Status of SM Higgs boson searches/studies at the Tevatron

Gregorio Bernardi,

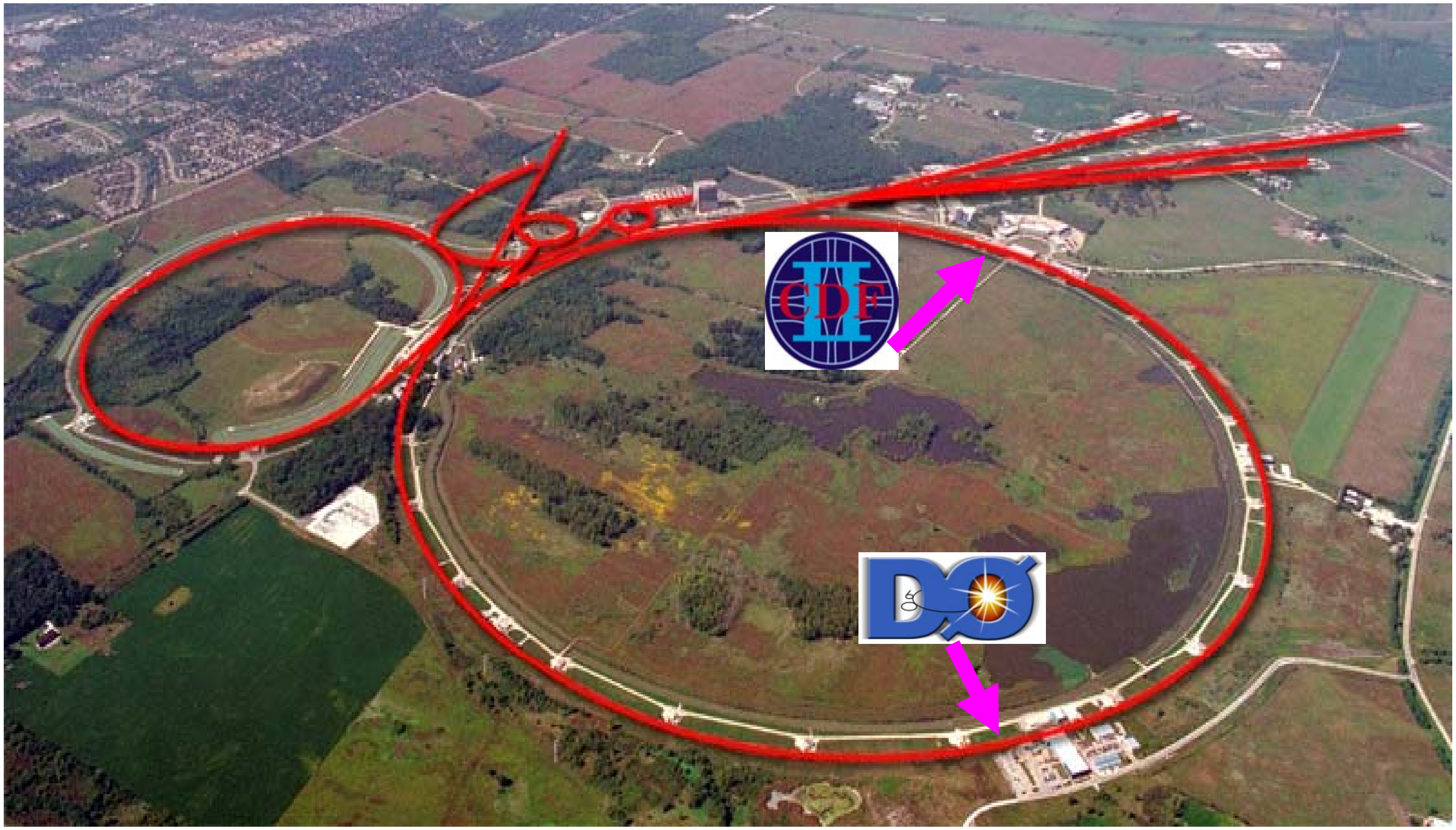
LPNHE Paris

On behalf of CDF and Dzero

Higgs Quo Vadis, Aspen, March 12, 2013

Thanks to all CDF & DZero colleagues,

Special thanks to W. Fisher, L. Zivkovic, W. Yao

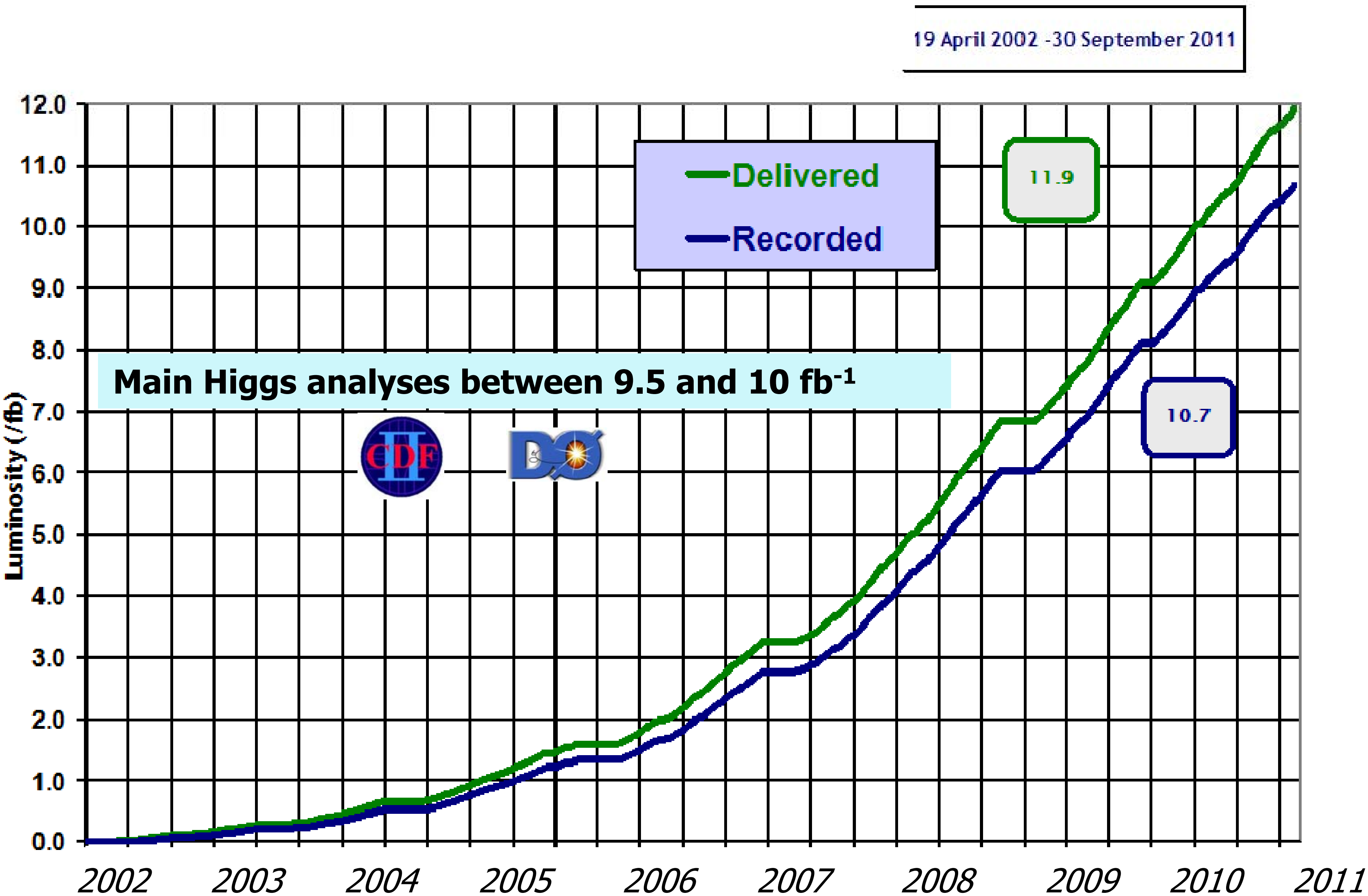


Outline

- **The Tevatron performance**
- **Low mass (H→bb) Higgs searches**
- **Combinations of Standard Model searches**
- **Higgs Couplings**
- **Prospects**

Final individual channels and combinations from CDF and D0 are published.
Full CDF+D0 combination will be submitted to publication soon.

Tevatron Luminosity



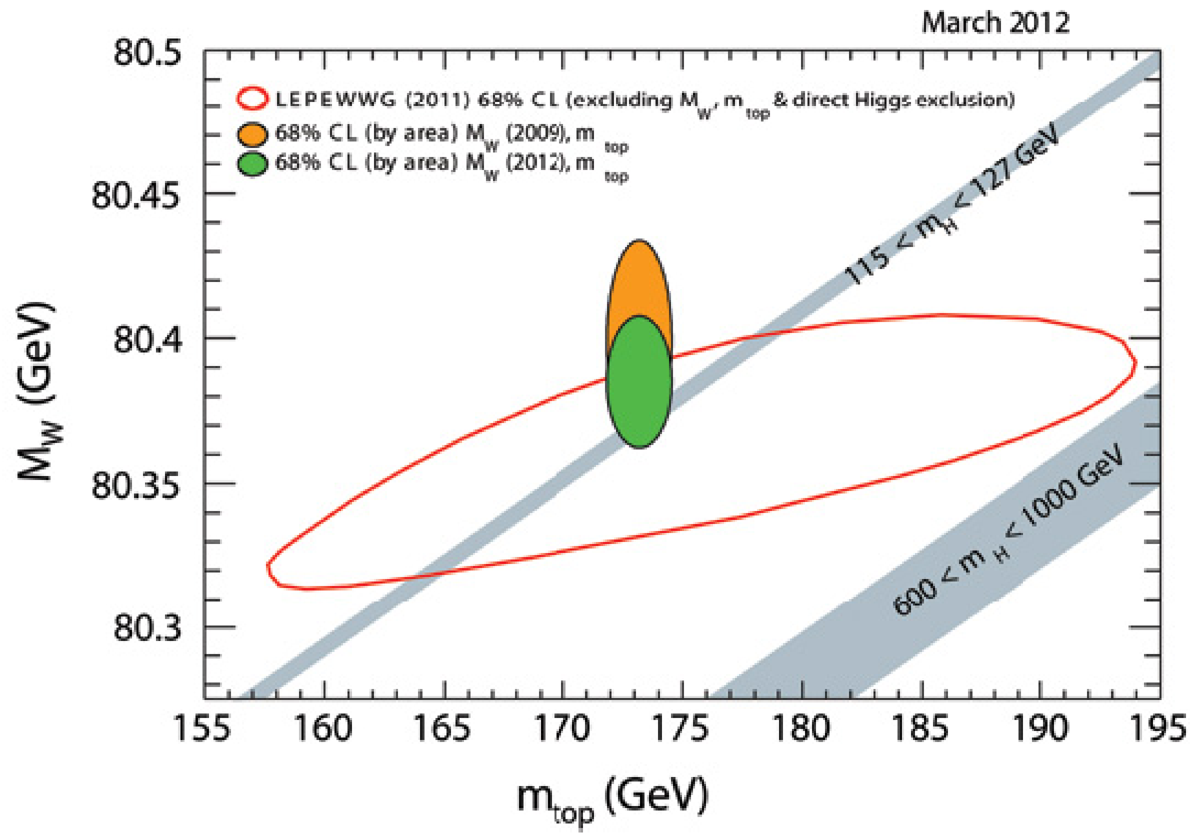
Thanks to the Tevatron Accelerator Group for such a performance!

Indirect SM Higgs constraints

Recently updated top quark and W boson mass measurements from the Tevatron

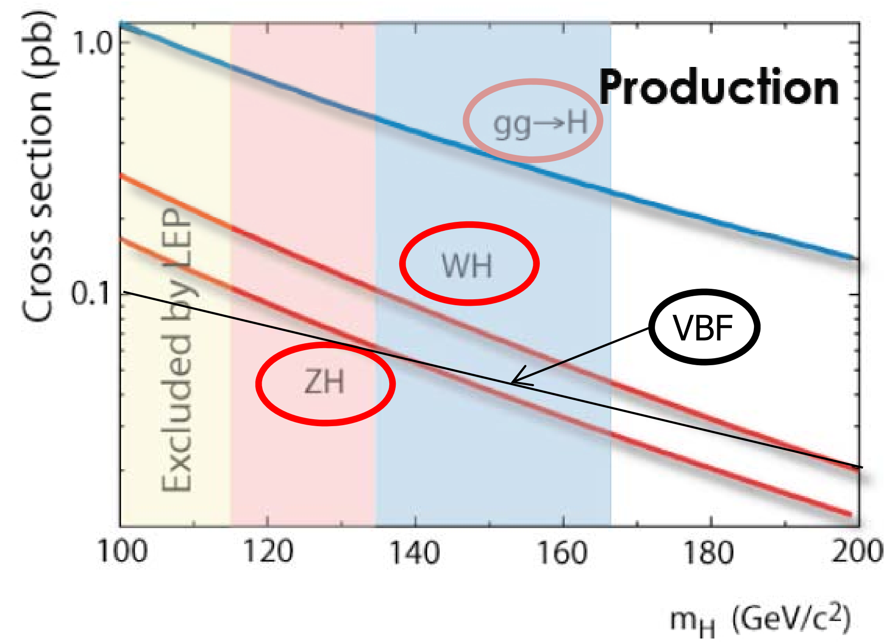
$m_W = 80385 \pm 15$ MeV

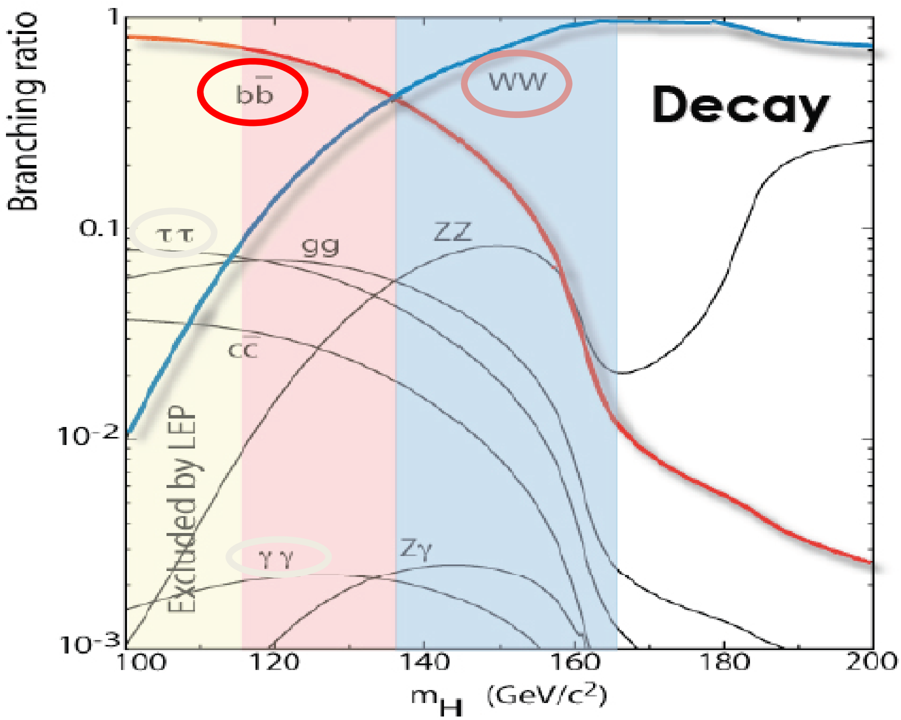
$m_t = 173.2 \pm 0.9$ GeV



The boson discovered at the LHC looks like the SM Higgs also from the indirect point of view

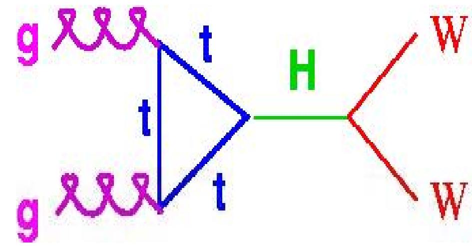
Higgs Production and Decay at the Tevatron





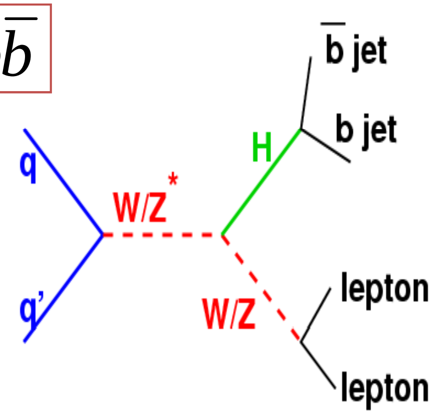
"High" mass (m_H > 135 GeV) dominant decay:

$H \rightarrow WW^{(*)}$ $gg \rightarrow H \rightarrow WW \rightarrow \ell\nu\ell'\nu'$



Low mass (m_H < 135 GeV) dominant decay:

