Implications (Perspectives) from Tevatron Higgs

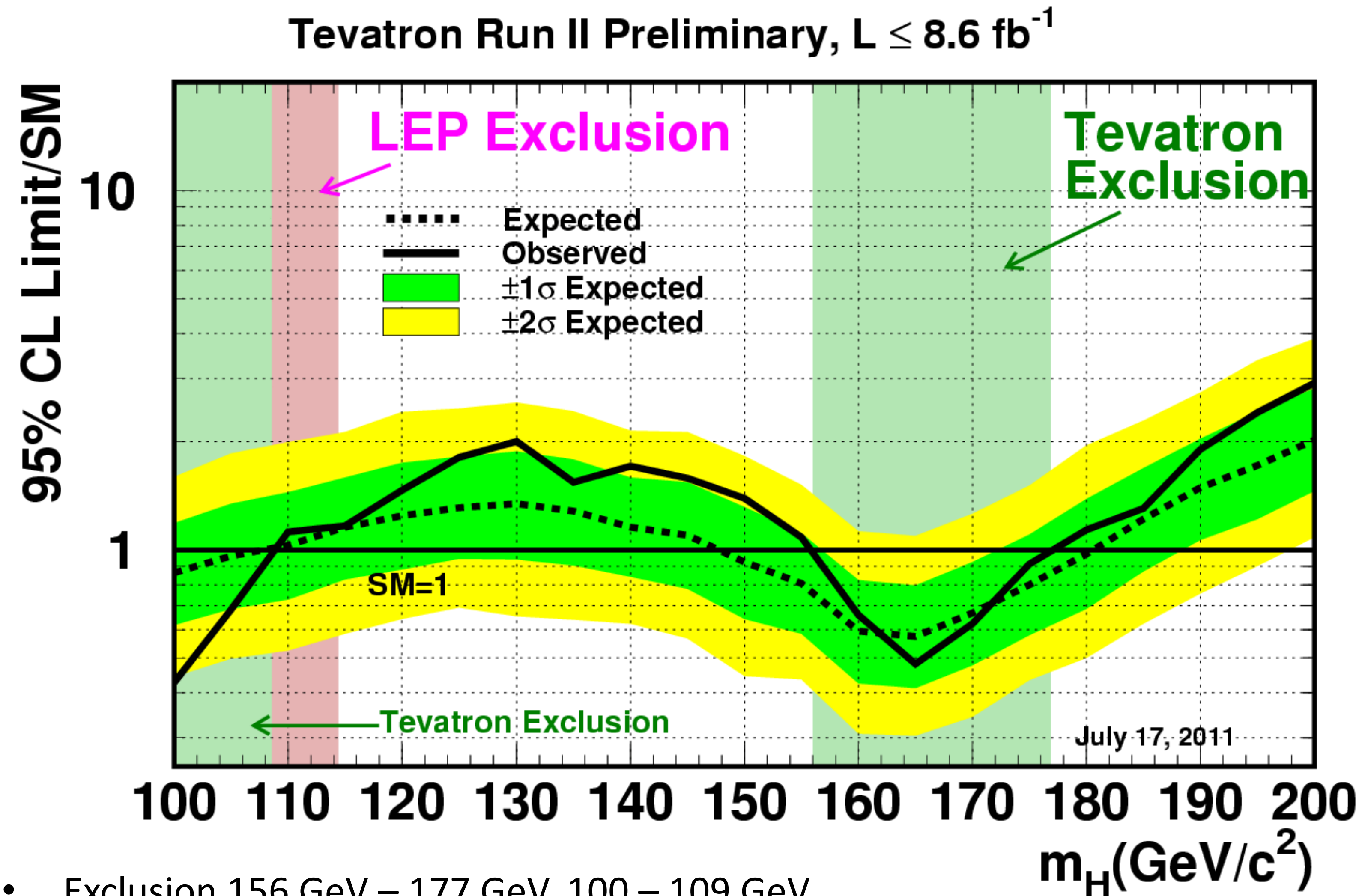
Ben Kilminster (Fermilab)

Workshop on Implications of LHC results for TeV-scale physics

August 29, 2011

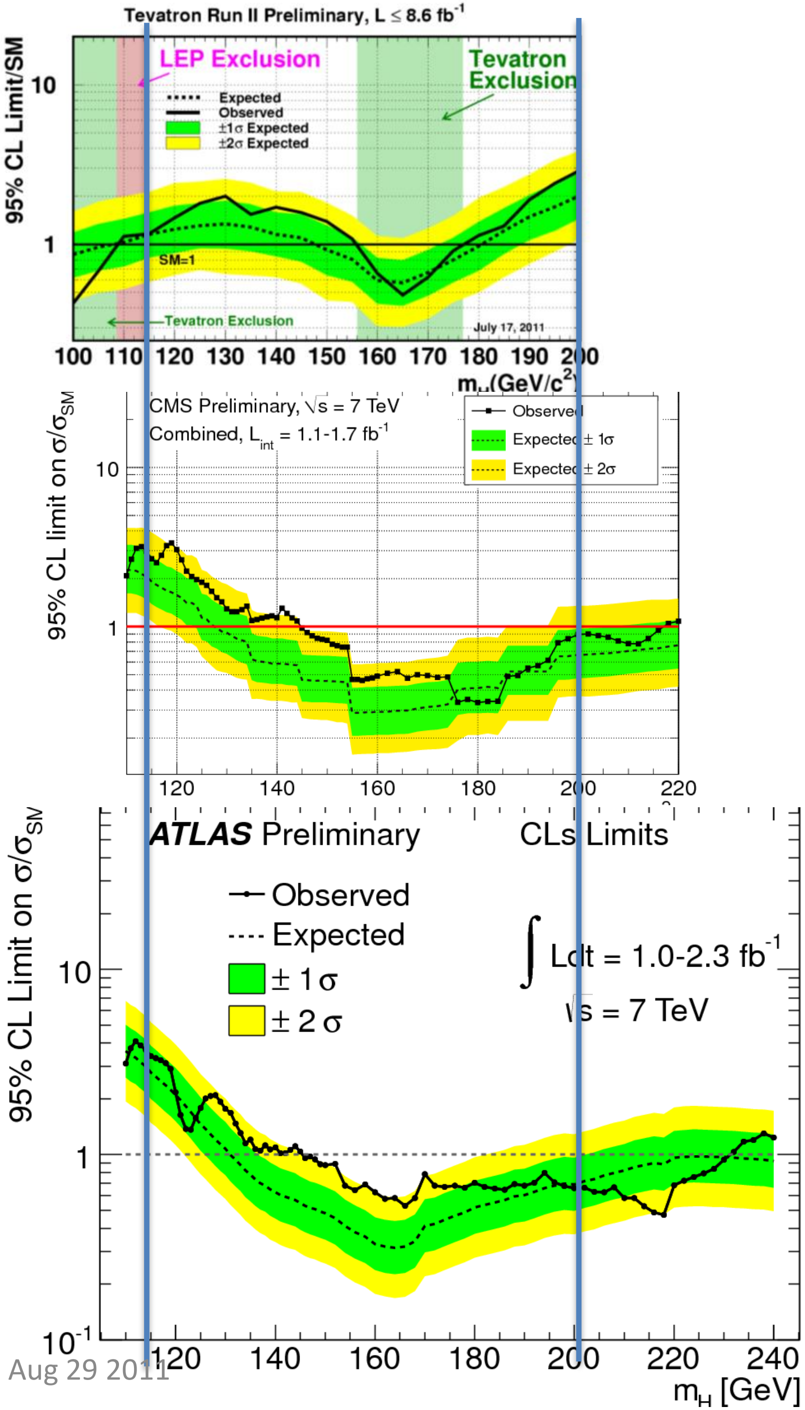
- Prospects
  - What are the most interesting Higgs results we can expect from Tevatron with full dataset of 10 fb-1 ?

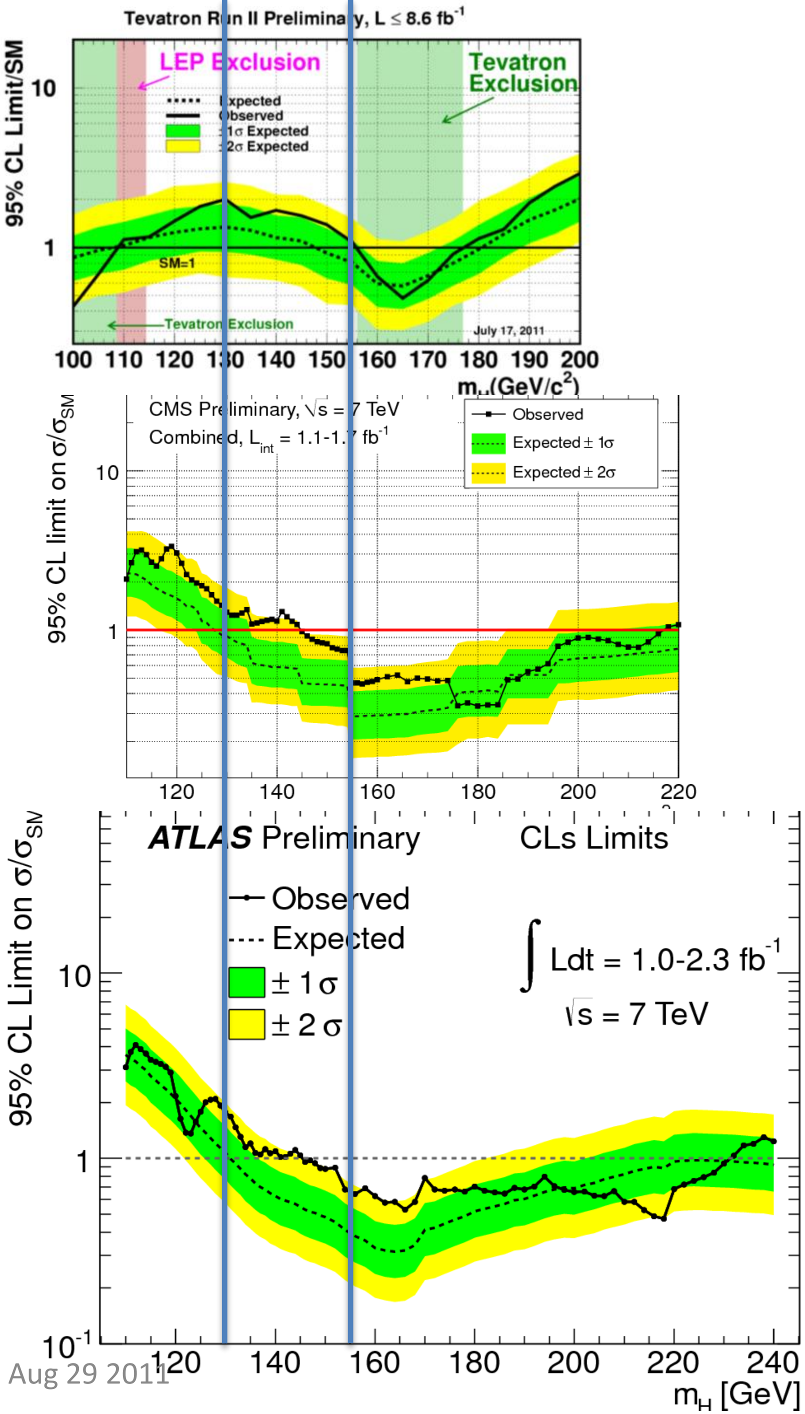
- Perspectives
  - What can Tevatron teach us given the recent CMS & ATLAS Higgs results ?



- Exclusion 156 GeV – 177 GeV, 100 – 109 GeV
- Below 115 GeV
  - Expected = observed
  - Almost at SM 95% CL exclusion
- Expected sensitivity less than 1.35*SM across interesting range (114 – 185 GeV)
  - Most difficult at 130 GeV

TEV, CMS, ATLAS



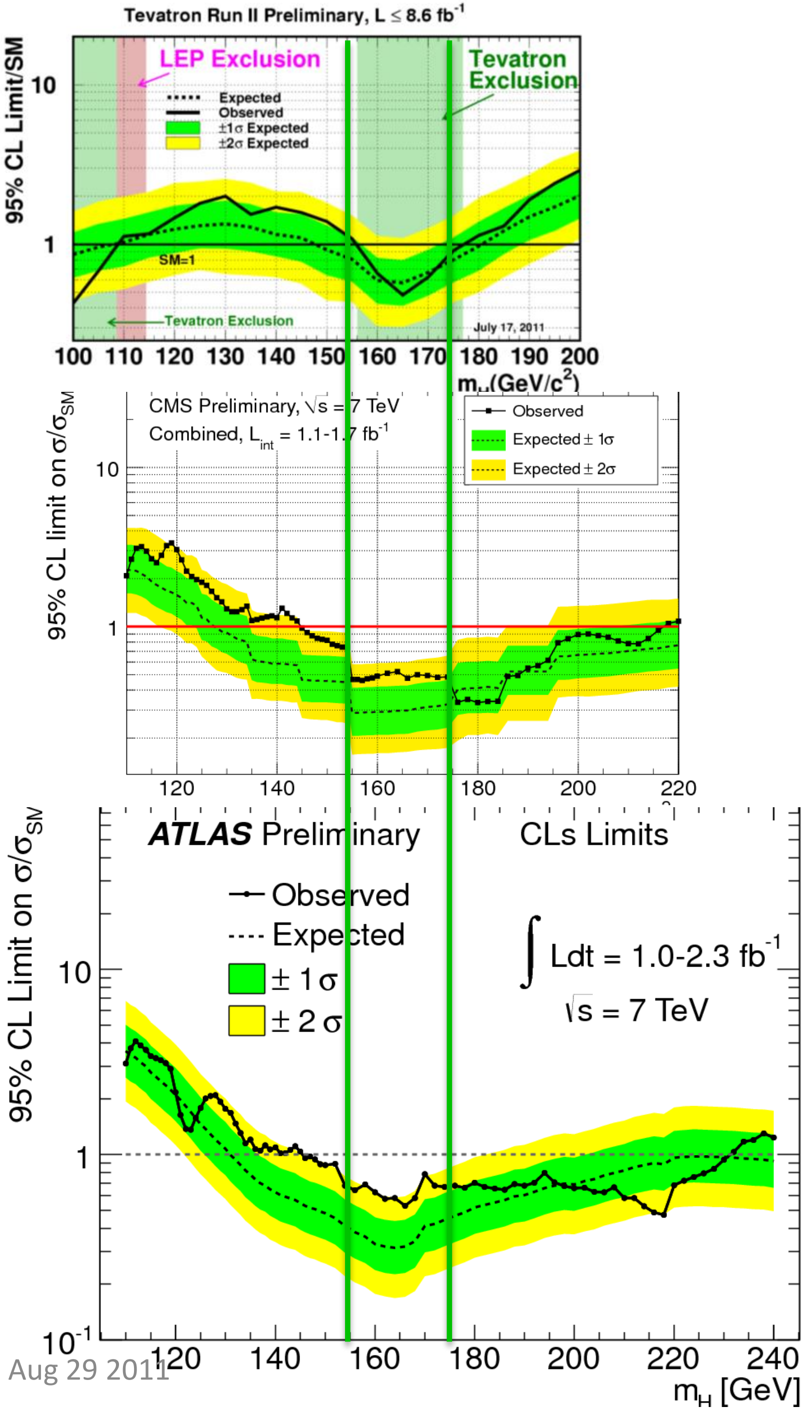


TEV, CMS, ATLAS

Consistencies TeV, CMS, ATLAS

- Sensitivities to < ~2*SM for 125 to 200 GeV
- Exclusion above 155 GeV
- Excesses overlap 130 to 155 GeV
  - But, CMS/ATLAS nearly exclude this range

- Sensitivity at 130 GeV
  - CMS : 0.9*SM
  - ATLAS : 1.1*SM
  - Tevatron : 1.35*SM

