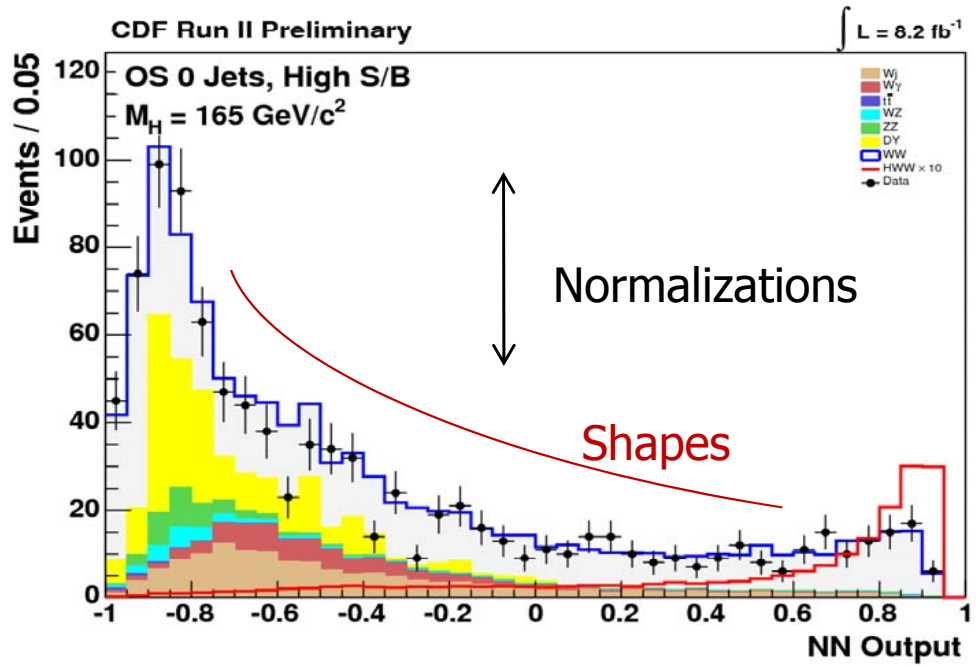
Several layers of MVA discriminants are used in some cases to reduce large background contained within inclusive candidate samples. Example:DY@D0: H→WW→μνμν channel ➔



Systematic Uncertainties

- We consider uncertainties both on the overall normalization of each signal/background process and on the shapes of the final discriminant templates for each signal or background process

- In the limit-setting procedure systematics are included as nuisance parameters, taking into account the correlations between different channels , and between experiments when needed (background cross sections for instance)



Using this approach we are able to further constrain our background uncertainties directly from the data

Theoretical Uncertainties/Limit Settings

Since we combine searches focusing on different Higgs production and decay modes, cross section limits are given with respect to nominal SM predictions

➔ we incorporate theoretical predictions and uncertainties for signal cross sections and branching ratios when deriving our results (we follow prescriptions from "LHC Higgs cross section working group")

Adapt in each iteration to reflect recent theo-retical developments: we now include updated uncertainties for H→WW search in jet multiplicity bins

channel	scale 0	scale 1	scale 2
0 jet	13.4%	-23.0%	-
1 jet	-	35.0%	-12.7%
2+ jets	-	-	33.0%

Stewart and Tackmann, arXiv:1107.2117v1

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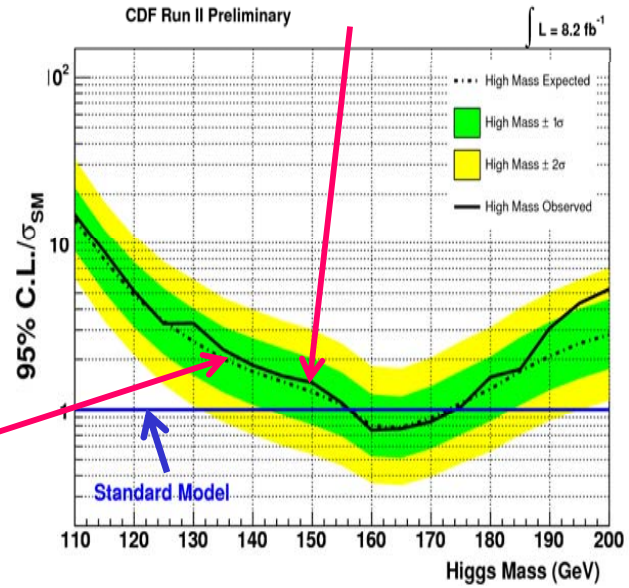
Observed limit (solid line) from data

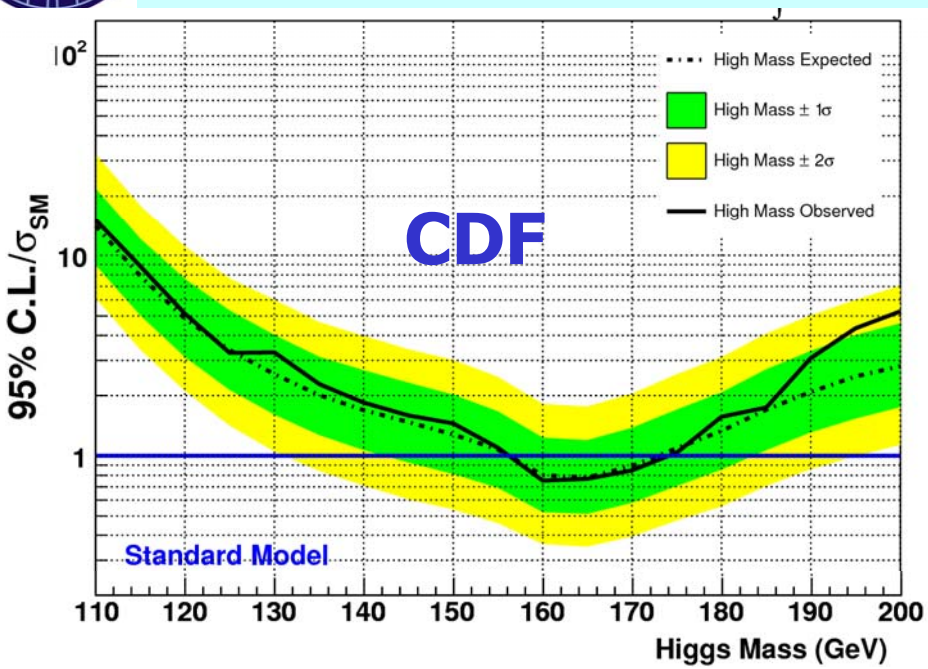
Upper cross section limit for Higgs production relative to SM prediction

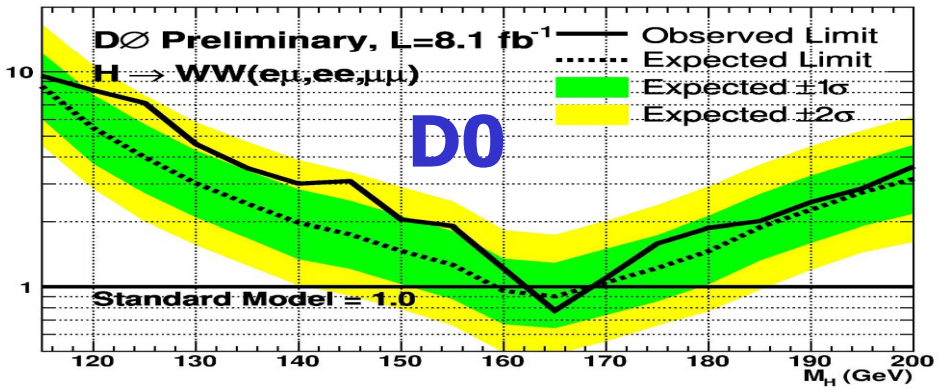


Limits are derived using Bayesian and CLs methods ➔

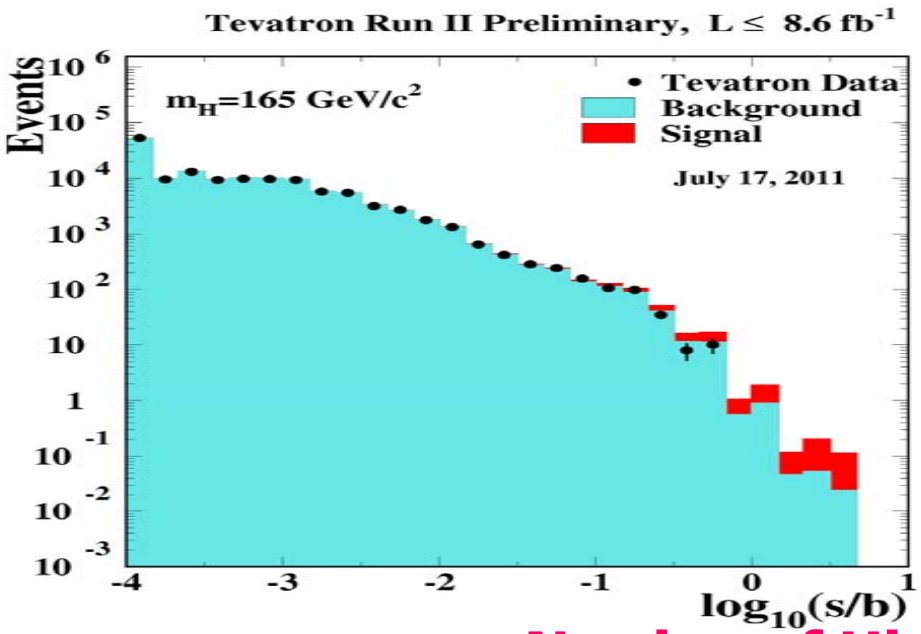
Median expected limit (dot-dashed line) and predicted 1σ/2σ (green/yellow bands) excursions from background only pseudo-experiments

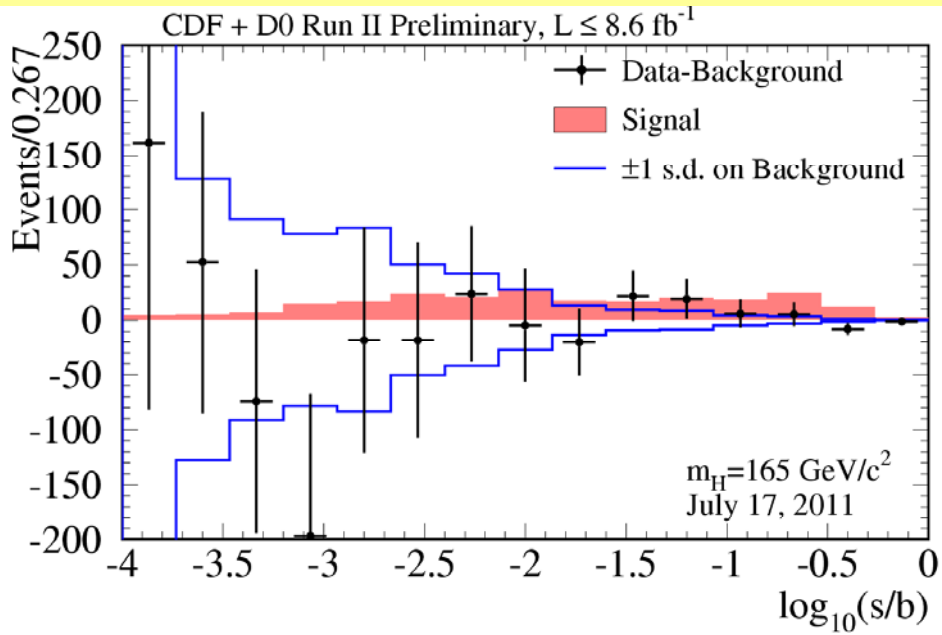
CDF/D0 H→WW→lνlν Limits





Both experiments exclude SM Higgs boson around 165 GeV ➔ combined yield:





