Higgs Boson Searches at CDF

Craig Group
for the CDF Collaboration
The University of Virginia
and Fermilab

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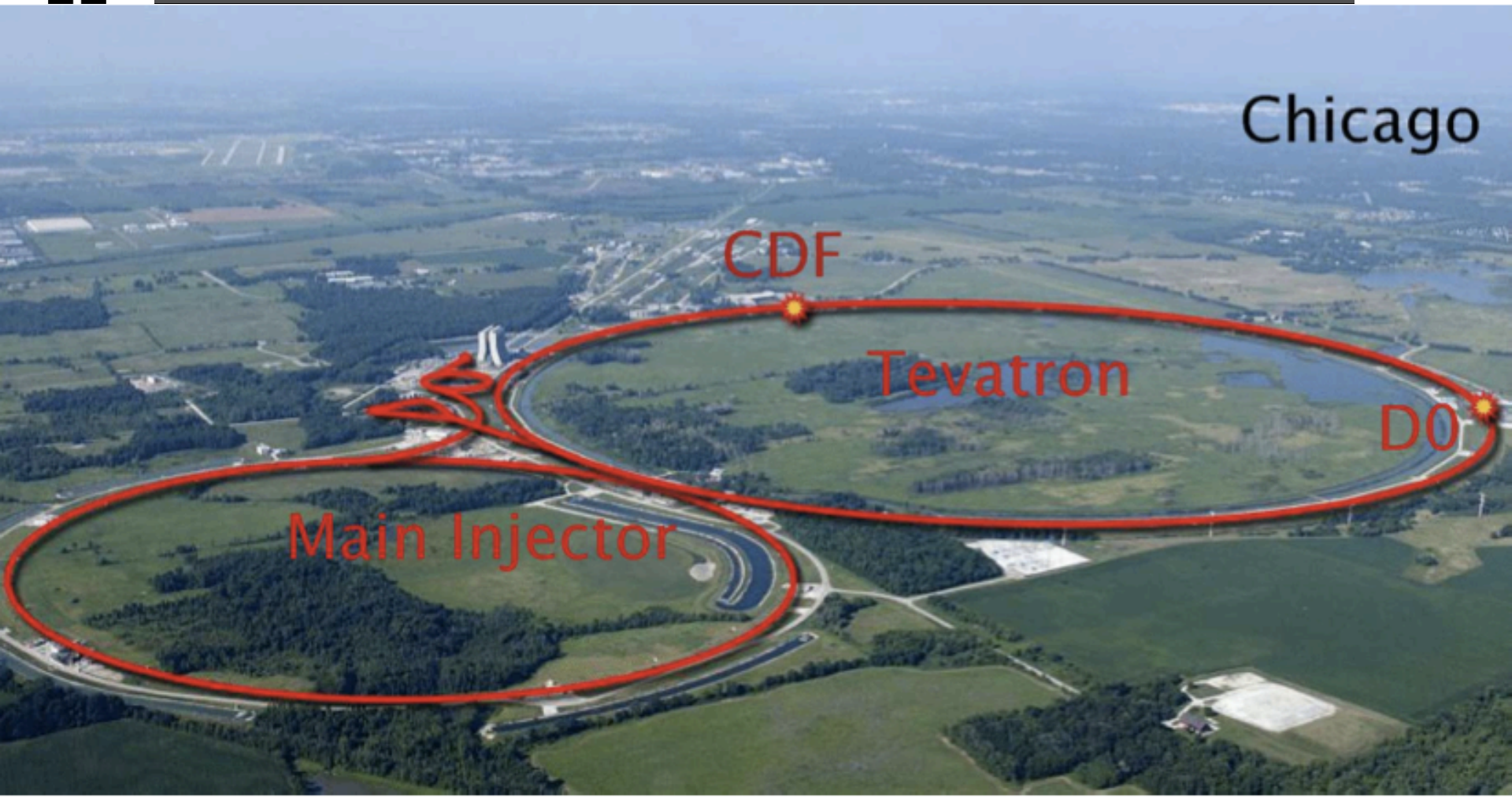
Very happy to be Back in 2013!