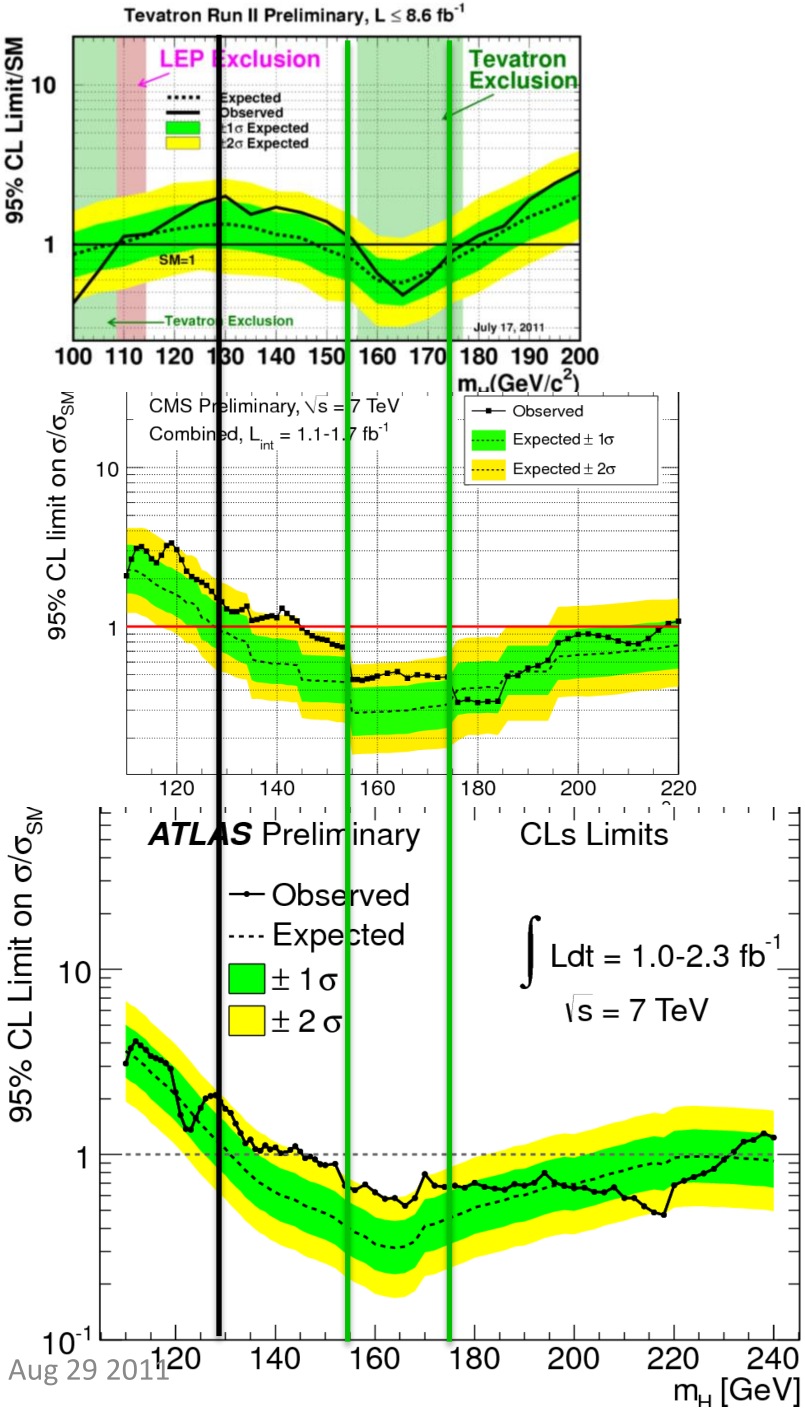


TEV, CMS, ATLAS

Differences TeV, CMS, ATLAS

- LHC is ~ 1.5 - 2 Sigma high ~155 to 175 GeV
  - No excess at Tevatron

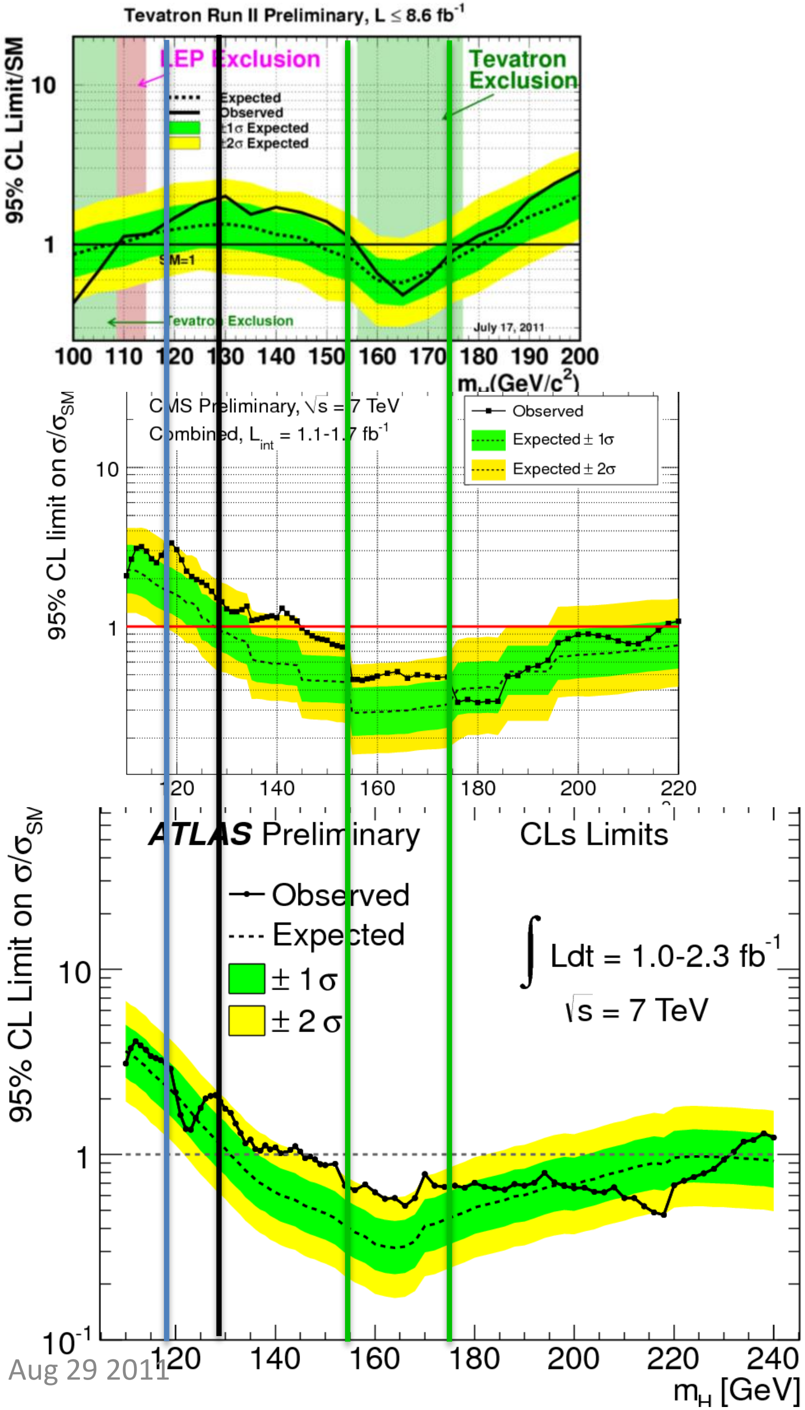
TEV, CMS, ATLAS



Differences TeV, CMS, ATLAS

- LHC is ~ 1.5 - 2 Sigma high ~155 to 175 GeV
  - No excess at Tevatron

- Tevatron sensitivity improves for less than 130 GeV as you go down in mass
  - Opposite at CMS, ATLAS



TEV, CMS, ATLAS

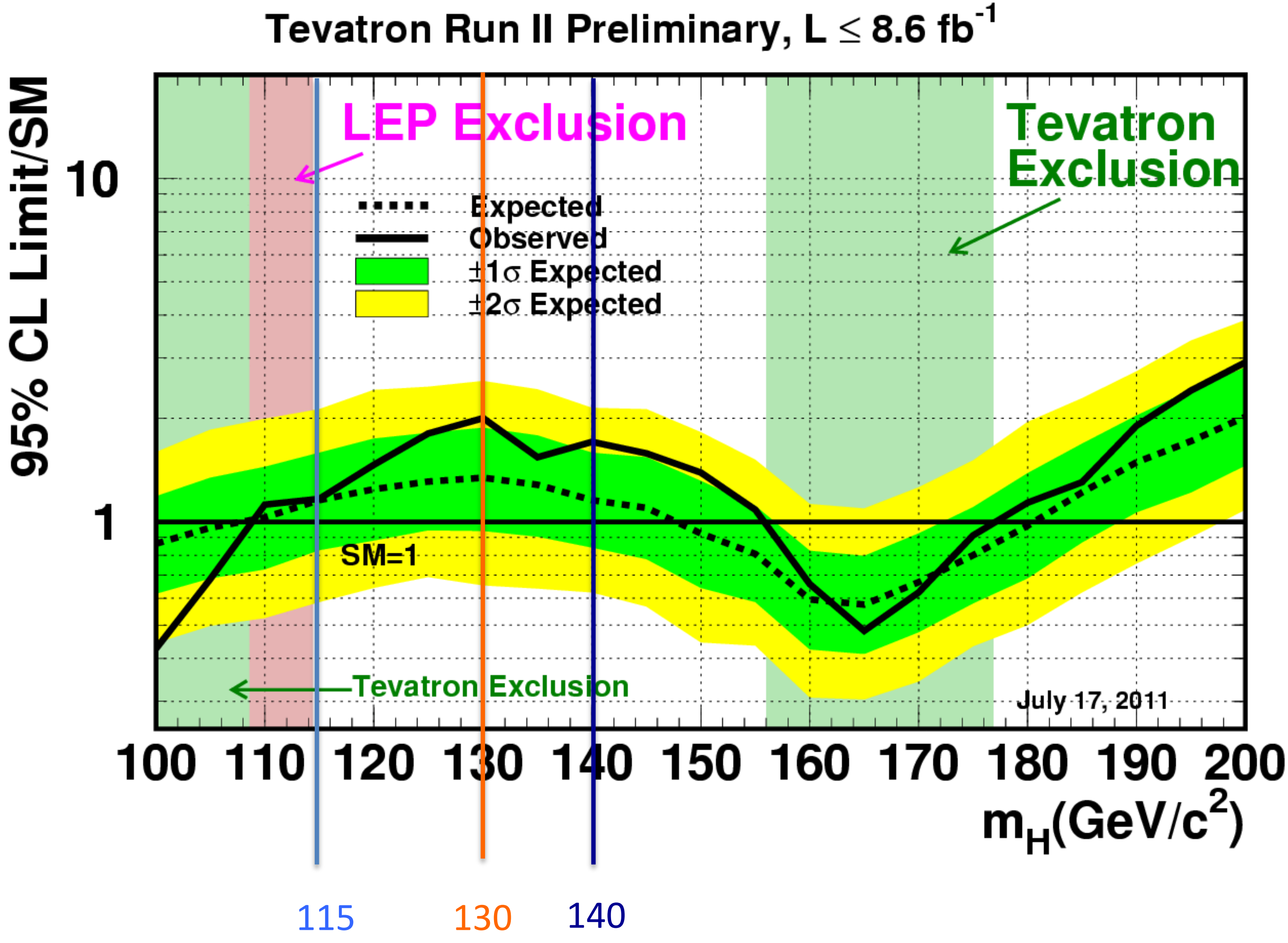
Differences TeV, CMS, ATLAS

- LHC is ~ 1.5 - 2 Sigma high ~155 to 175 GeV
  - No excess at Tevatron
- Tevatron sensitivity improves for less than 130 GeV as you go down in mass
  - Opposite at CMS, ATLAS
- CMS & ATLAS fluctuate high mH < 120 GeV
  - Tevatron sees no excess
- Sensitivity at 115 GeV
  - Tevatron : 1.15*SM
  - CMS : 1.95*SM
  - ATLAS : 2.8*SM

Interesting regions for study

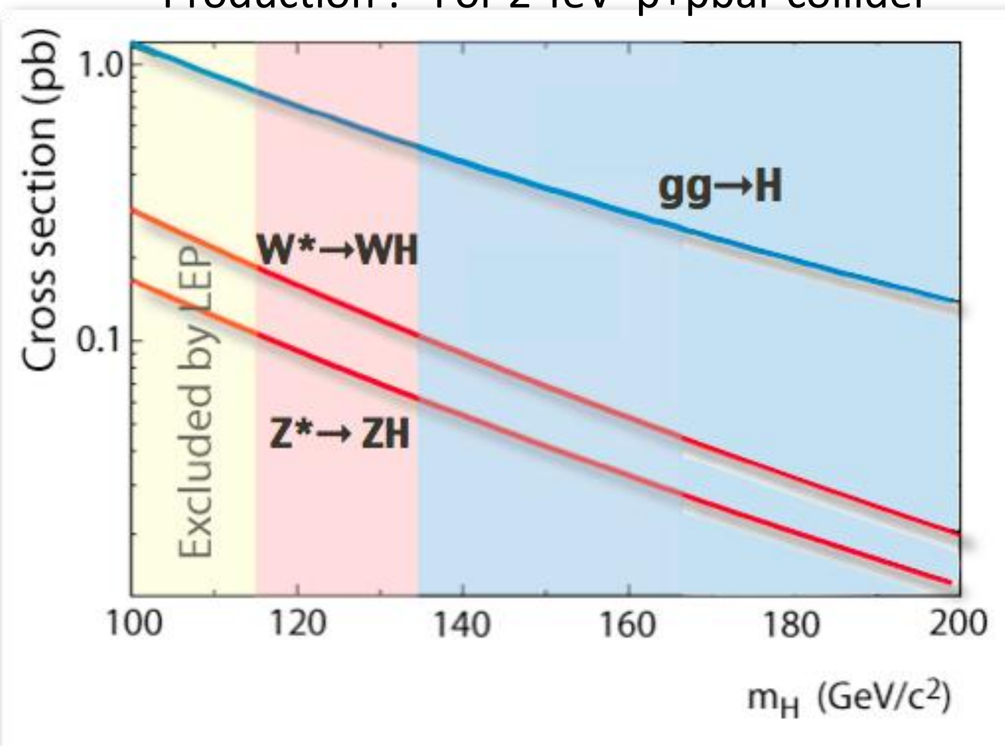
- ~115 GeV
  - CMS, ATLAS see some excess
- ~130 GeV
  - Tevatron, ATLAS see some excess
- ~140 GeV
  - Tevatron, CMS, ATLAS see some excess
    - Though CMS, ATLAS prefer very small signal
      - Ie, CMS best fit is 0.6*SM

- Interesting regions for Tevatron to study

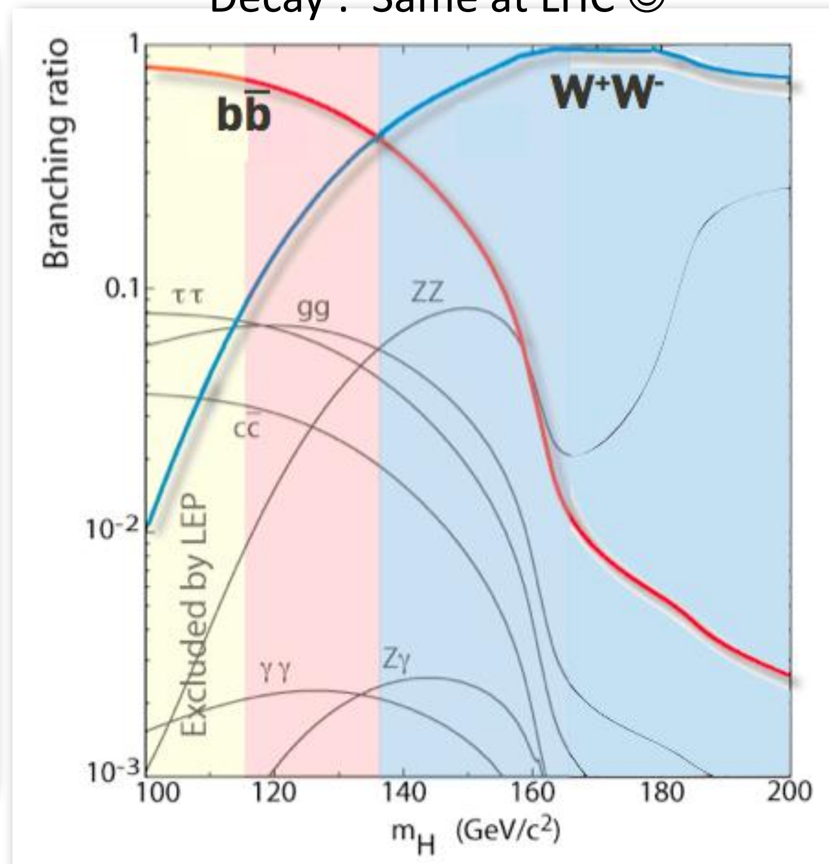


Primary Higgs interactions at Tevatron

Production : For 2 TeV p+pbar collider



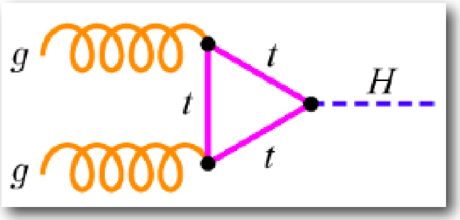
Decay : Same at LHC ☺



Tevatron vs. LHC

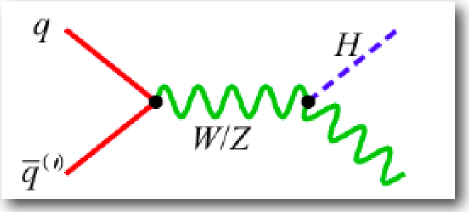
- LHC has higher cross-sections for signal processes

Gluon fusion



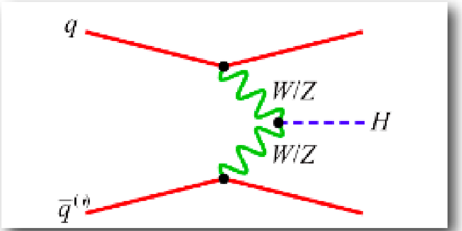
40x more at LHC

Associated Production



10x more at LHC

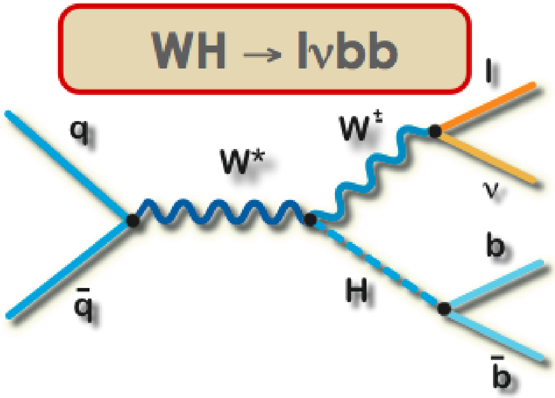
Vector boson fusion

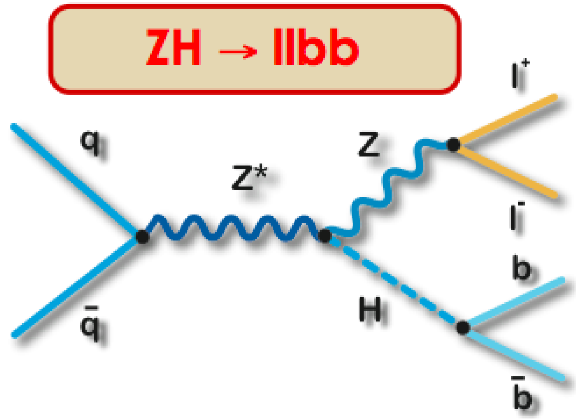


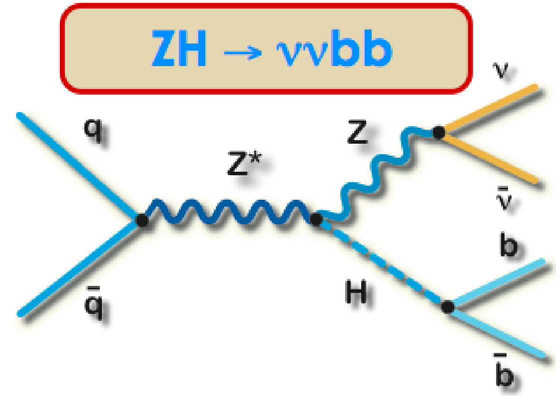
50x more at LHC

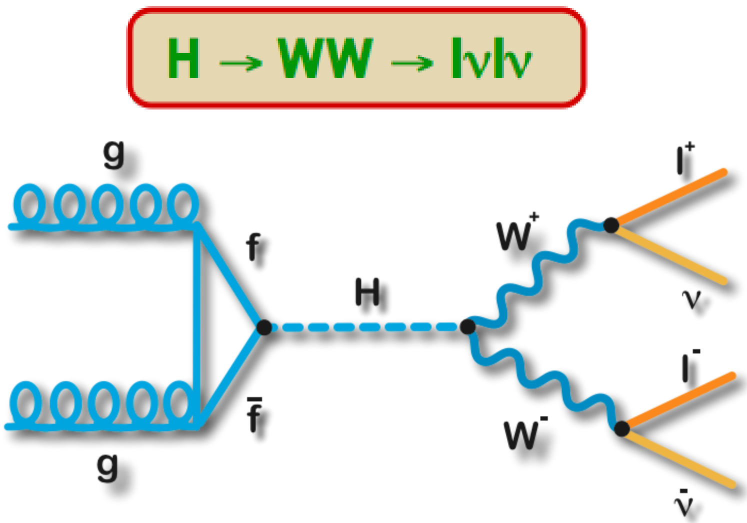
- But …
  - Tevatron currently better at lowest allowed masses
    - Anti-quarks from pbars yield WH and ZH
    - Much less W+jets, Z+jets than LHC
  - Tevatron has different background compositions