$H \rightarrow b\bar{b}$



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

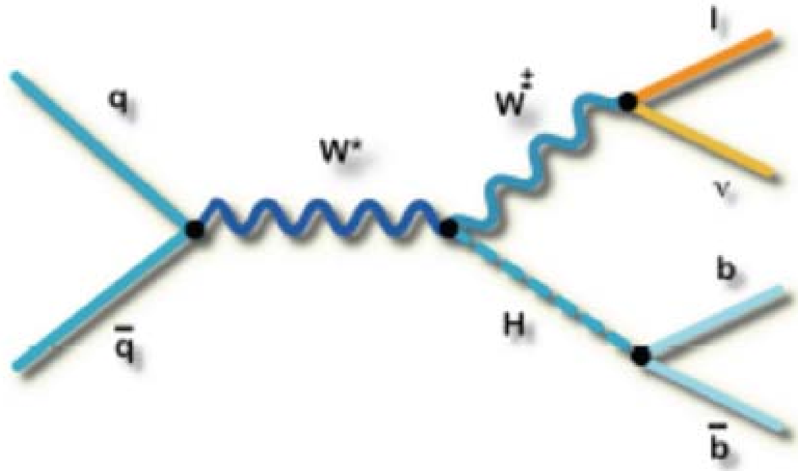
$ZH \rightarrow \ell^+\ell^- b\bar{b}$

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

use associated production modes to get better S/B

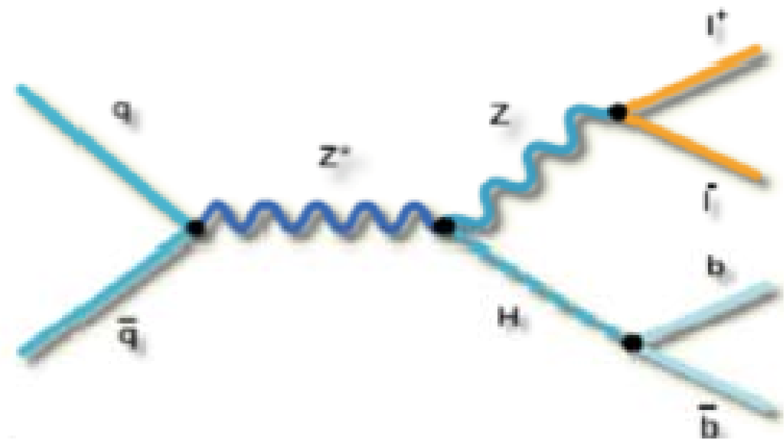
These are the main search channels, but there is an extensive program of measurements in other channels to extend the sensitivity to a SM Higgs

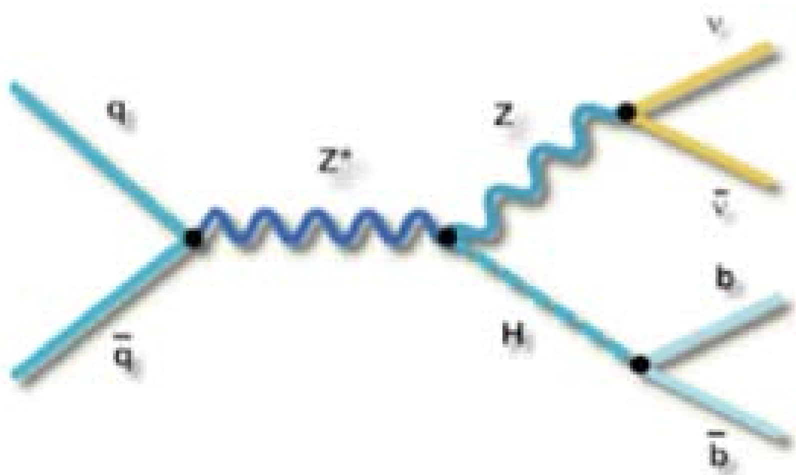
Low Mass Higgs Channels



WH→lνbb: MET+l+bb
Large production cross section
Higher backgrounds than in ZH→llbb

ZH→llbb: ll+bb
Low background
Fully constrained
Small Signal



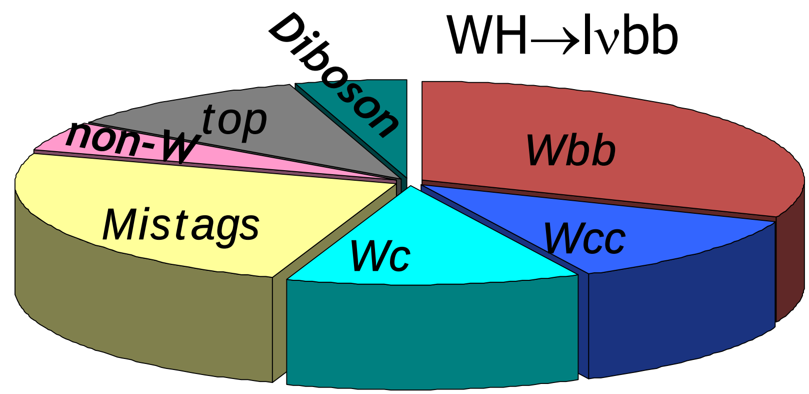


ZH→ννbb: MET+bb
signal 3x larger than ZH→llbb
(+ contributions from WH)
difficult backgrounds

Low Mass Higgs Searches

Increase lepton reconstruction and selection efficiencies

Understand background



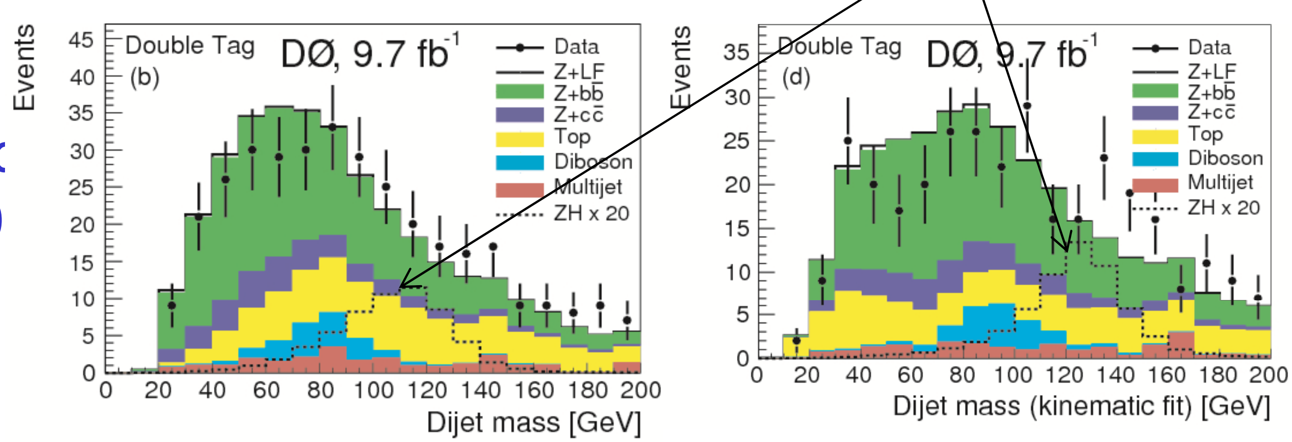
Specific to low mass analyses:

B-tagging (next slide)

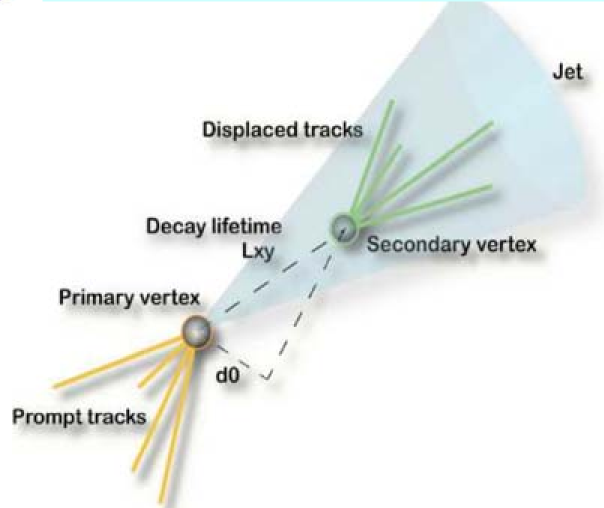
Optimize dijet mass resolution

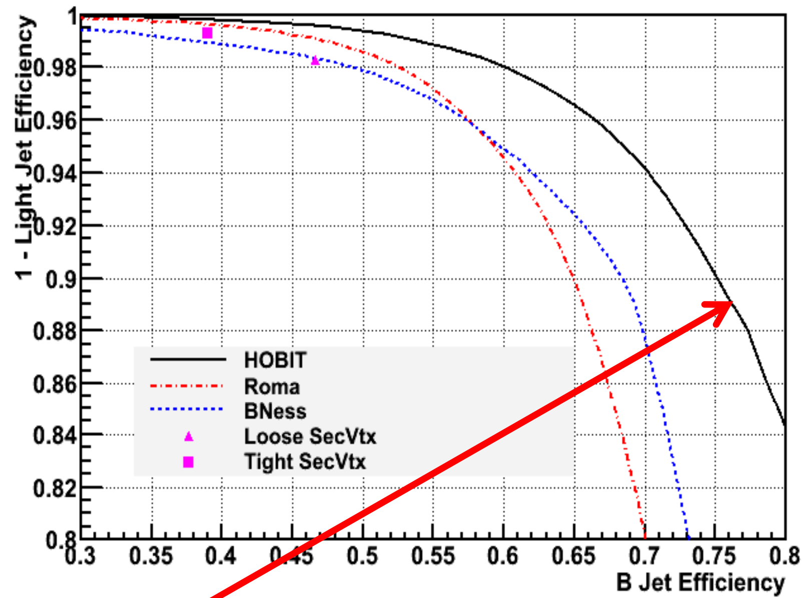
➔ needs precise calibration and resolution for gluon and quark jets separately
➔ new techniques still explored (NN, tracks + calorimeter cells)

We also optimize dijet mass resolution with Kinematic fit in ZH→llbb (15% sensitivity gain)



Low Mass Higgs Searches





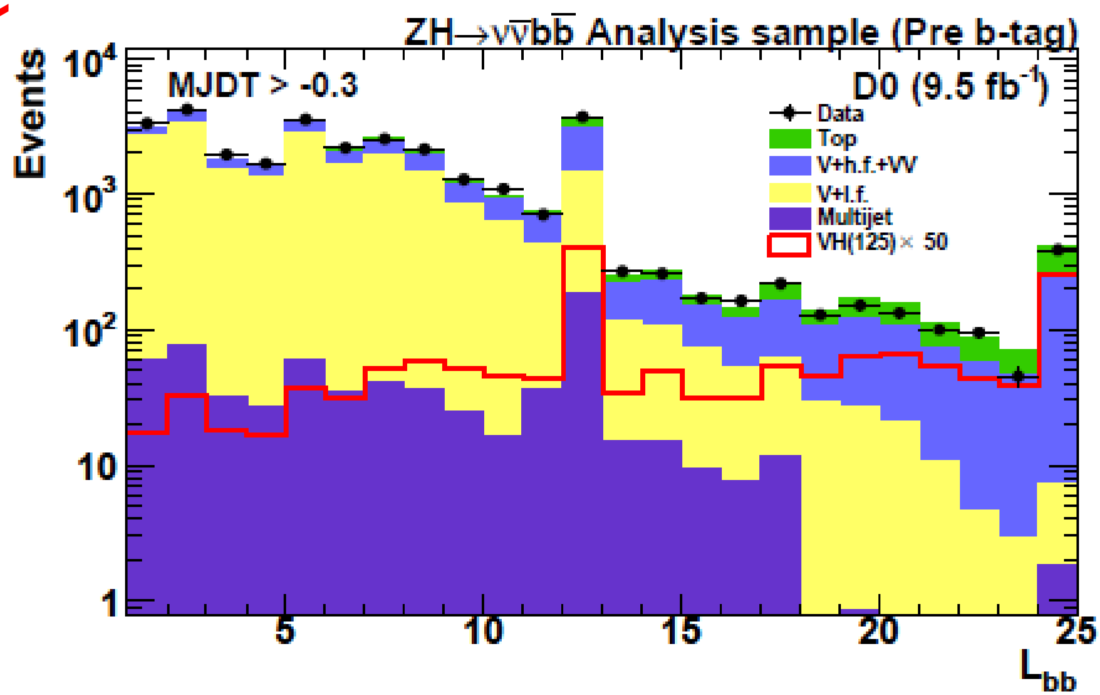
75% eff. for 10% mistag
42% eff. For 0.9% mistag

Reduce the background by tagging b-quark jets

Major step forward with HOBIT, MVA tagger @ CDF (D0 already use one)

- separate b-jet from light-jets

24 operating points allows for s/b optimizations in sub-samples ➔



- next step would be to separate b from c with dedicated algorithm

From Dijet mass to Multi Variate Analysis

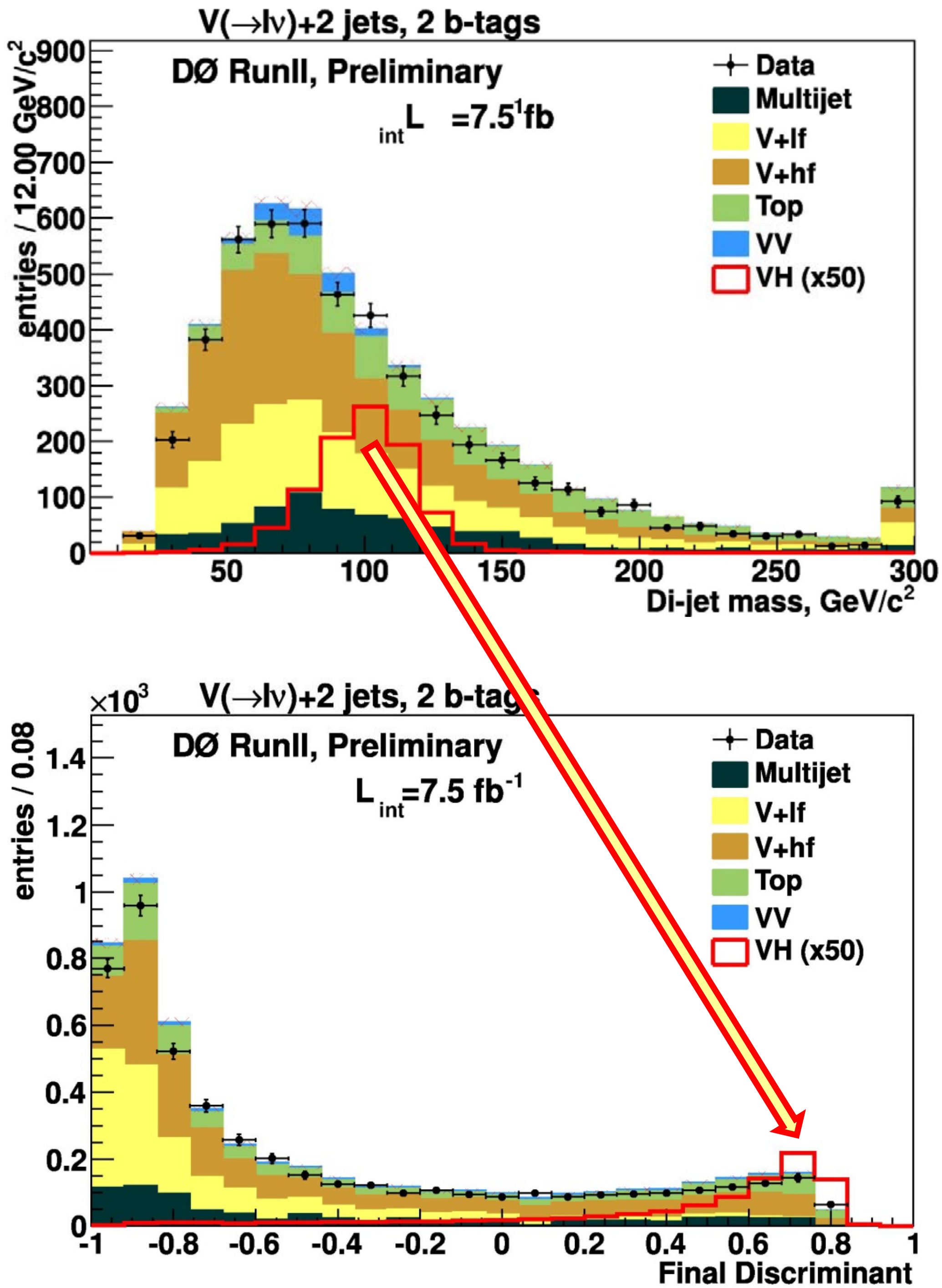
- **To improve S/B ➔ utilize full kinematic event information**

- **Multi Variate Analyses**
  - Neural Networks
  - Boosted Decision Trees

  Or use Matrix Element Calculations to determine probability for an event to be signal or background like

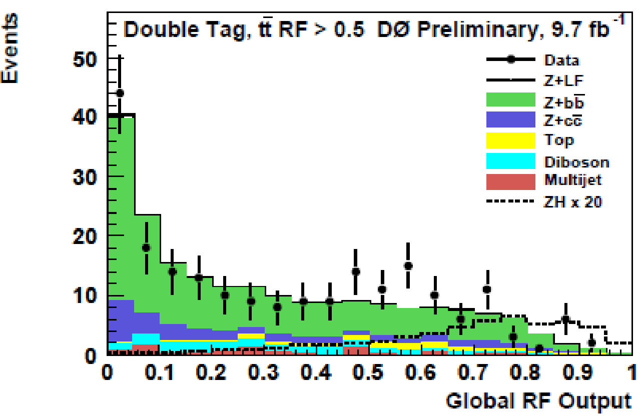
- **Approaches validated in Single Top observation @ Tevatron**
- **Combine these approaches**

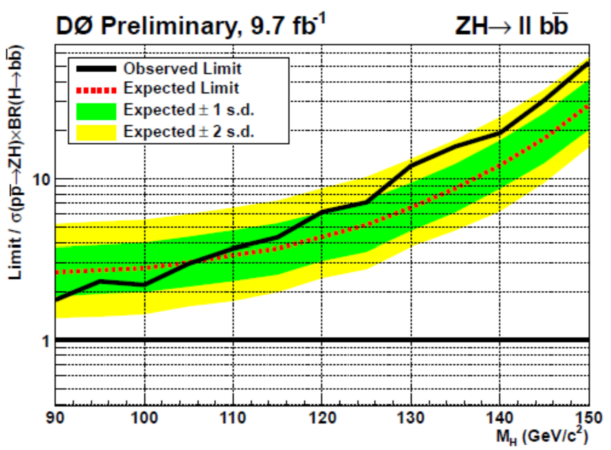
- **Visible gain obtained (~25% in sensitivity)**