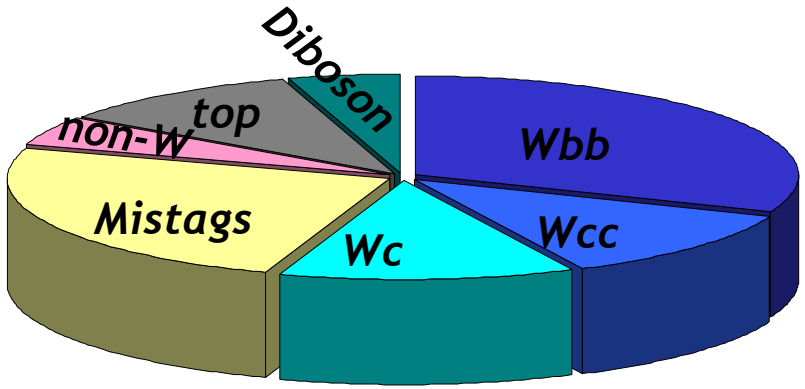
No sign of Higgs here, let's move to low mass!

Low Mass Higgs Searches

Increase lepton reconstruction and selection efficiencies

Understand background

$WH \rightarrow l\nu bb$

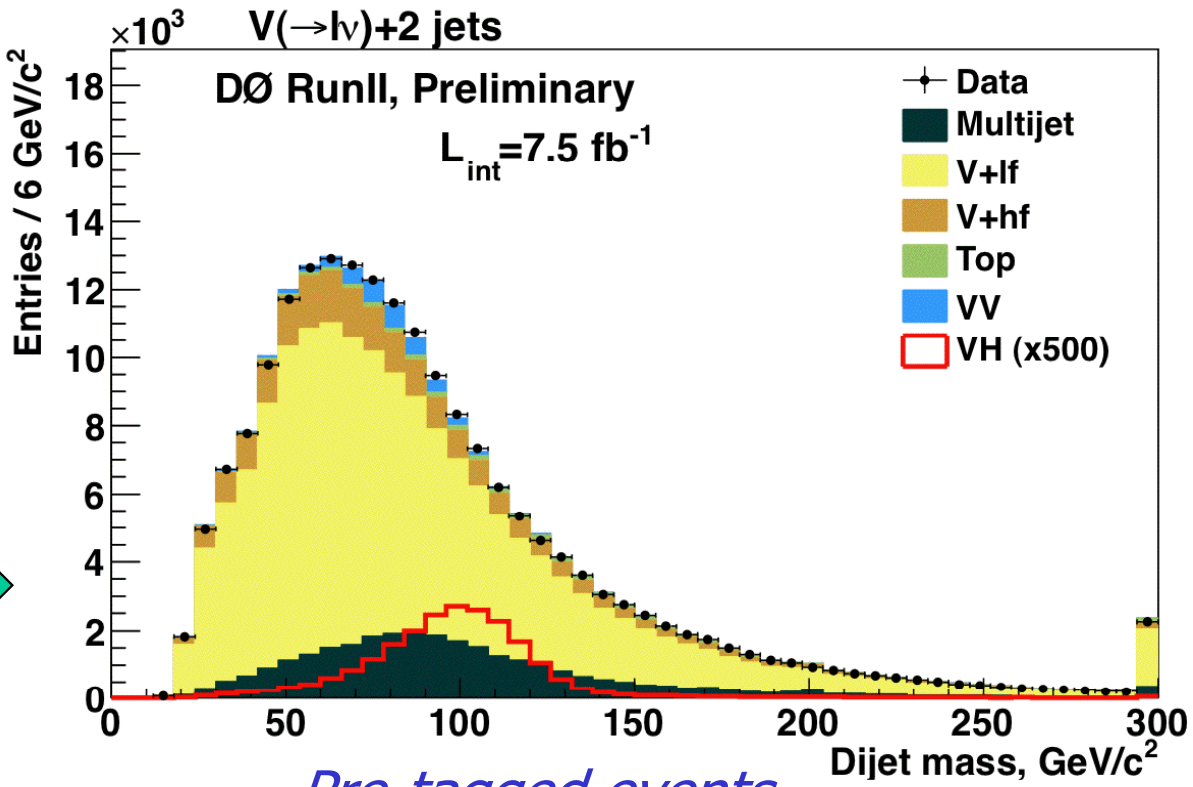


Specific to low mass analyses:

Optimize dijet mass resolution
➔ needs precise calibration and resolution for gluon and quark jets separately
➔ new techniques explored (NN, tracks + calorimeter cells)
we are not done yet!

- **Improve the efficiency for tagging b-quark jets**

- separate b,c,light.



Pre-tagged events

Low Mass Higgs Searches

Increase lepton reconstruction and selection efficiencies

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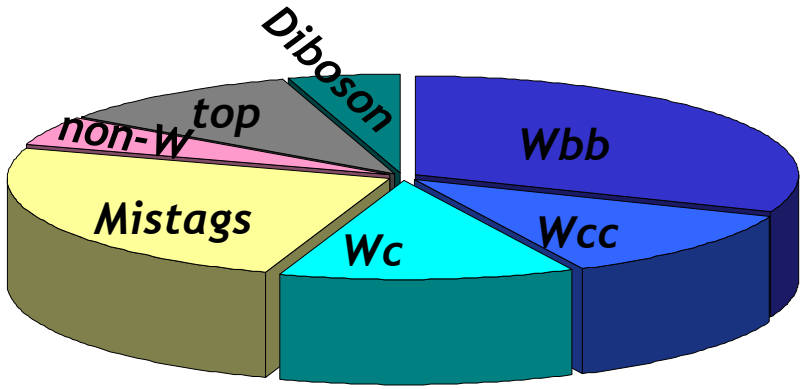

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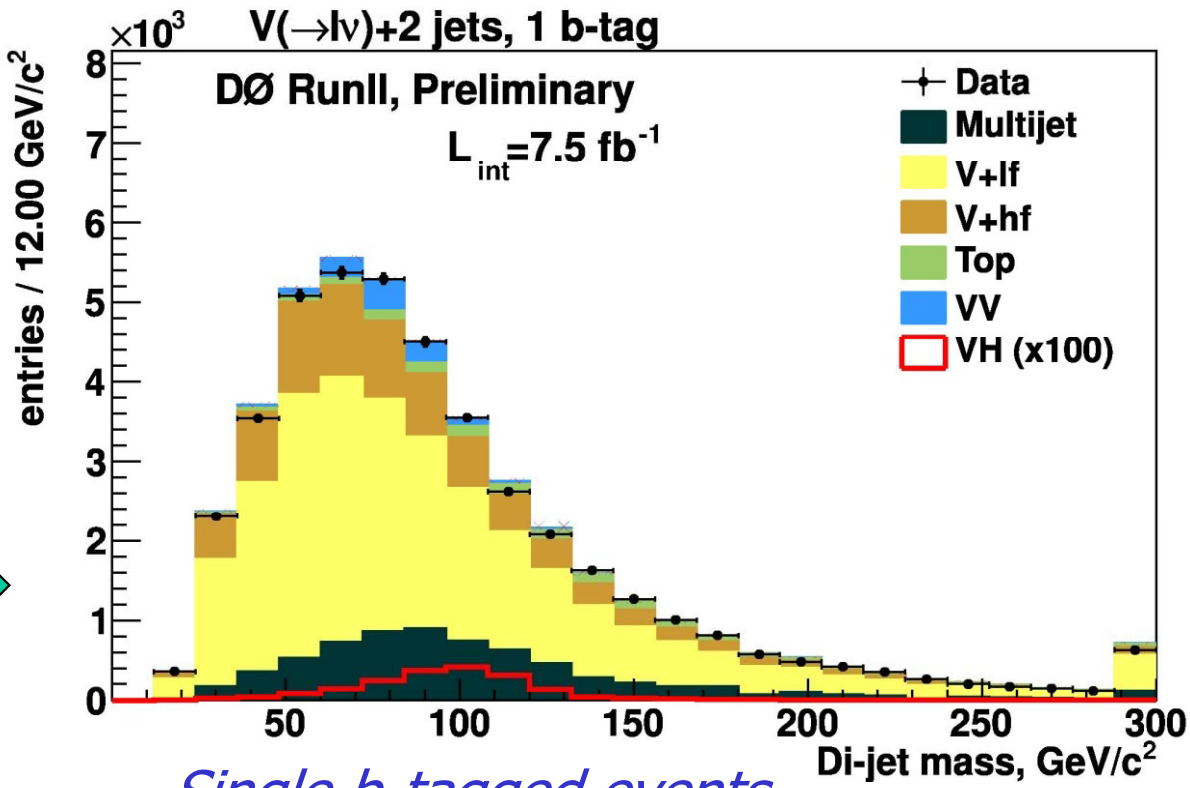

Single b-tagged events

Low Mass Higgs Searches

Increase lepton reconstruction and selection efficiencies

Understand background

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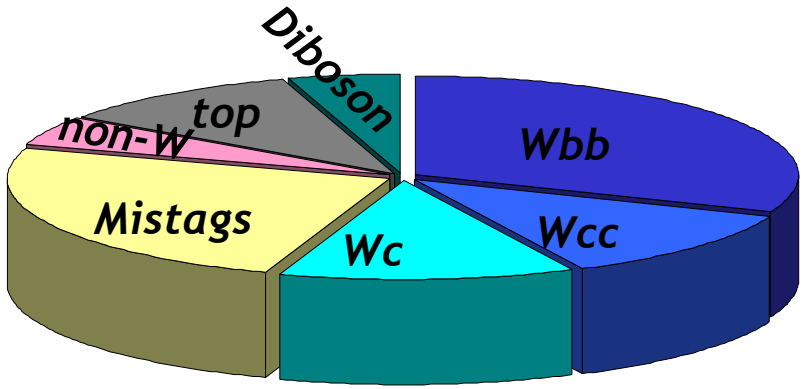