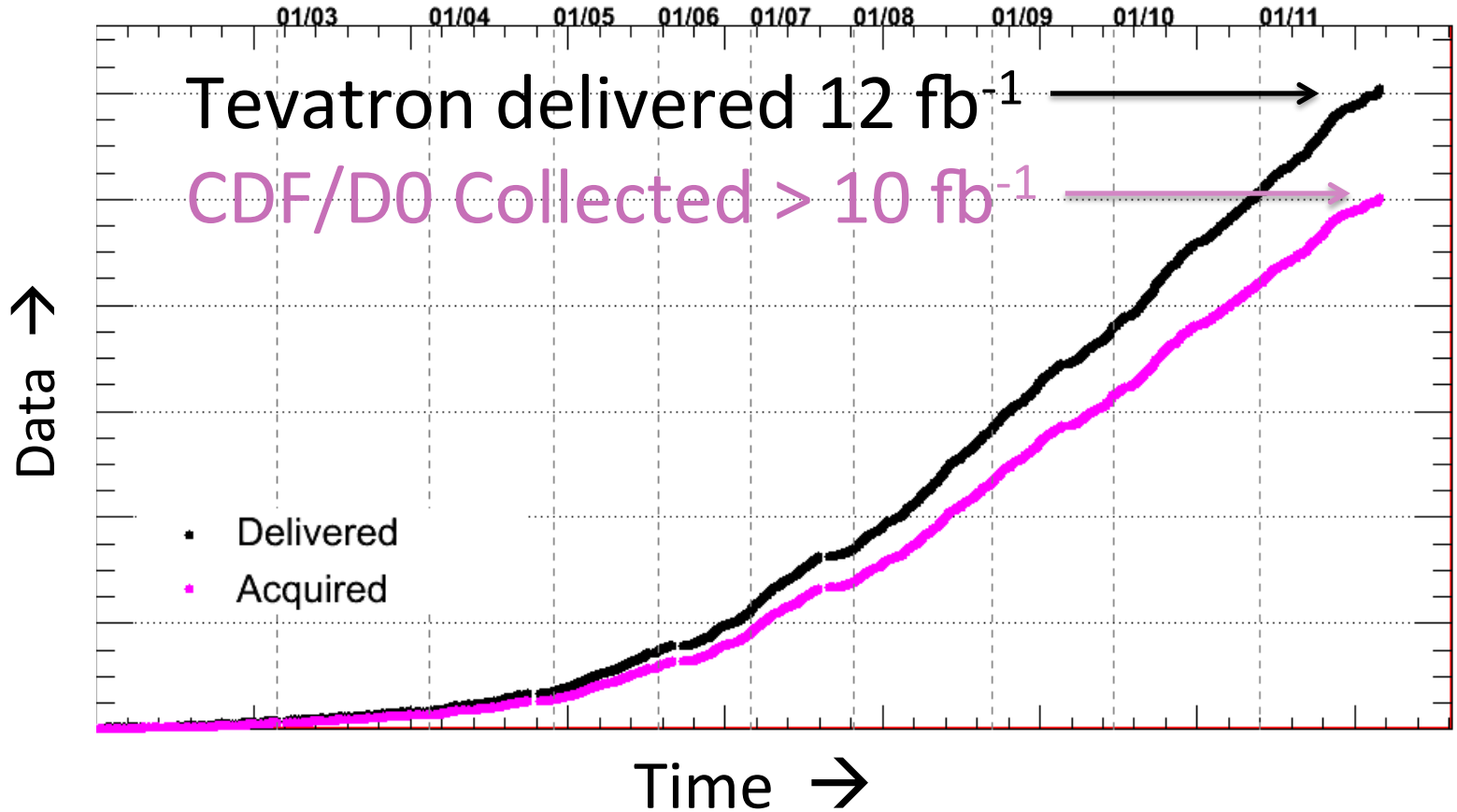
The Fermilab Tevatron



The Tevatron provided the highest energy proton-antiproton collisions in the world: $\sqrt{s}$ = 1.96 TeV

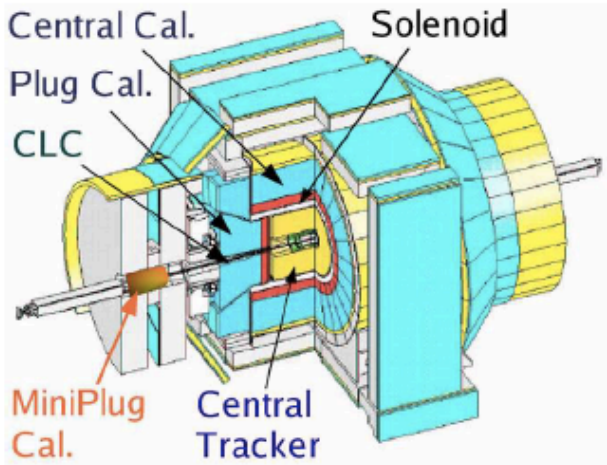
Tevatron Performance

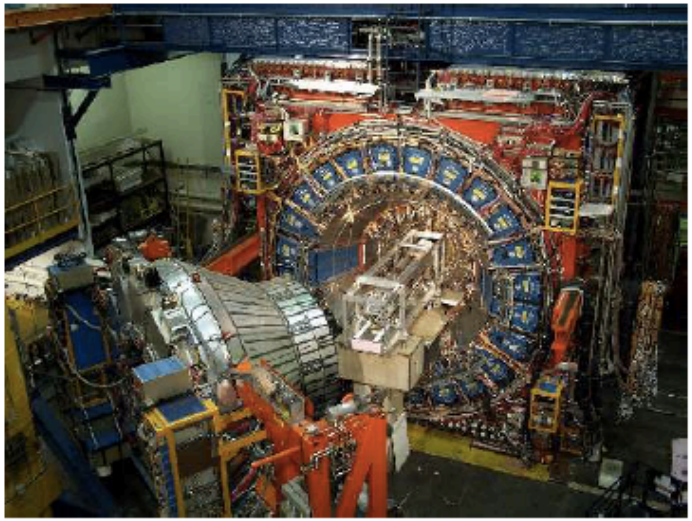
An enormous thanks to the Fermilab Accelerator Division for an outstanding performance!



Winter 2009 analyses contained up to 3 fb^{-1}

The CDF Experiment



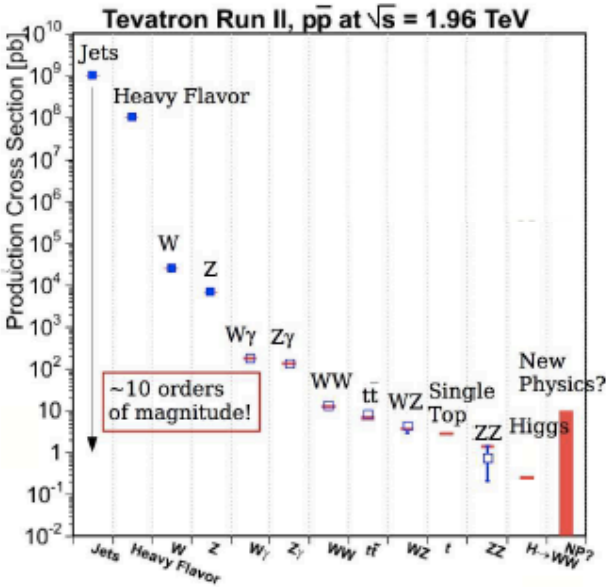


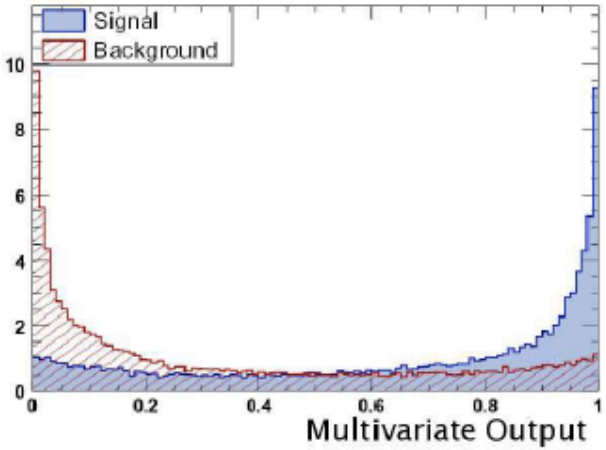
General-purpose detector:

- Luminosity measurement
- Silicon vertex detector
- Central tracking chamber
- Electromagnetic Calorimeters: Jets, e, and γ
- Hadronic Calorimeters: Jets
- Muon chambers

Higgs Searches "in a nutshell"