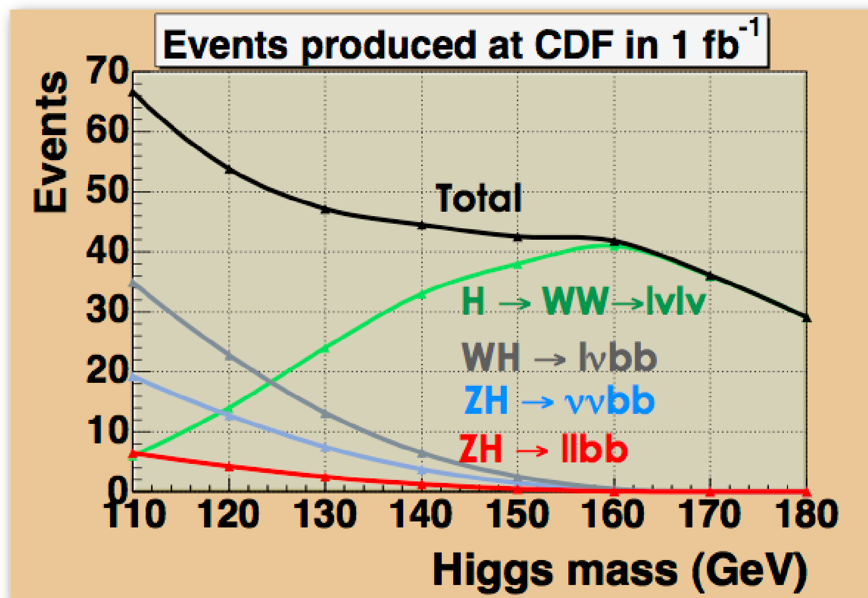
Higgs at the Tevatron





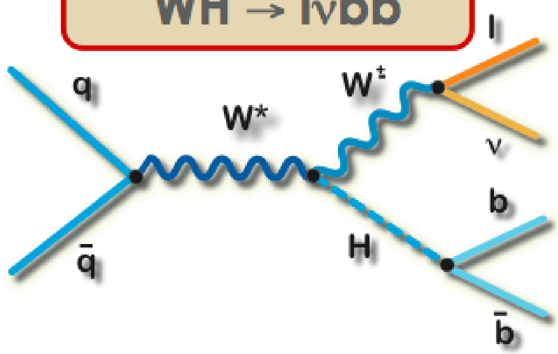




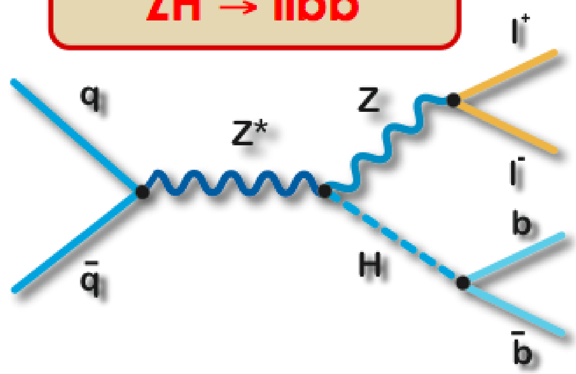


Higgs at the Tevatron

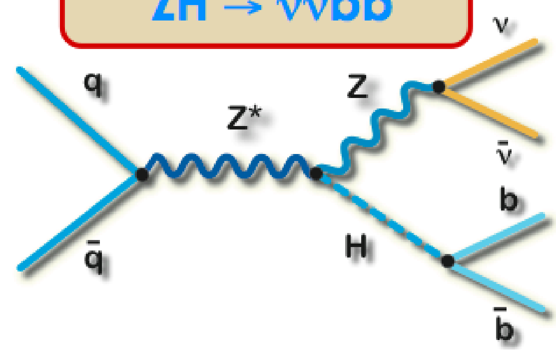
WH → lνbb



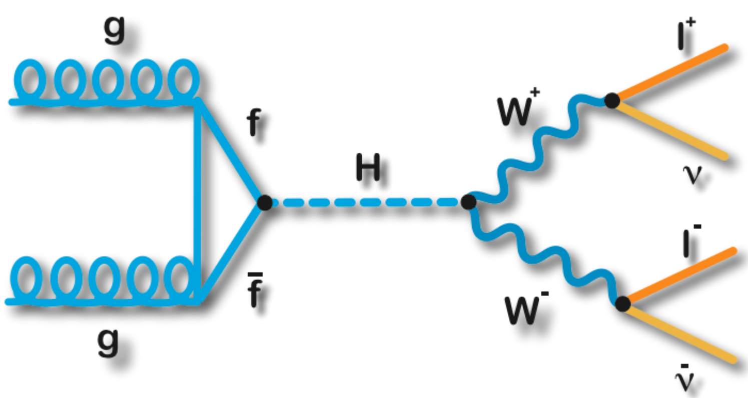
ZH → llbb

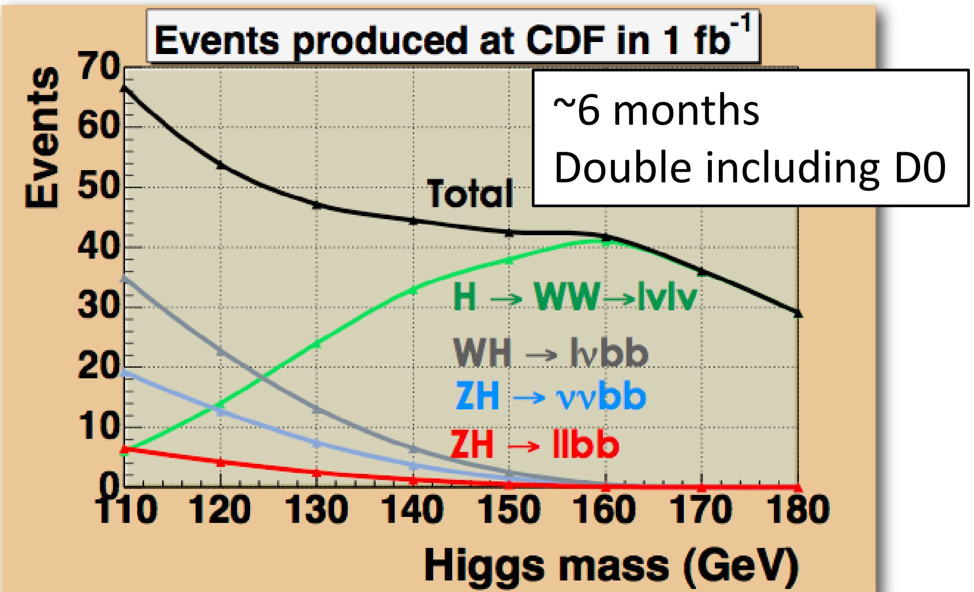


ZH → ννbb

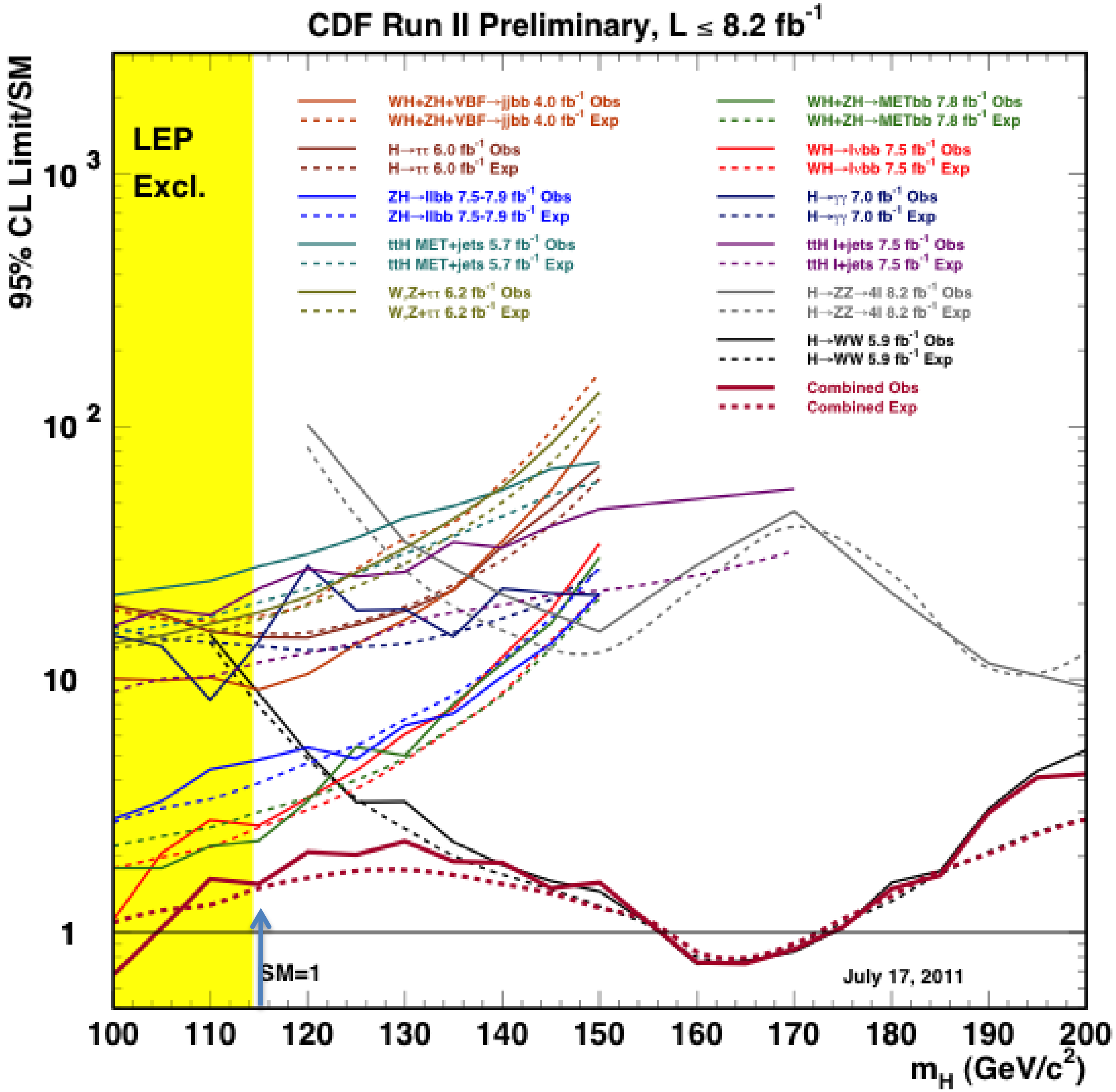


H → WW → lνlν

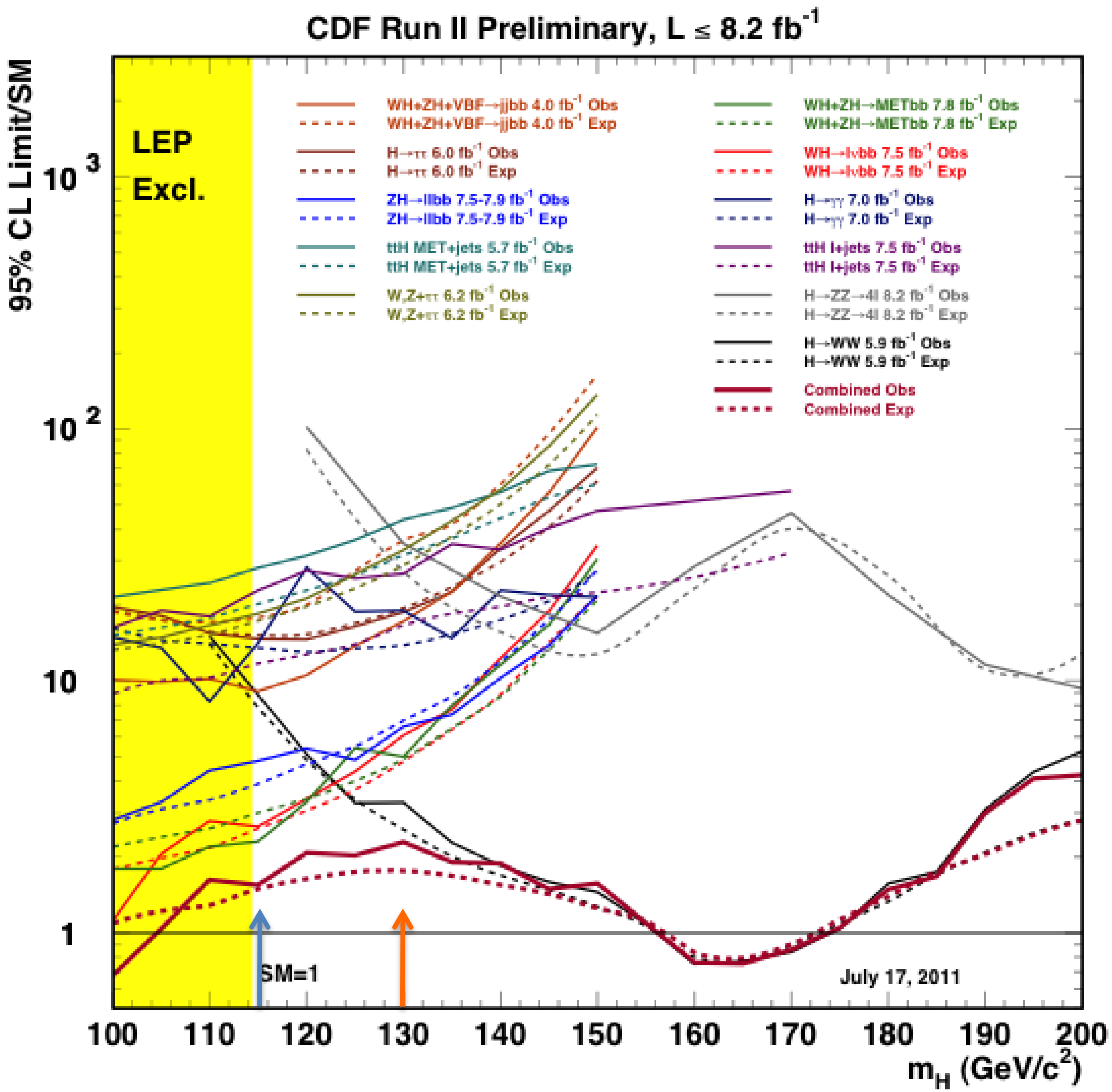




~6 months
Double including D0

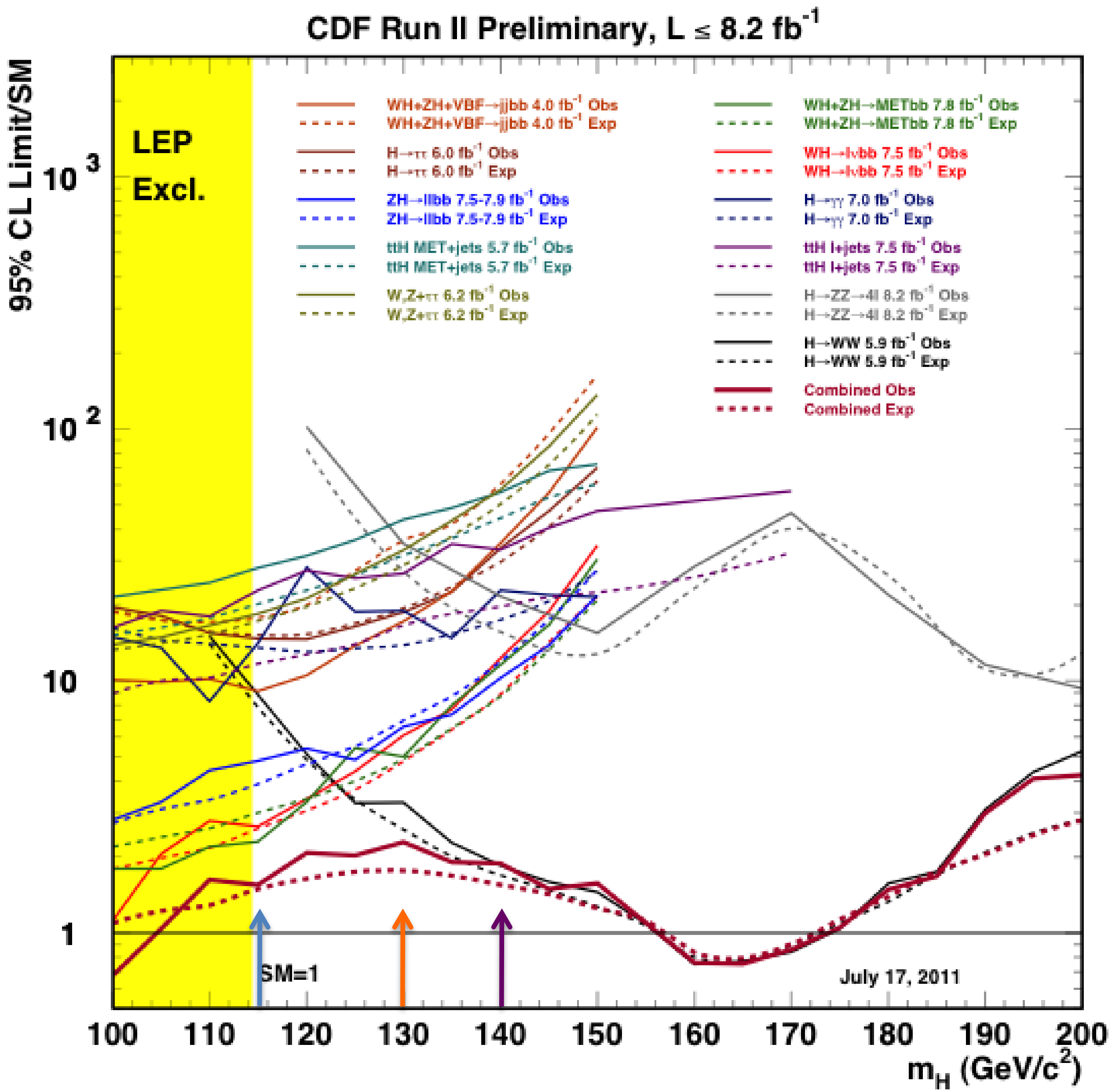


115 (expected) :
WH→lvbb
WH/ZH→MET+bb
ZH→llbb
H→WW



115 (expected) :
WH→lνbb
WH/ZH→MET+bb
ZH→llbb
H→WW

130 (expected) :
H→WW
WH→lνbb
WH/ZH→MET+bb
WH/ZH→WWW/ZWW
ZH→llbb



115 (expected) :
WH→lvbb
WH/ZH→MET+bb
ZH→llbb
H→WW

130 (expected) :
H→WW
WH→lvbb
WH/ZH→MET+bb
WH/ZH→WWW/ZWW
ZH→llbb

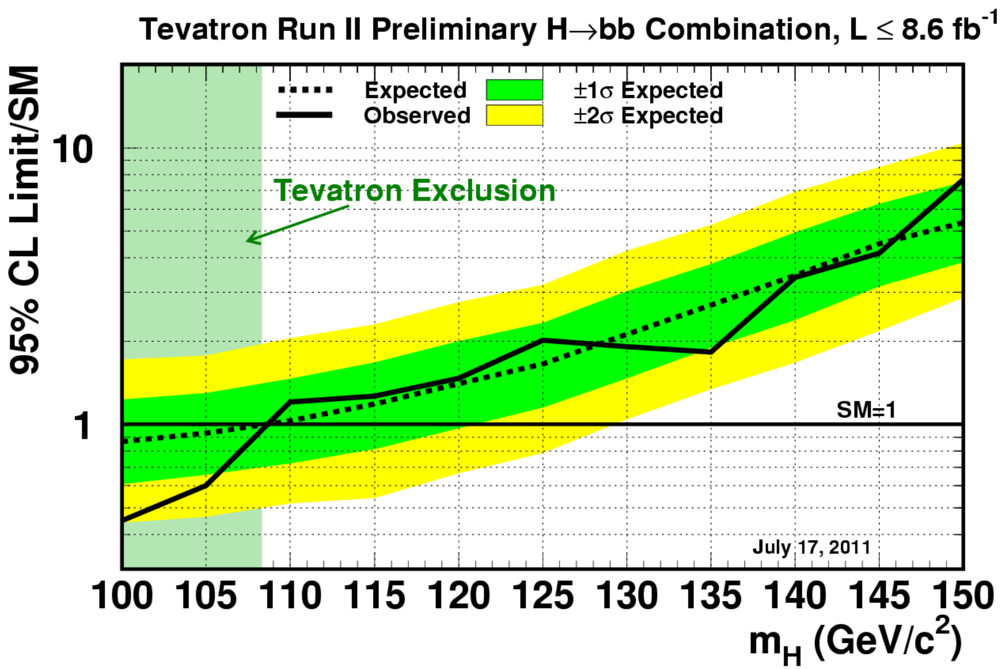
140 (expected) :
H→WW
WH/ZH→WWW/ZWW

Tevatron perspective at 115 GeV

Dominated by WH/ZH→leptons+bb

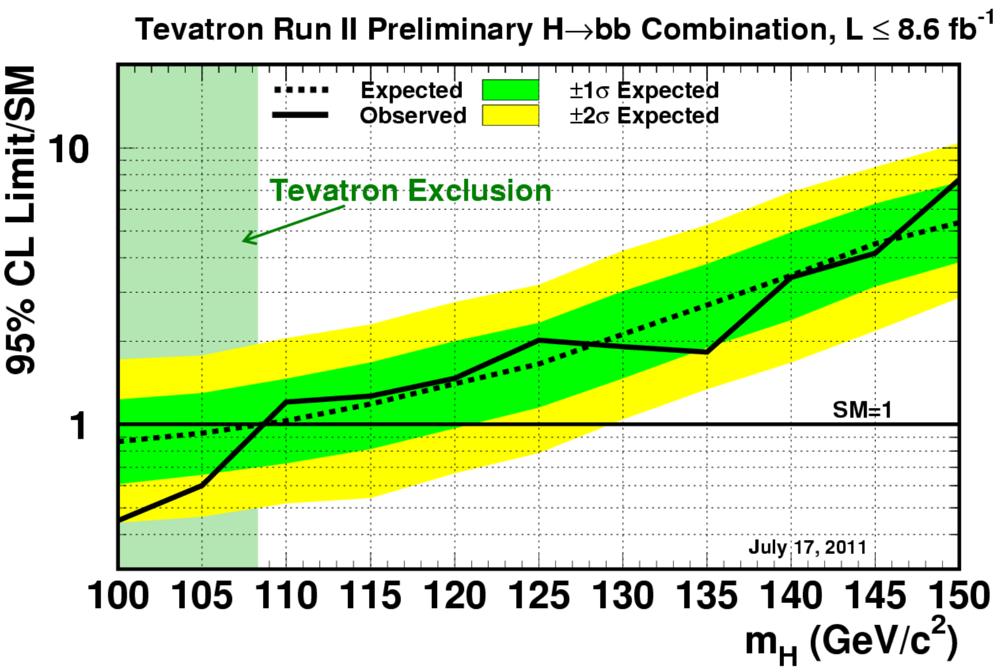
Expected sensitivity : 1.2*SM

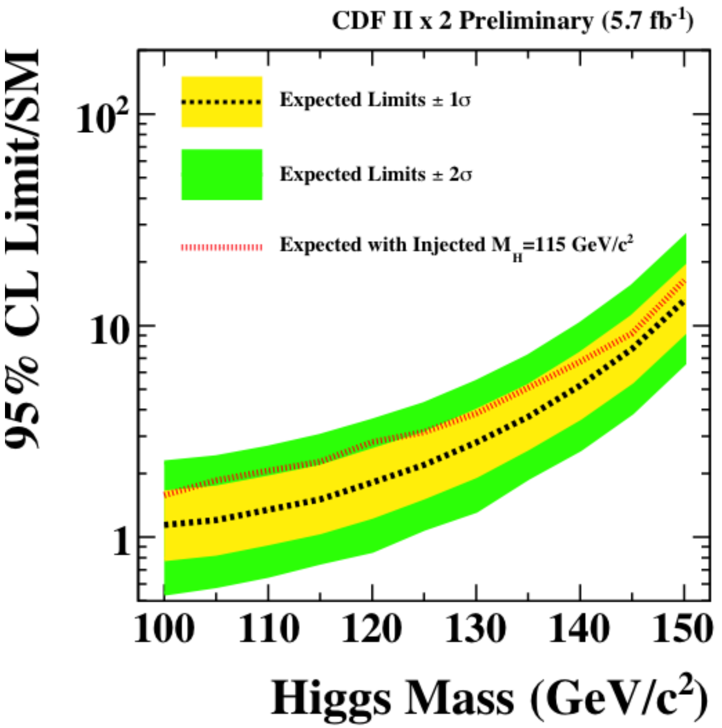
Tevatron H→bb



- At 115-120 GeV
  - Almost at 1*SM sensitivity
  - No excess seen
  - Inconsistent with CMS & ATLAS

Tevatron H→bb



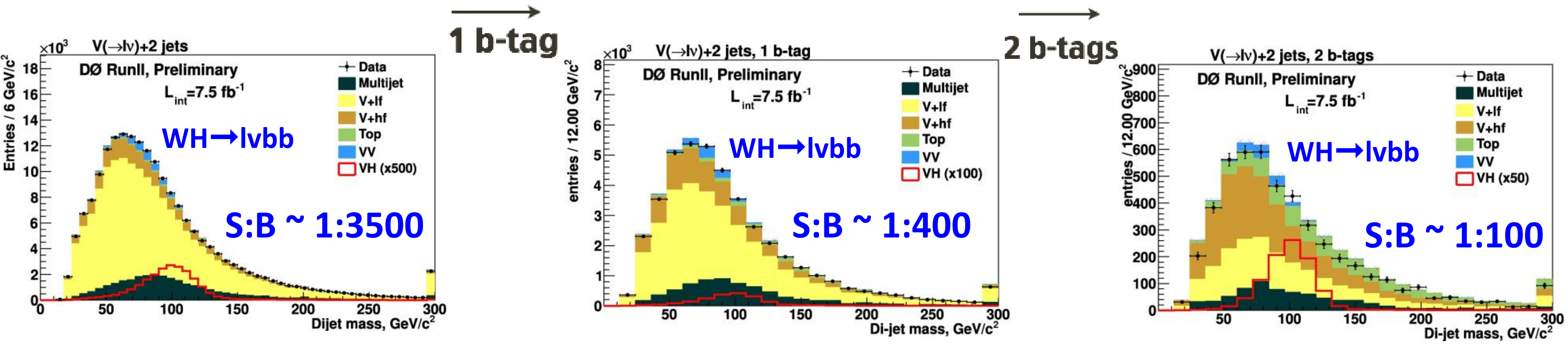


- At 115-120 GeV
  - Almost at 1*SM sensitivity
  - No excess seen
  - Inconsistent with CMS & ATLAS

Signal injected at 115 GeV

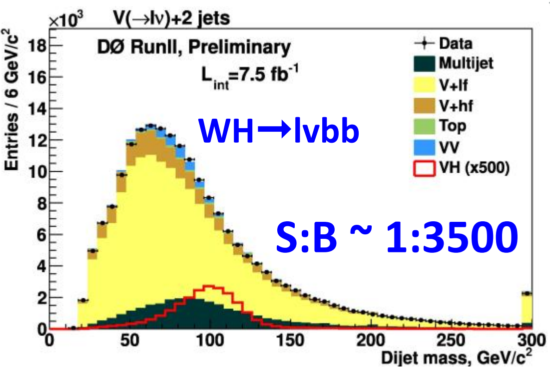
Not consistent with signal

Basics of WH/ZH ➞ leptons + bb

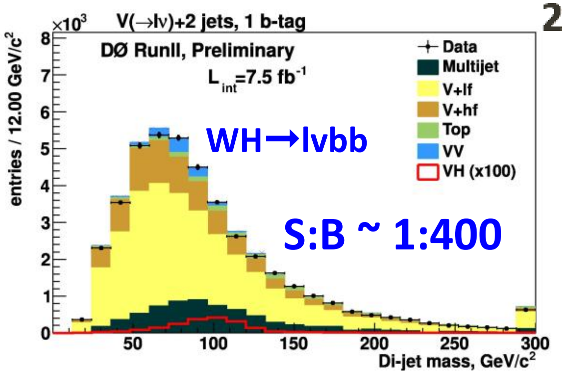


Before b-tagging, rich control sample