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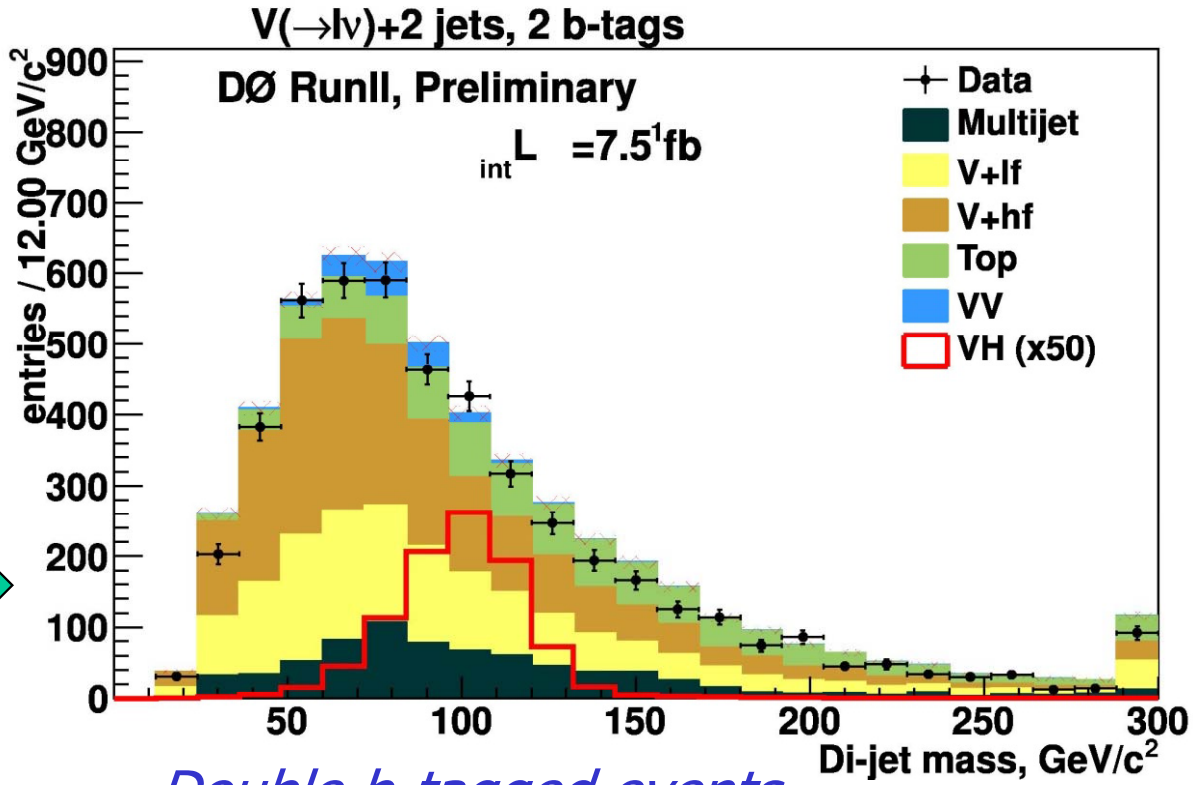
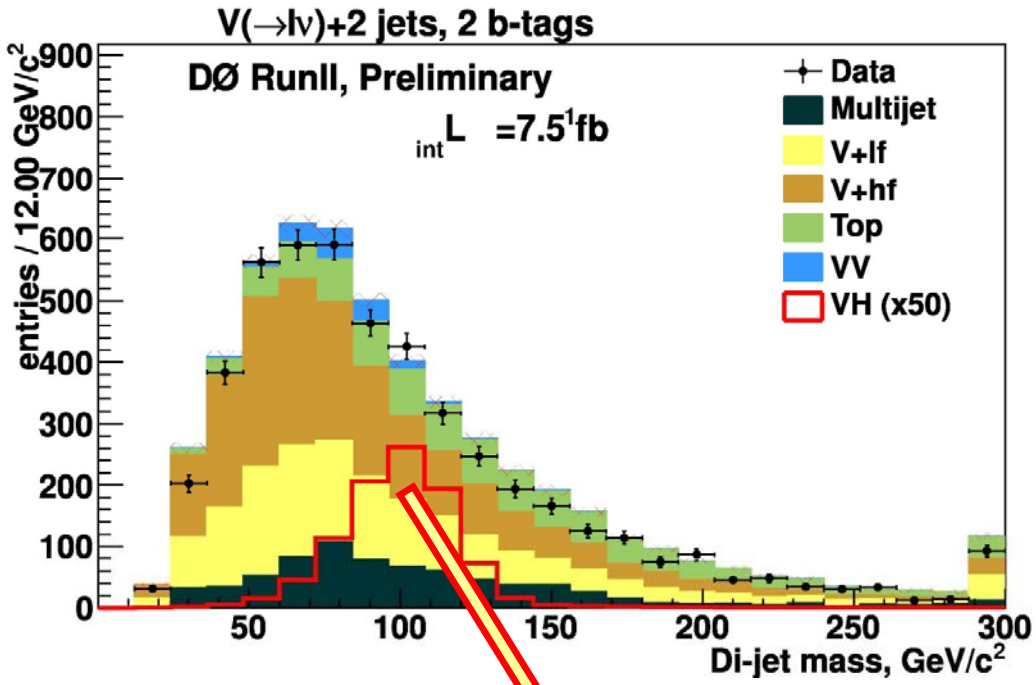
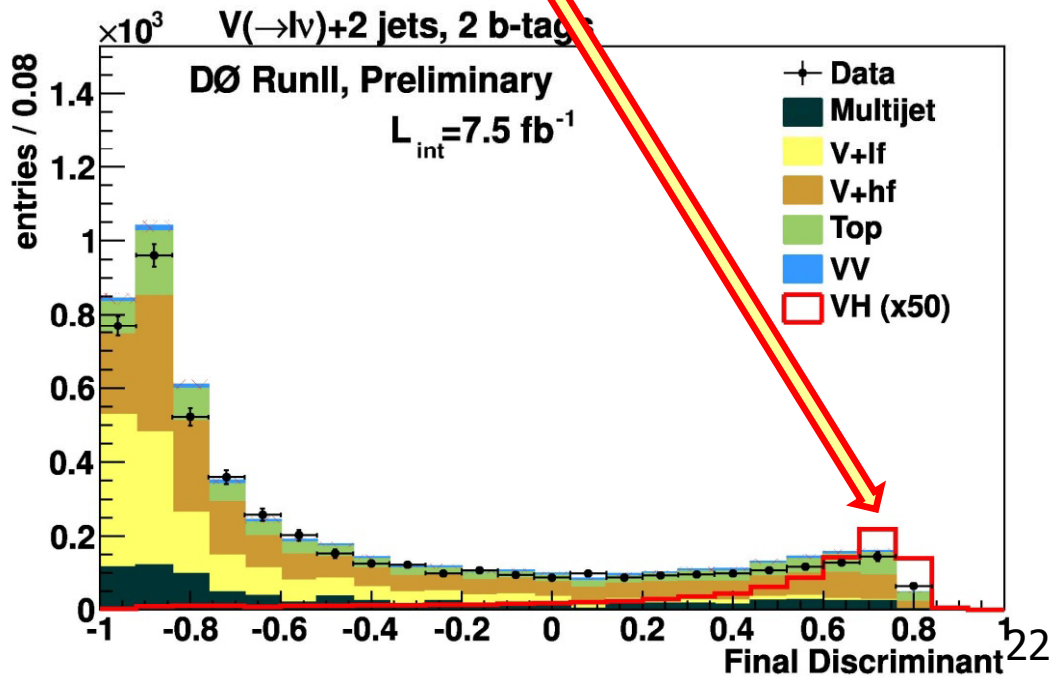


Double b-tagged events

From Dijet mass to Multi Variate Analysis

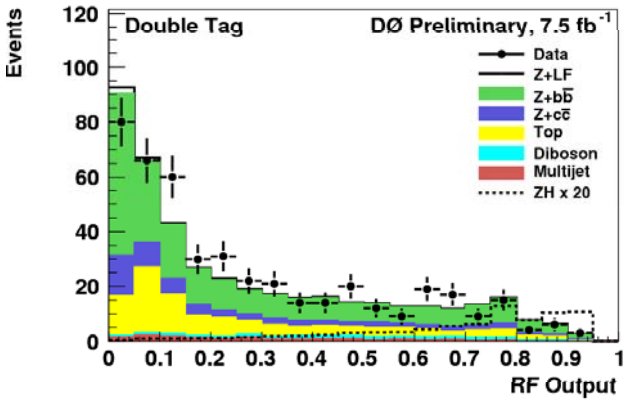
- To improve S/B ➔ utilize full kinematic event information
- Multi Variate Analyses are used to maximize search sensitivities
  - Neural Networks
  - Boosted Decision Trees
  - Matrix Element Calculations
- Visible gain obtained (~20% in sensitivity)