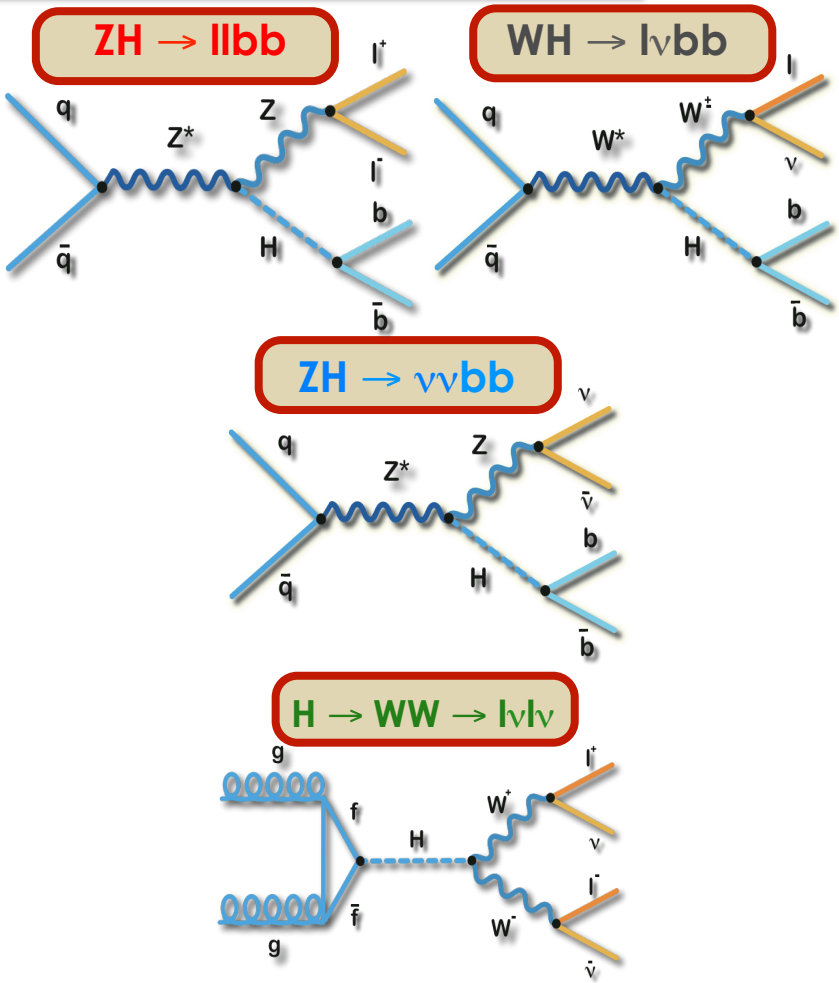
- The Challenge: extract Higgs signal from a background 10 orders of magnitude larger
- Triggers
  - High p_T leptons (e, μ), MET+Jets, ...
- Lepton ID: optimized on large W/Z samples
- b-jet tagging
  - Multiple "b-tagging" categories
  - Multivariate b tagger
- Background estimation
  - MC predictions: W/Z+jets, diboson, top,...
  - Data driven: mistags, QCD
- Advance analysis techniques
  - To separate signal from background
  - Neural Network (NN), Matrix Elements (ME), Boosted Decision Trees (BDT),...
  - Exhaustive checks in control regions