B-tags enhance signal

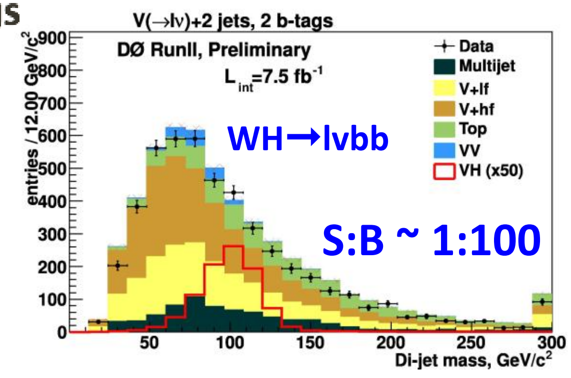
Basics of WH/ZH → leptons + bb



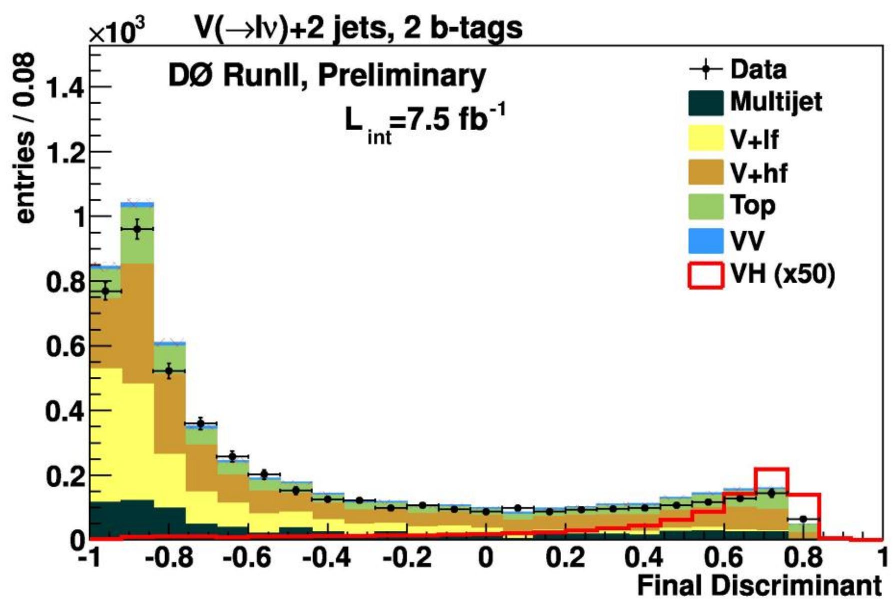
1 b-tag



2 b-tags



Before b-tagging, rich control sample
B-tags enhance signal

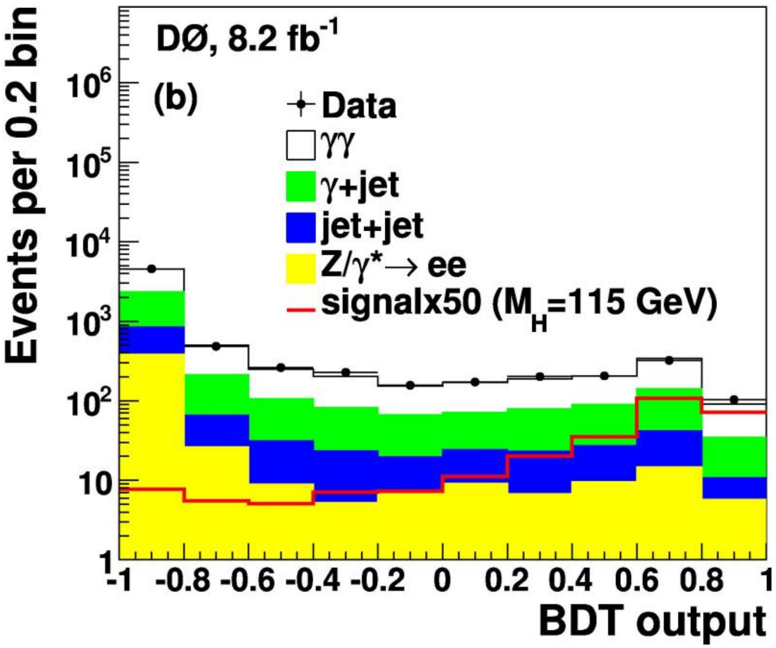


Multivariate output reduces background

Other channels at 115 GeV

- At Tevatron, small gain in sensitivity from including other channels besides WH/ZH➞leptons+bb
- Currently analyzed :
  - H➞γγ
  - H➞ττ
  - ttH➞l+v+bb+jets
  - ttH➞met+bb+jets
  - ttH➞jets+bb
  - WH/ZH➞qqbb
  - WH/ZH➞leptons+ττ
  - H➞ZZ
- Expected sensitivity = 5.4*SM combined for all above channels
  - Similar to single experiment primary WH/ZH➞lep+bb channel
  - However, techniques are quite advanced
    - Can be useful at the LHC

H➞γγ



D0 analysis models di-photon background

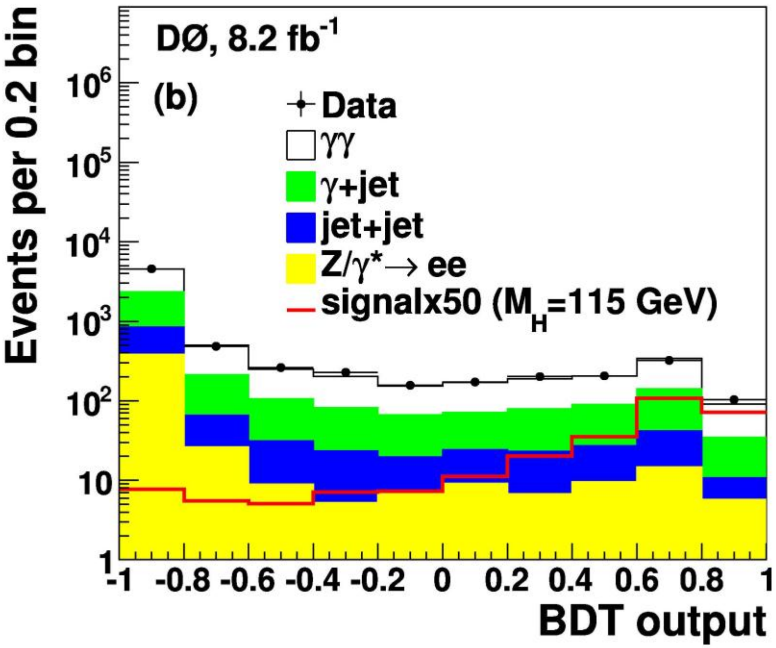
(Rather than data sideband fit of $M_{\gamma\gamma}$ of CMS,ATLAS)

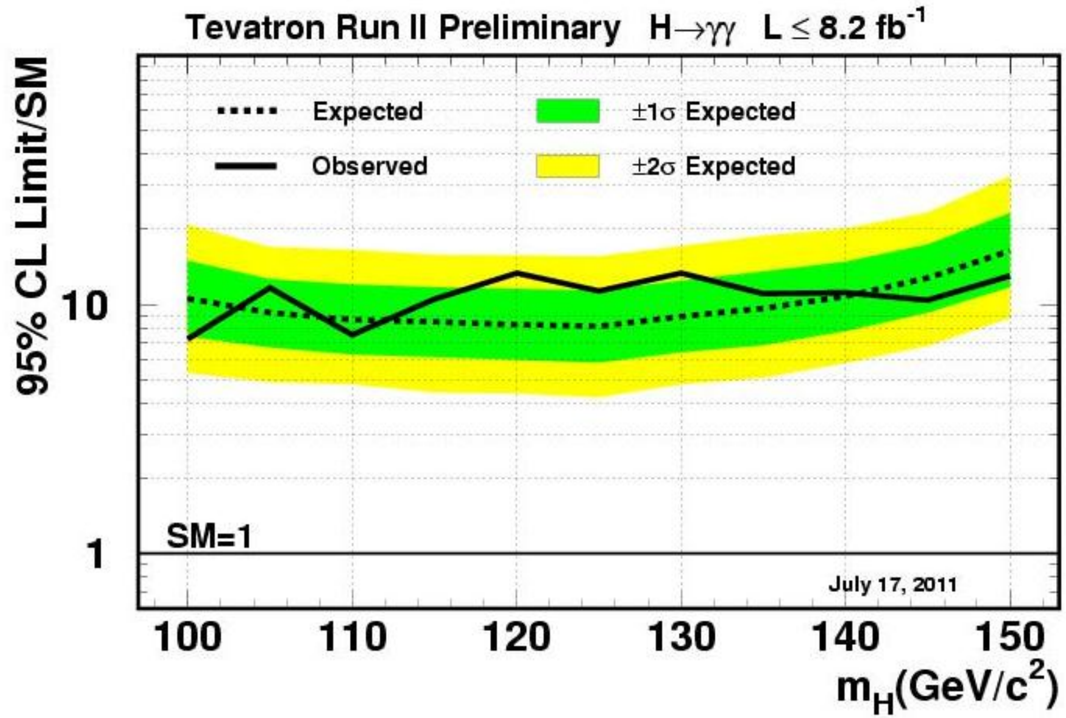
Multivariate analysis correlates $M_{\gamma\gamma}$ with

$PT_{\gamma\gamma}$, $d\Phi_{\gamma\gamma}$, $PT_{\gamma 1}$, $PT_{\gamma 2}$

➞ signal fit of MVA output

$H \rightarrow \gamma\gamma$



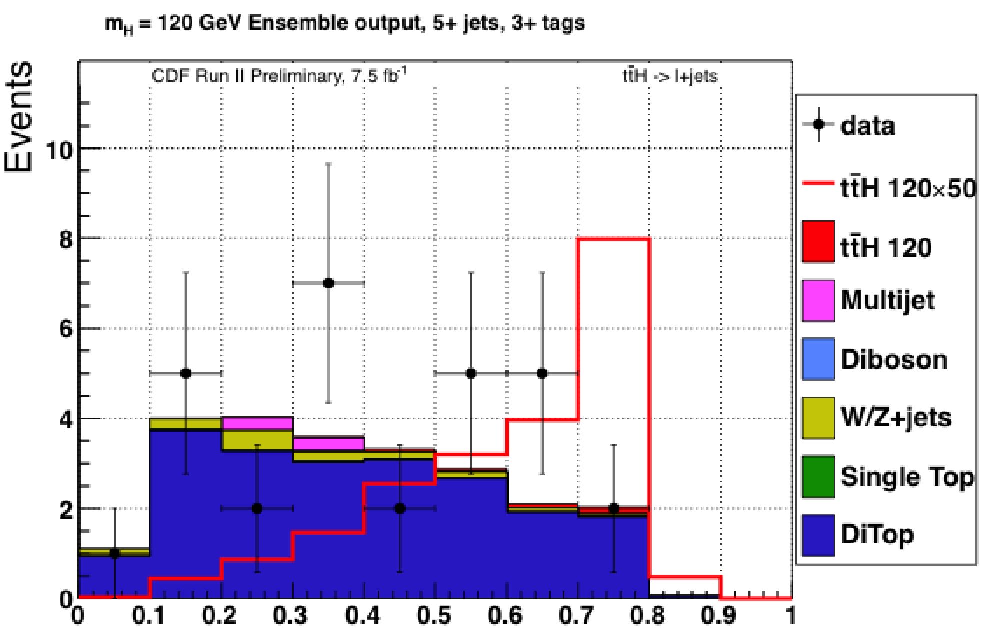


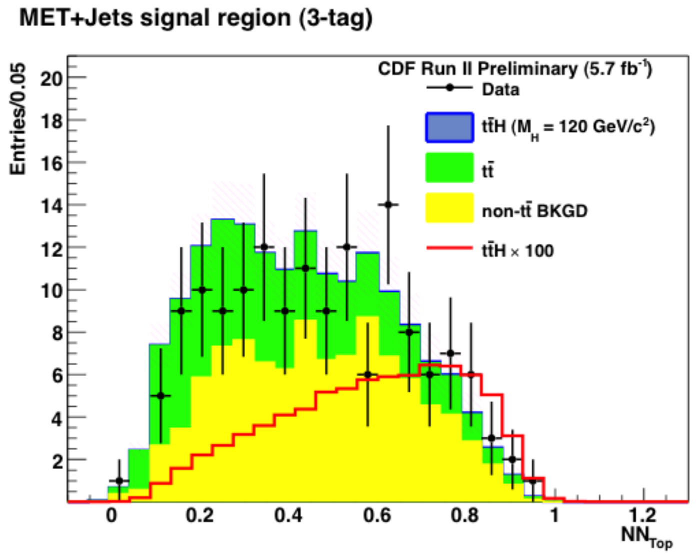
D0 analysis models di-photon background
(Rather than data sideband fit of $M_{\gamma\gamma}$ of CMS,ATLAS)
Multivariate analysis correlates $M_{\gamma\gamma}$ with
$PT_{\gamma\gamma}$, $d\Phi_{\gamma\gamma}$, $PT_{\gamma 1}$, $PT_{\gamma 2}$
→ signal fit of MVA output