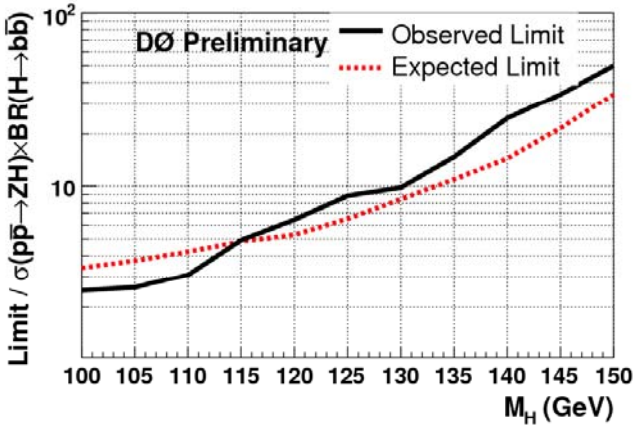




Results from DØ

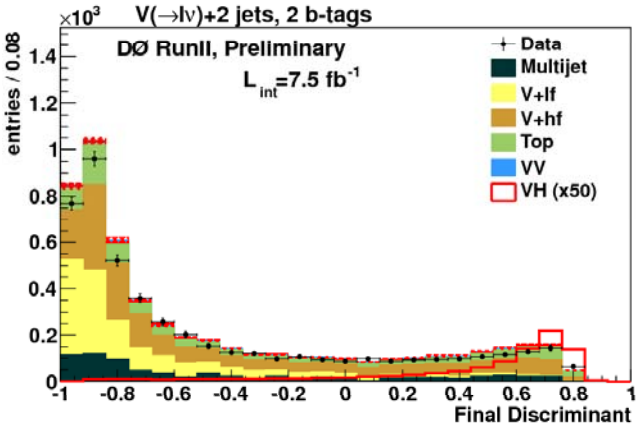
ZH→llbb̄ ∫Ldt=**8.6** fb^{-1}

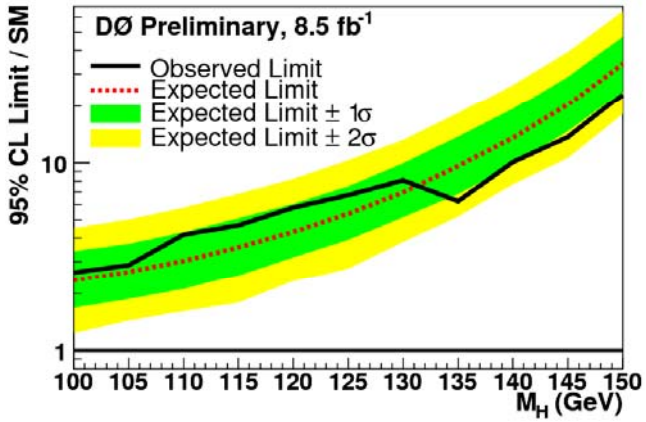




95% CL Exp (obs)
Limit **4.8** (**4.9**) x SM
@ MH=115 GeV

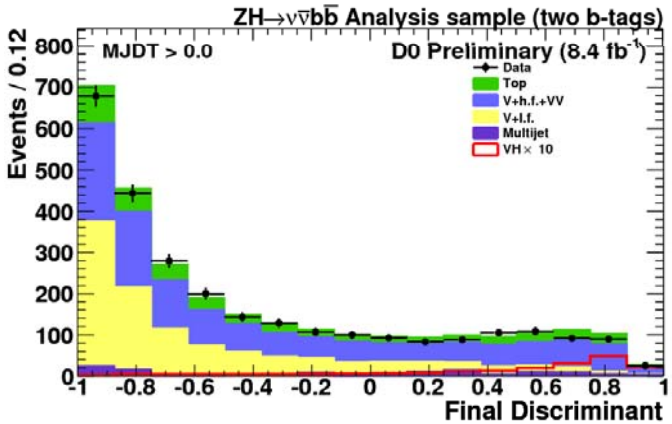
WH→lνbb̄ ∫Ldt=**8.5** fb^{-1}

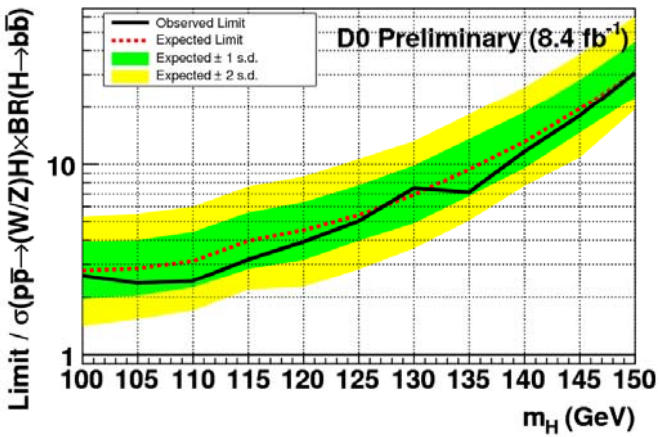




95% CL Exp (obs)
Limit **3.5** (**4.6**) x SM
@ MH=115 GeV

ZH→ννbb̄ ∫Ldt=**8.4** fb^{-1}



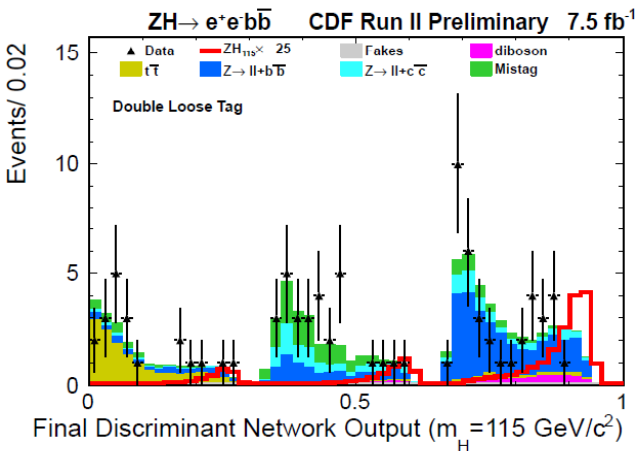


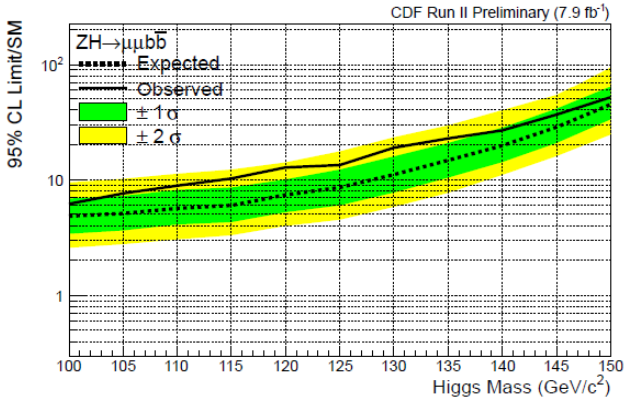
95% CL Exp (obs)
Limit **4.0** (**3.2**) x SM
@ MH=115 GeV

~10% gain on sensitivity
(i.e. on top of gain due to luminosity)

Results from CDF

ZH→llbb̄ ∫Ldt=7.9 fb^{-1}

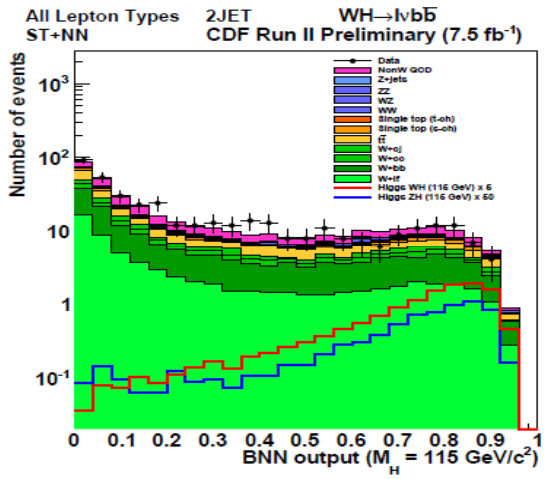


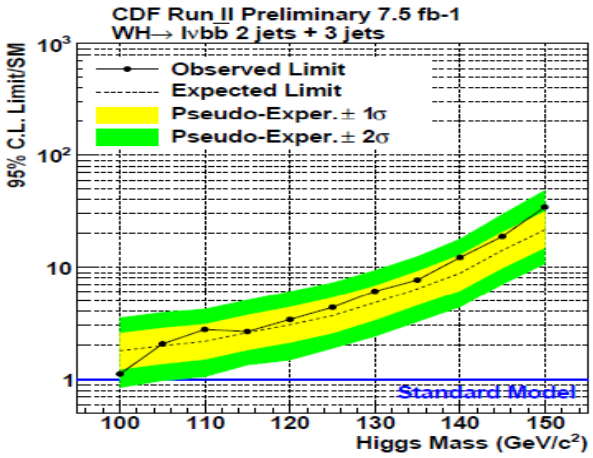


95% CL Exp (obs)
Limit **3.9** (**4.8**) x SM
@ MH=115 GeV

20% gain on sensitivity

WH→lνbb̄ ∫Ldt=7.5 fb^{-1}

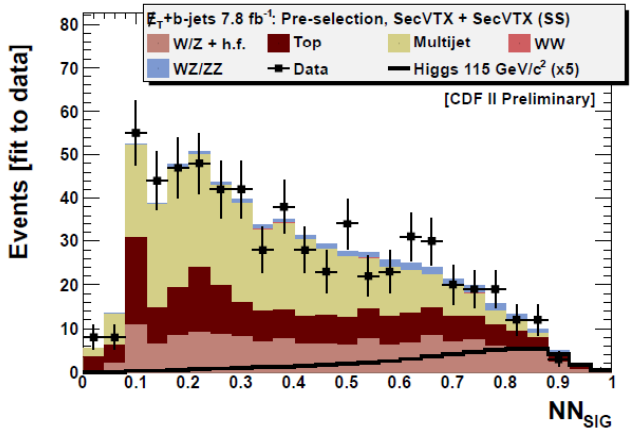


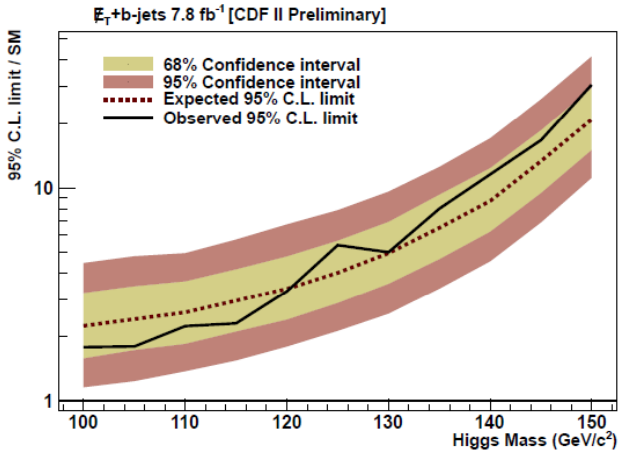


95% CL Exp (obs)
Limit **2.7** (**2.6**) x SM
@ MH=115 GeV

13% gain on sensitivity

ZH→ννbb̄ ∫Ldt=7.8 fb^{-1}





95% CL Exp (obs)
Limit **2.9** (**2.3**) x SM
@ MH=115 GeV

18% gain on sensitivity

Cross check on Diboson process

- **Benchmark of H→bb searches with real data.**
- **VZ→leptons + heavy flavor jets**

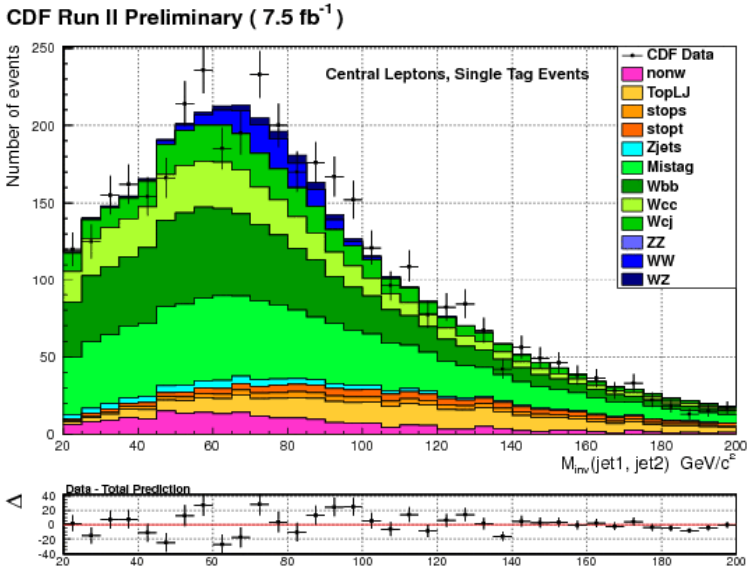
For m_H=115 GeV	Replace H with Z
WH→lνbb: σ = 26 fb	WZ→lνbb: σ = 105 fb
ZH→ ννbb:σ = 15 fb	ZZ →ννbb: σ = 81 fb
ZH→ llbb: σ = 5 fb	ZZ → llbb: σ = 27 fb
Total VH: σ = 46 fb	**Total VZ: σ = 213 fb**

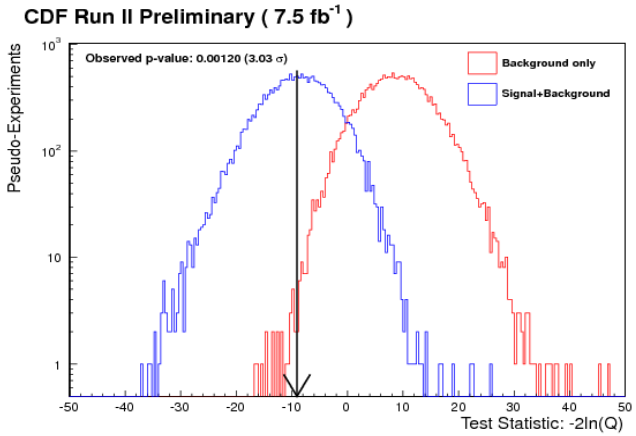
Z→bb yields is 5 times larger, but more W+jets, and also background from WW.