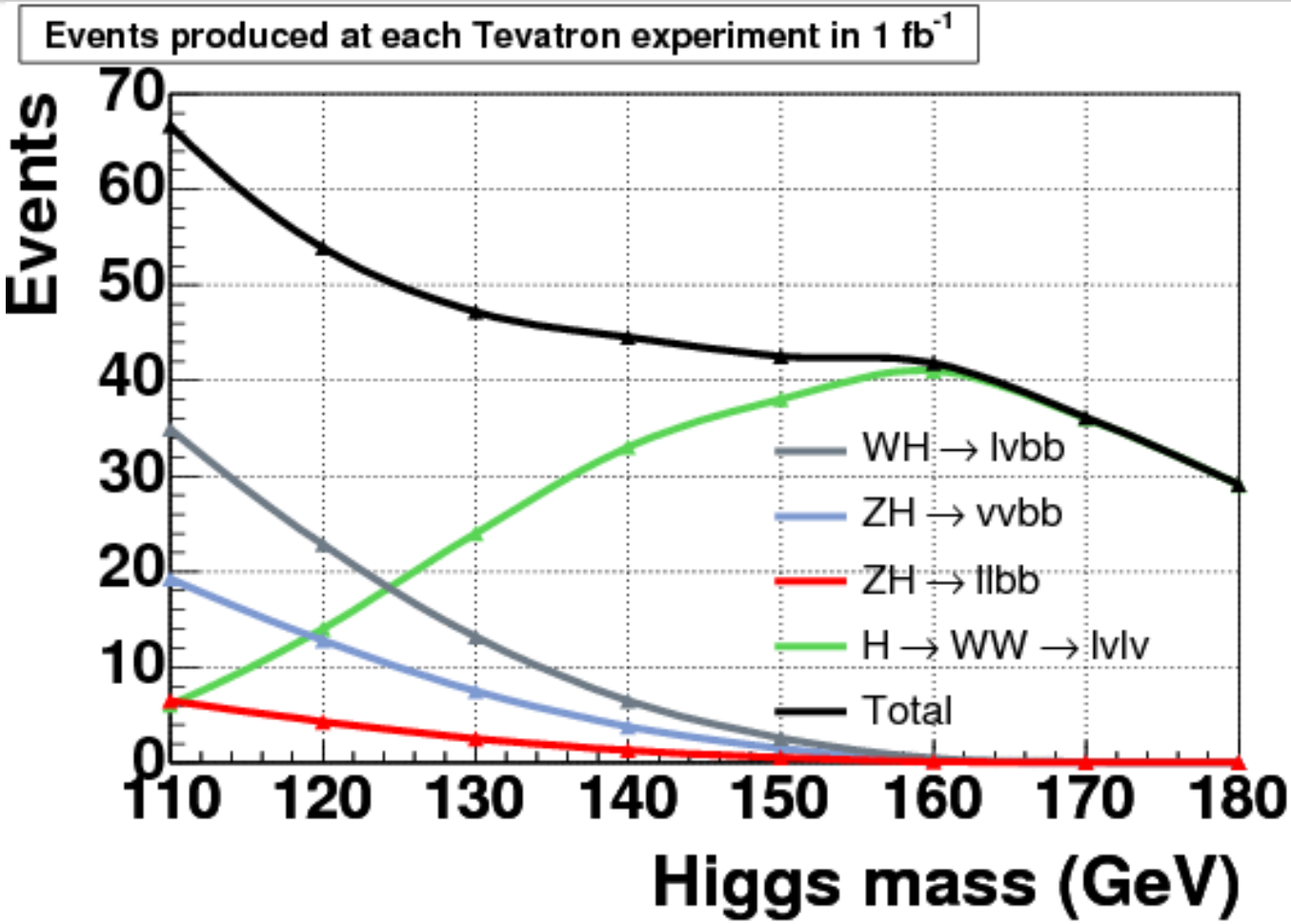
Higgs Searches: The basics

	Low Mass	High Mass
Primary Production:	WH, ZH	gg->H
Decay:	H -> bb	H -> WW
Main modes:	bb+lν bb+νν bb+ll	ll+νν
Important features:	• B-tagging • Dijet resolution	• Lepton acceptance • Angular correlations



Note: These are the most sensitive channels but all non-negligible production and decay modes are considered.

Higgs Production Rates



About 500 Higgs events produced in the main search channels with the full Tevatron dataset (10 fb^-1)

Combining All Channels

Low-Mass Channels	Sensitivity (m_H = 120 GeV)
	CDF [SM]
WH → lν bb	2.0
VH → MET + bb	2.7
ZH → ll + bb	2.6
H → γγ	11
VH, VBF, ggH → 1/2 jet + ττ	41

High-Mass Channels	Sensitivity (m_H = 165 GeV)
	CDF [SM]
gg → H → WW → lνlν	0.7
H→ZZ→ llll	20

etc.

etc.

CDF Higgs Papers (2012/2013)

Combinations:

CDF Full Combination : Submitted to PRD (arXiv:1301.6668)
CDF H→bb: Phys. Rev. Lett. **109**, 111802 (2012)
Tevatron H→bb: Phys. Rev. Lett. **109**, 071804 (2012)

H-bb

lvbb: Phys. Rev. Lett. **109**, 111804 (2012)
llbb: Phys. Rev. Lett. **109**, 111803 (2012)
METbb: Phys. Rev. Lett. **109**, 111805 (2012)
arXiv: 1301.4440 (Updated b tagger; accepted by PRD)

Other:

HWW: To be submitted soon
H-ZZ-llll: Phys. Rev. D **86** 072012 (2012)
tth: Phys. Rev. Lett. **109** 181802 (2012)
All-hadronic: J. High Energy Phys. 02 (2013) 004
H-ττ: Phys. Rev. Lett. **108** 181804 (2012)
H-ϒϒ: Physics Letters B 717 (2012) 173–181

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I will focus on this one!

H-bb

lvbb: Phys. Rev. Lett. **109**, 111804 (2012)

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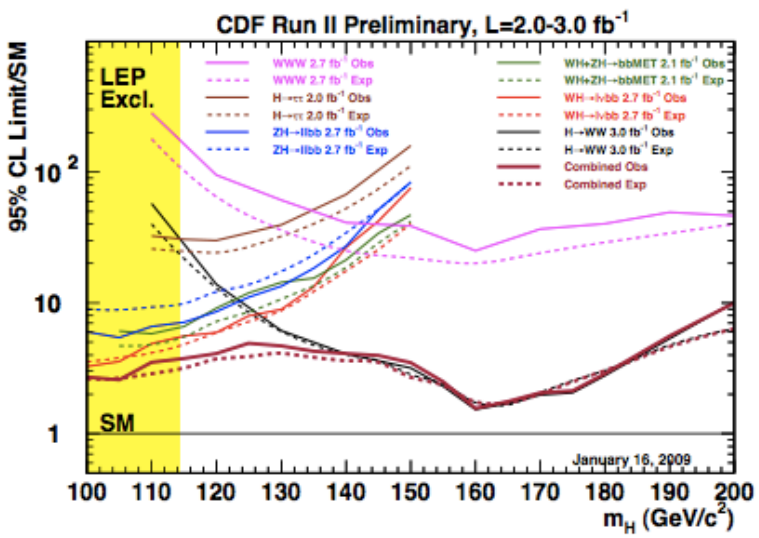
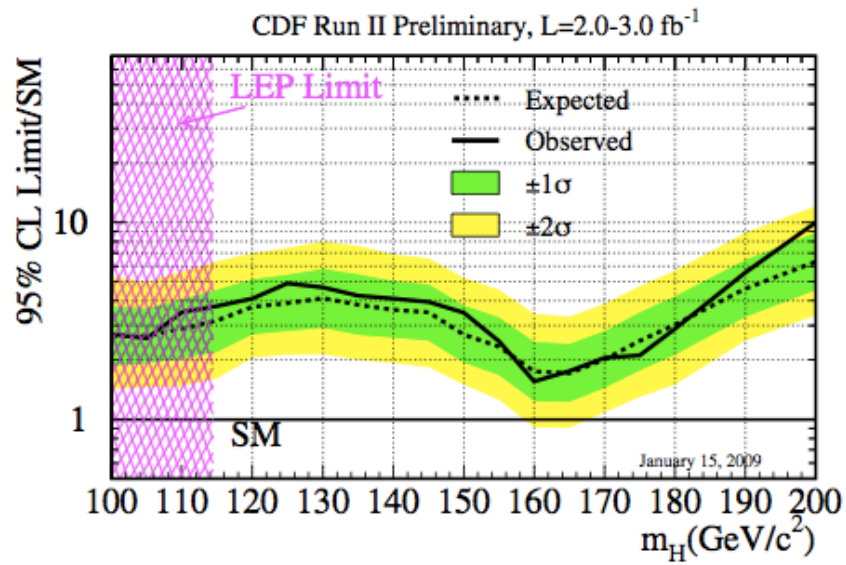
CDF Combination from 2009