Latest Results from DØ

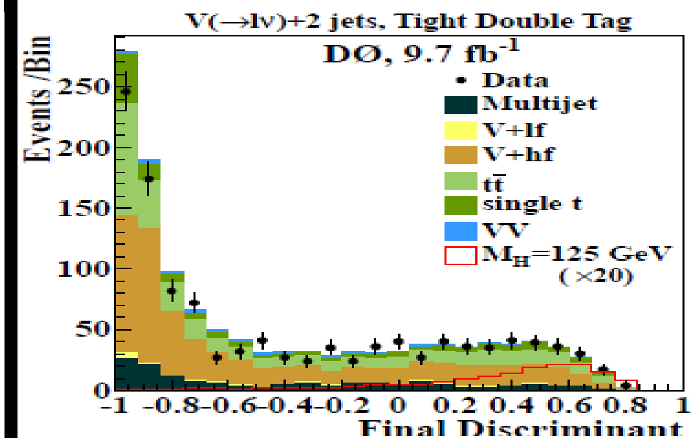
ZH→llbb̄ $\int Ldt = 9.7 fb^{-1}$

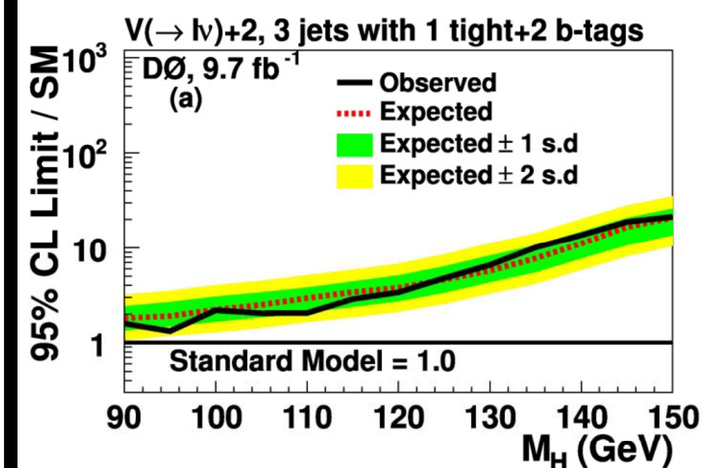




95% CL Exp (obs)
Limit **5.1** (**7.1**) x SM
@ MH=125 GeV

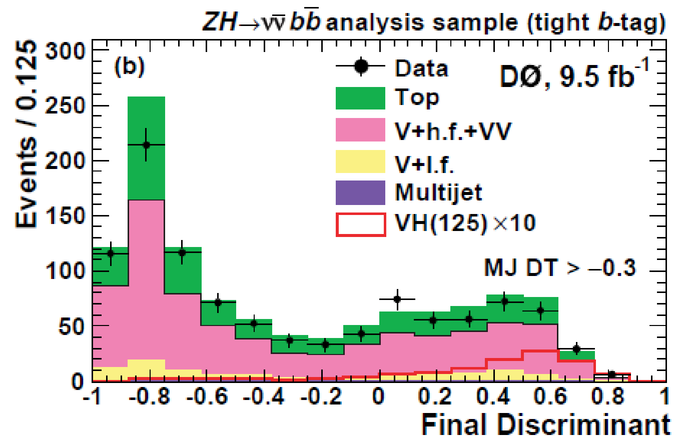
WH→lνbb̄ $\int Ldt = 9.7 fb^{-1}$

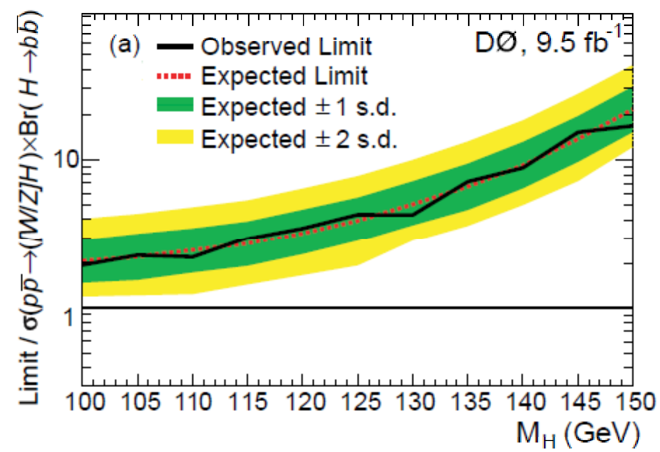




95% CL Exp (obs)
Limit **4.7** (**4.8**) x SM
@ MH=125 GeV (updated 01/13)

ZH→ννbb̄ $\int Ldt = 9.5 fb^{-1}$



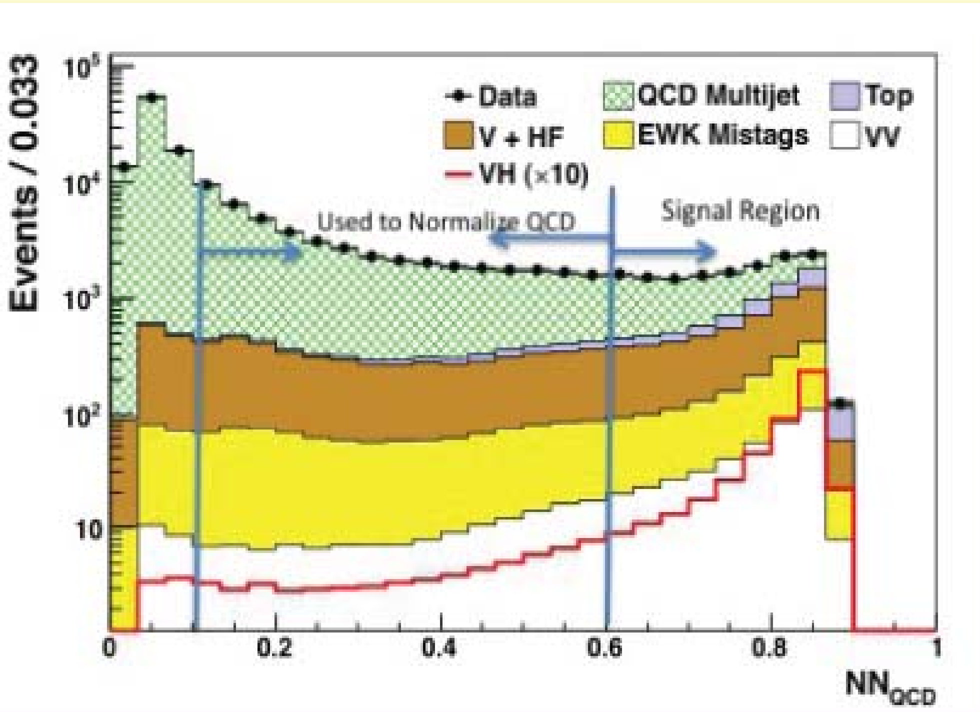


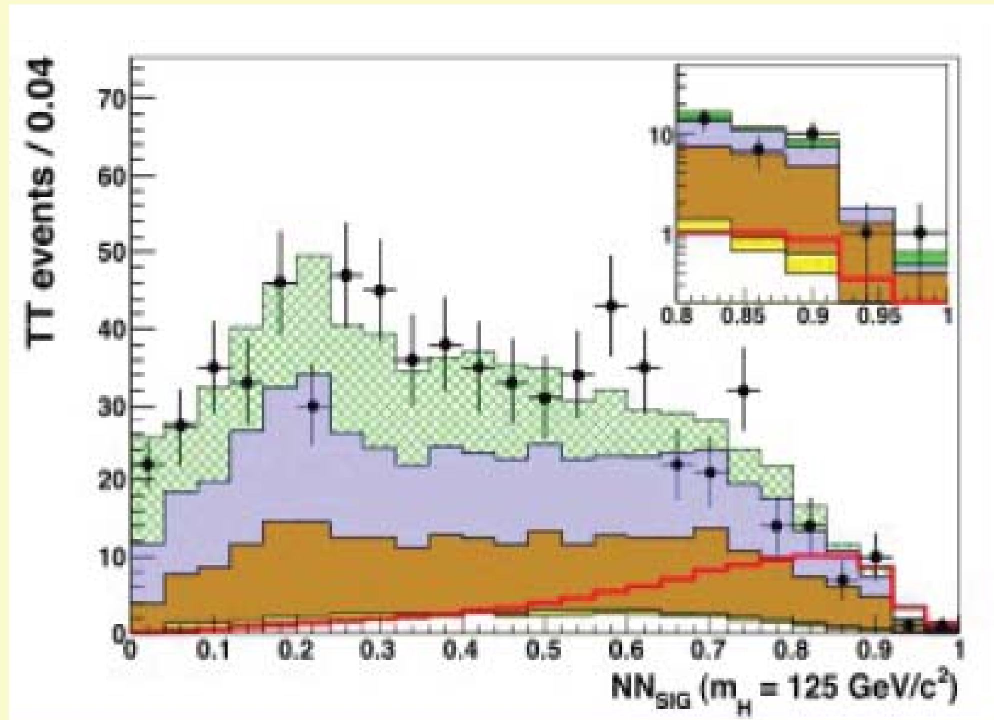
95% CL Exp (obs)
Limit **3.9** (**4.3**) x SM
@ MH=125 GeV

~10-15% gain on intrinsic sensitivity compared to Moriond 2012 result
(i.e. on top of gain due to luminosity)

Updated νν bb (METbb) channel at CDF

- Reject Multijet background with dedicated Neural Network
- Separate signal from the remaining backgrounds using second NN

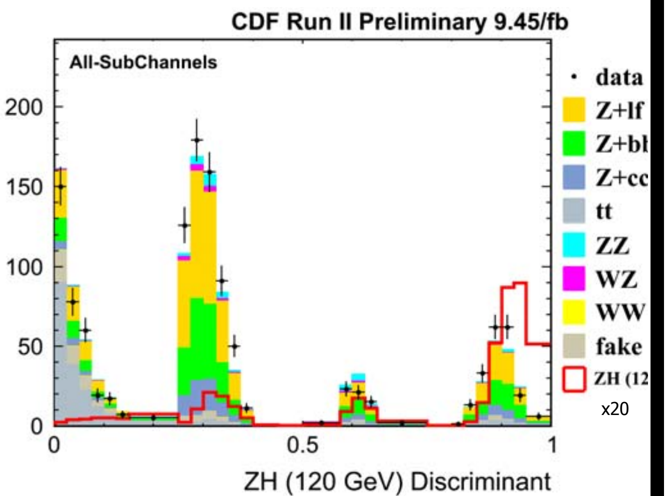


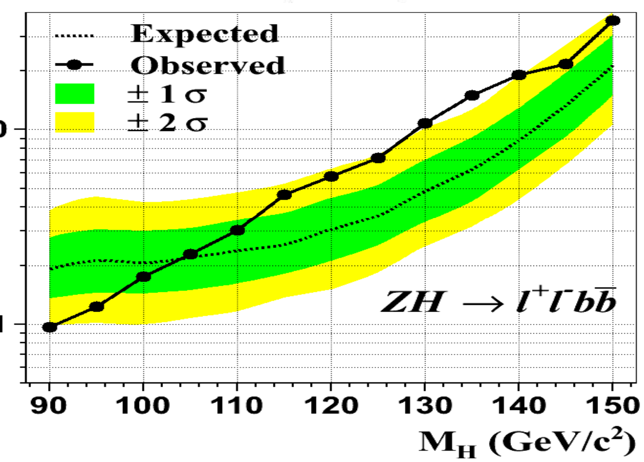


- At m_H=125 GeV: obs = 3.06*SM; exp = 3.33*SM
- 8% sensitivity improvement at m_H=125 GeV (Compared to July 2012)
- Average expected improvement over the whole mass range: 14%

Latest Results from CDF

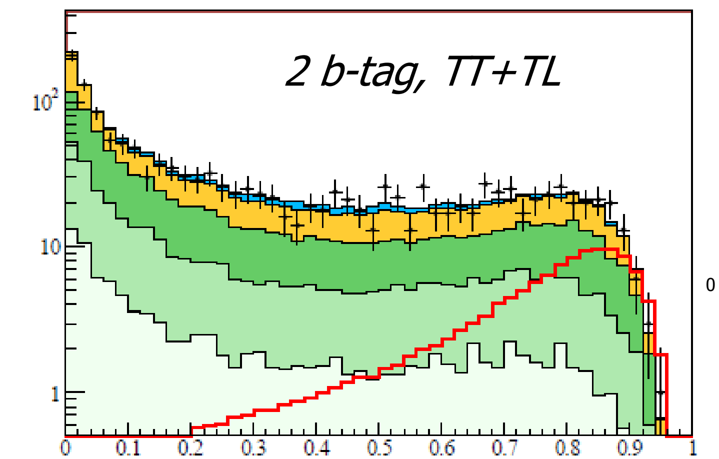
ZH→llbb̄ ∫Ldt=**9.5** fb^{-1}

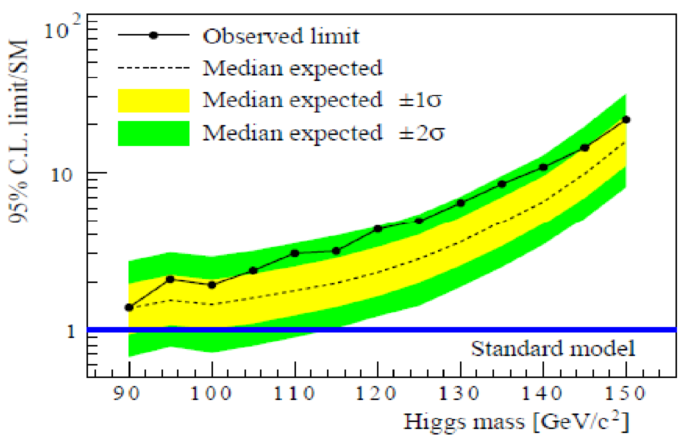




95% CL Exp (obs)
Limit **2.6** (**4.7**) x SM
@ MH=125 GeV

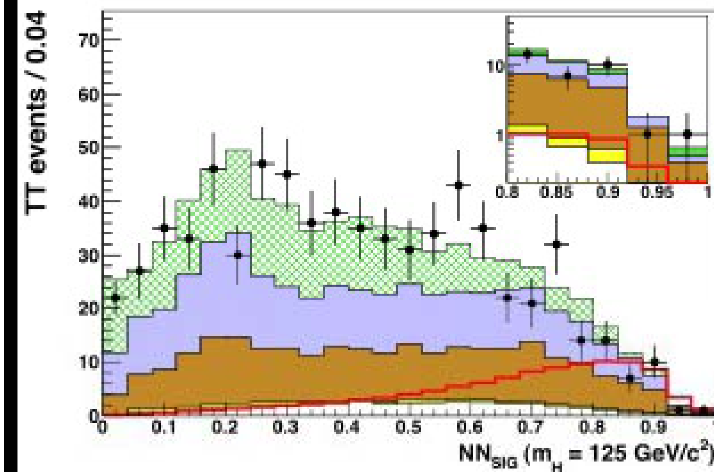
WH→lνbb̄ ∫Ldt=**9.5** fb^{-1}

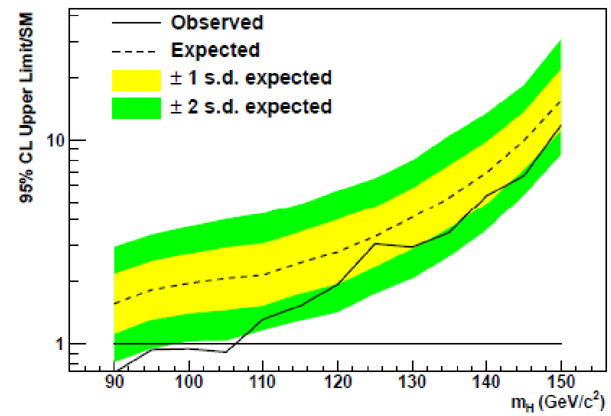




95% CL Exp (obs)
Limit **2.8** (**4.9**) x SM
@ MH=125 GeV

ZH→ννbb̄ ∫Ldt=**9.5** fb^{-1}





95% CL Exp (obs)
Limit **3.3** (**3.1**) x SM
@ MH=125 GeV (updated 01/13)

>20% gain on intrinsic sensitivity compared to 2011

Cross check on Diboson process

Benchmark of H→bb searches with real data.

VZ→leptons + heavy flavor jets

<u>For m_H=115 GeV</u>

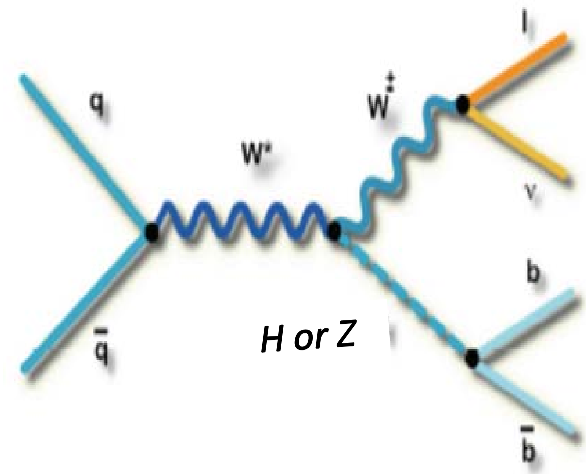
WH→lνbb: σ = 26 fb
ZH→ ννbb:σ = 15 fb
ZH→ llbb: σ = 5 fb

Total VH: σ = 46 fb

<u>Replace H with Z</u>

WZ→lνbb: σ = 105 fb
ZZ →ννbb: σ = 81 fb
ZZ → llbb: σ = 27 fb

Total VZ: σ = 213 fb

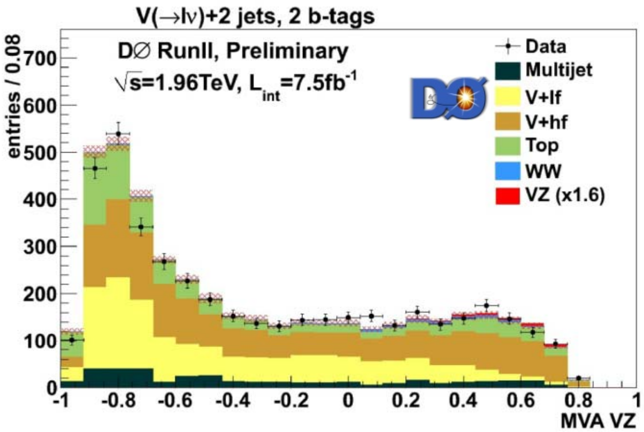


At 115 GeV, Z→bb yields is 5 times larger, but lower BR than H→bb, much more W+jets backgrounds, and difficult background from WW.