- **Apply similar analysis as low mass H→bb analysis, and check sensitivity.**

Dibosons with Heavy Flavor Jets

L+MET + HF jets

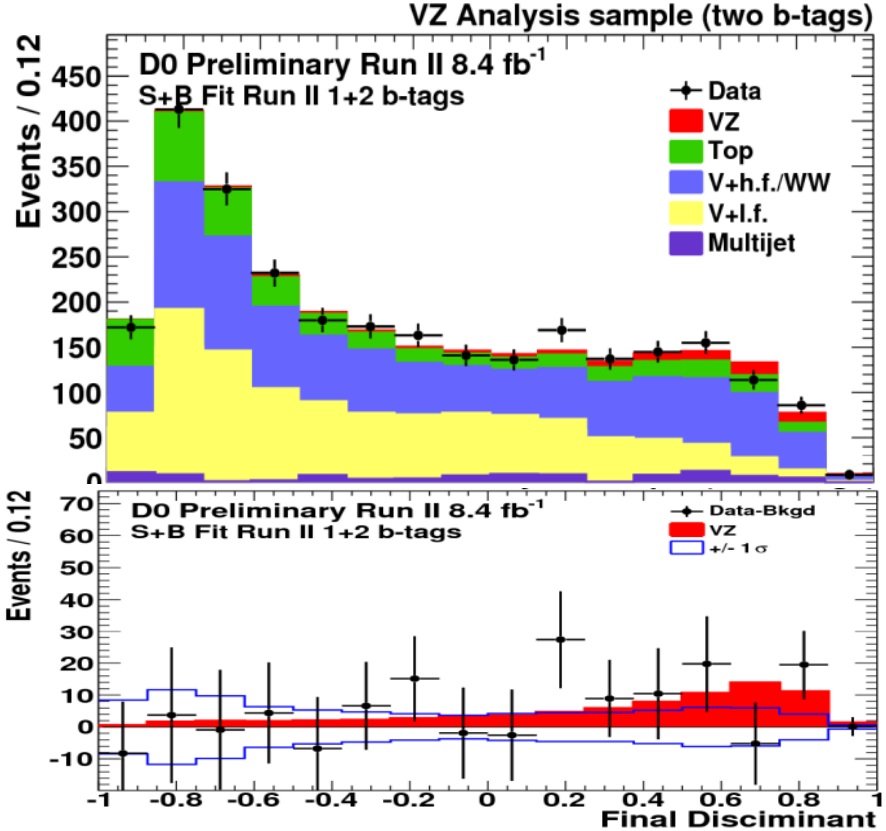




Cross-section measurement:
$\sigma(WW+WZ)_{mes}/\sigma_{SM} = \mathbf{1.1}\ ^{+0.3}_{-0.4}$

3.0 s.d. from BG-only hypothesis

_MET + HF jets



Cross-section measurement:
$\sigma(WZ+ZZ)_{mes}/\sigma_{SM} = \mathbf{1.5 \pm 0.5}$

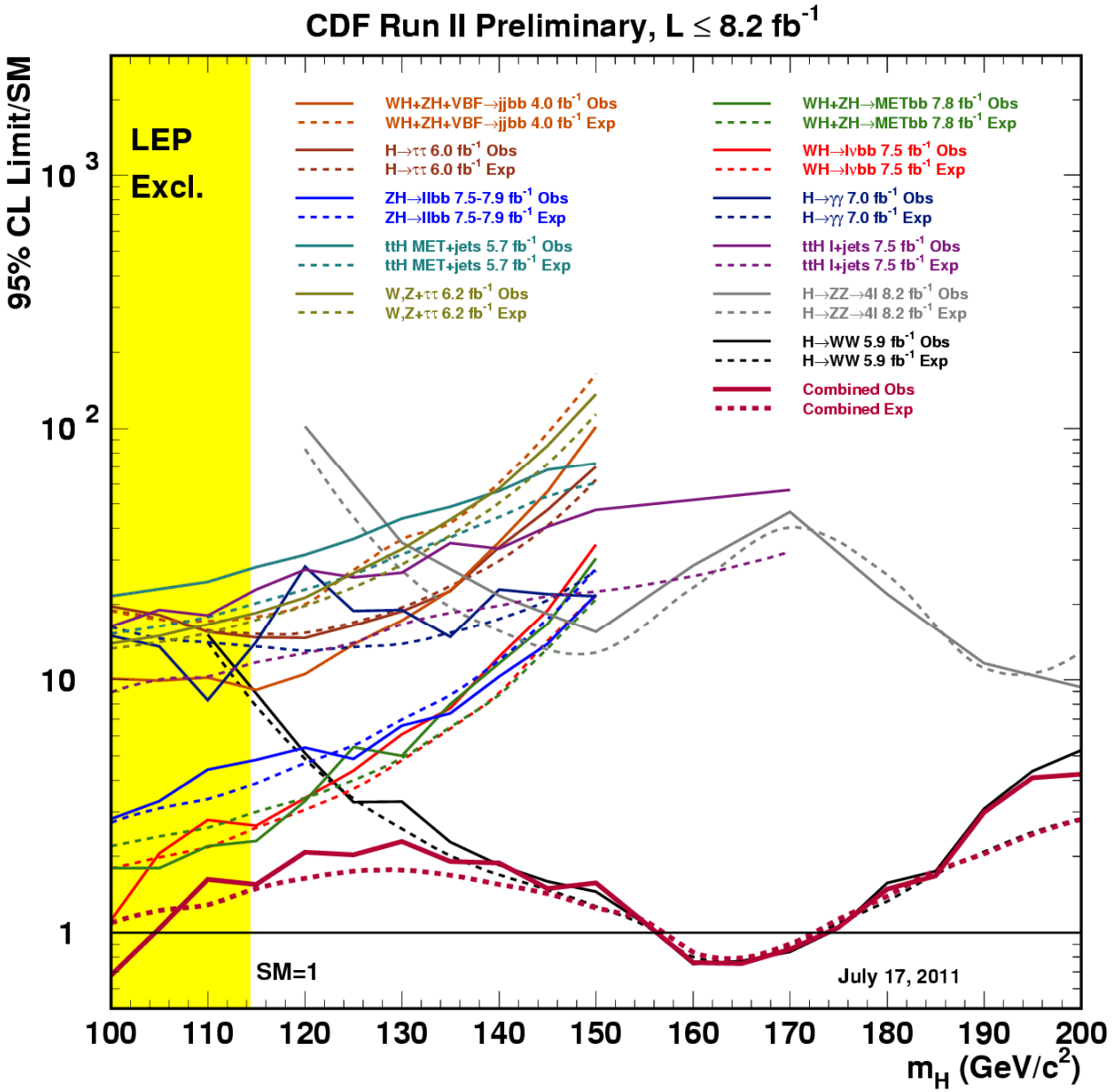
2.8 s.d. from BG-only hypothesis

Combining Channels

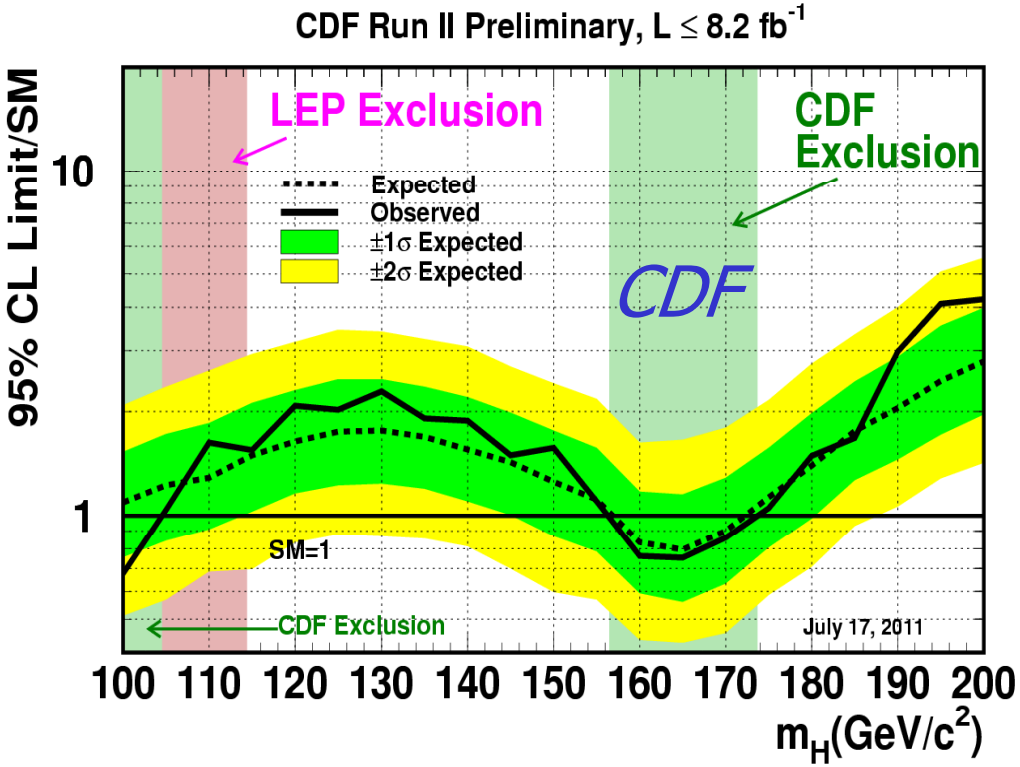
Best sensitivity ➔combination of many independent search channels