CDF+D0 expected 8*SM at 115 GeV

ttH

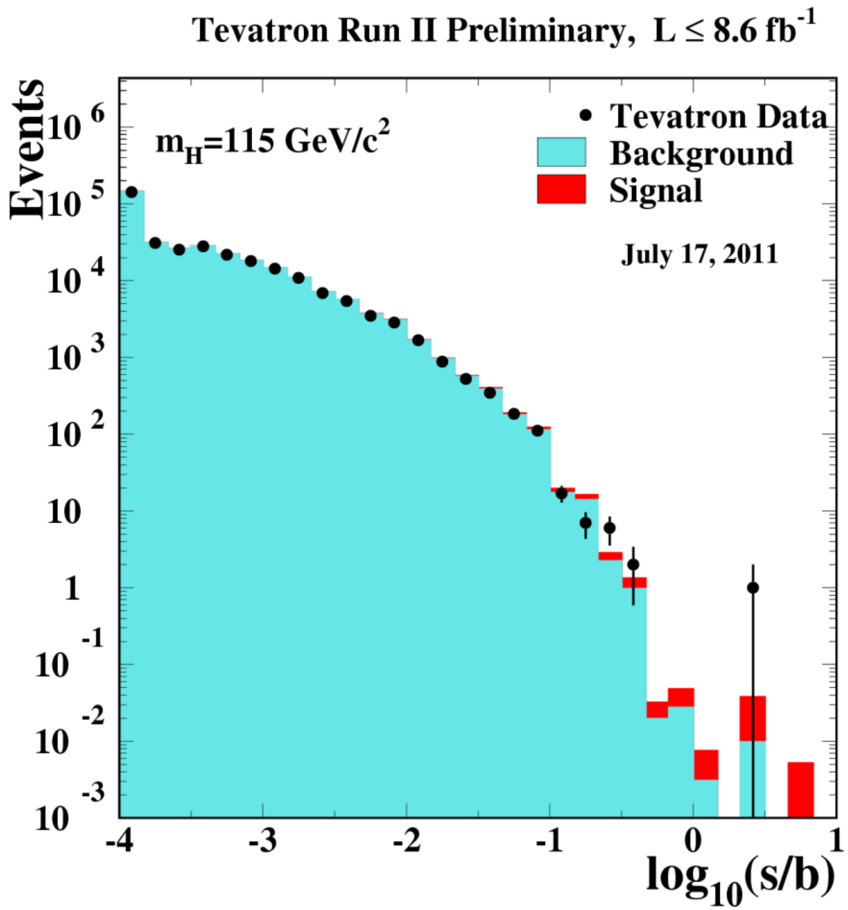
- Many final states tested
  - Simultaneous fits over 2 or 3+ b-tags, in bins of jet multiplicity
    - 8 signal regions
  - Multivariate tools to remove top-pair and multijet backgrounds

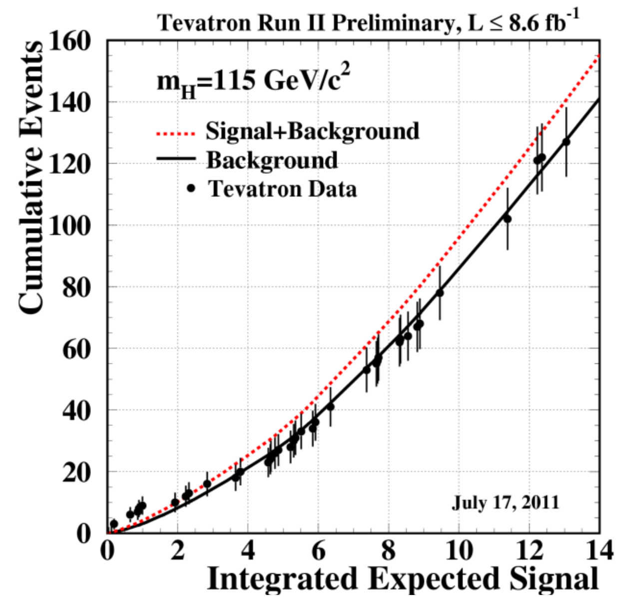


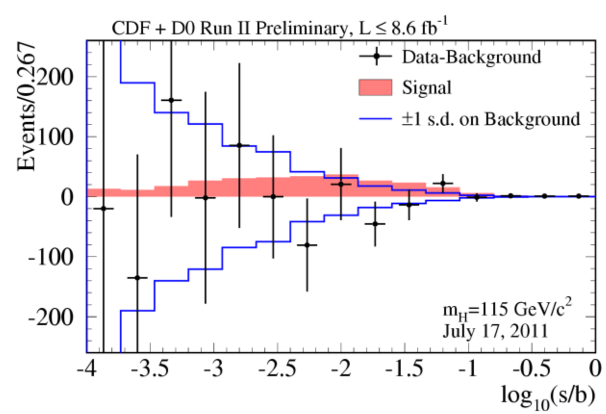


Combined expected 10*SM limit at 120 GeV (just CDF)

Background modeling at 115 GeV







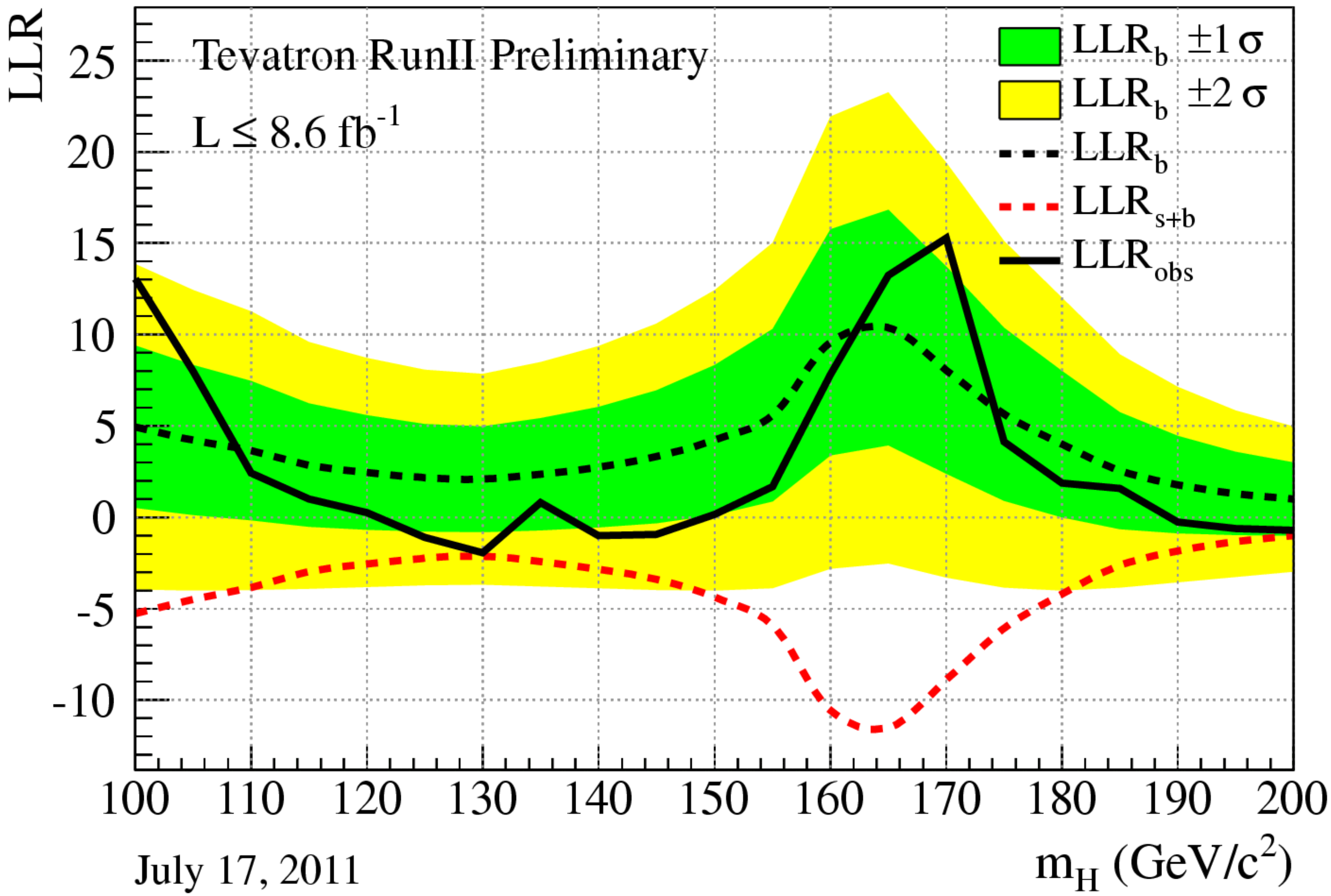
- BKG modeling impressive over 7 orders of magnitude
  – Dominated by b-tagged W+jets, Z+jets

Tevatron perspective at 130 GeV

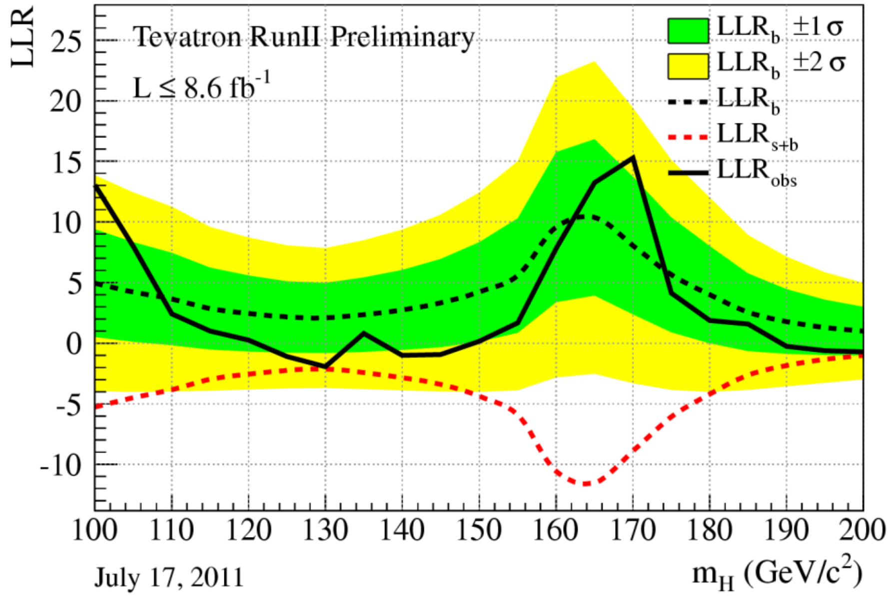
Most difficult mass at Tevatron
Equal sensitivity between WH/ZH→bb and H→WW

Expected sensitivity : 1.35*SM

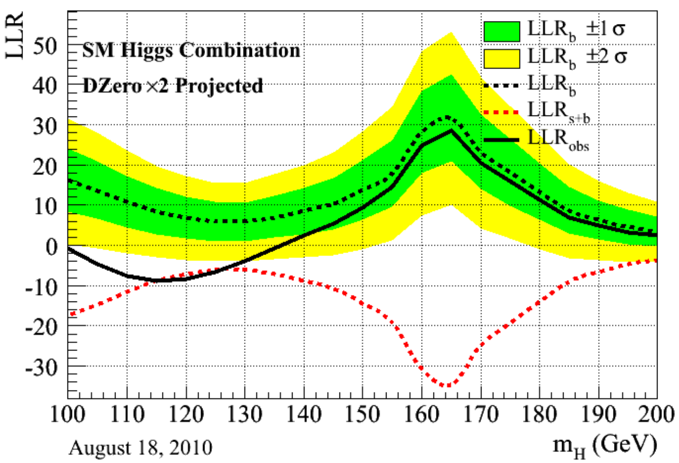
Most signal-like value



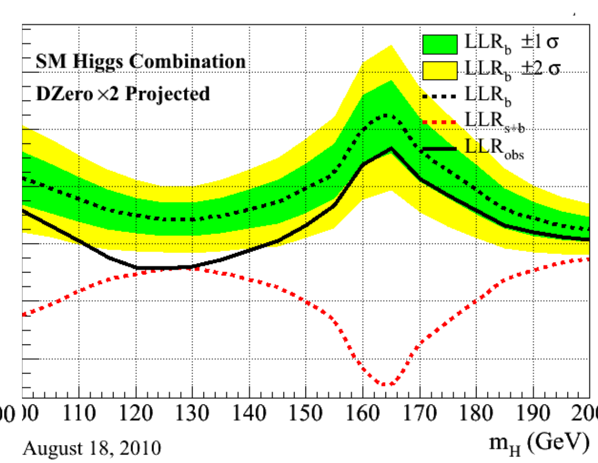
- Most signal-like excess at 130 GeV (only ~1.5 σ)