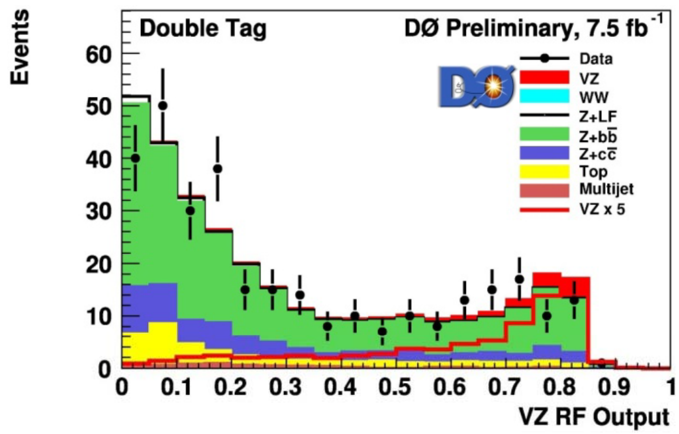
Apply similar analysis as low mass H→bb analysis, and check sensitivity.

Benchmarks : Dibosons to Heavy Flavor

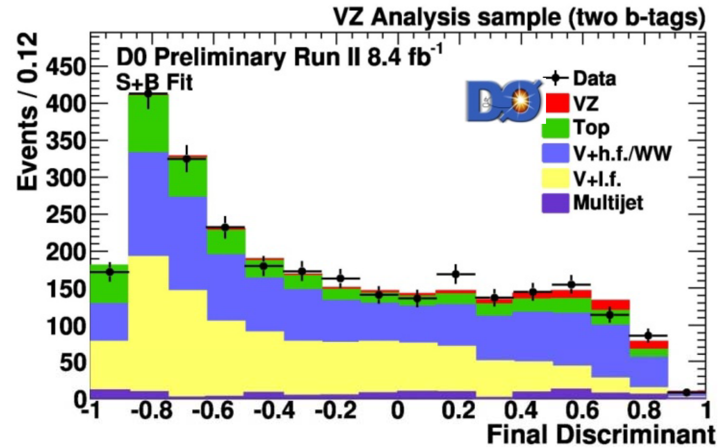
Diboson lvbb



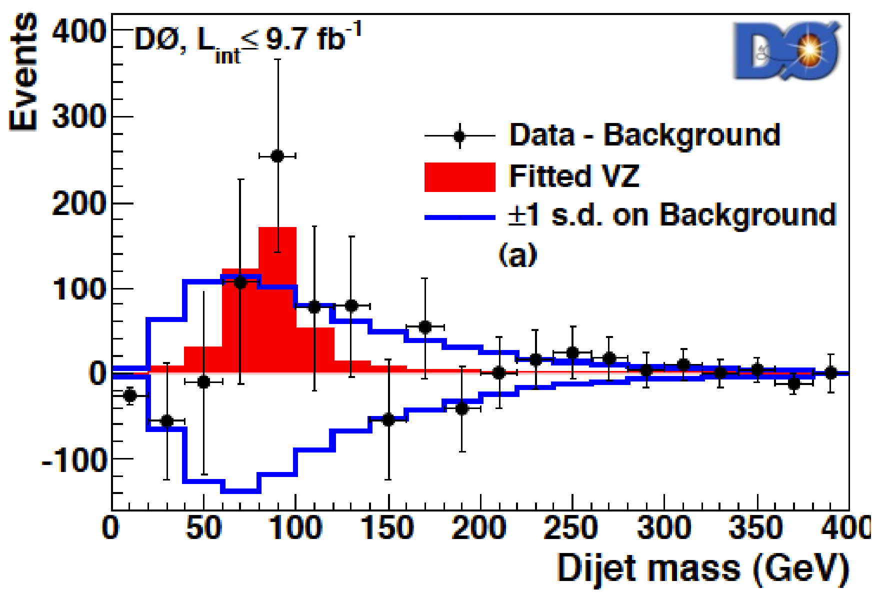
Diboson llbb

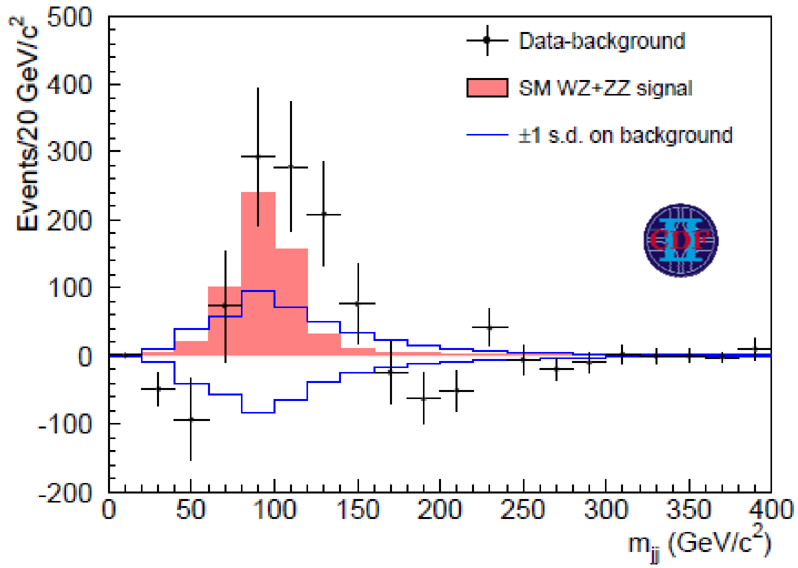


Diboson vvbb



Combining all three channels, maintaining proper correlation among channels, keeping WW as background, ➔ Evidence (>3 sigma / experiment) for WZ/ZZ decaying to H.F



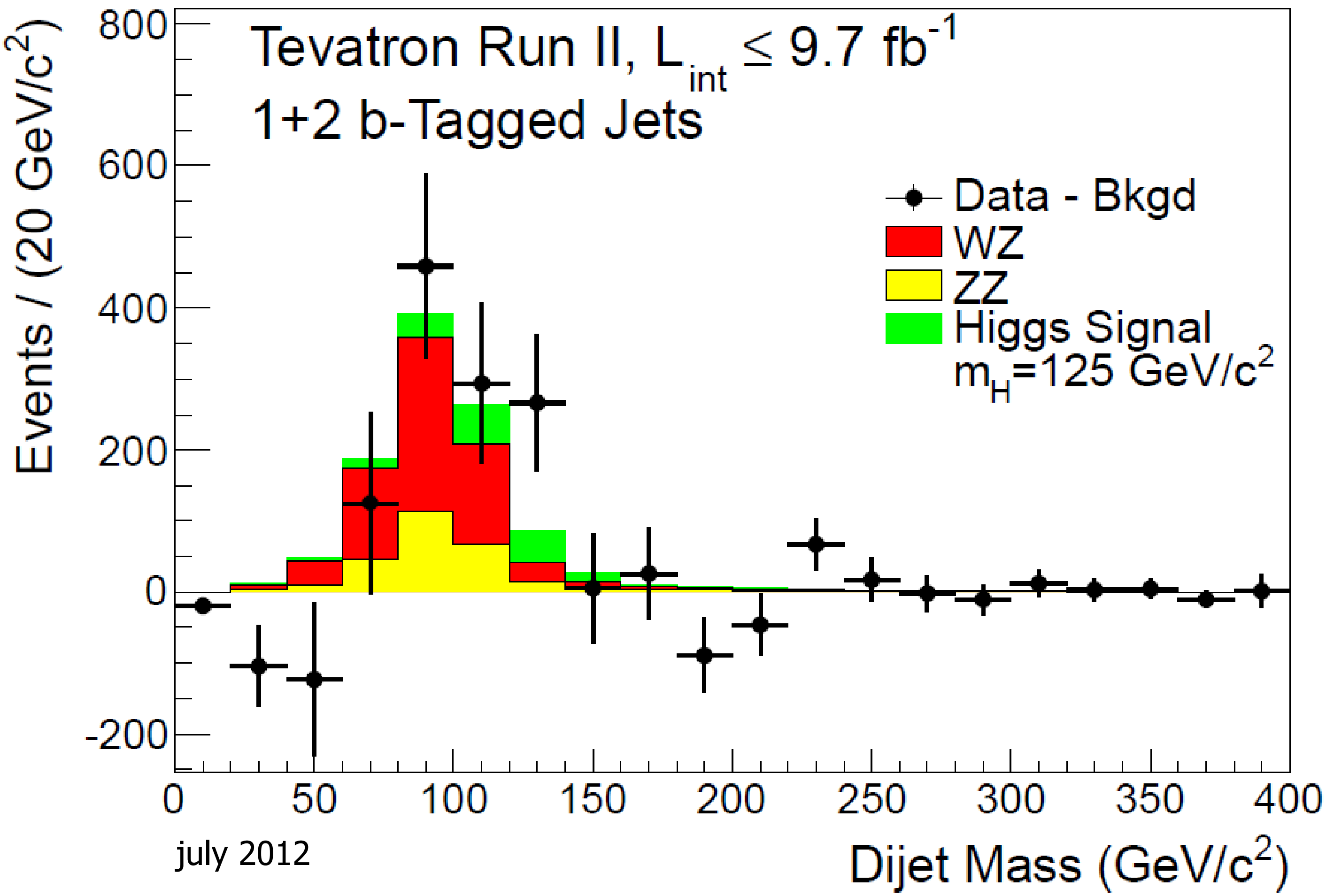


Benchmarks : Dibosons to Heavy Flavor

CDF- D0 combination on the same dataset/techniques as for H→bb:

→ ~ 4.5 sigma significance

cross-section: 3.9 +/- 0.9 pb (NLO: 4.4 +/- 0.3 pb)

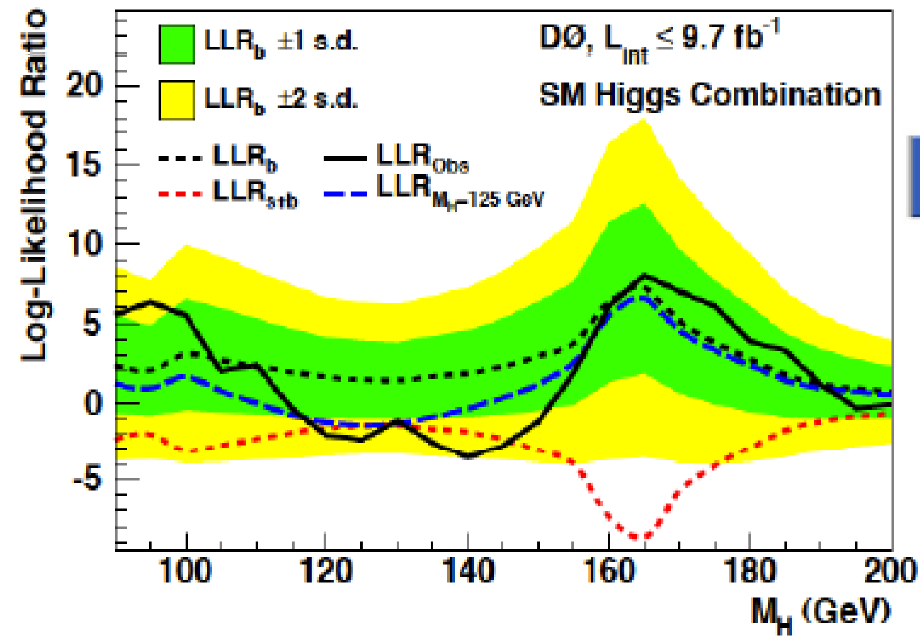


→ Since there is a light SM Higgs, we should "see" it!

Sensitivity of the search / LLR plot

Background-like outcomes

Signal-like outcomes

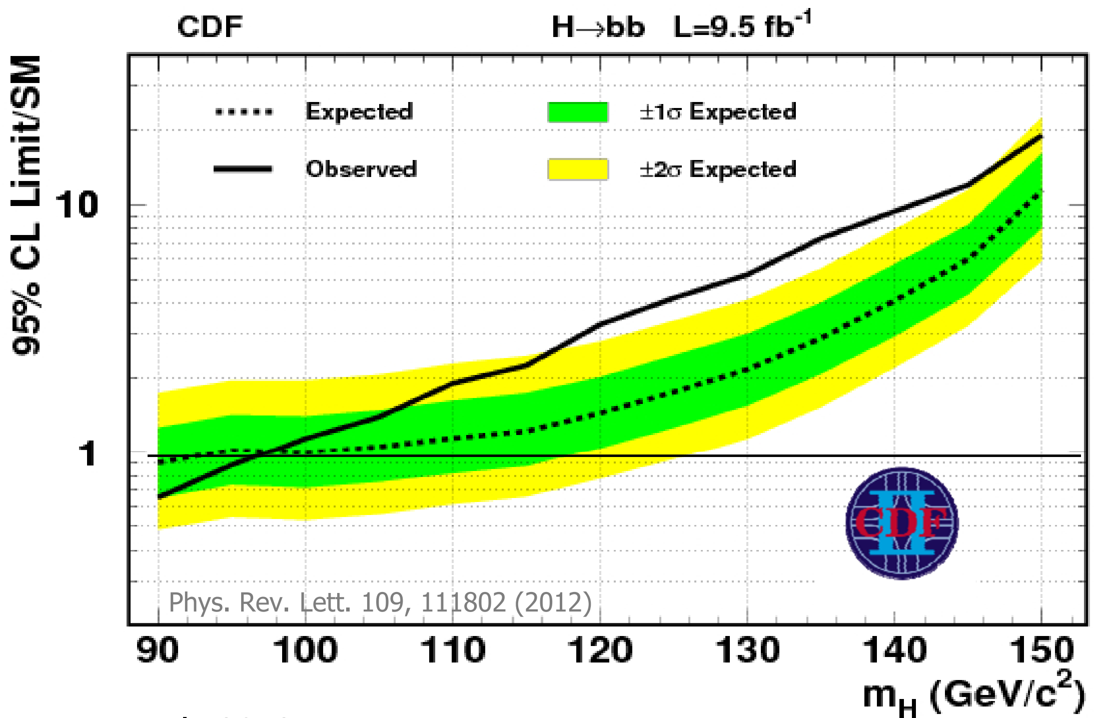


The separation between LLR_b and LLR_{s+b} provides a measure of the discriminating power of the search

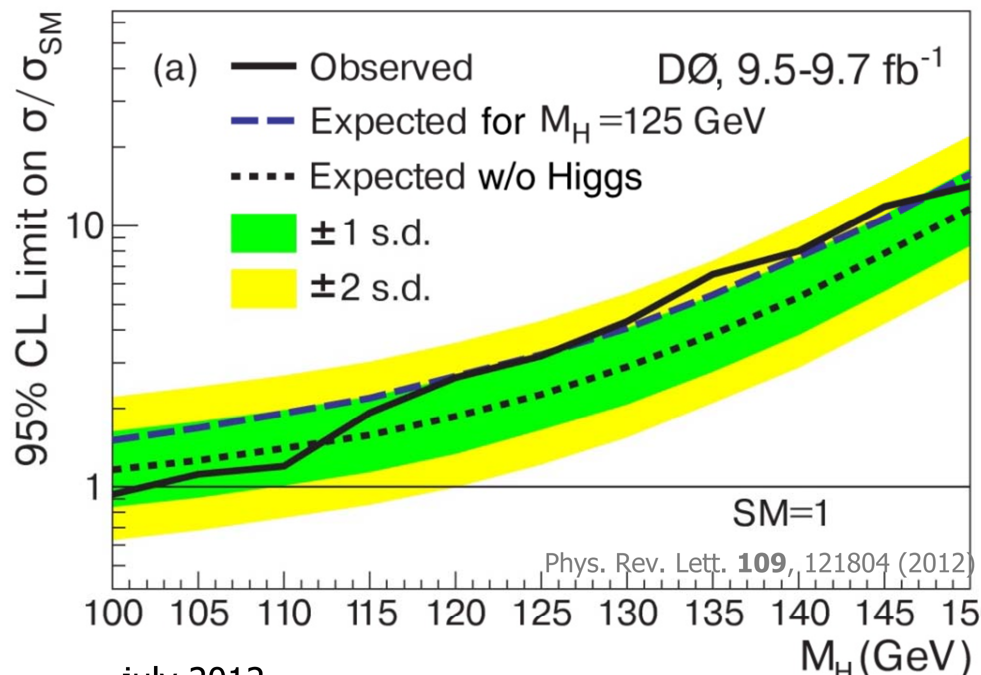
The width of the Log Likelihood Ratio, LLR_b, distribution (1 s.d. and 2 s.d. bands) provides an estimate of how sensitive the analysis is to a signal-like background fluctuation in the data, taking account of the presence of systematic uncertainties

The value of LLR_{obs} relative to LLR_{s+b} and LLR_b indicates whether the data distribution appears to be more like signal-plus-background or background-only.