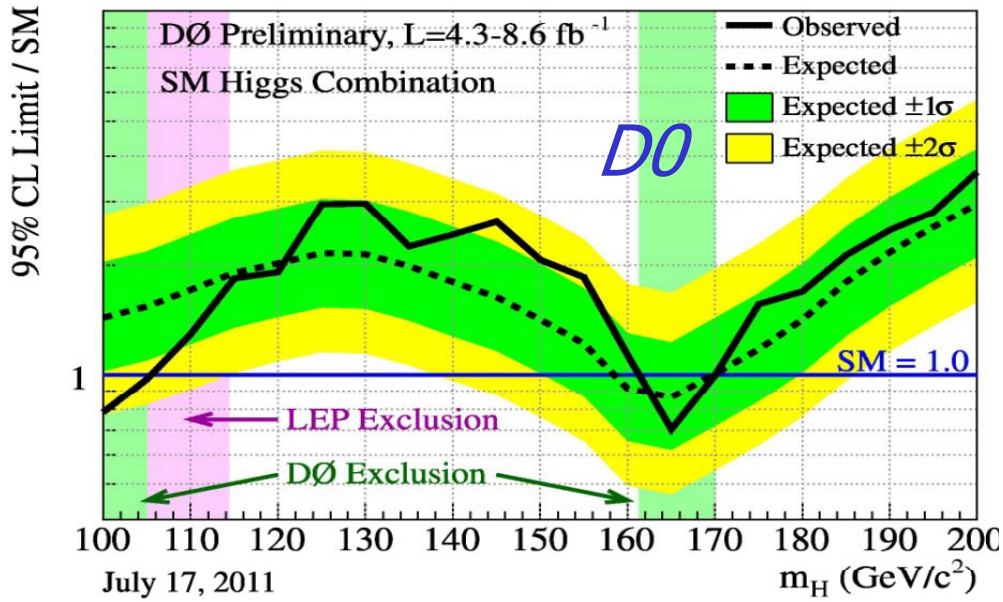
See parallel sessions for a description of the other analyzed channels listed here below:

WH→lνbb
ZH→ννbb
ZH→llbb
WH/ZH→jjbb
ttH→WbWbbb
H→γγ
H→ττ
WH→lνττ / ZH→llττ
H→WW→lνlν
H→WW→lνjj
WH→WWW / ZH→ZWW
H→ZZ



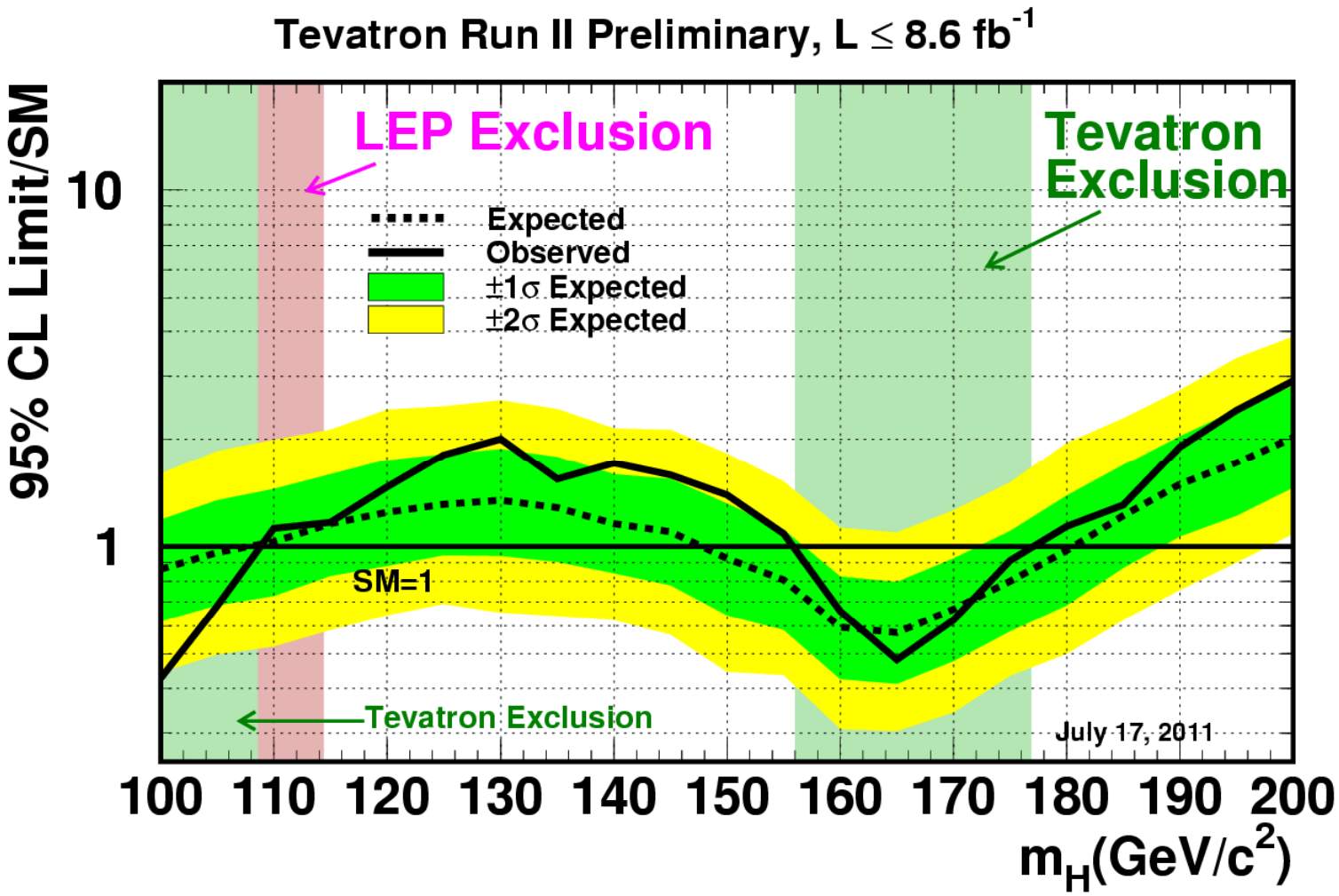
CDF/D0 Limits





Similar shapes: small deficit below 115 GeV,
small but broad excess around 130 GeV,
exclusion around 160 GeV

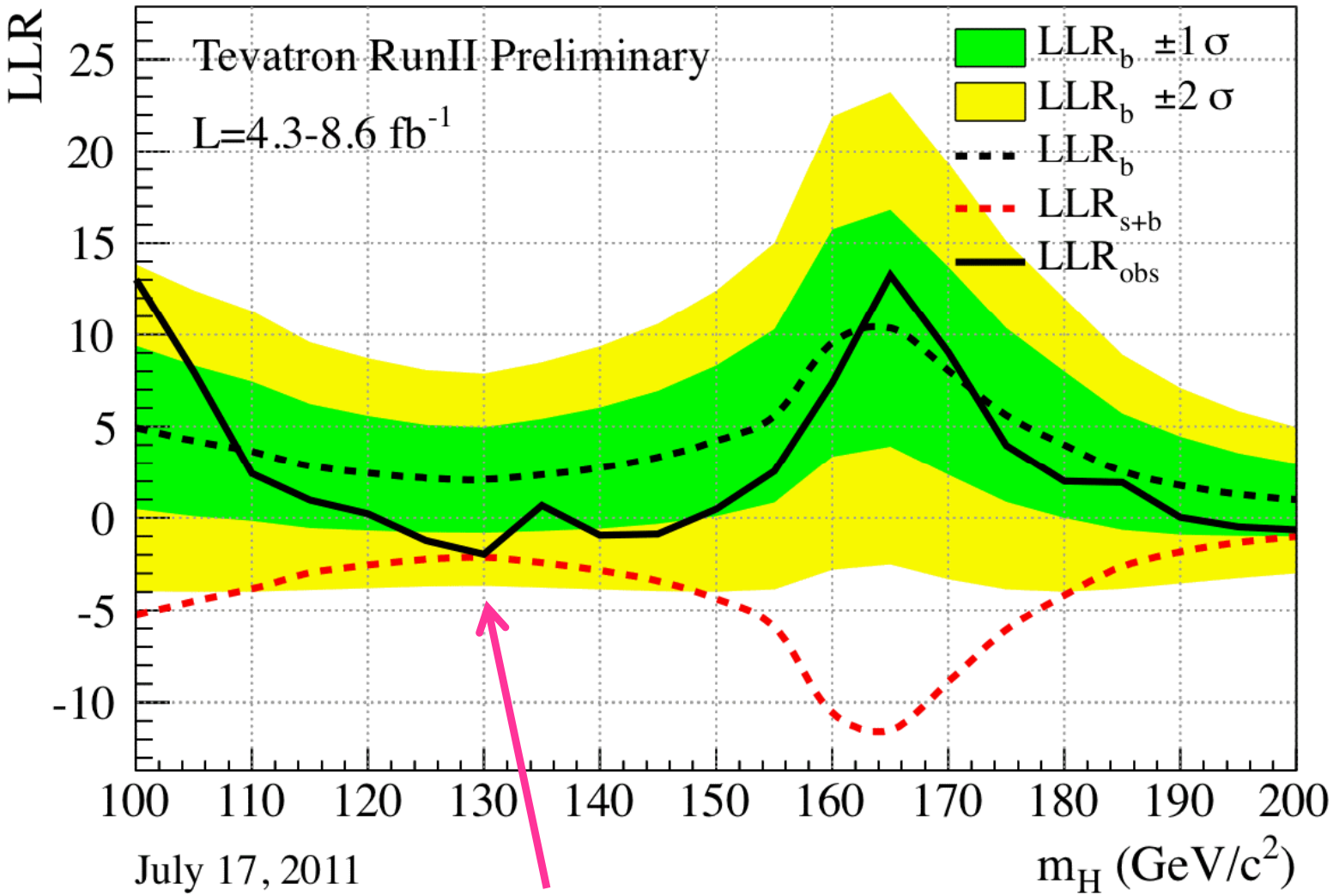
New Tevatron Combination



Observed Exclusion : 100-109 and 156-177 GeV

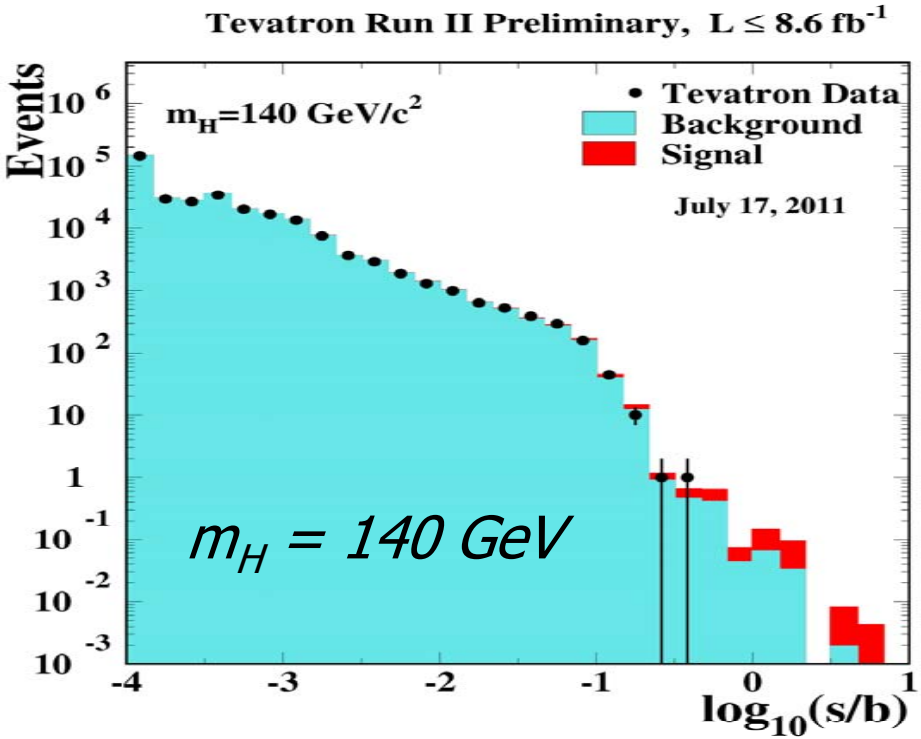
Expected Exclusion : 100-108 and 148-181 GeV