SM Higgs Combined Limits

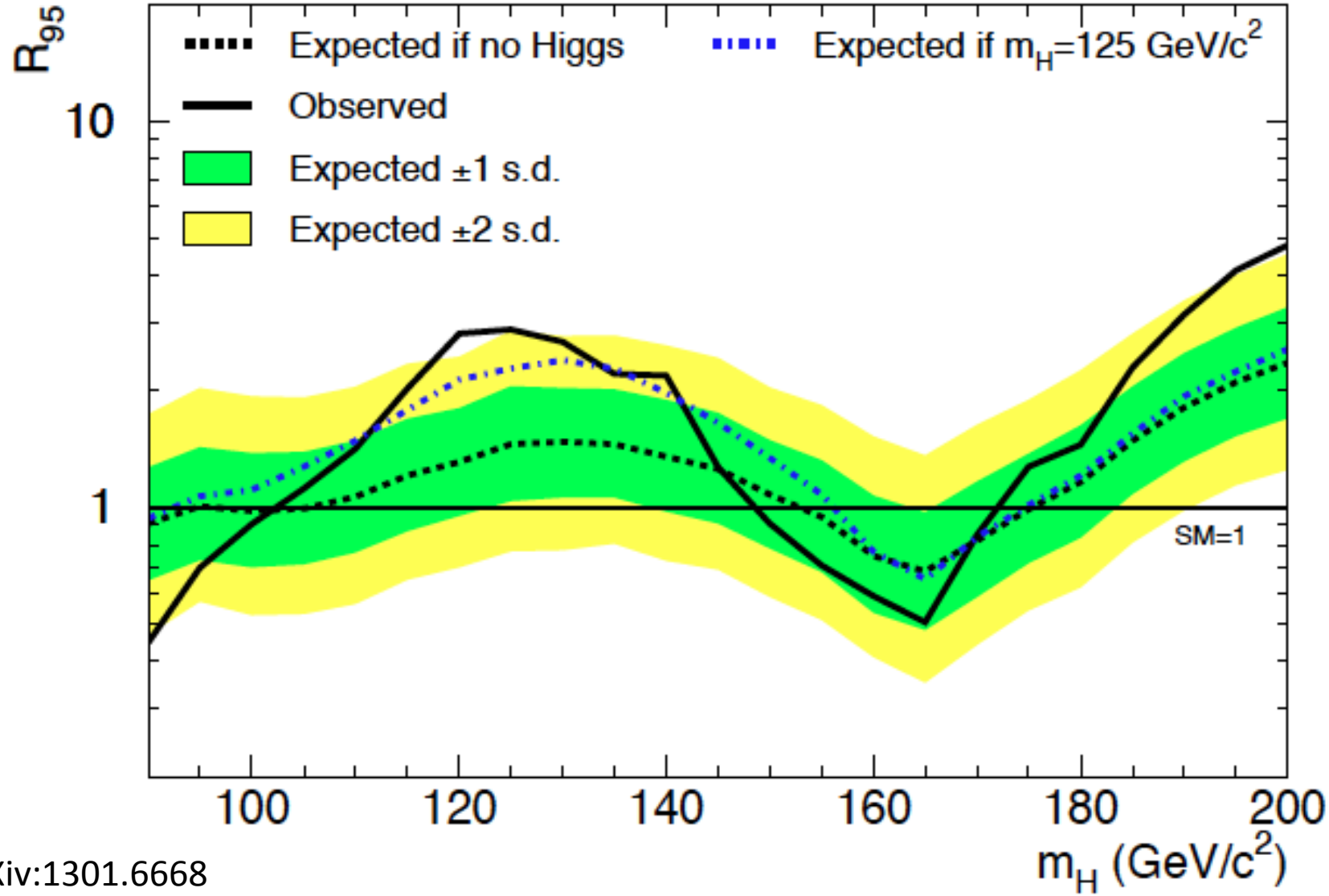
- Systematics and their correlation between channels and experiments taken into account
- Difficult combination with over 70 nuisance parameters
- CDF combined expected (observed) limits:
  - 115 GeV: 3.2 (3.8) × SM
  - 165 GeV: 1.6 (1.6) × SM





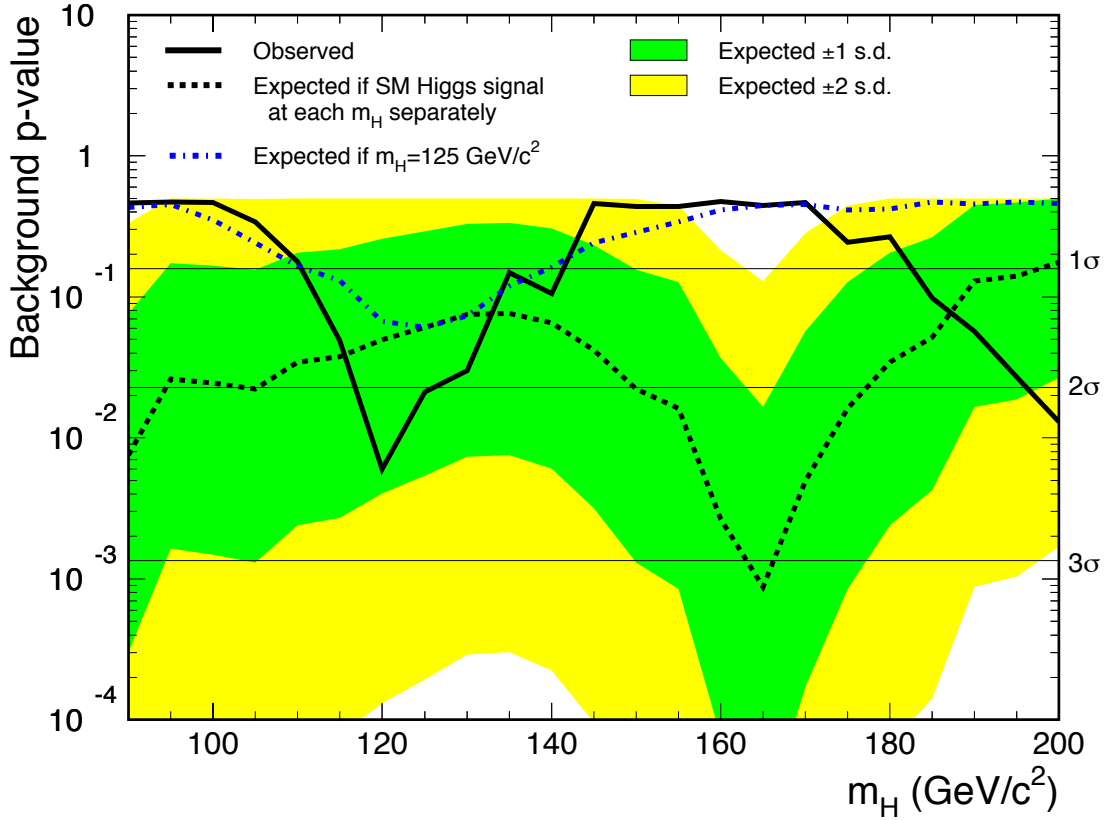
Combination with DØ provides about $\sqrt{2}$ in improved sensitivity