H→bb, Individual Experiment Results



july 2012



july 2012

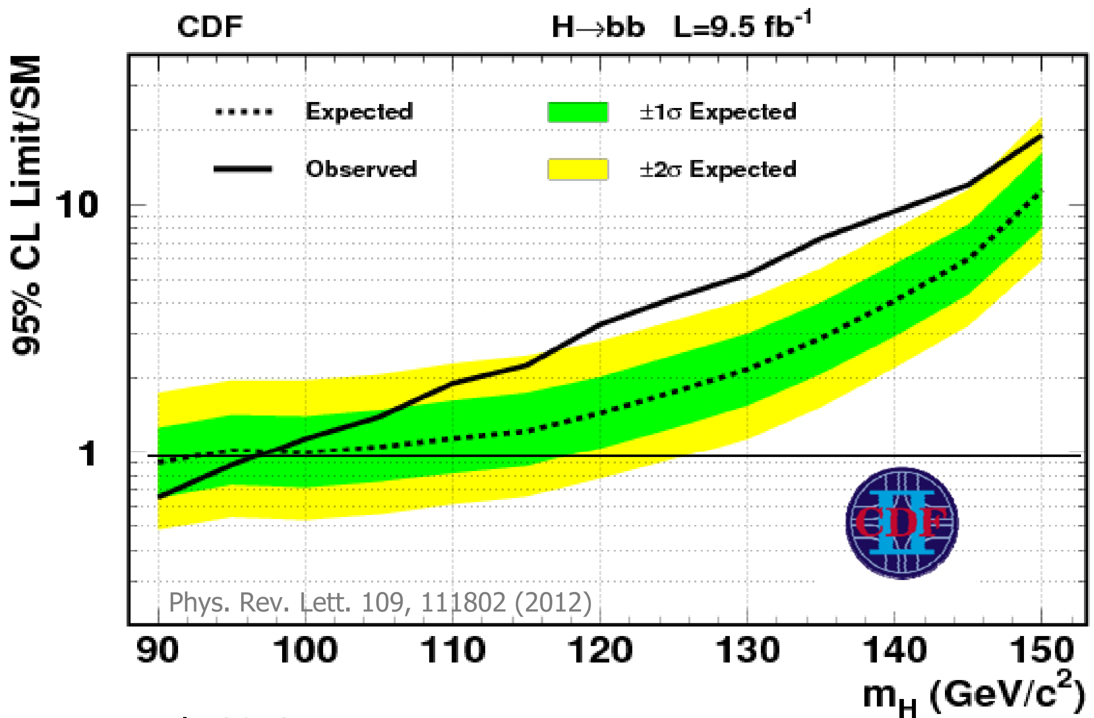
> 2 sigma excess in 120-145 GeV
Global significance **2.5 σ**

> 1 sigma excess in 120-145 GeV
Global significance **1.5 σ**

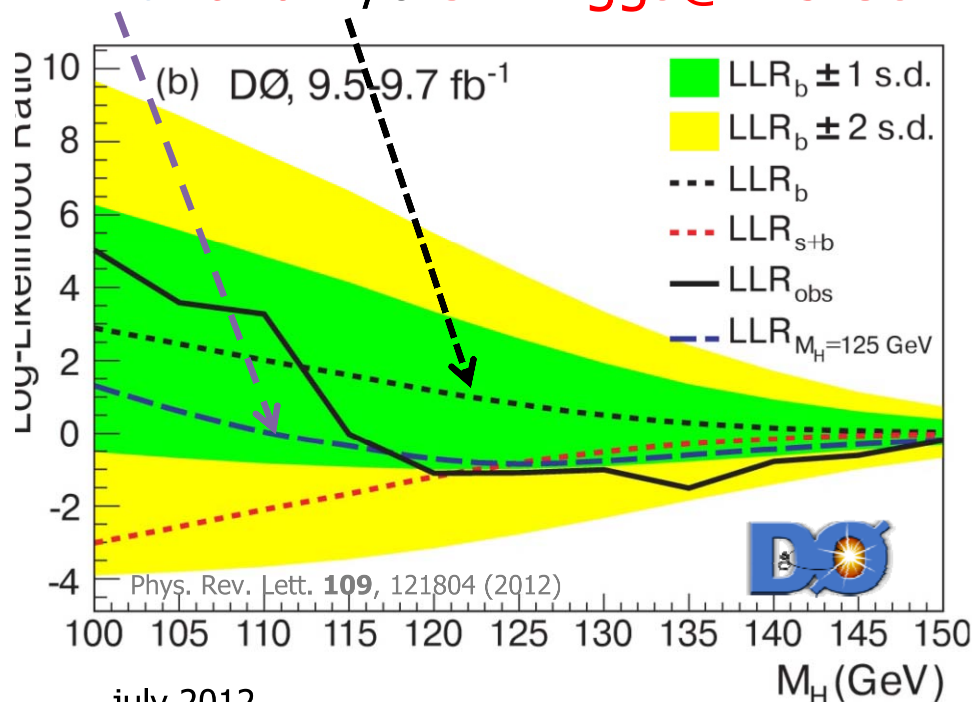
Using LEE for 115-150 GeV, since
<115 GeV excluded in H→bb by LEP

H→bb, Individual Experiment Results

LLR plot compared to SM
with and w/o SM Higgs@125 GeV



july 2012



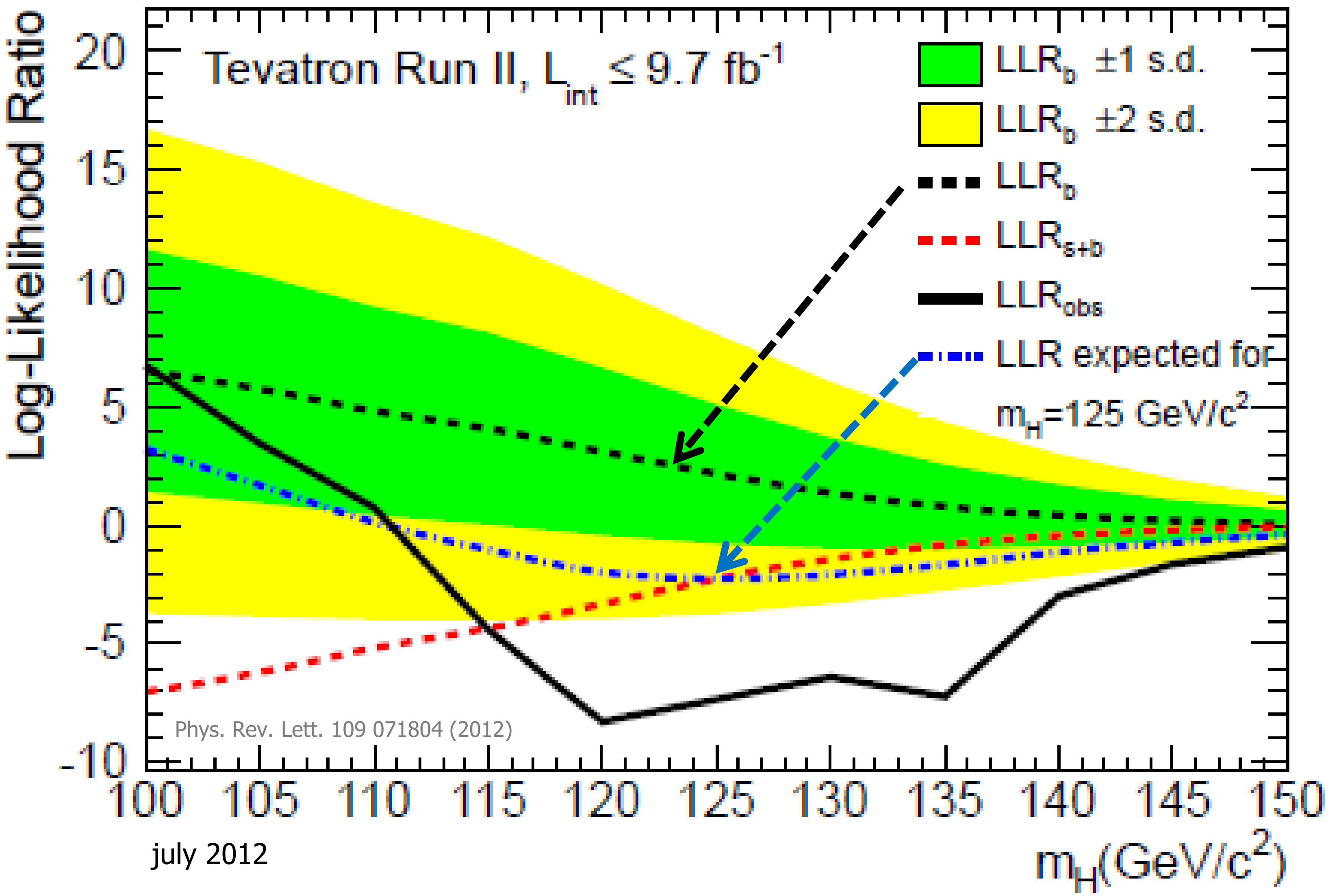
july 2012

> 2 sigma excess in 120-145 GeV
Global significance **2.5 σ**

> 1 sigma excess in 120-145 GeV
Global significance **1.5 σ**

Using LEE for 115-150 GeV, since
<115 GeV excluded in H→bb by LEP

Combined LLR for H→ bb and signal injection



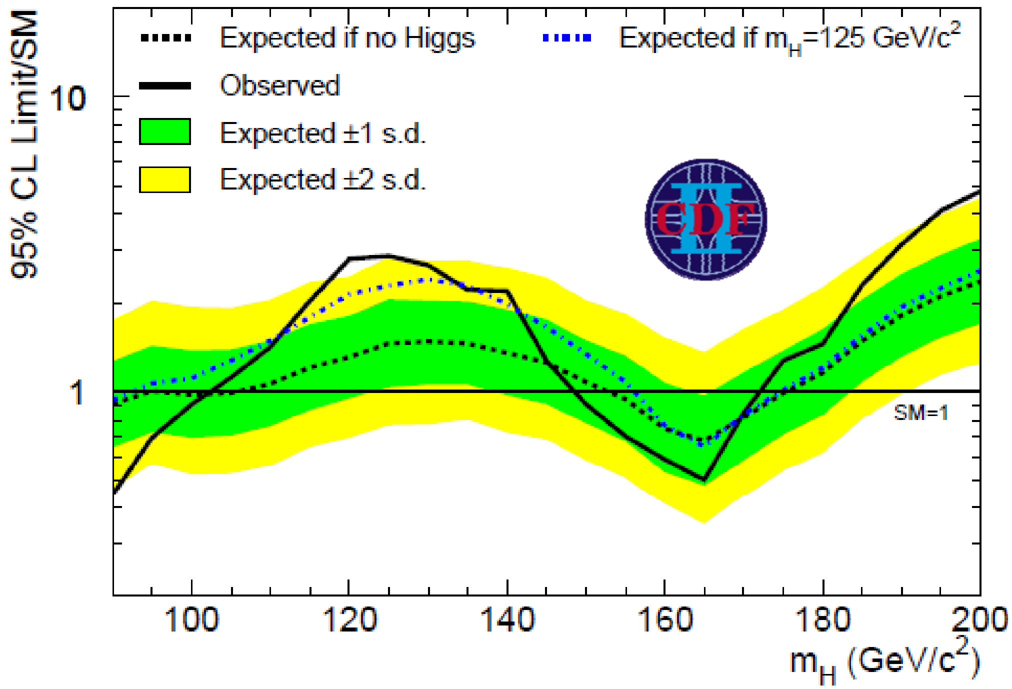
july 2012

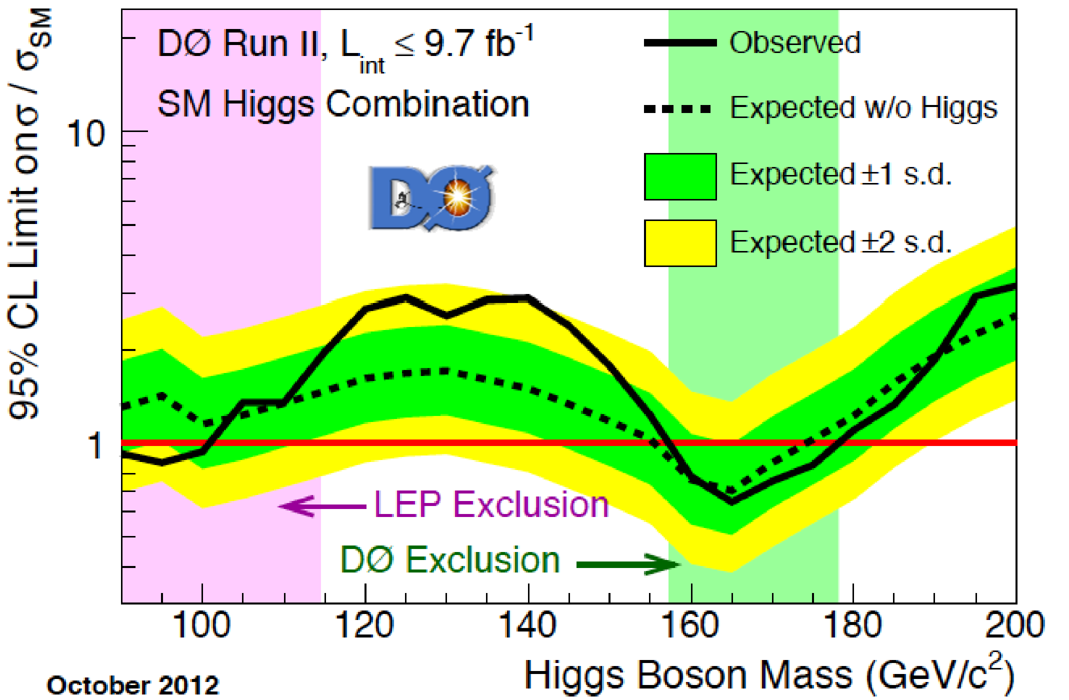
shape is OK, excess more pronounced than expected with a 120-135 GeV SM Higgs

➔ Data prefer higher x-section*BR than SM with 125 GeV Higgs

Individual Experiment Results

CDF & D0 single-experiment combinations of all SM Higgs search channels($H \to WW$, $H \to bb$, $H \to \gamma\gamma$ + other)





October 2012

Remarkably similar shapes: excess <1 sigma below ~110 GeV,
broad excess around ~120-140 GeV,
exclusion around ~165 GeV

Observed 95% CL exclusion:

$90 < m_H < 102$ GeV, $152 < m_H < 172$ GeV

At m_H = 125 GeV:
Exp. limit: 1.46 x SM
Obs. limit: 2.89 x SM

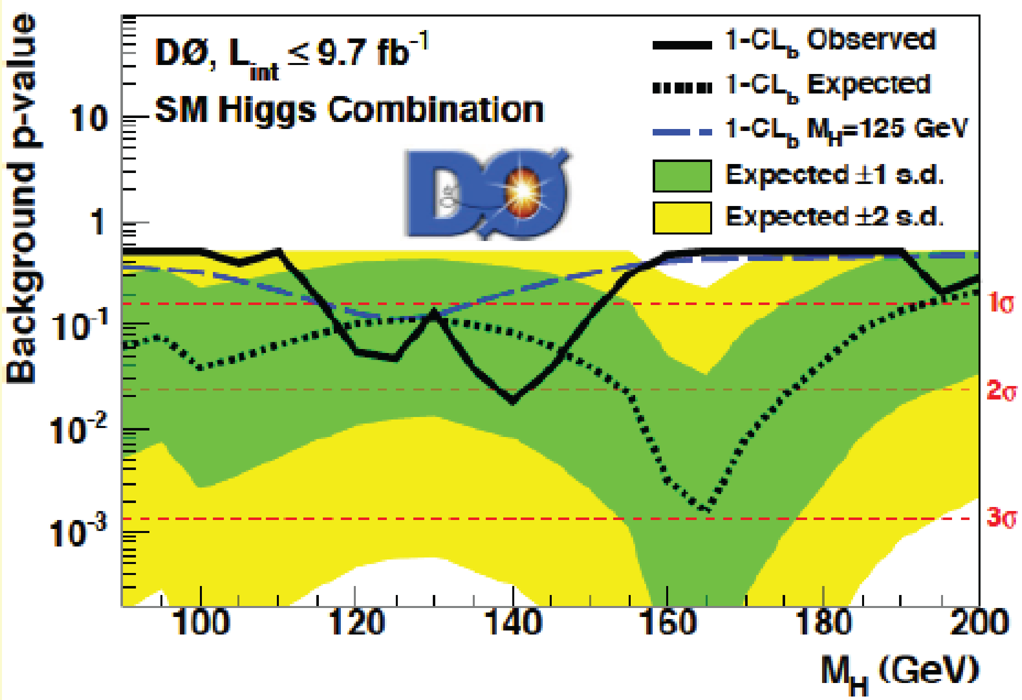
Observed 95% CL exclusion:

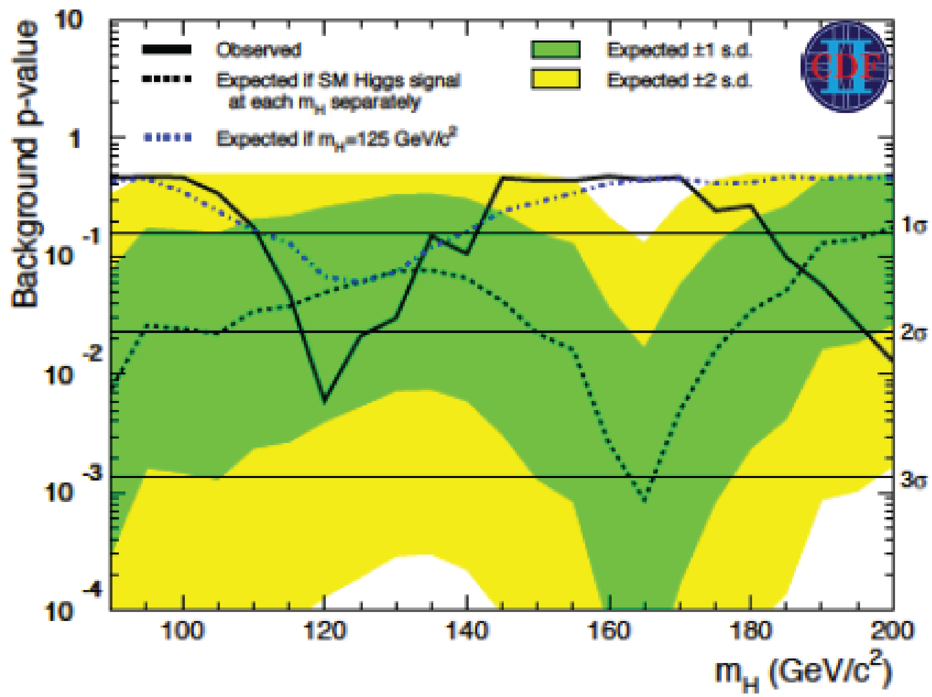
$90 < m_H < 101$ GeV, $157 < m_H < 178$ GeV