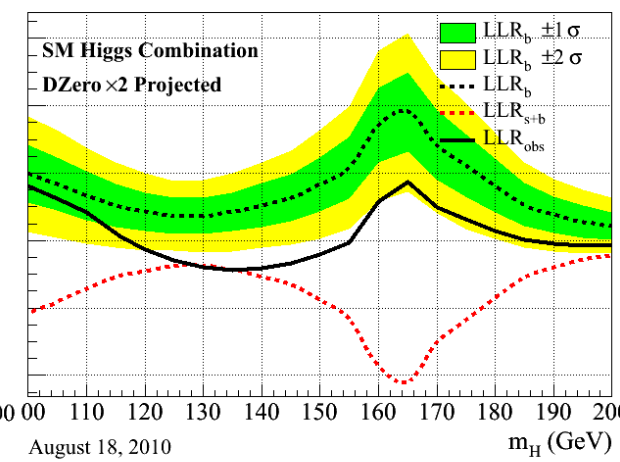
Actual Tevatron data



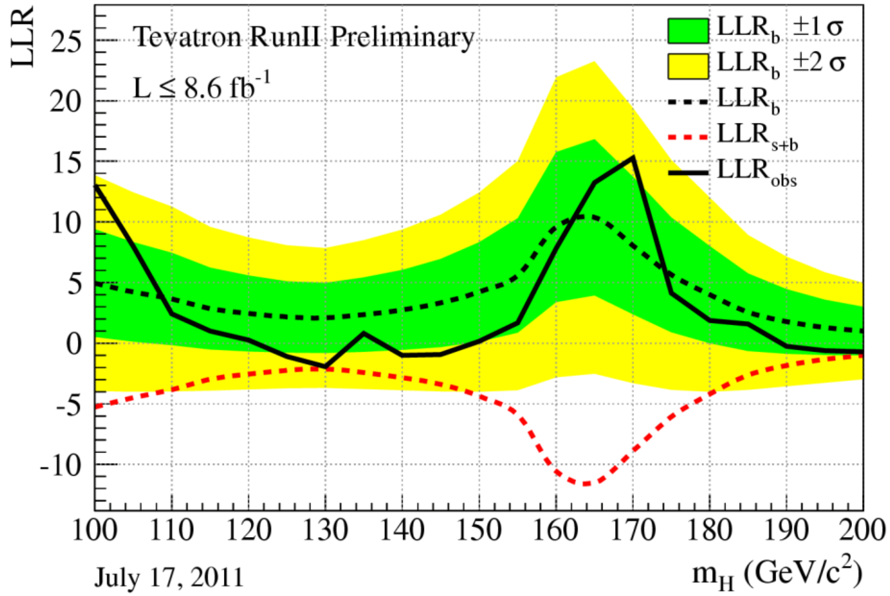
Signal injected at 115 GeV



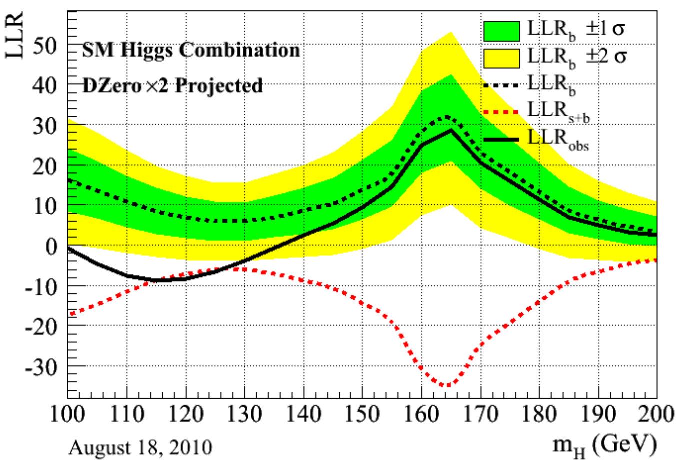
Signal injected at 125 GeV



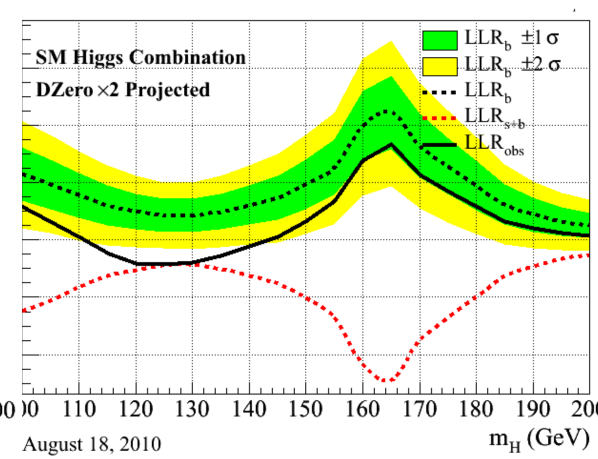
Signal injected at 135 GeV



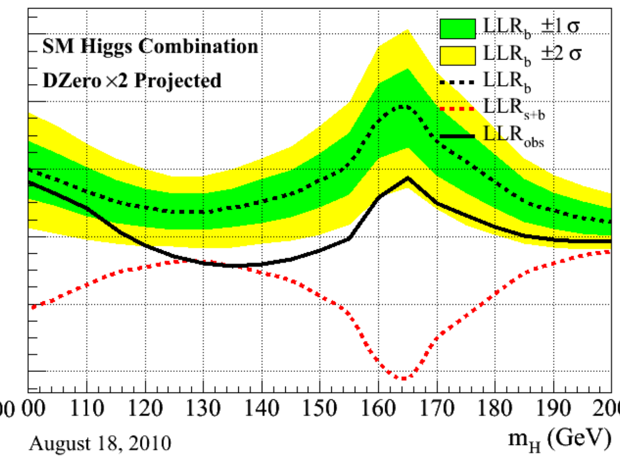
Actual Tevatron data



Signal injected at 115 GeV

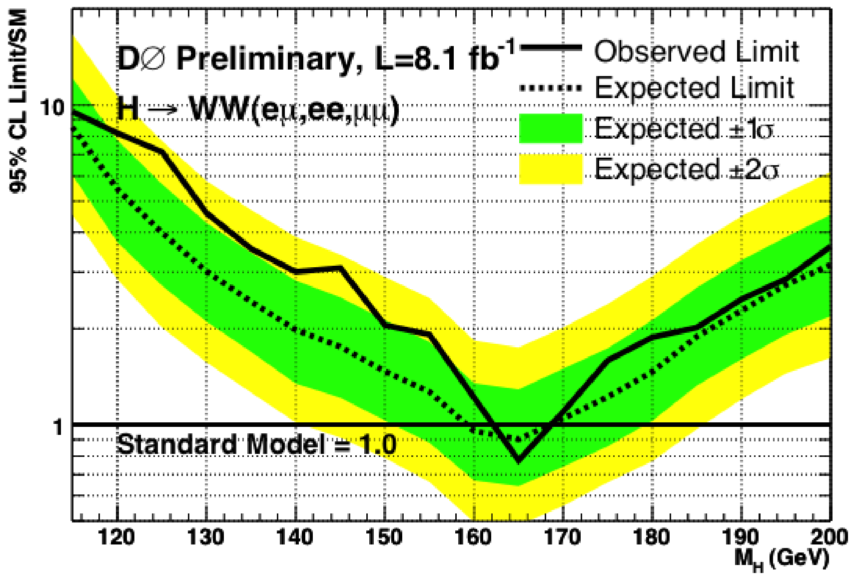


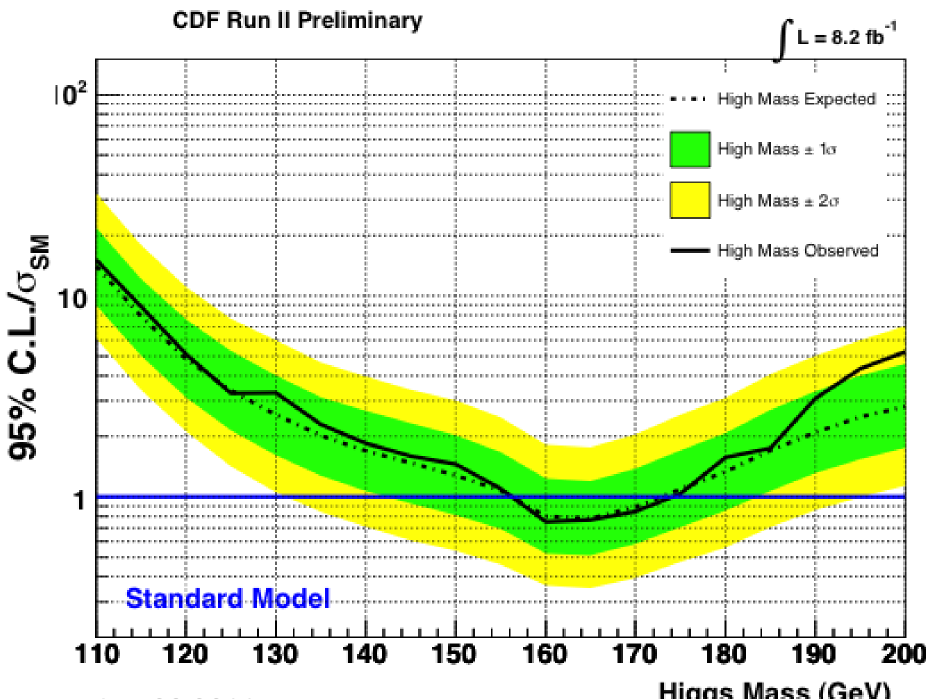
Signal injected at 125 GeV



Signal injected at 135 GeV

Not consistent with 130 GeV injection at either end

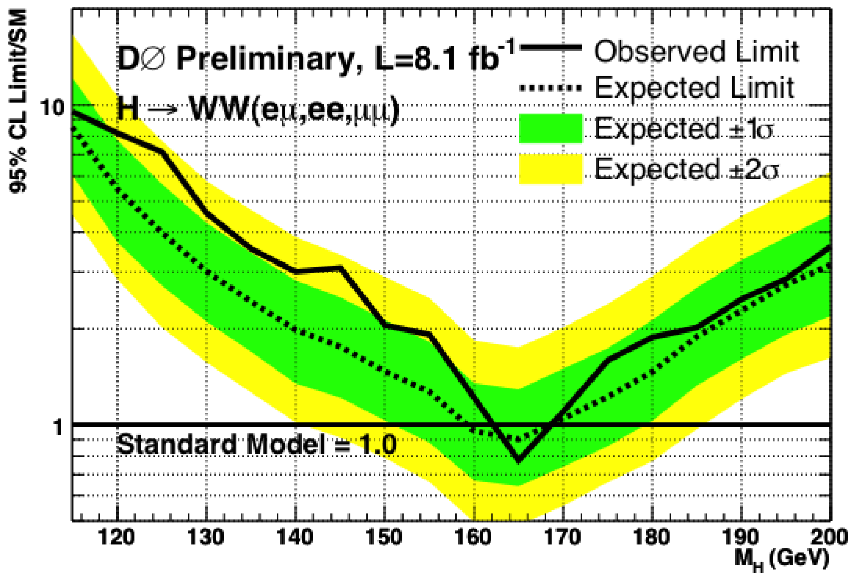




Excess at 130 GeV mainly $H\rightarrow WW$

Mostly from D0
Exp: 3*SM, Obs: 4.5*SM

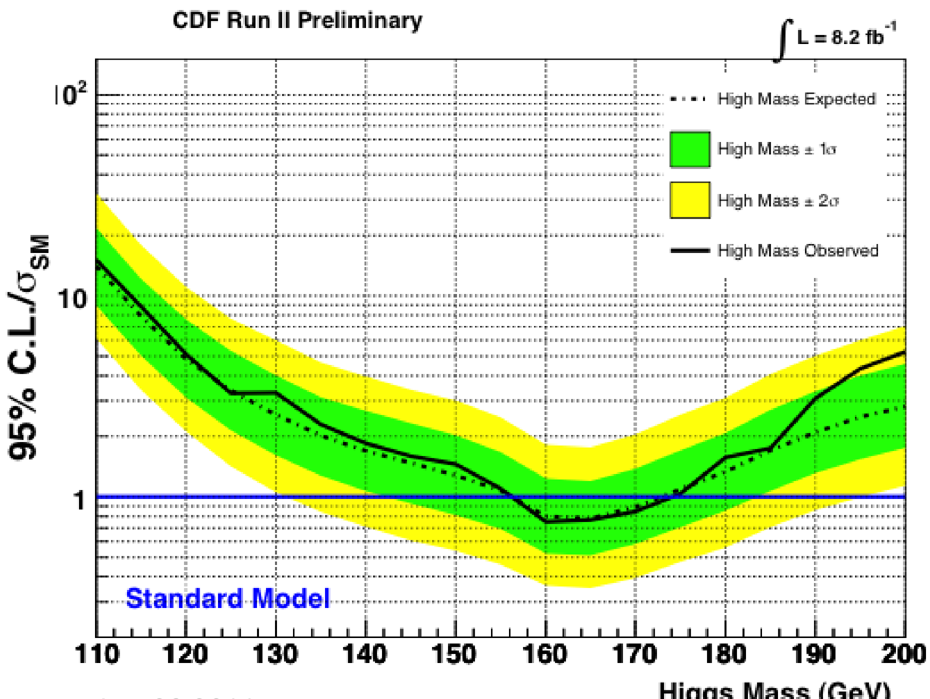
CDF contributes at 0.5 σ level
Exp: 2.5*SM, Obs: 3.2*SM

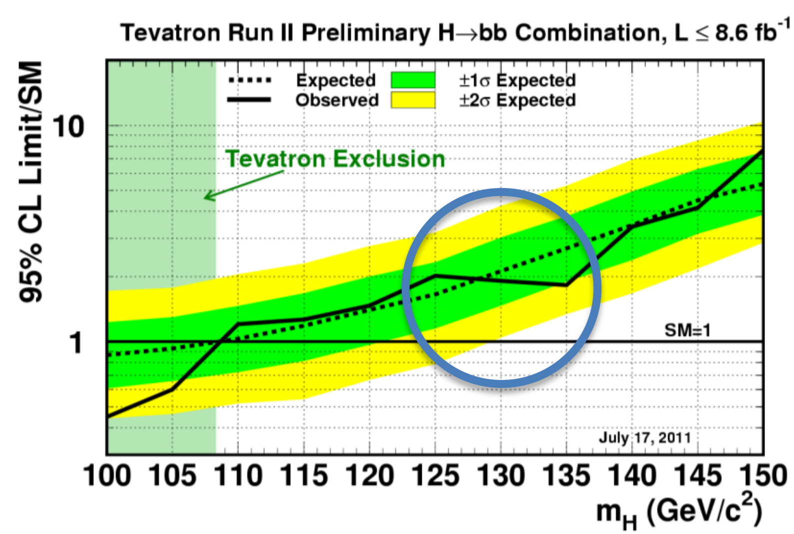


Excess at 130 GeV mainly H→WW

Mostly from D0
Exp: 3*SM, Obs: 4.5*SM

CDF contributes at 0.5 σ level
Exp: 2.5*SM, Obs: 3.2*SM





H→bb sees nothing :
Exp: 2*SM, Obs: 2*SM

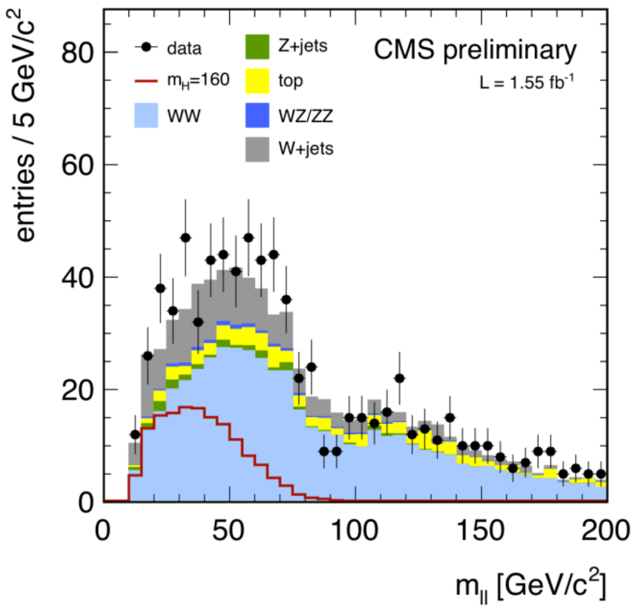
Tevatron perspective at 140 GeV

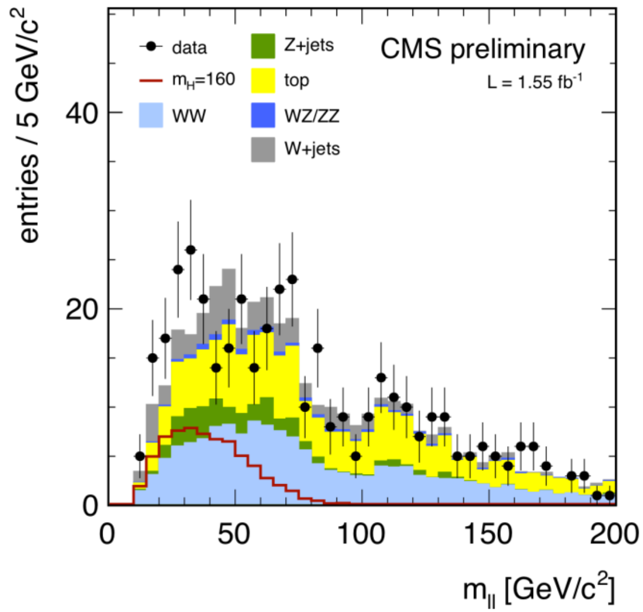
gg → H → WW dominates

Expected sensitivity : 1.2*SM

WW excesses at CMS & ATLAS

CMS 0-jet

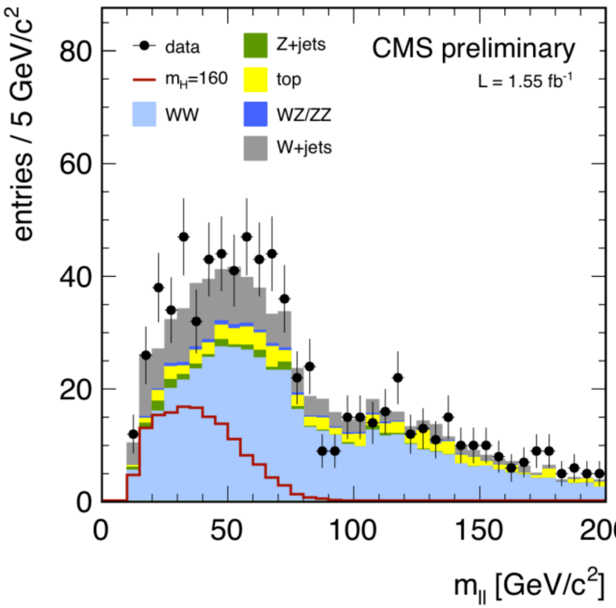




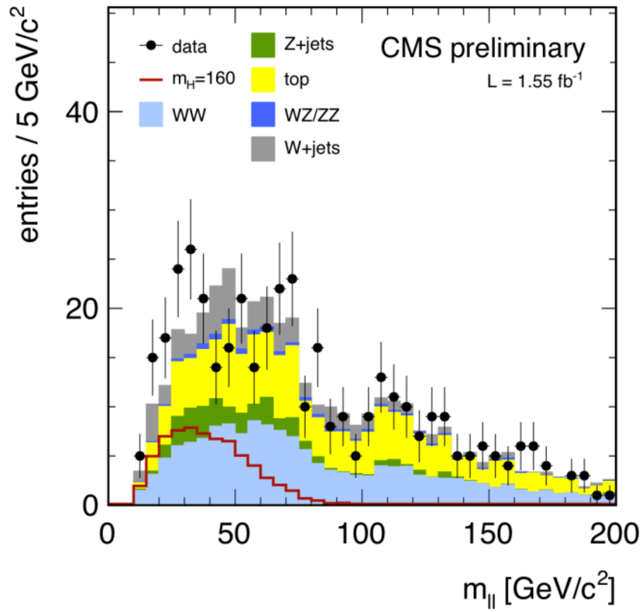
CMS 1-jet

WW excesses at CMS & ATLAS

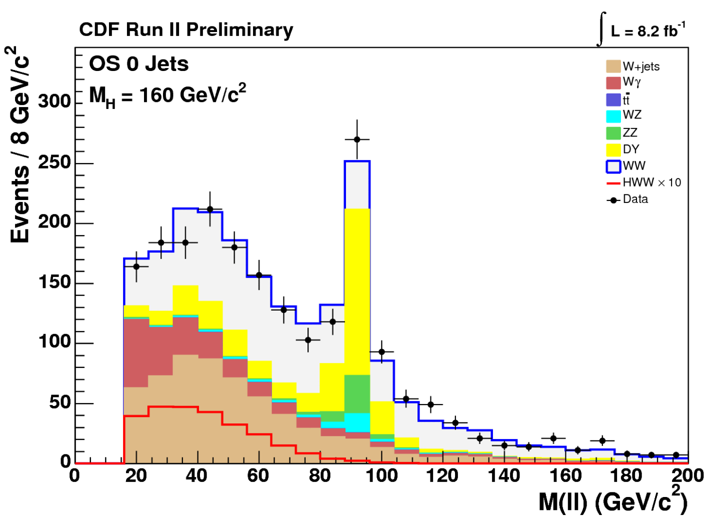
CMS 0-jet



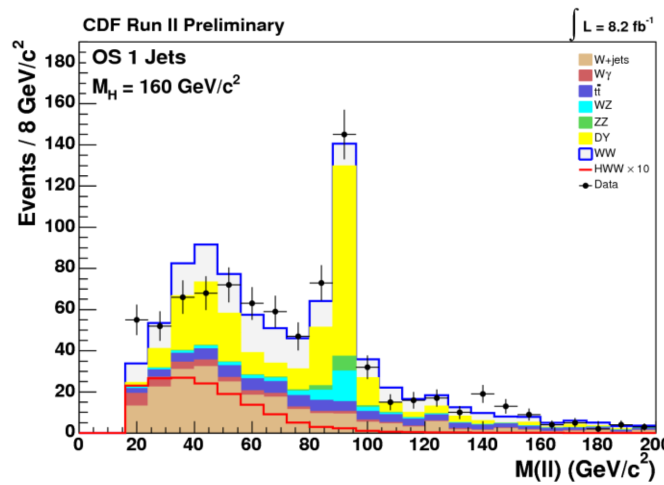
CMS 1-jet



CDF 0-jet

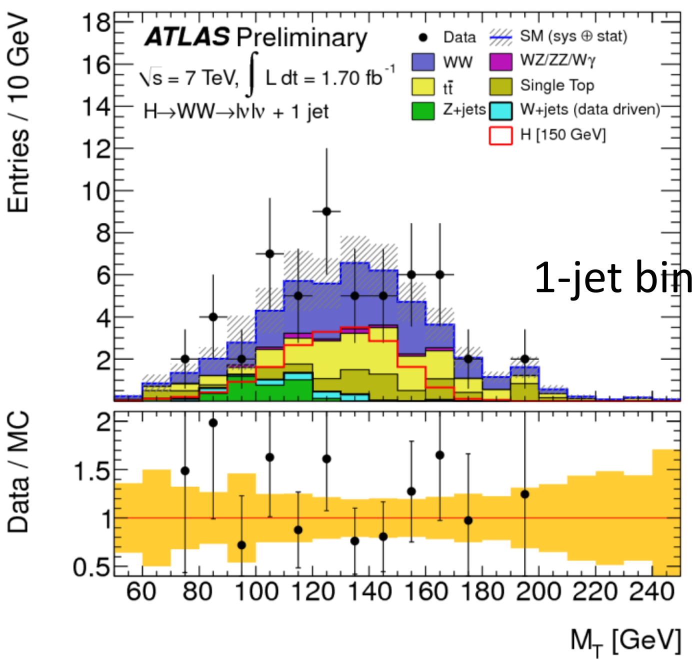


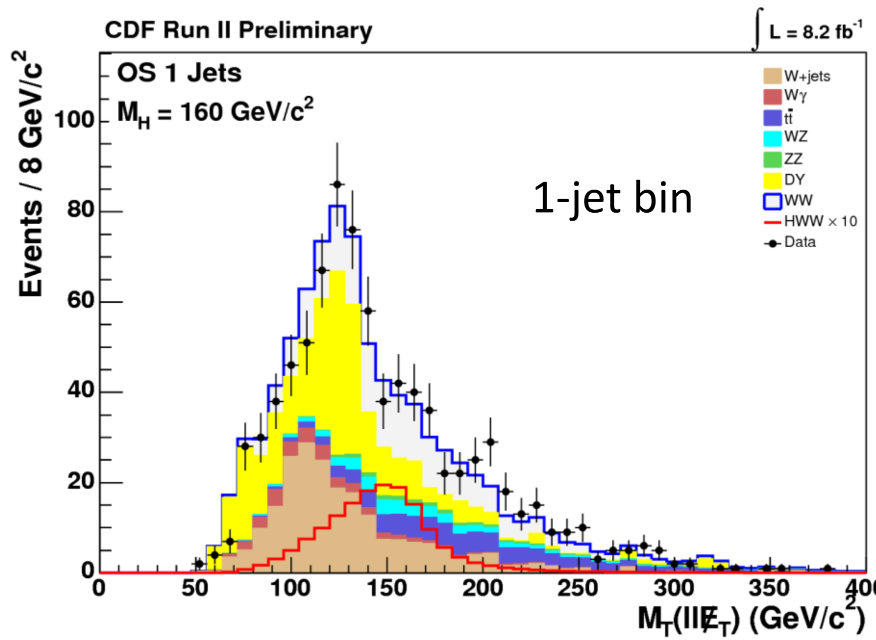
CDF 1-jet



Tevatron has different background composition

Tevatron can provide independent crosscheck





ATLAS (and CMS) have small Z+jets (green), larger ttbar (yellow) contribution at low M_T where excess is