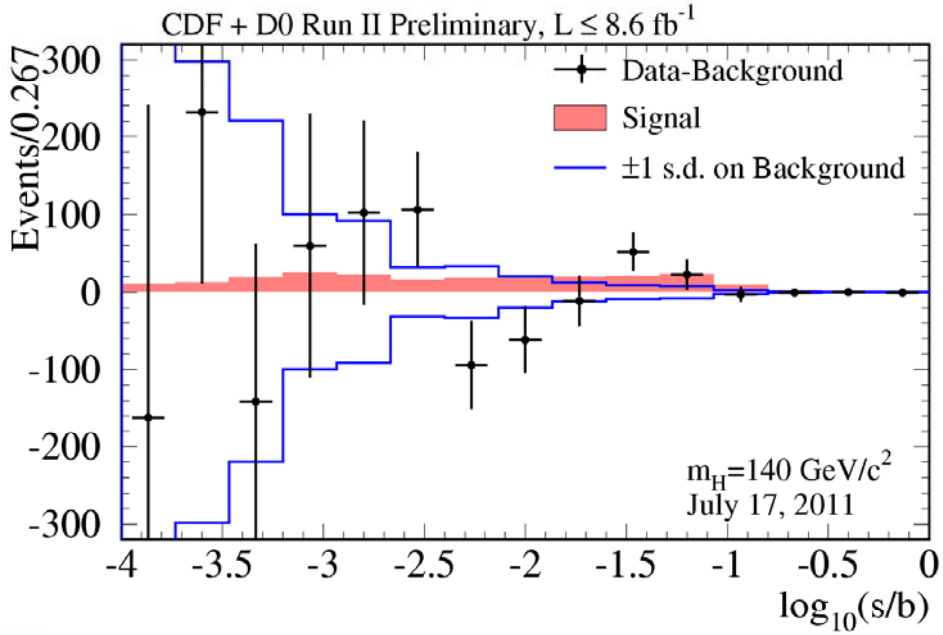
S+B versus B-only Hypotheses

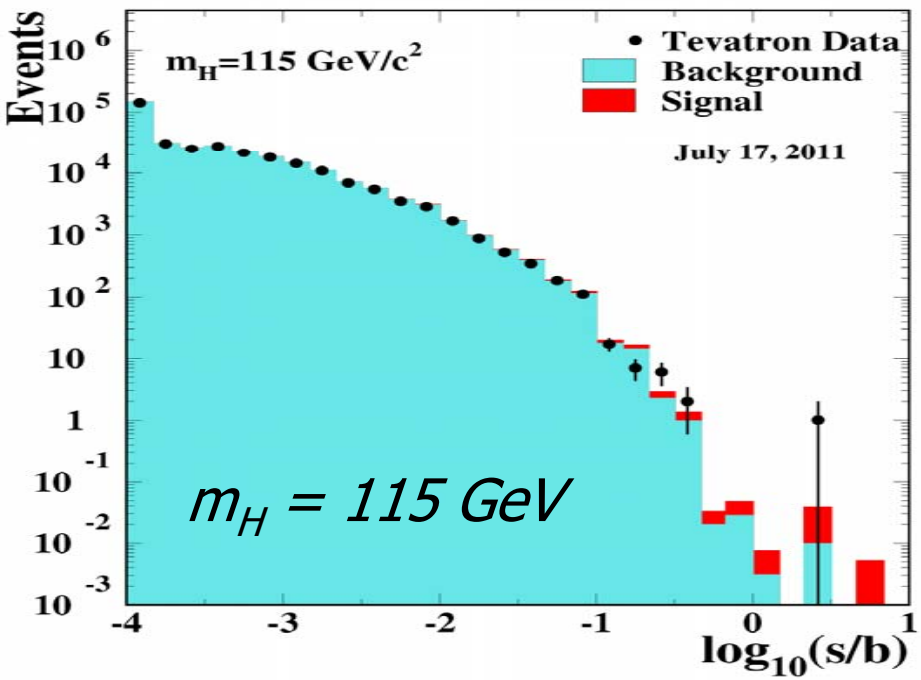


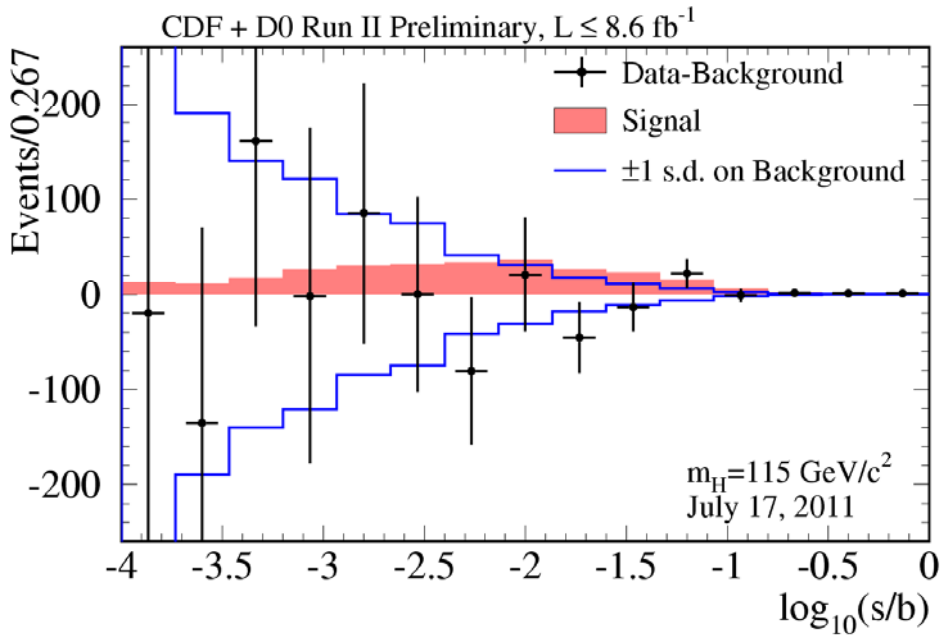
excess around 130 GeV consistent with SM Higgs but with only ~ 1.3 sigma sensitivity