At m_H = 125 GeV:
Exp. limit: 1.66 x SM
Obs. limit: 2.92 x SM

Full combination: P-values

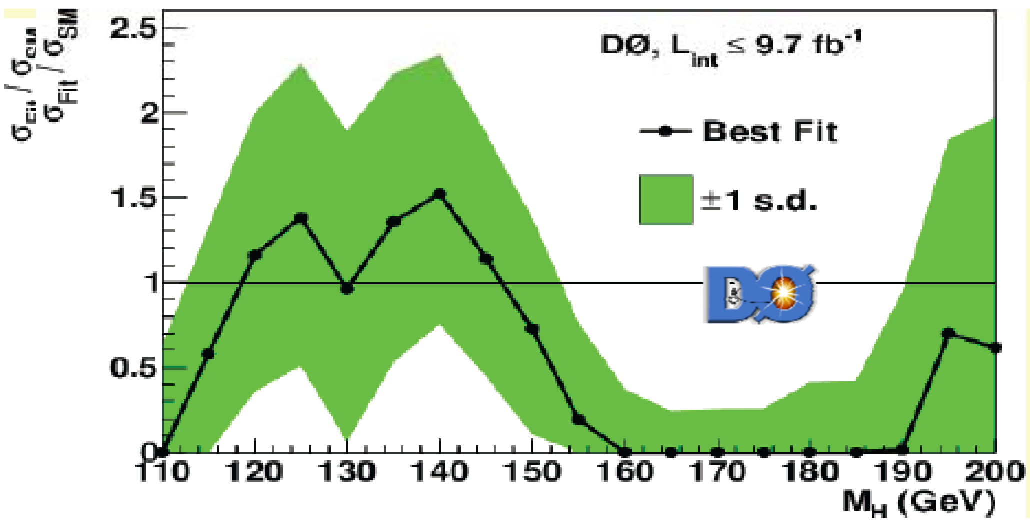
- p-value for background hypothesis provides information about the consistency with the observed data
- Local p-value distribution for background only expectation:
  - D0: 1.7 s.d. (@125 GeV)
  - CDF: 2.0 s.d. (@125 GeV)

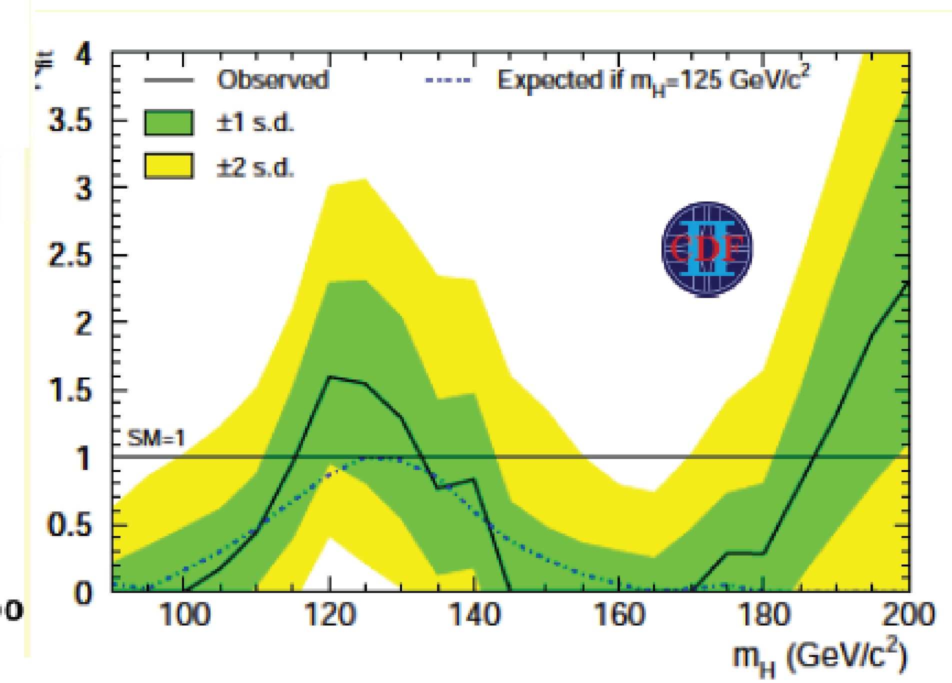




Signal strenght: CDF and D0 combinations

For m_H @ 125 GeV



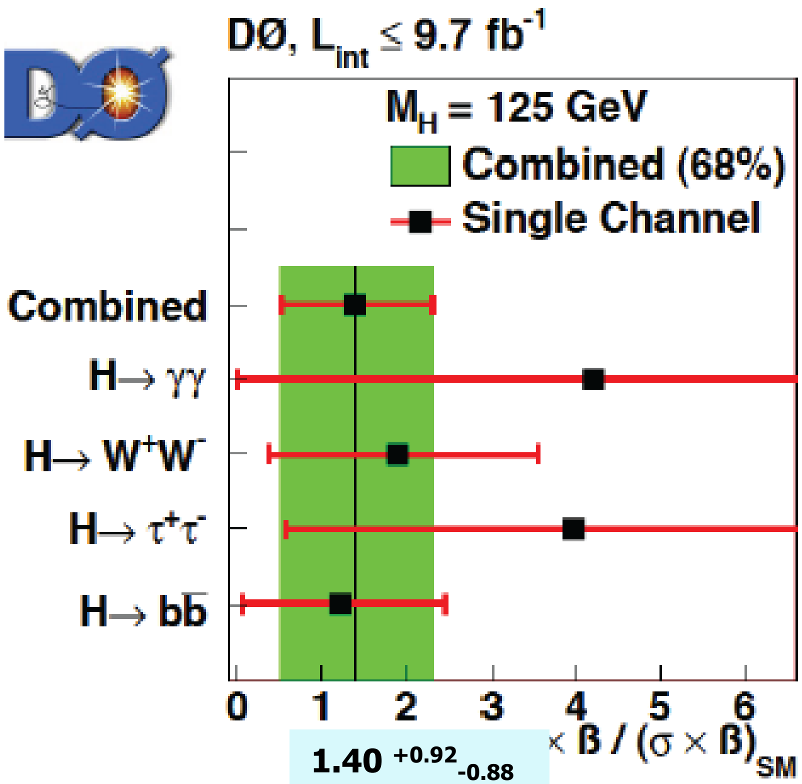


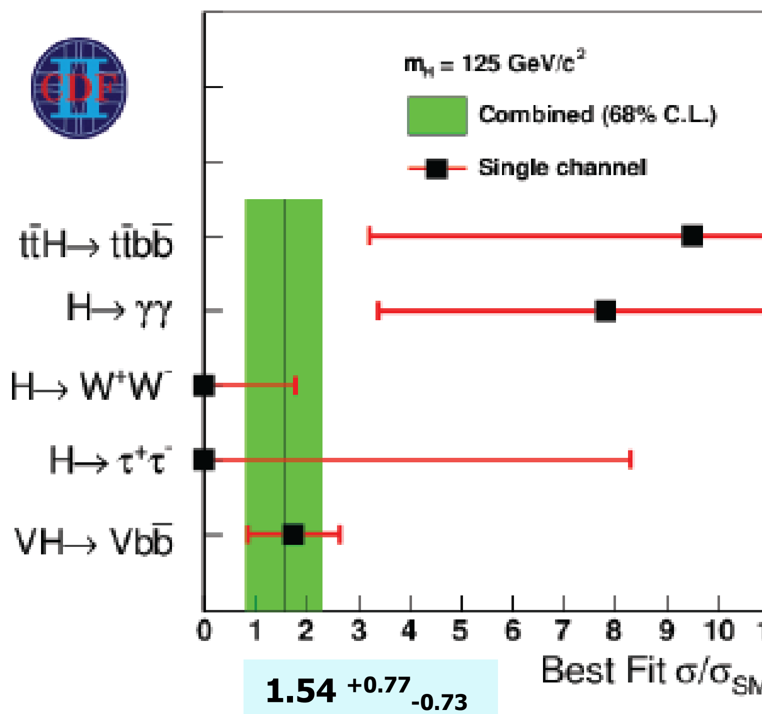
$1.40^{+0.92}_{-0.88}$

$1.54^{+0.77}_{-0.73}$

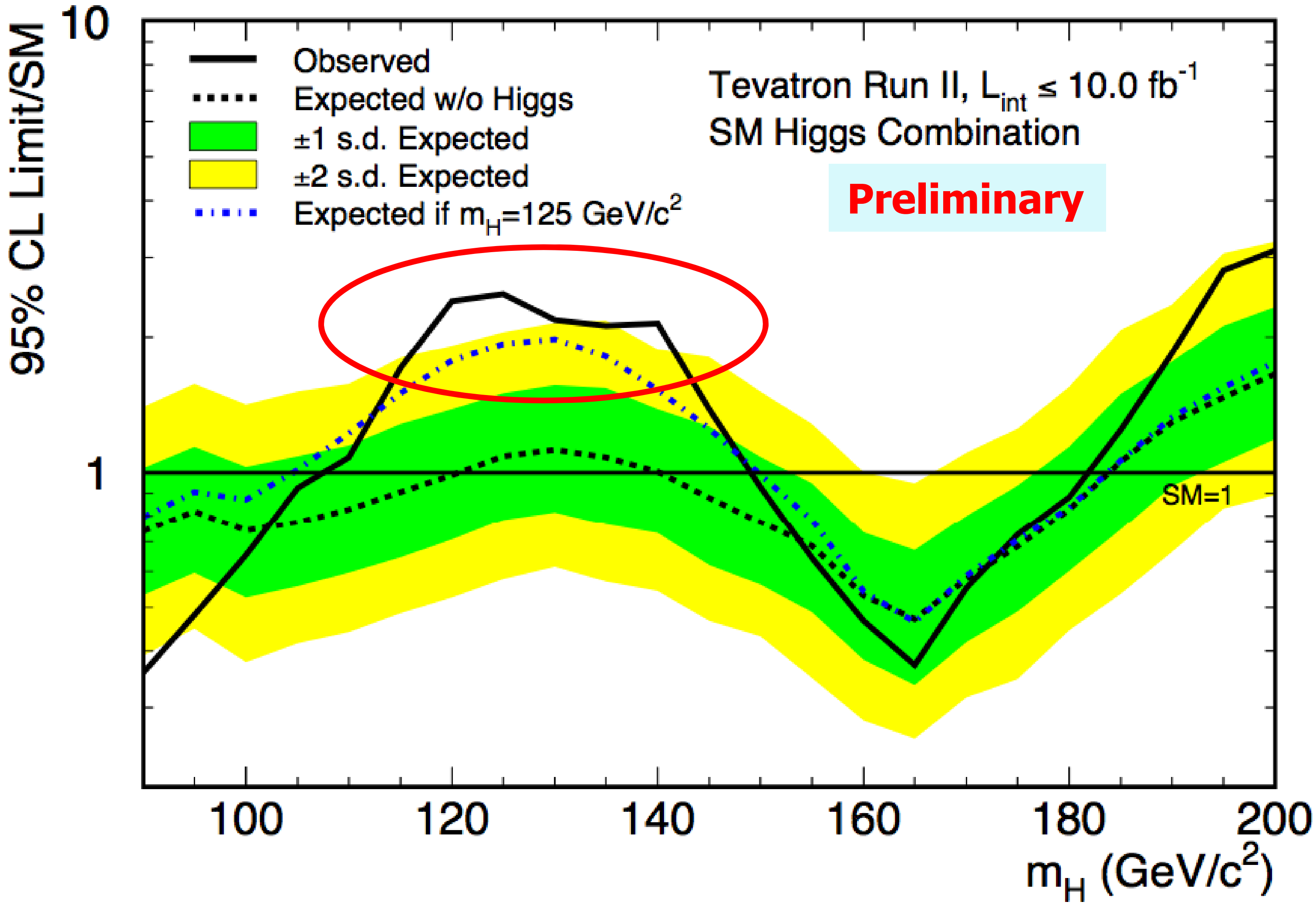
Signal strenght per channel

	DØ	CDF
Combination	$1.40^{+0.92}_{-0.88}$	$1.54^{+0.77}_{-0.73}$
$H \to \gamma\gamma$	$4.20^{+4.60}_{-4.20}$	$7.81^{+4.61}_{-4.42}$
$H \to \tau^+\tau^-$	$3.96^{+4.11}_{-4.38}$	$0.00^{+8.44}_{-0.00}$
$H \to W^+W^-$	$1.90^{+1.63}_{-1.52}$	$0.00^{+1.78}_{-0.00}$
$VH \to Vb\bar{b}$	$1.23^{+1.24}_{-1.17}$	$1.72^{+0.92}_{-0.87}$
$t\bar{t}H \to t\bar{t}b\bar{b}$	N/A	$9.49^{+6.60}_{-6.28}$





HCP 2012 Tevatron combination

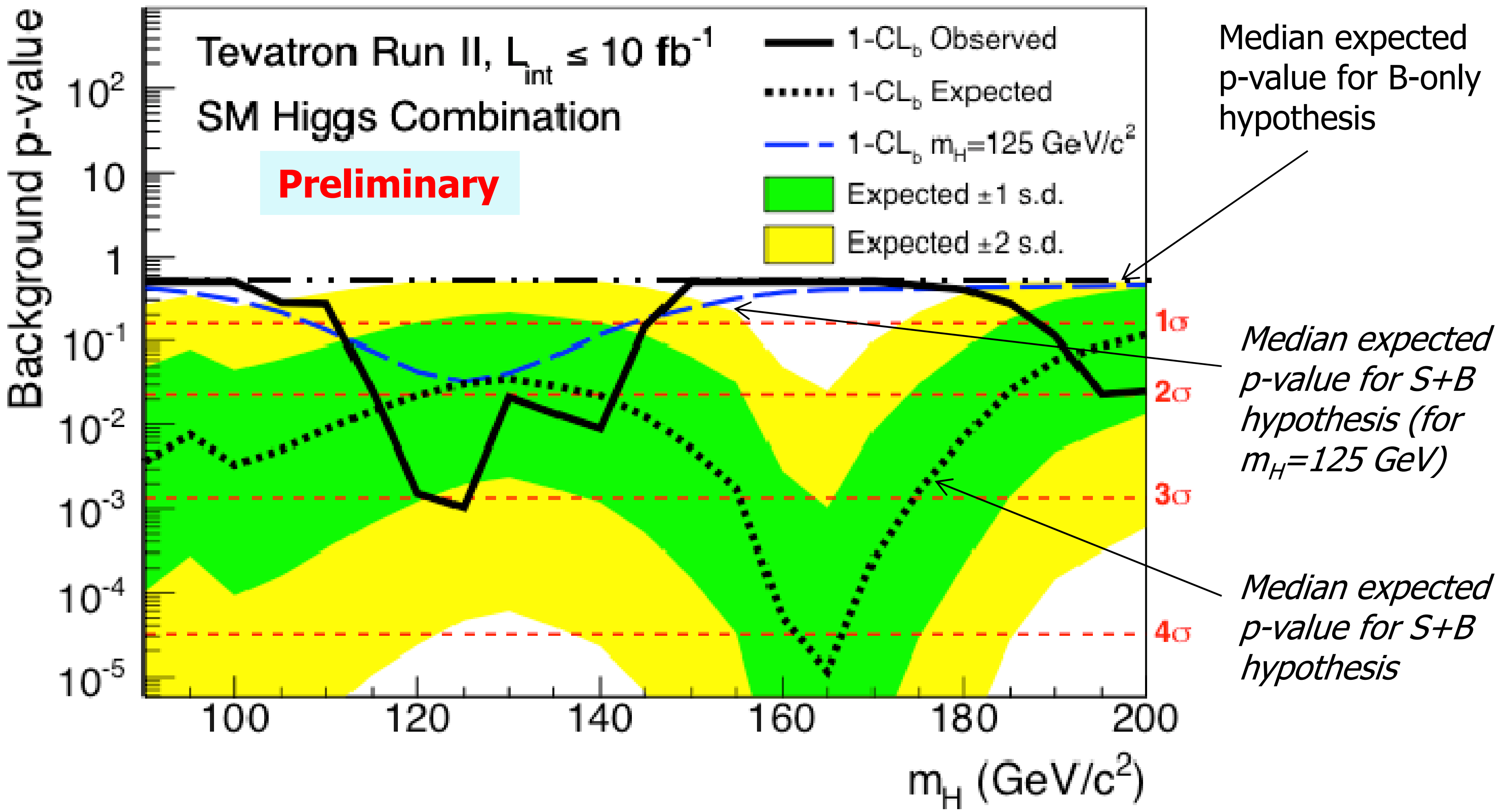


- Expected exclusion: 90 < m_H < 121 GeV, 140< m_H < 184 GeV
  Observed exclusion: 90 < m_H < 107 GeV, 149 < m_H < 182 GeV
- 95% CL limit at m_H=125 GeV: 1.09xSM (expected), 2.49xSM (observed)