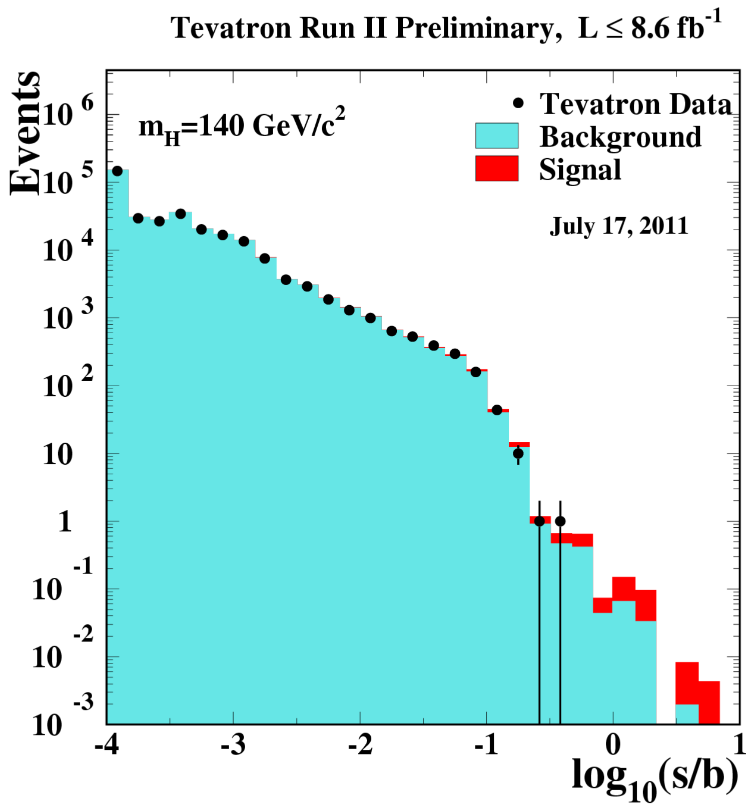
CDF has large Z+jets (yellow), smaller ttbar (purple) at low M_T in same region

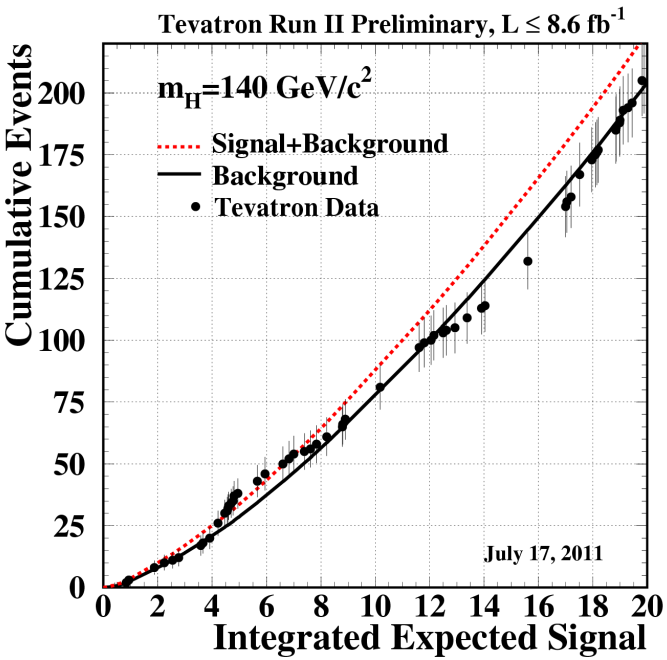
- And much smaller ttbar

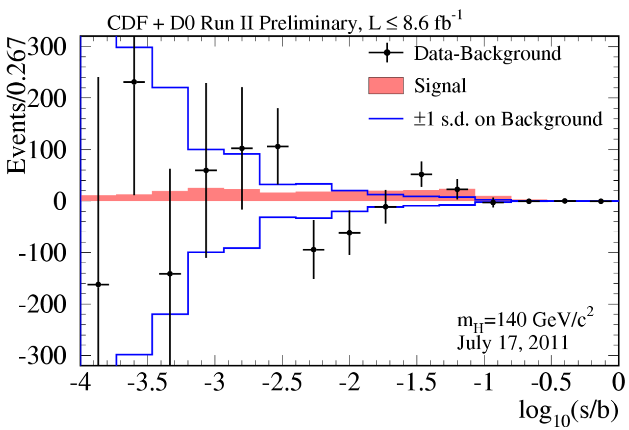
Tevatron cross-checks of excesses

- Excesses at LHC or Tevatron could be due to different backgrounds
  - Consistent excesses between Tevatron and LHC
    - Constrain interpretation of possible background fluctuation
- Tevatron also more sensitive to WH/ZH production in high mass analysis, whereas LHC has more from VBF
  - Consistent excesses between Tevatron and LHC could indicate SM Higgs boson relationship (ggH, WH/ZH, VBF)
    - Constrain interpretation as a Higgs signal

Background modeling at 140 GeV







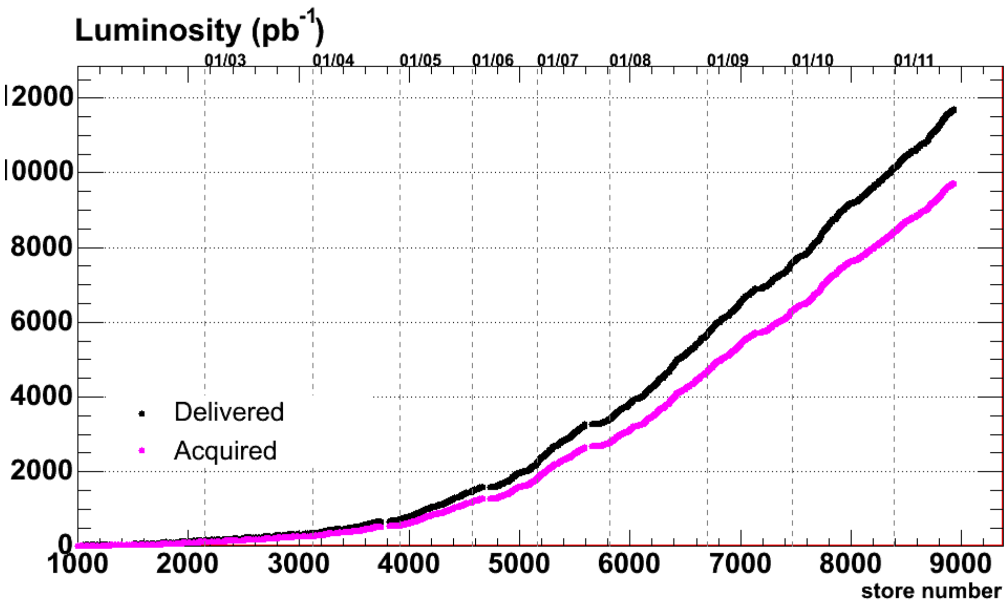
- BKG modeling over 7 orders of magnitude
  - Dominated by WW, Drell-Yan

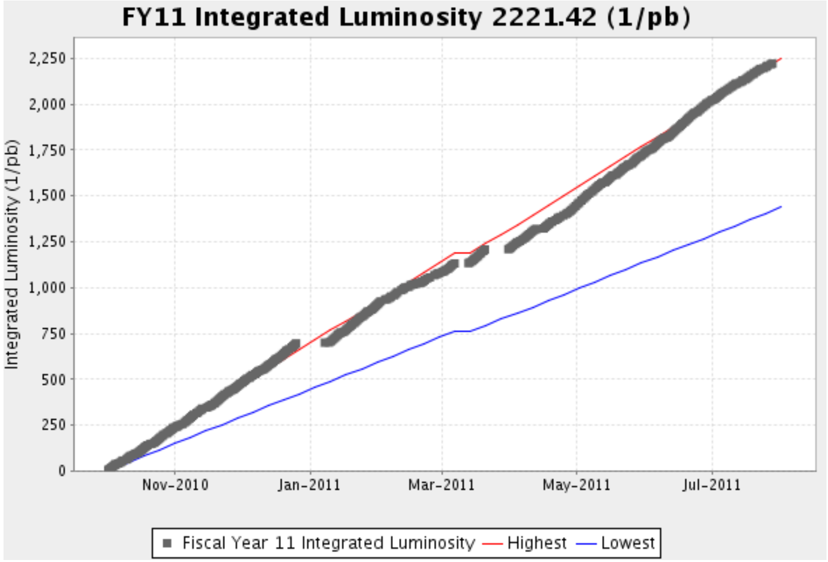
Tevatron perspectives

- 115 GeV
  - Tevatron can crosscheck excesses seen in CMS, ATLAS data from $H \rightarrow WW$, $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ$ using different Higgs signal mode
    - Tevatron $WH/ZH \rightarrow bb$ provides best sensitivity
- 130 GeV
  - Most consistent excesses between CMS, ATLAS, Tevatron
    - Tevatron $H \rightarrow WW$ & $WH/ZH \rightarrow bb$ provide equal sensitivity
      - But no excess in $H \rightarrow bb$
- 140 GeV
  - Largest excesses seen at CMS, ATLAS
    - Tevatron $H \rightarrow WW$ provides best sensitivity
  - Even when LHC has more data …
    - Tevatron $H \rightarrow WW$ has different background composition
    - Tevatron $H \rightarrow WW$ has different signal composition (More WH, less VBF)

Future

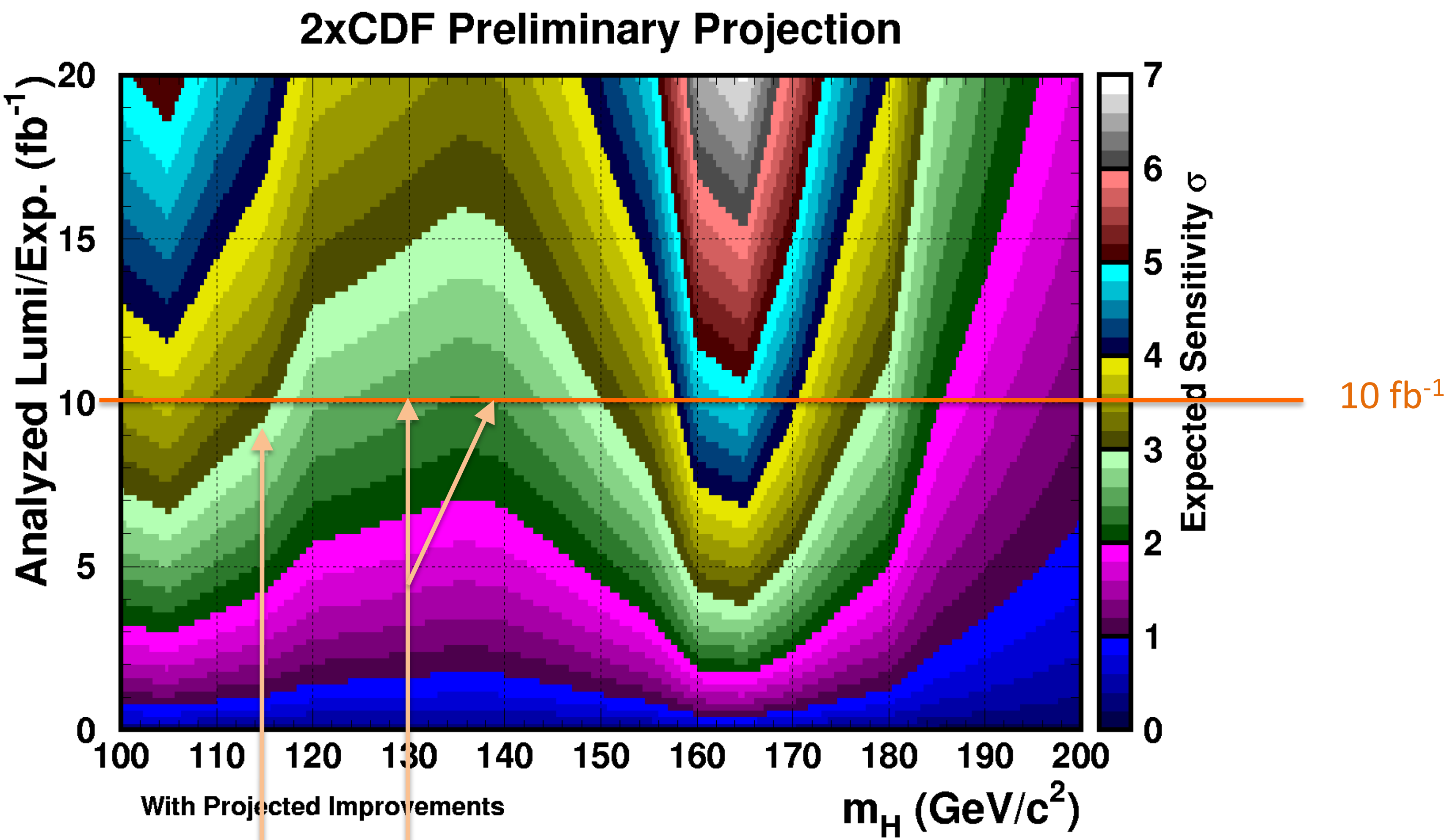
Tevatron expectations





- Only 1 month left !
- Tevatron will have delivered over 12 fb^{-1} by Sept. 30, 2011
  - 10 fb^{-1} acquired data by CDF and D0
    - Effectively means ~9 fb^{-1} for use with all detector systems good (necessary WH, ZH b-tagged analyses)

Tevatron projections 10 fb^{-1} analyzed



3 σ :
115 GeV
w/9 fb^{-1}

2.4 σ :
130 - 140 GeV
w/10 fb^{-1}

Are there potential improvements left ?

Improvements (e.g. DØ)

Type	Projected Improvement	WH→lvbb	ZH→llbb	ZH→vvbb	H→WW	Other Channels
Lepton ID	MVA Electron ID	1%	5%	-1%	3%	3%
	Improved MuonID/tracking	4%	3%	-2%	Done	3%
	Add Isolated Tracks	2%	Done	-1%	3%	2%
	Add ICR Electrons	2%	Done	-1%	3%	2%
	Add EC Electrons	Done	Done		Done	2%
	Improved energy scale	1%	2%		2%	5%
Trigger / Reco	Trigger/Reconstruction Efficiency	5%	3%	Done	Done	5%
Jet Selection	Di-jet Mass Resolution	10%	10%	10%		
	MVA B-ID	5%	5%	5%		
	MVA Bottom vs Charm	4%	4%	4%		
MVA Analysis	Enhanced Techniques	10%	10%	10%	10%	10%
	New signal separation variables	5%	5%	5%	5%	5%
	MVA QCD Rejection	3%	1%	Done	3%	3%
	Matrix Element Discriminants	5%	5%	5%	5%	3%
	Kinematic Fitting	5%	Done			3%
Optimization	Track Variables	5%	3%	Done	5%	5%
	Optimized B-ID Usage	3%	3%	3%		
	Optimized Jet Treatment	3%	8%	Done		
New Channels	H→WW→e/mu+tau				5%	
	VH→etau+jj					3%
	H→ZZ					3%
	VH→VVV→trileptons					3%
	Additional Decay Modes	5%	5%	Done	5%	5%
	Existing Improvements:	57%	70%	29%	41%	
	Planned Improvements:	36%	27%	20%	18%	

- Yellow cells are existing improvements to be propagated to final analysis.
- White cells with numbers are the areas the experiment is actively working on.

15 Oct 2011 Denisov/Punzi/Roser/Söldner-Rembold 13

from P5 report Oct. 2010

Some of these Improvements were made this summer

Estimates of remaining :
35% WH
65% ZHllbb
12% ZHvvbb

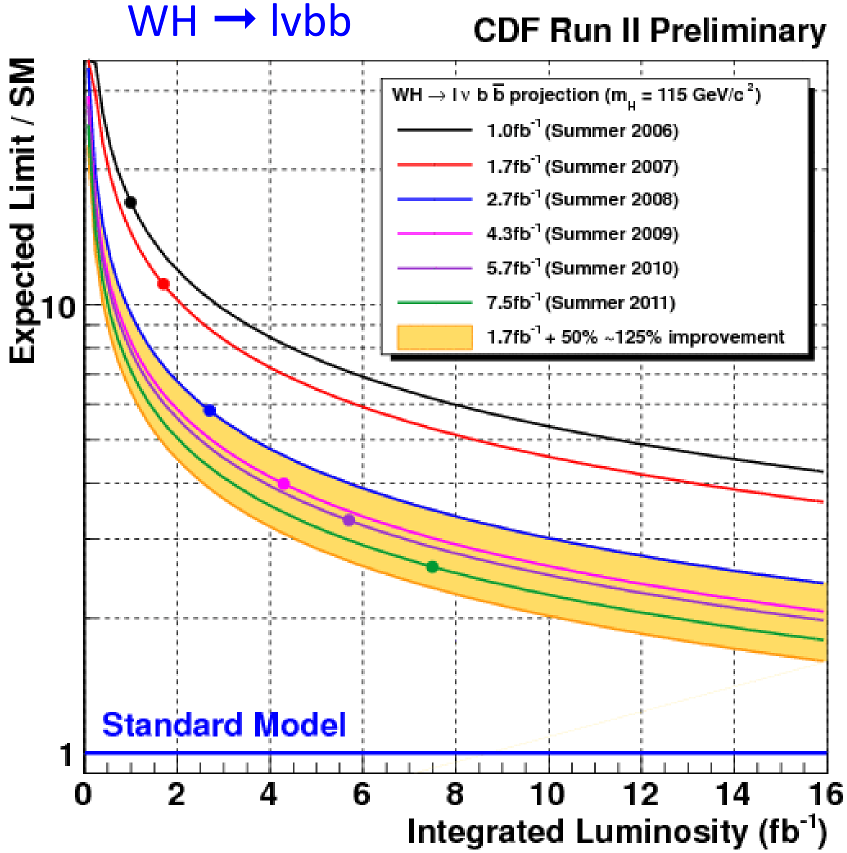
More importantly, can Tevatron achieve all projected improvements on time-scale of Moriond 2012?

- Are improvements slowing down due to reduced personnel ?

More importantly, can Tevatron achieve all projected improvements on time-scale of Moriond 2012?

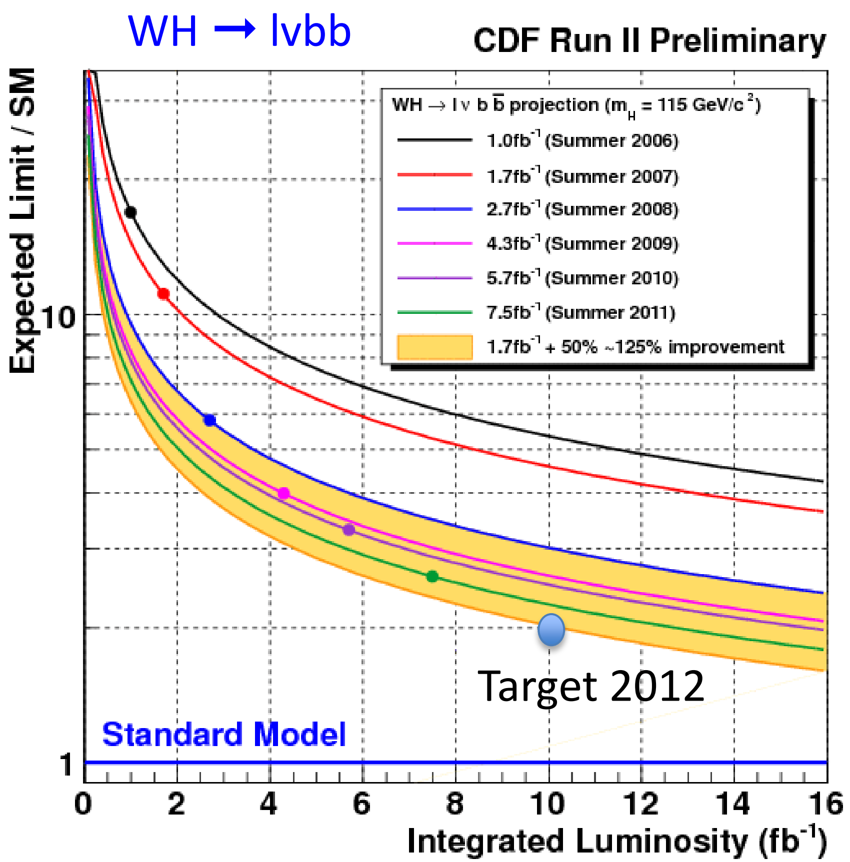
- Are improvements slowing down due to reduced personnel ?