Combined Discriminants

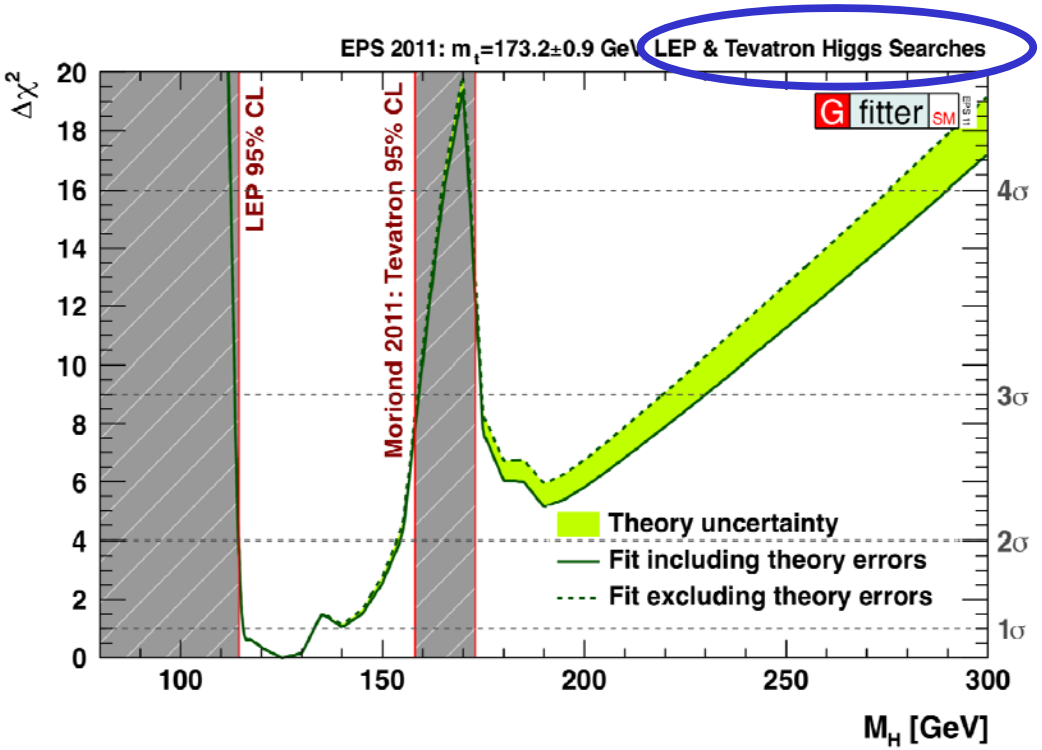


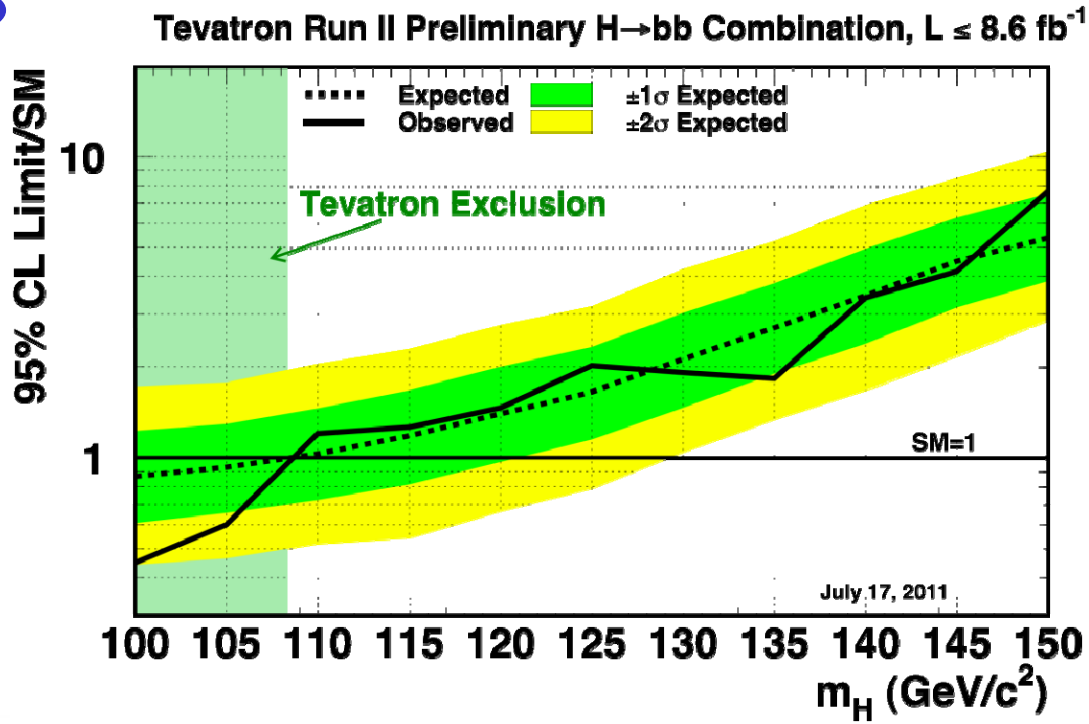






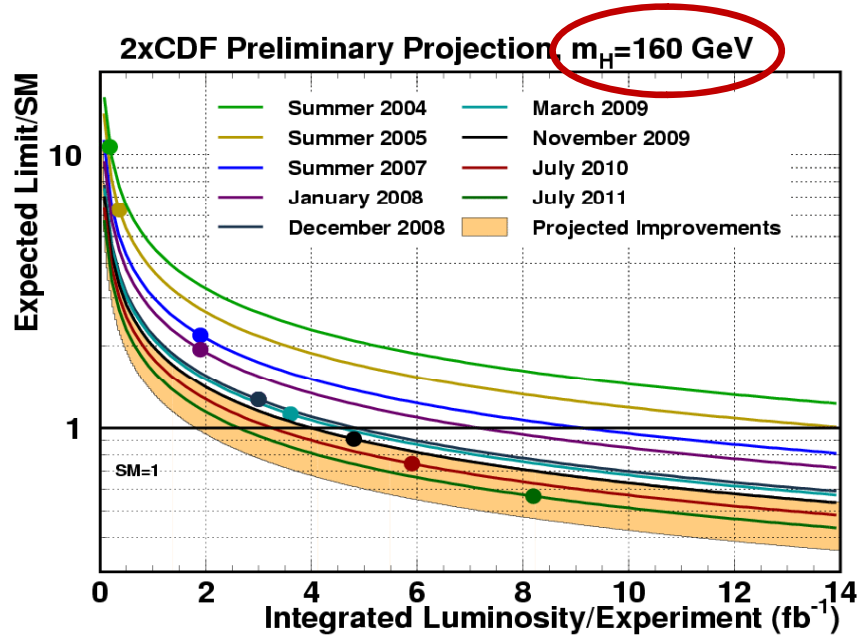
Global EWK Fit / H→bb

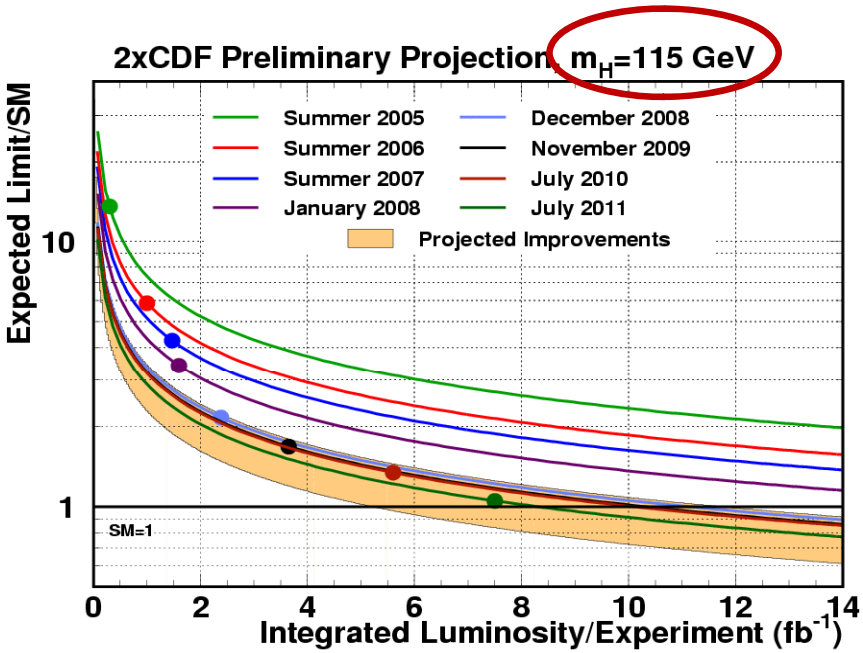




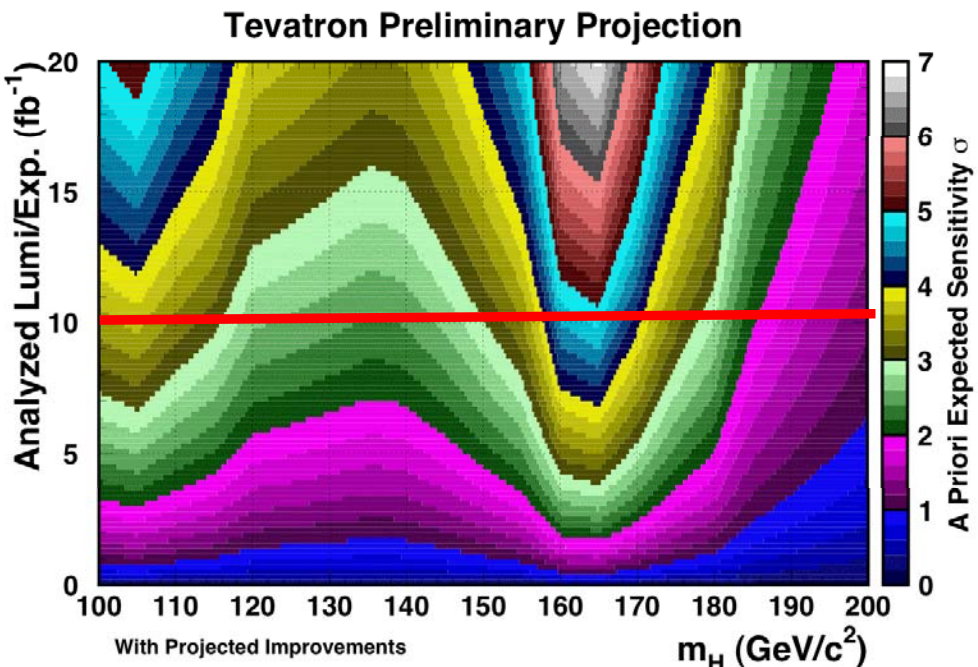
- Favored region did not change much; must include LHC limits in future to be realistic
- H→bb channel provides best sensitivity in the mass region just above the LEP bounds
- Evidence/observation of this decay mode is important for establishing that a Higgs-like signal found in other channels is in fact the SM Higgs. It will be best done at the Tevatron in the foreseeable future.

Sensitivity Gains Prospects





- With our analysis improvements, we continue to progress significantly in search sensitivity, beyond that expected from simply adding more data
- Tevatron is working to deliver Higgs search results next spring based on the full 10 fb^{-1} datasets that achieve our expected sensitivity goals
- The Tevatron should reach 95% C.L. exclusion sensitivity over the entire Higgs mass range (100 -185 GeV) and better @ 115 GeV



Conclusions and Outlook

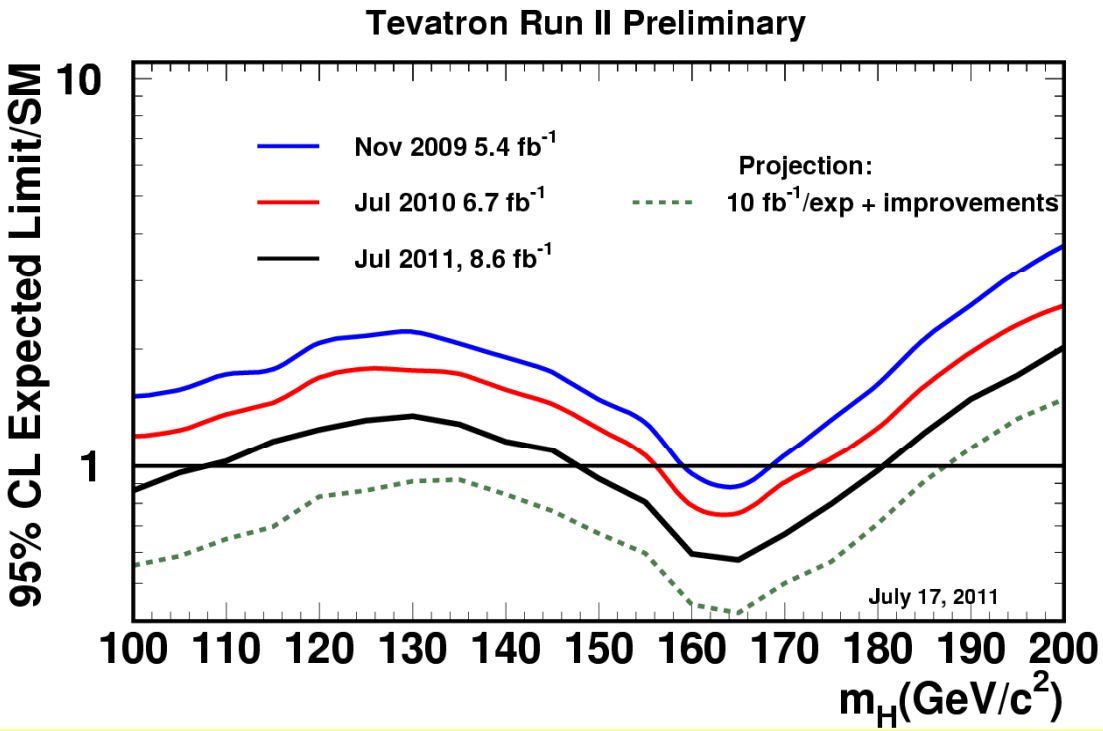
Tevatron exclusion has been extended at high mass, but small excess around 130-140 GeV prevents realizing expected exclusion ;)

Tevatron is reaching exclusion sensitivity at lowest mass (~115 GeV)

Expect to collect 10 fb^{-1} of analyzable data by end of September 2011

On track to reach 95% CL exclusion sensitivity over expected m_H range, i.e. from 100 to 185 GeV

Best sensitivity to H→bb ,
→Tevatron will remain complementary to LHC at least until 14 TeV Run



We are fast progressing on one of the most central questions in HEP: How is EWSB happening? Is there a SM Higgs Boson?