Significant excess, 2-3 sigma for 115→140 GeV

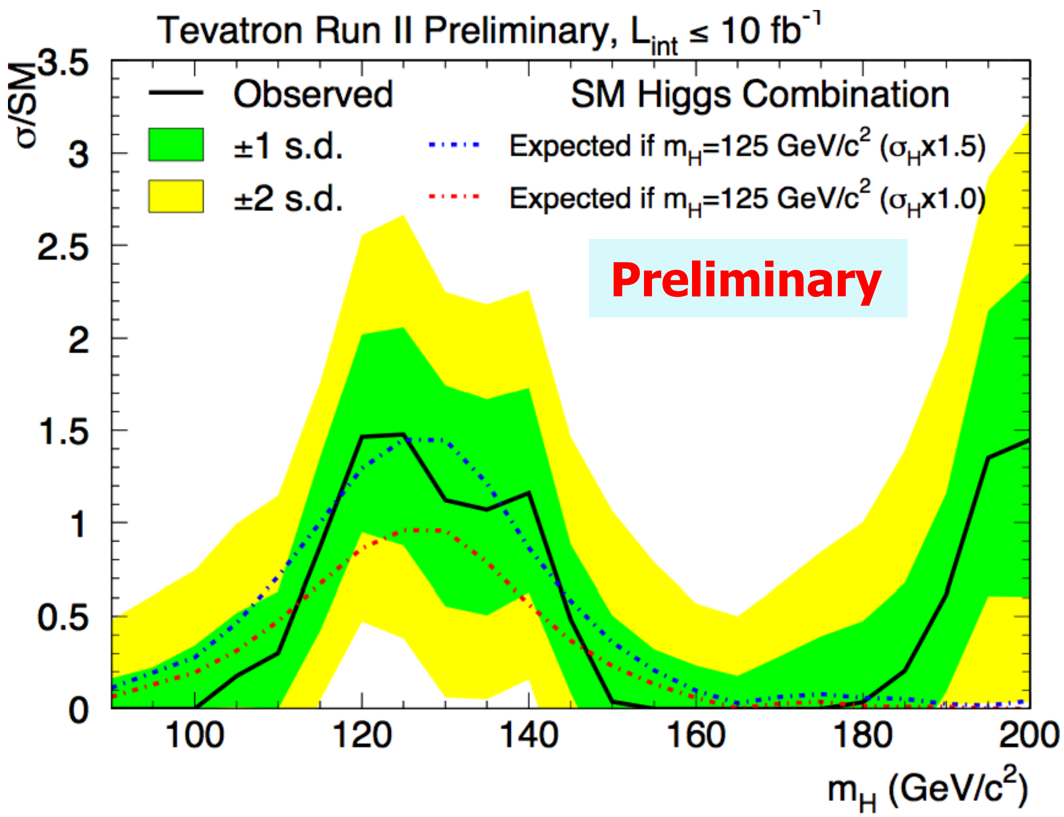
Quantifying the Excess: p-values

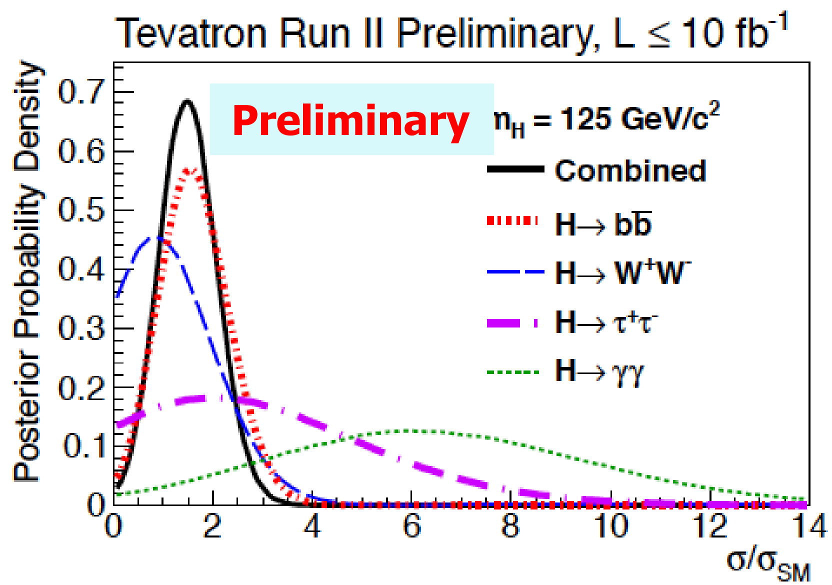
- Local p-value distribution for background-only hypothesis:

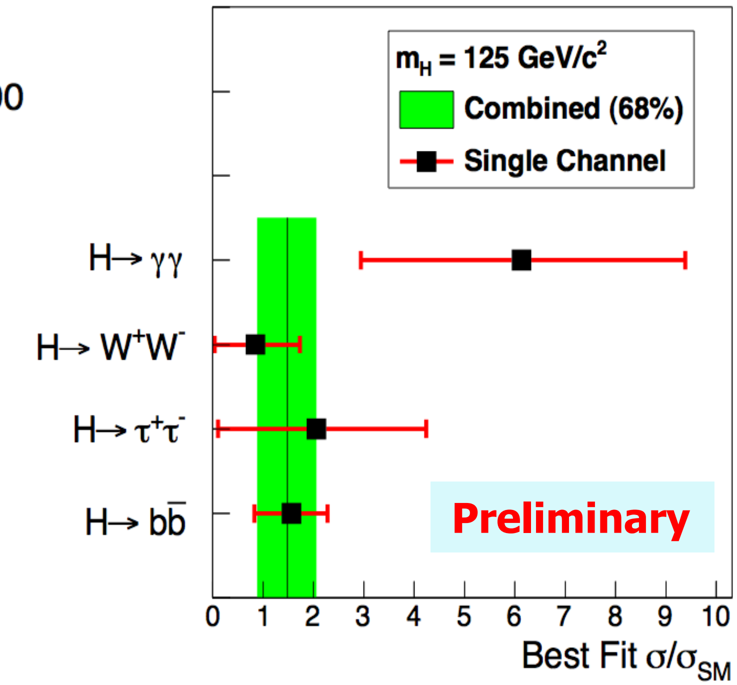


- **Minimum local p-value at m_H=125 GeV: 3.1σ (1.9σ expected)**

Quantifying the Excess: Best Fit Signal Rate







- Maximum likelihood fit to data with signal rate as free parameter.
- Best-fit signal rate at m_H=125 GeV:

$$\sigma_{fit} / \sigma_{SM} = 1.5 \pm 0.6$$

Consistent with SM Higgs.

Reasonably consistent across channels.

Probing Higgs Boson Couplings

- Several production and decay mechanisms contribute to signal rates per channel
  ➔ interpretation is difficult
- A better option: measure deviations of couplings from the SM prediction (arXiv:1209.0040).
  Basic assumptions:
  - there is only one underlying state at m_H~125 GeV,
  - it has negligible width,
  - it is a CP-even scalar (only allow for modification of coupling strengths, leaving the Lorentz structure of the interaction untouched).

  Additional assumption made in this study:
  - no additional invisible or undetected Higgs decay modes.
- Under these assumptions all production cross sections and branching ratios can be expressed in terms of a few common multiplicative factors to the SM Higgs couplings.
  Examples:

$$\sigma(gg \to H)BR(H \to WW) = \sigma_{SM}(gg \to H)BR_{SM}(H \to WW)\frac{\kappa_g^2 \kappa_W^2}{\kappa_H^2}$$

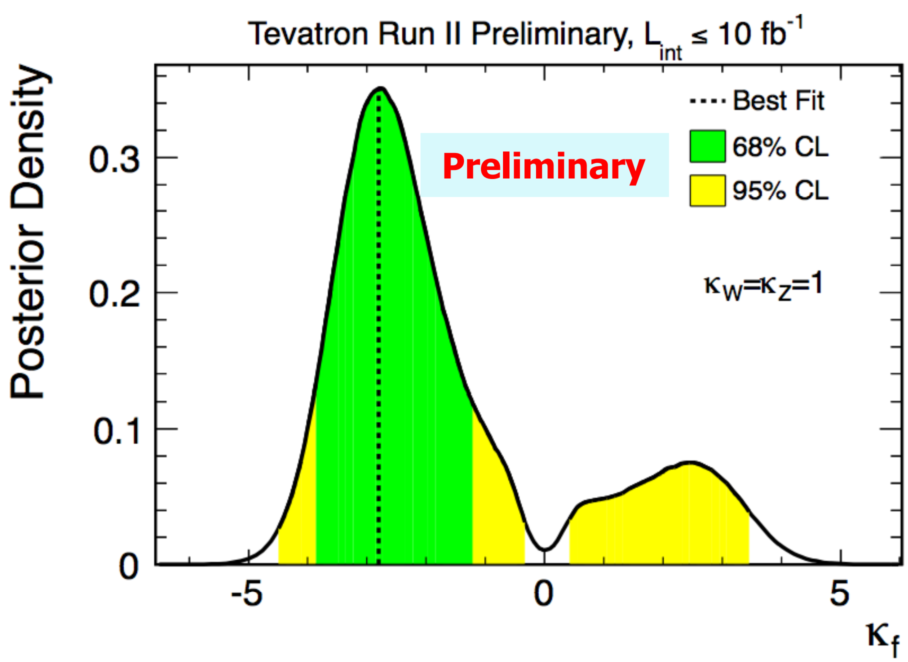
$$\sigma(WH)BR(H \to bb) = \sigma_{SM}(WH)BR_{SM}(H \to bb)\frac{\kappa_W^2 \kappa_b^2}{\kappa_H^2}$$

$$\kappa_g = f(\kappa_t, \kappa_b, M_H)$$

$$\kappa_H = f'(\kappa_t, \kappa_b, \kappa_\tau, \kappa_W, \kappa_Z, M_H)$$

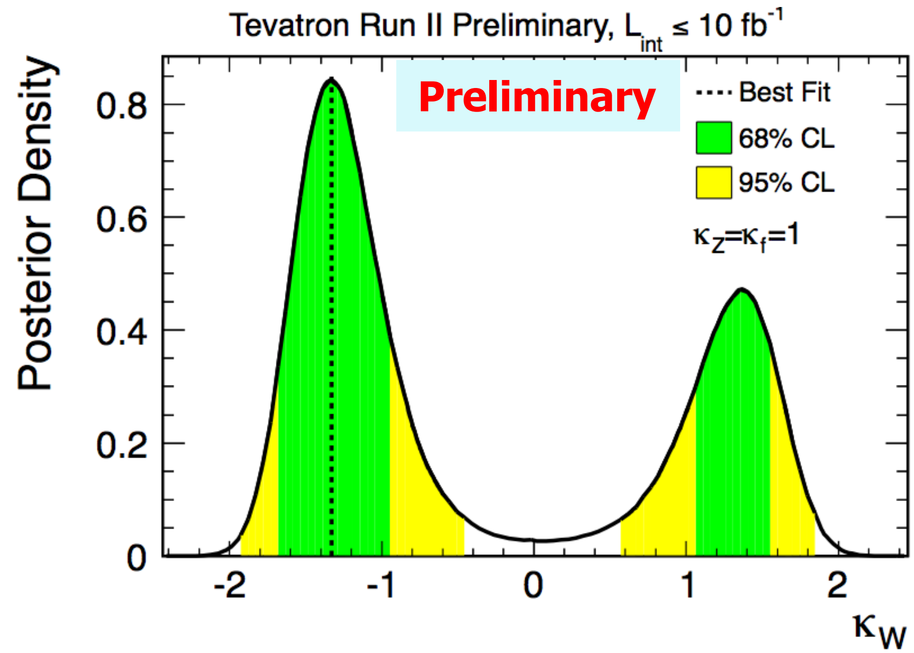
Probing Higgs Boson Couplings: Benchmark I

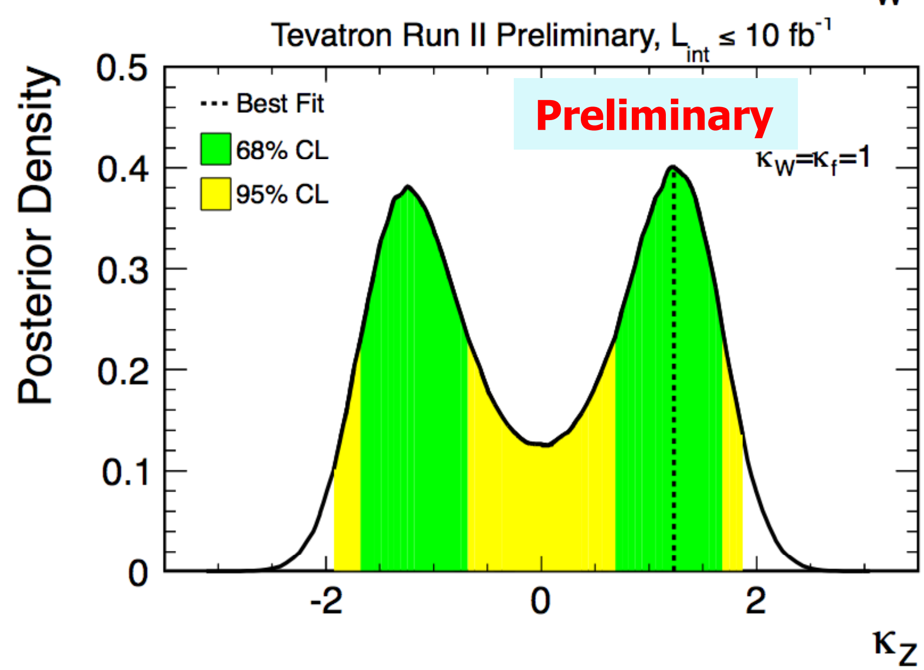
- Simplest scenario of measuring one coupling at a time assuming SM value for the rest.



- Preference for negative value for $\kappa_W(\kappa_f)$ when $\kappa_f=1(\kappa_W=1)$ due to mild excess in $H\rightarrow\gamma\gamma$ (enhancement if BR($H\rightarrow\gamma\gamma$)).

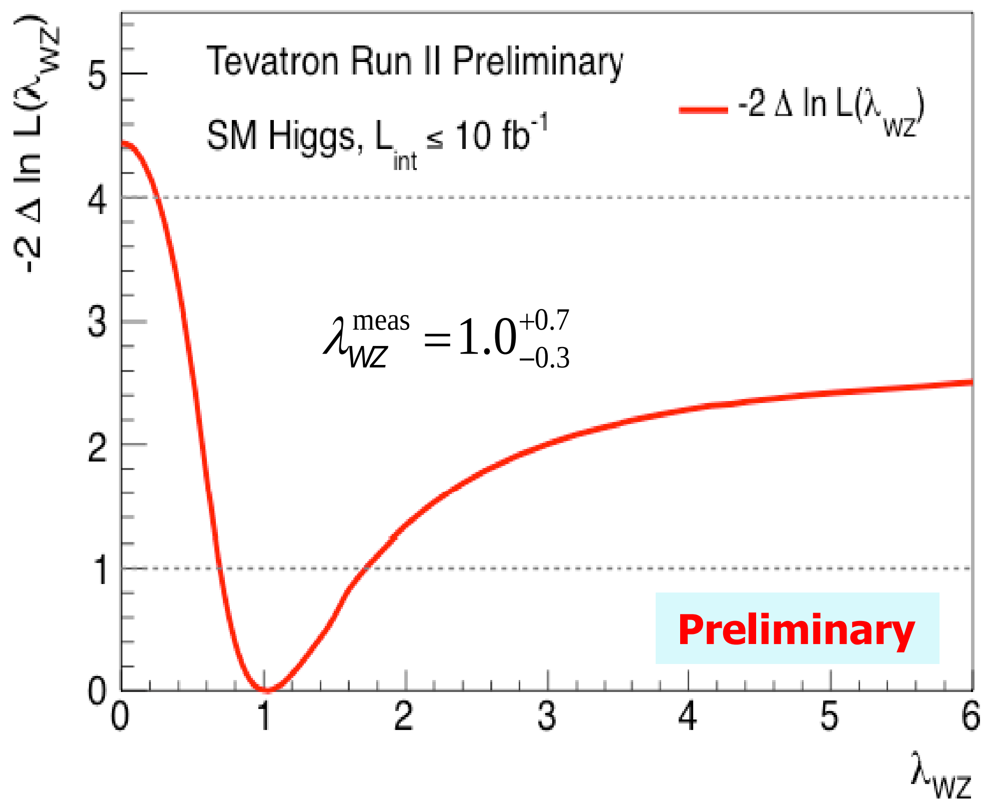
- Sensitivity to κ_Z mainly though $ZH\rightarrow llbb$, $\nu\nu bb$ channels.

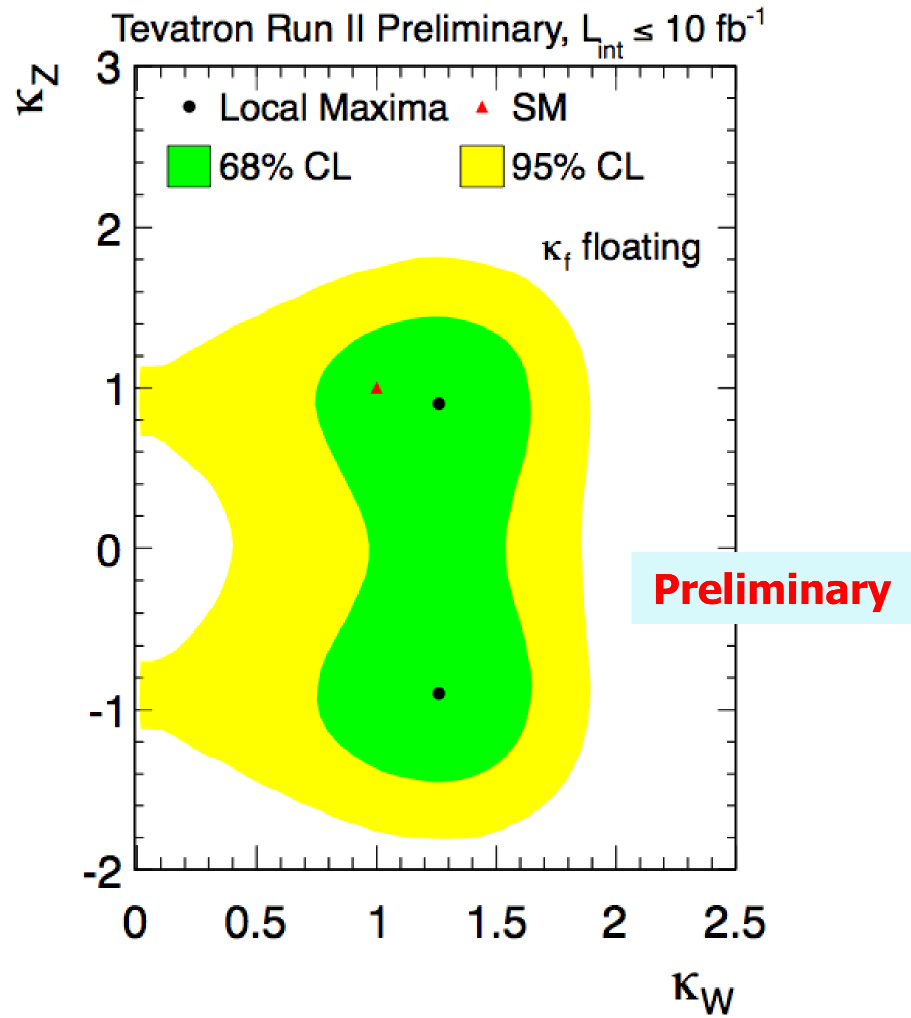




Probing Higgs Boson Couplings: Benchmark II

Probe SU(2)$_V$ custodial symmetry by measuring the ratio $\lambda_{WZ}=\kappa_W/\kappa_Z$ (integrate over κ_f).
Measure simultaneously κ_W and κ_Z (integrate over κ_f).