Final CDF Combination (2013)



arXiv:1301.6668

Combined SM Higgs Boson Search p-value



-Observed local significance at m_H=125 GeV/c^2 is 2.0σ

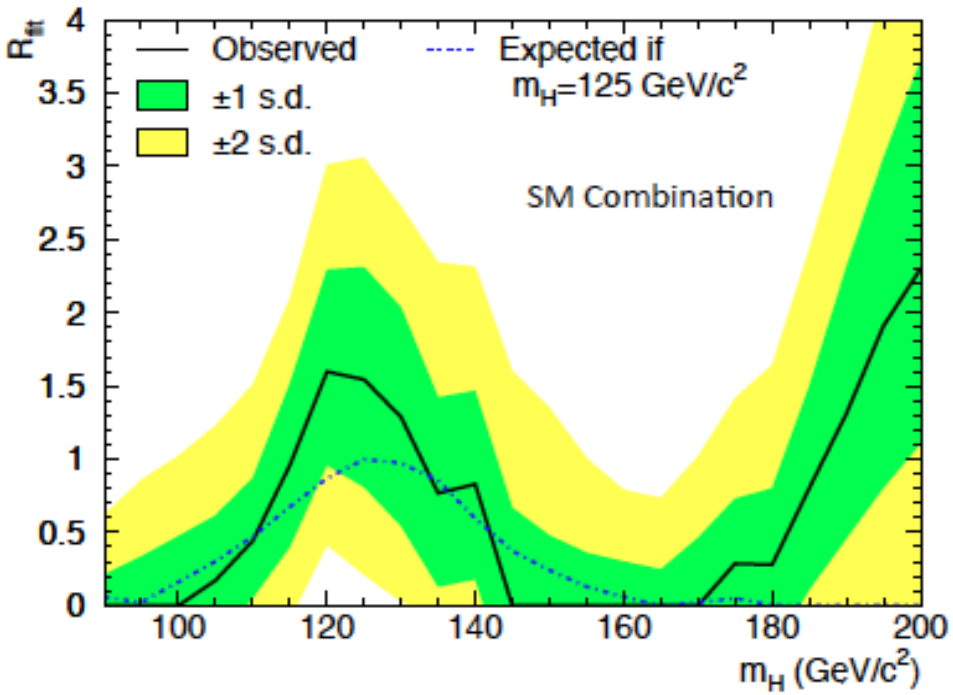
-Expected significance at m_H=125 GeV/c^2 is 1.6σ assuming a signal is present.

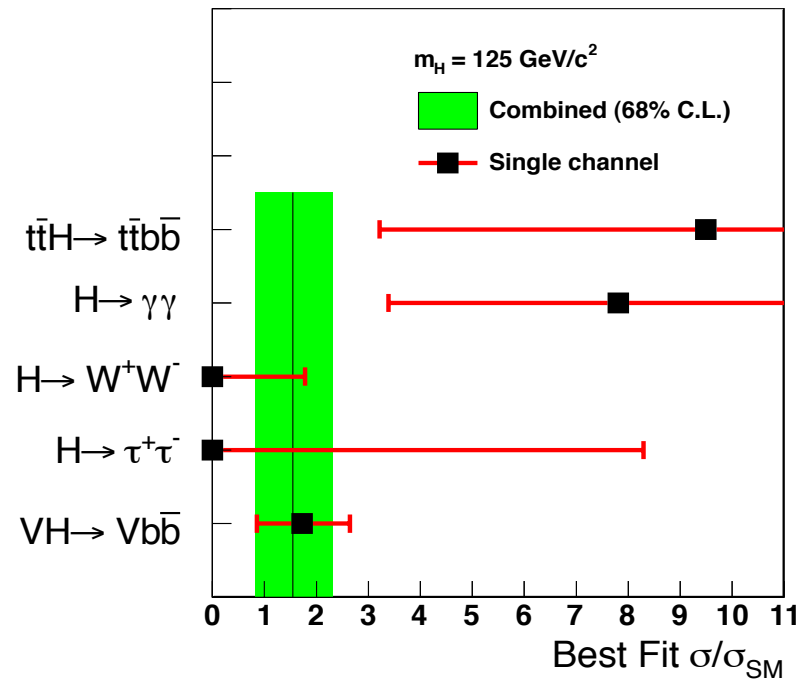
-2.5σ local significance at m_H=120 GeV/c^2

We see some excess → Moving onto the more interesting questions:

-- What can we say about the production rate and coupling strengths with our data?

Cross-section Measurements





$t\bar{t}H \to t\bar{t} + b\bar{b}$	$9.49^{+6.60}_{-6.28} \times$ SM	$H \to \tau^+\tau^-$	$0.00^{+8.44}_{-0.00} \times$ SM
$H \to \gamma\gamma$	$7.81^{+4.61}_{-4.42} \times$ SM	$VH \to V + b\bar{b}$	$1.72^{+0.92}_{-0.87} \times$ SM
$H \to W^+W^-$	$0.00^{+1.78}_{-0.00} \times$ SM	Combined	$1.54^{+0.77}_{-0.73} \times$ SM

Constraining Higgs Couplings

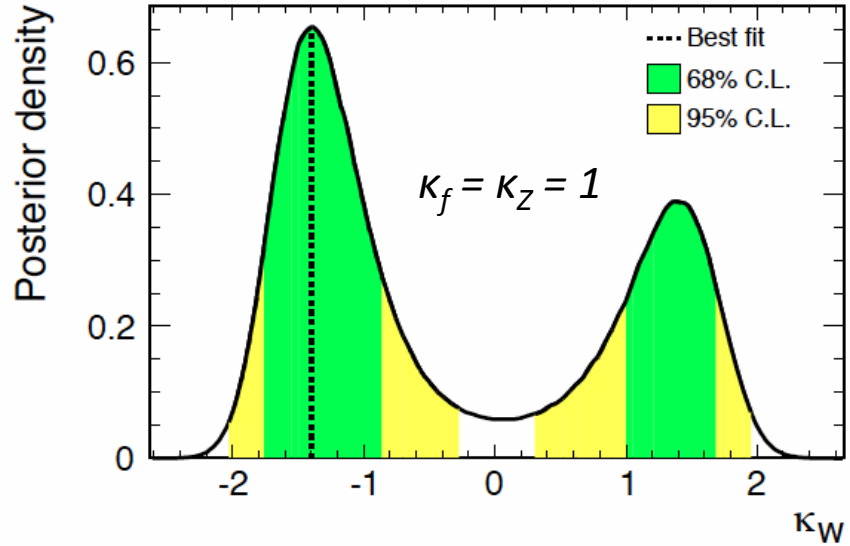
- Window to exotic physics can be parameterized through coupling factors:
  - Hff coupling scaled by: κ_f
  - HWW / HZZ / HVV scaled by: $\kappa_W, \kappa_Z, \kappa_V$ ($\lambda_{WZ} = \kappa_W/\kappa_Z$)
  - Standard model is obtained when:

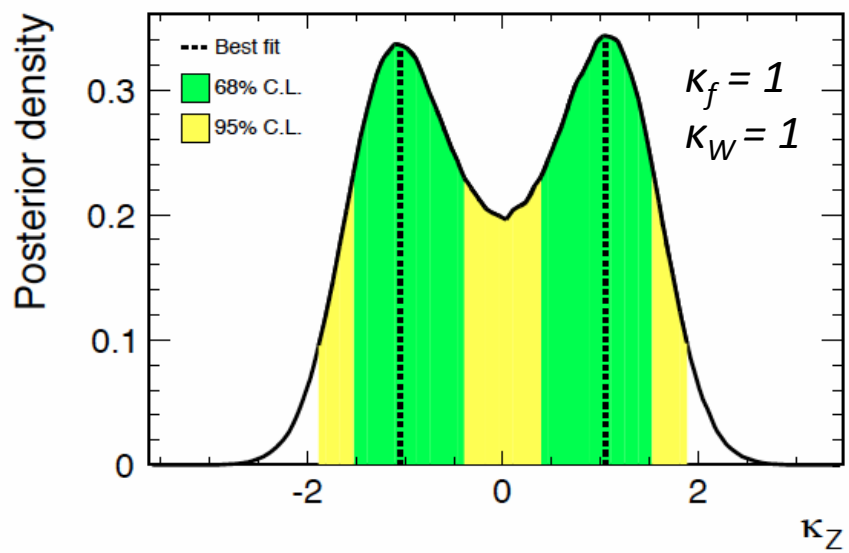
$$\kappa_f = \kappa_W = \kappa_Z = 1 .$$

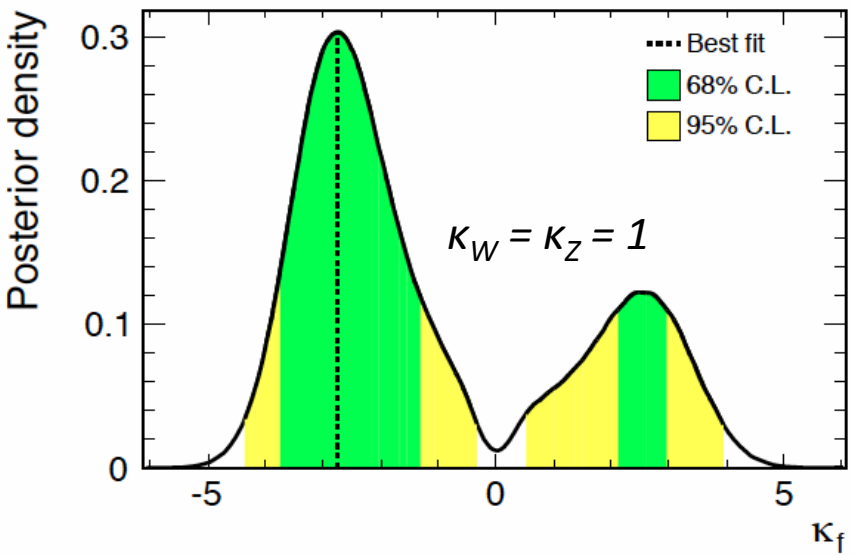
- Expressions for Higgs boson production/decay processes are modified based on production mechanism and decay channel
  - Can get complicated expressions that suggest sensitivity to channels that are not all that dominant in the SM Higgs combination

- Test coupling factors using Bayesian method:
  - Uniform priors assumed for κ 's