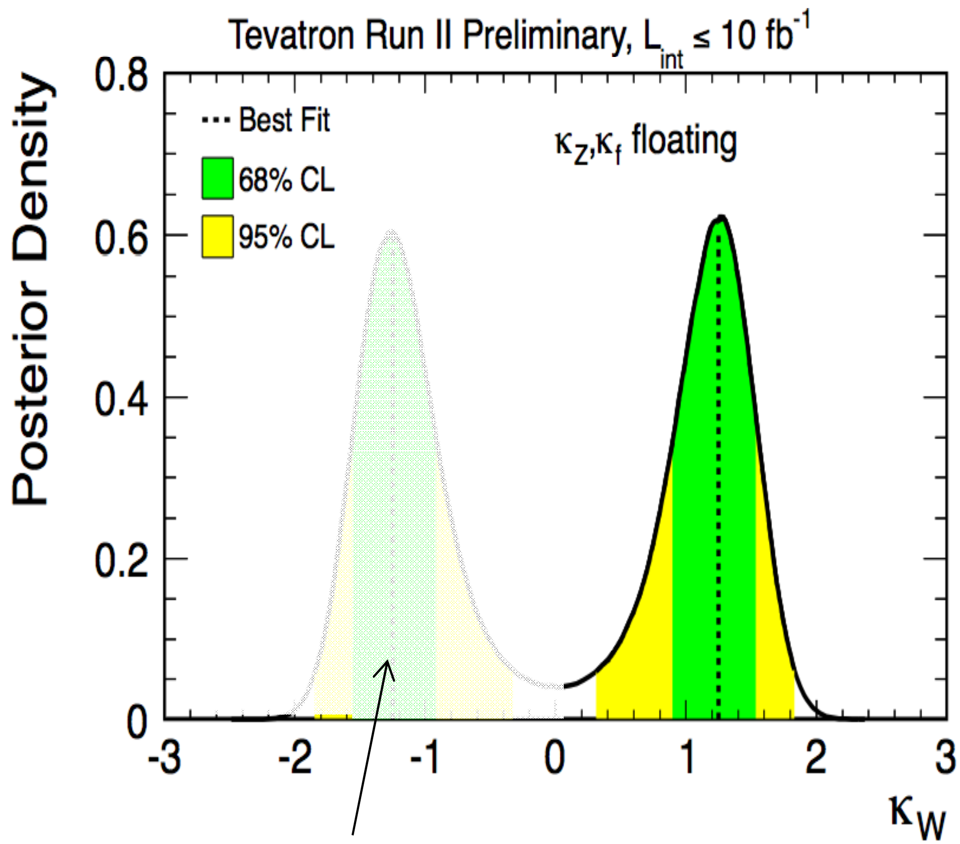


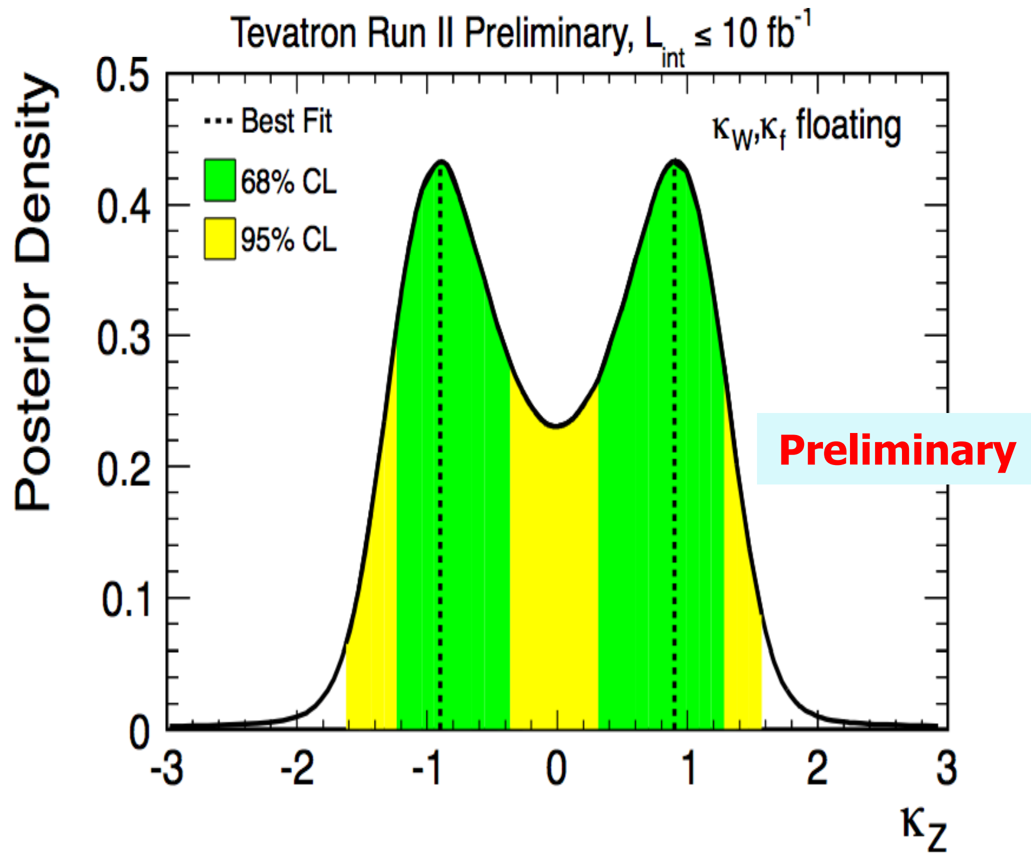


Probing Higgs Boson Couplings: Benchmark II

- Measure simultaneously κ_W and κ_Z (integrate over κ_f) and do projections.

1-dimensional projections

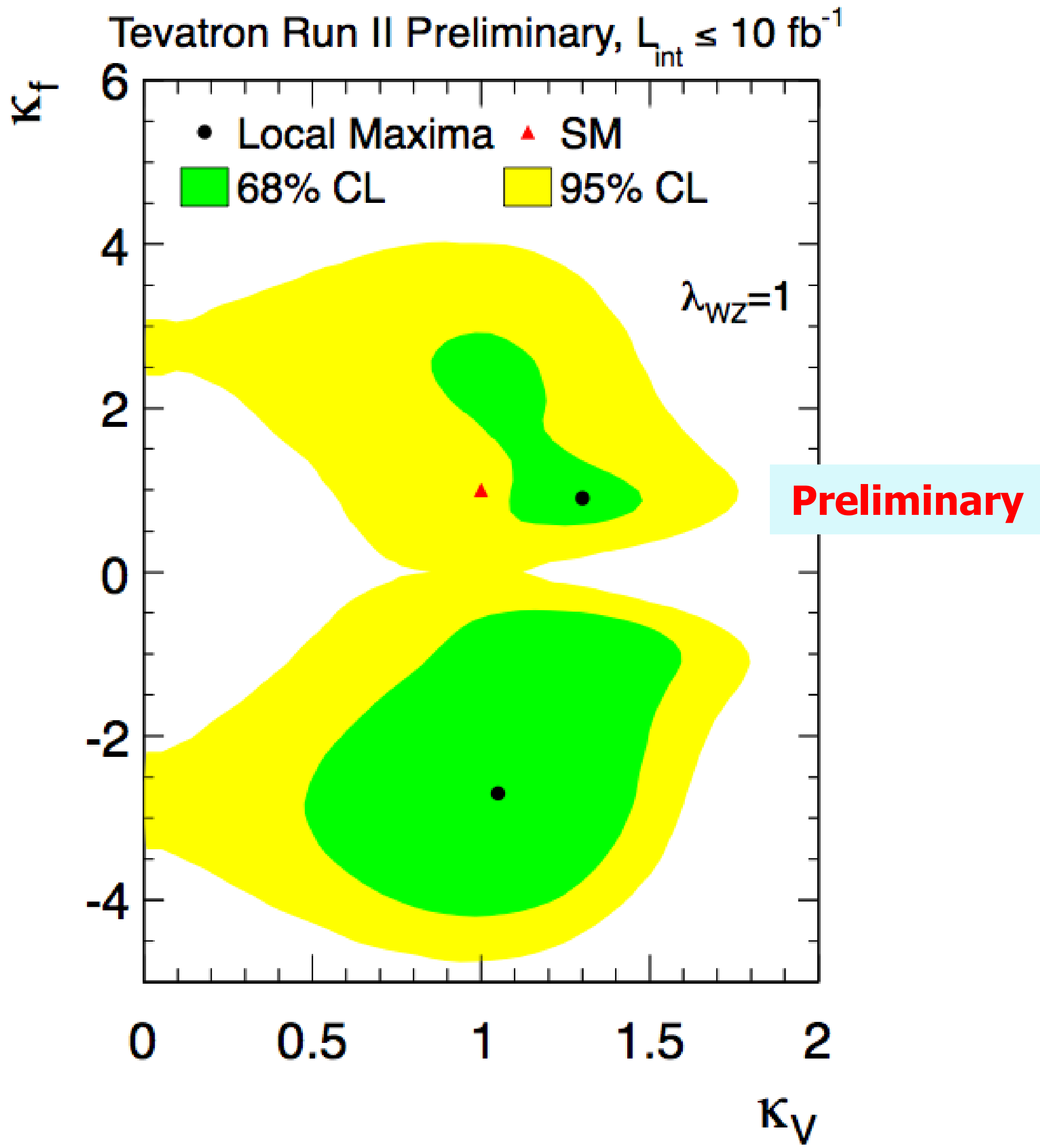




We are sensitive only to K_V^2 hence the symmetric plots.

Probing Higgs Boson Couplings: Benchmark III

- Measure simultaneously κ_V and κ_f (assuming λ_{WZ}=1).

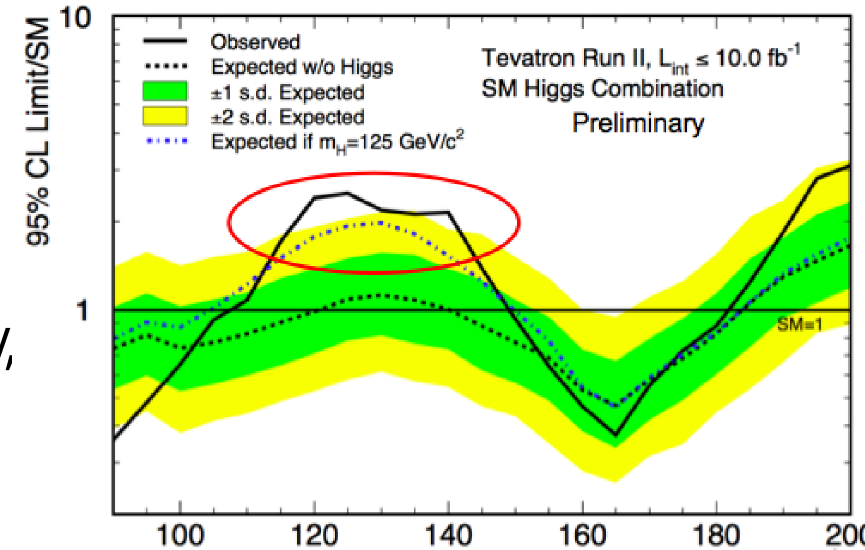


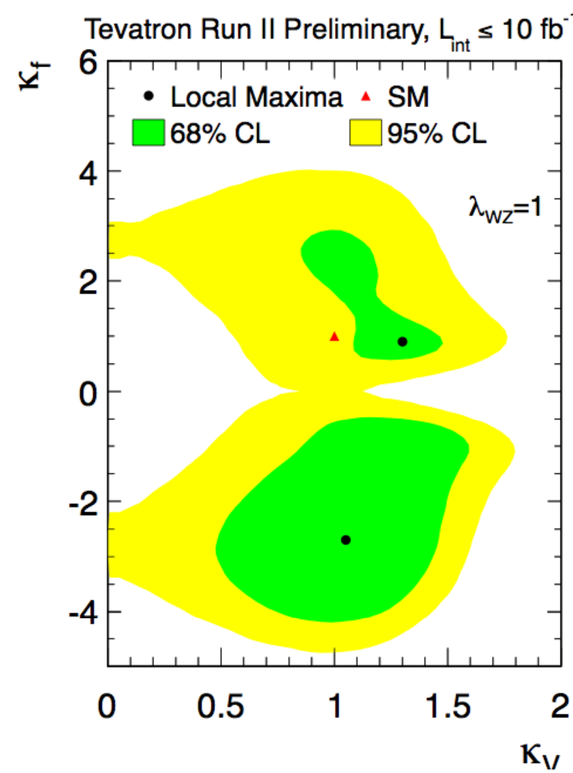
Summary and Outlook

- Latest Tevatron results based on full Run II dataset in most search channels, publication of the final tevatron combination /couplings coming soon.
- Published evidence for WX/ZX production with X→bb, where X is consistent with a SM Higgs boson of 125 GeV, as the newly discovered particle by ATLAS & CMS
- Combining all channels, Tevatron has achieved 95%CL SM sensitivity over almost all the foreseen accessible mass range (90 – 185 GeV) !

.

- Results on Higgs couplings are consistent with the SM.
- Despite the impressive progress on H→bb searches at the LHC, the Tevatron has still some valuable information to provide (spin-parity results under preparation).
- The H→bb channel is unlikely to be seen at the 5 sigma level before the 2015 LHC Run, except maybe through combination of all results available.

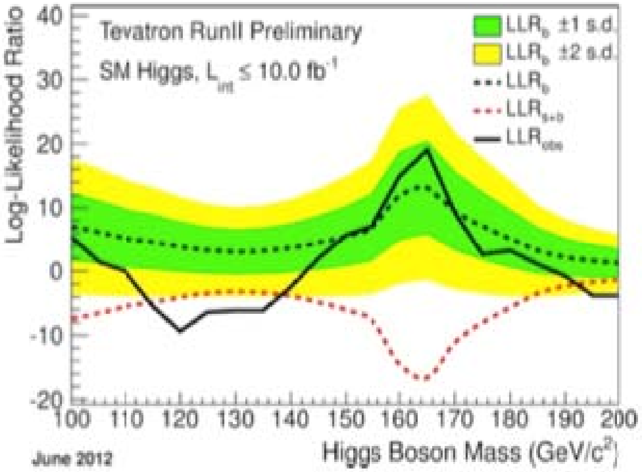




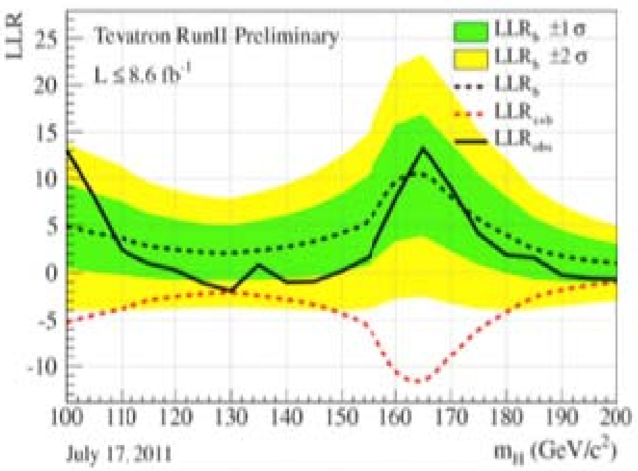
Backup Slides

Many steps back: LLR time evolution 2007-2012

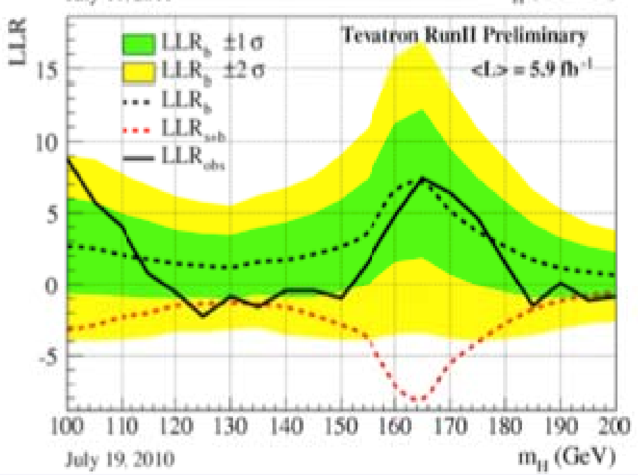
2012



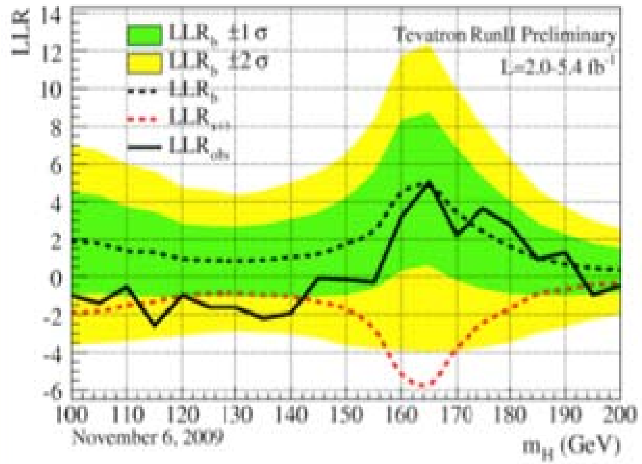
2011



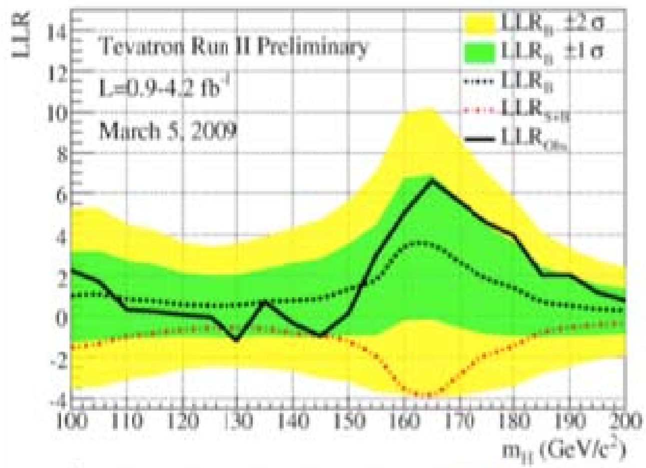
2010



2009



2008



2007