Constraining Higgs Couplings

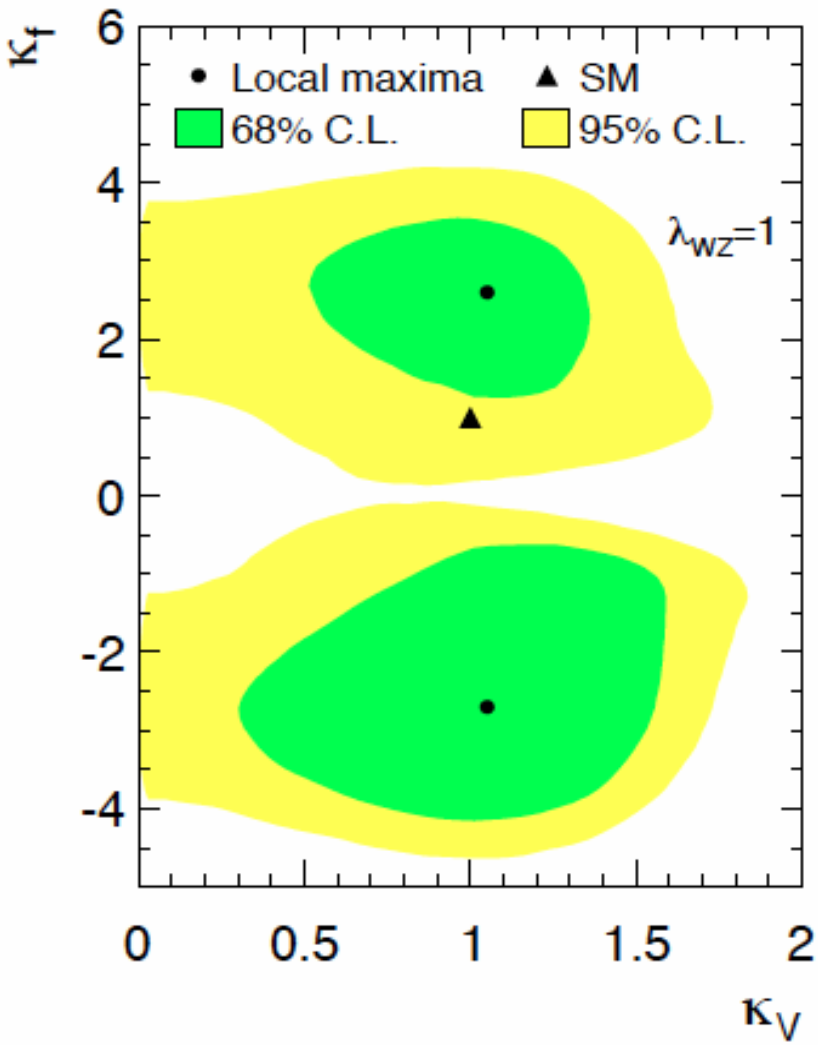


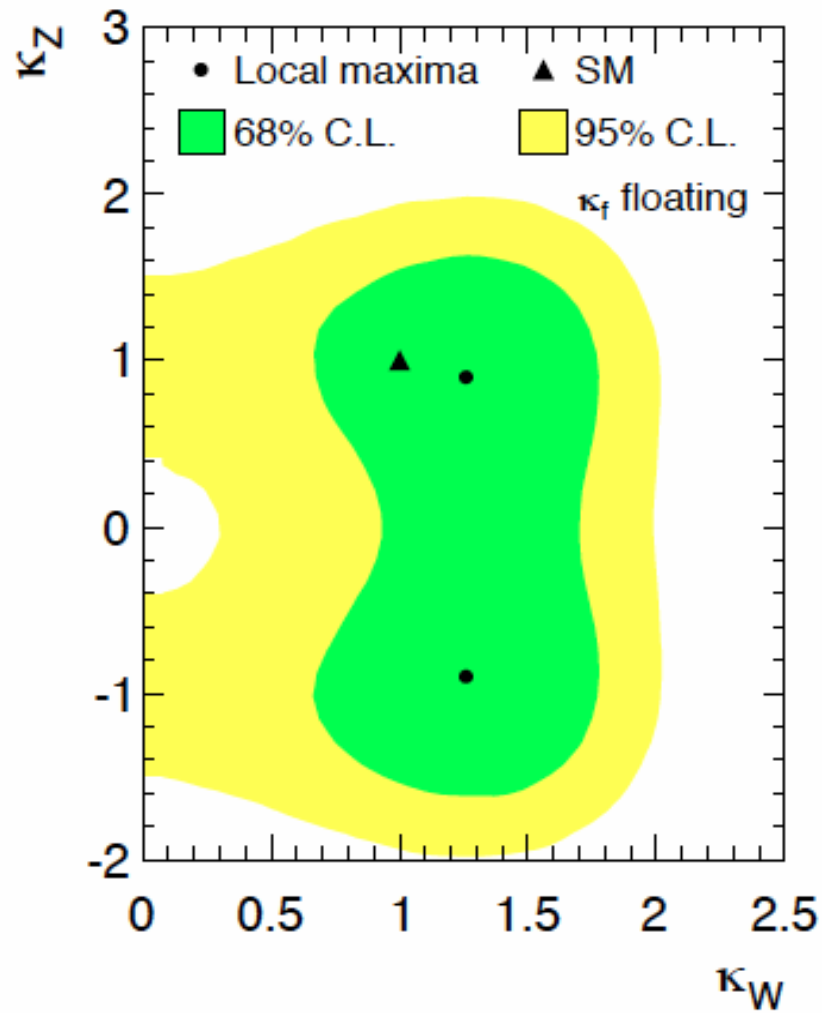




- Dominant peak at negative κ_f and κ_W results from excess in $H \rightarrow \gamma\gamma$ channel.
- All results consistent with standard model

Constraining Higgs Couplings





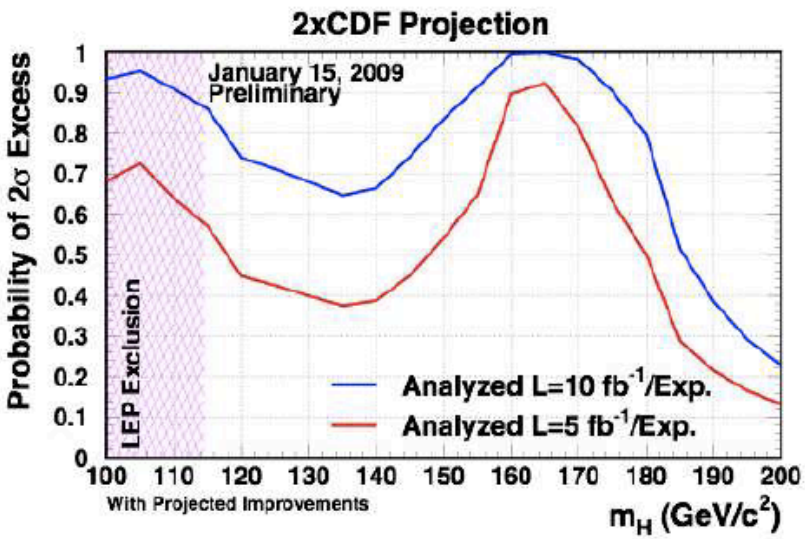
Marginalized over κ_f

Conclusions from 2009

Conclusions

- Exciting era for Higgs boson searches at the Tevatron
- CDF is thoroughly searching for SM and BSM Higgs bosons (Many other searches that were not covered here)
- Reaching sensitivity to SM Higgs over full mass range

- No evidence for signal found yet...
- Sensitivity $\sim$ 3.2 times SM at low mass
- Tevatron performing great, so luminosity quickly increasing! ($> 2\ fb^{-1}$ / year)
- Tevatron will exclude over the full mass range with 8-10 fb^{-1}
- Stay tuned!



Exclusion has begun!

2 σ excess is likely with 10 fb^{-1} !

Conclusion

We have come a long way since 2009:

- We have incorporated the full Tevatron dataset into most of the major search channels.
- There is a broad excess in the data that is inconsistent with the background only hypothesis at about the 2-sigma level
- Tevatron excesses are in channels complimentary to the LHC and provide supporting evidence for a SM-like Higgs interpretation and the strongest evidence to date for h-bb
- 2012 was the year of the Higgs boson!