WH ⟶ lvbb



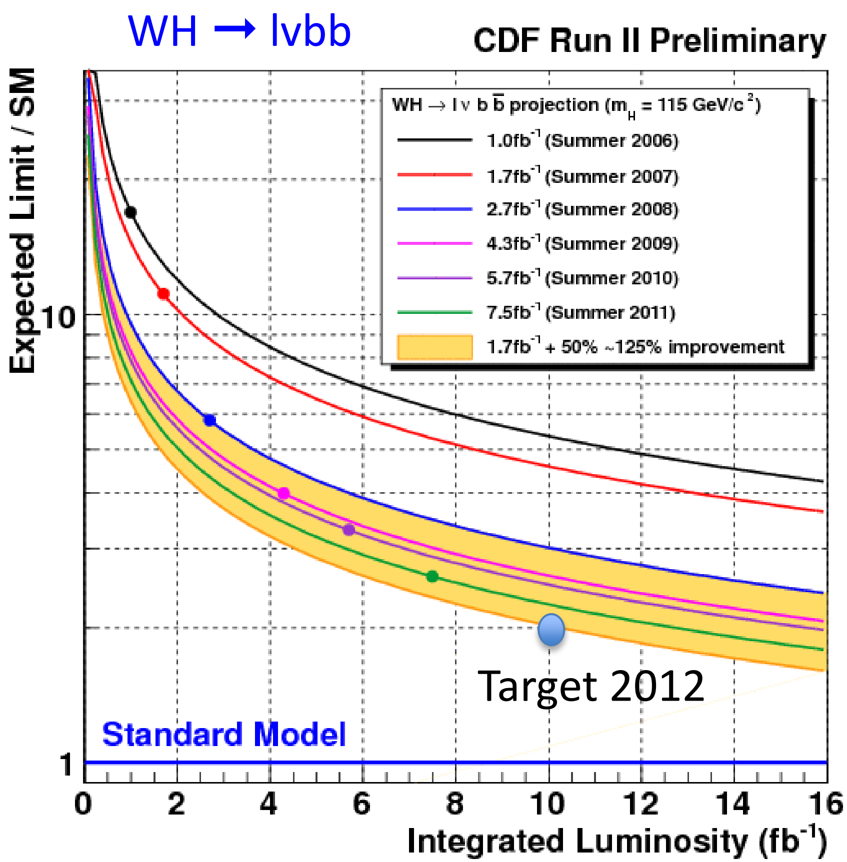
More importantly, can Tevatron achieve all projected improvements on time-scale of Moriond 2012?

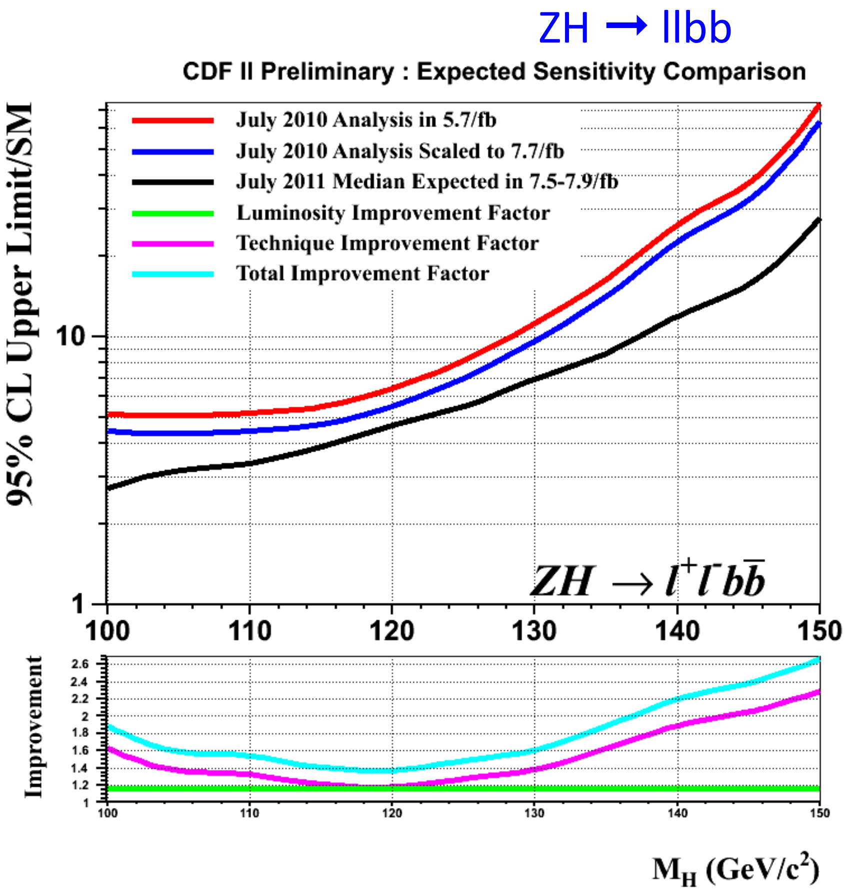
- Are improvements slowing down due to reduced personnel ?



More importantly, can Tevatron achieve all projected improvements on time-scale of Moriond 2012?

- Are improvements slowing down due to reduced personnel ?





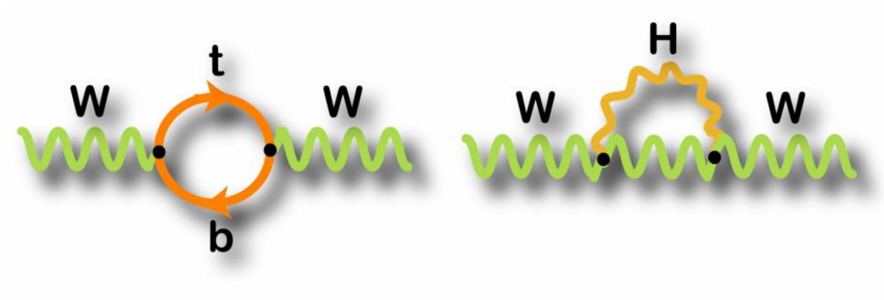
Still incorporating new channels to improve sensitivity at 120 GeV and 130 GeV

- New additions for summer 2011 Tevatron combination
    - ttH → met+jets
    - ttH → leptons+jets
    - ttH → all-jets
    - WH → lνττ
    - ZH → llττ
  - Good review at Higgs Hunting Workshop talk from E. Pianori on "Challenging channels at Tevatron"

What else can Tevatron say about the SM Higgs boson mass ?

Indirect Higgs mass constraints

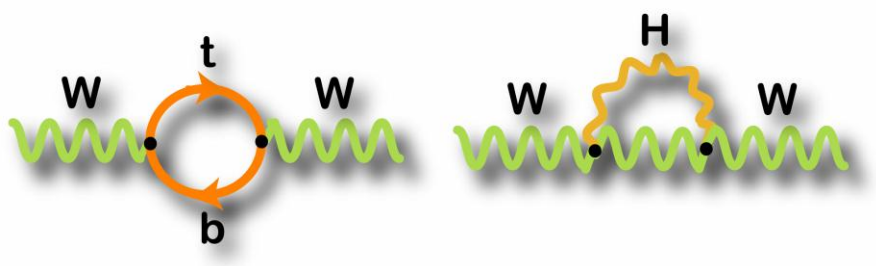
- $\Delta m_W \propto m_t^2$
- $\Delta m_W \propto \ln m_H$



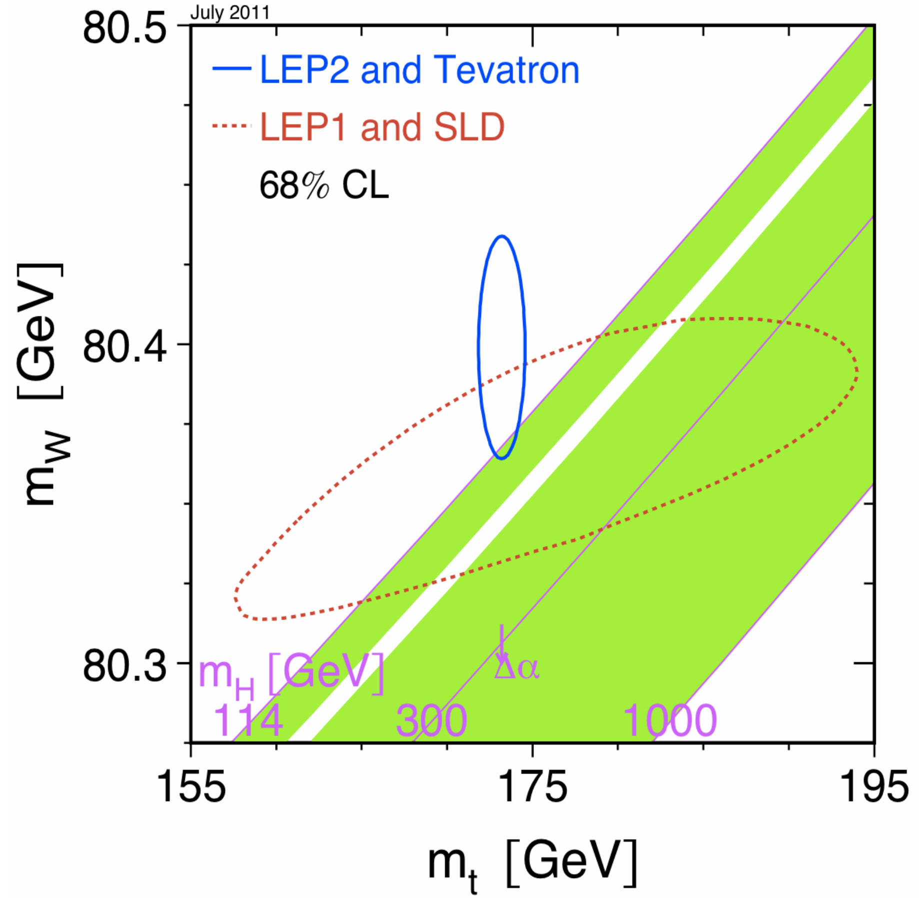
Tevatron : $m_t = 173.2 \pm 0.9$ GeV (0.5%)

Indirect Higgs mass constraints

- $\Delta m_W \propto m_t^2$
- $\Delta m_W \propto \ln m_H$



Tevatron : $m_t = 173.2 \pm 0.9$ GeV (0.5%)

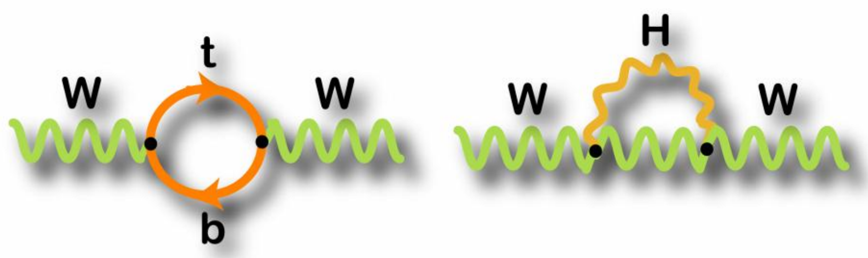


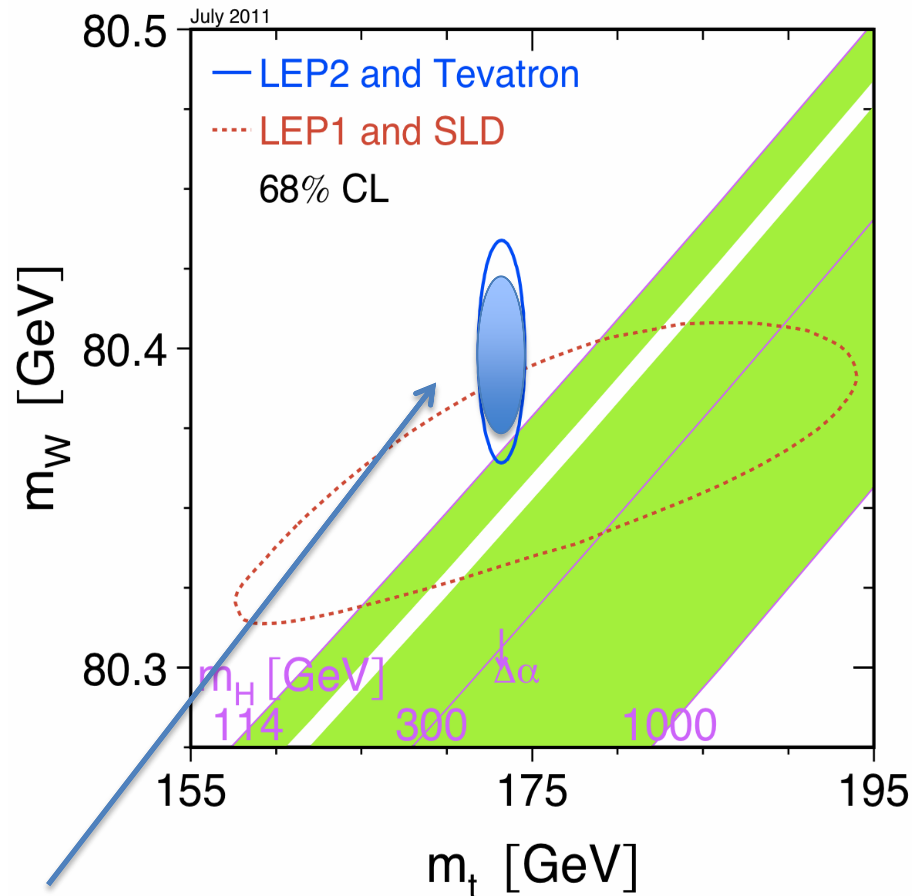
$m_H = 92^{+34}_{-26}$ GeV

With all indirect measurements

Indirect Higgs mass constraints

- $\Delta m_W \propto m_t^2$
- $\Delta m_W \propto \ln m_H$





Tevatron : m_t = 173.2 ± 0.9 GeV (0.5%)

CDF alone δm_W : 48 → ~25 MeV 2 fb-1 ~6 months
~15 MeV 10 fb-1

$m_H = 92\ ^{+34}_{-26}$ GeV

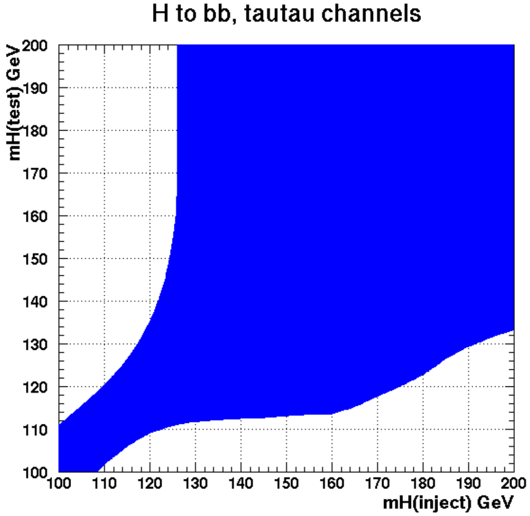
With all indirect measurements

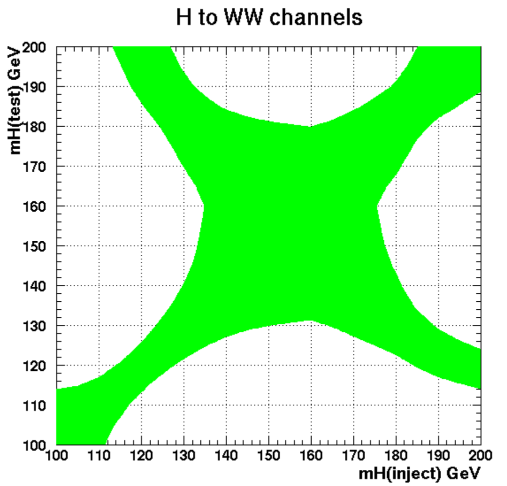
Can Tevatron be even more precise about mass determination ?

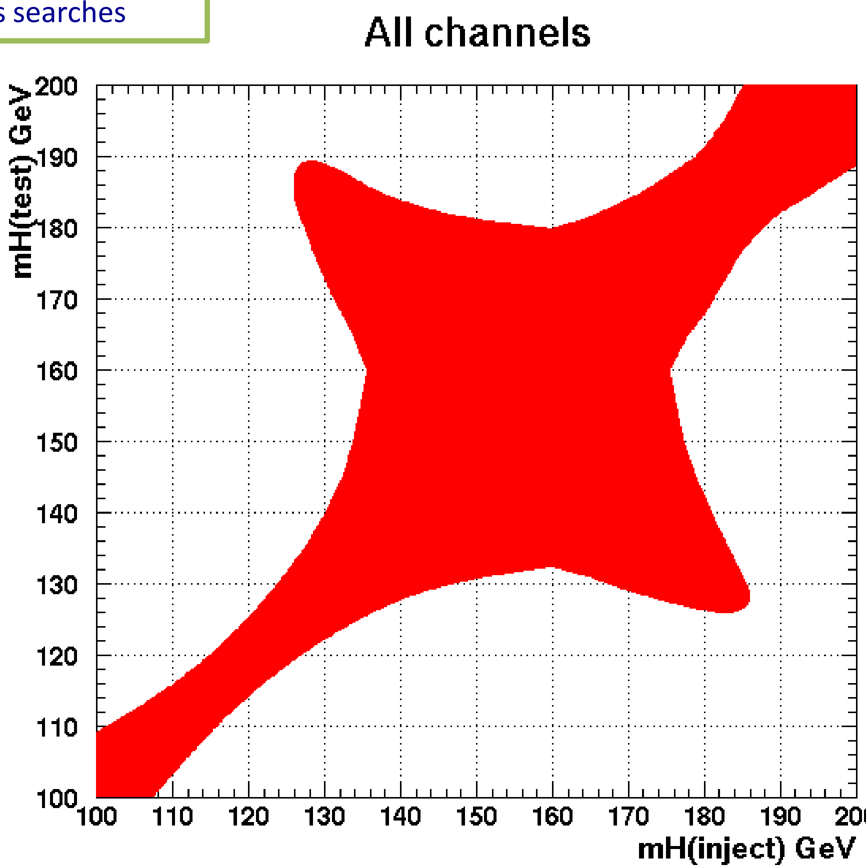
How well could we measure Higgs mass given a 3 Sigma excess ?

- Higgs boson mass is more sensitive to cross-section than kinematic resolution

Assuming Cross Section x Branching Fraction Measurement Uncertainty
is 2x Larger at the same Luminosity for low-mass than it is for high-mass searches







Using resolution from LLR, median outcomes
Resolution at 115 GeV: ±5 GeV
Resolution at 135 GeV: ~±10 GeV

And if there is no SM Higgs boson ?

- Mechanism for electroweak symmetry breaking and fermion mass may reveal itself in strange ways
  - Tevatron provides > 10 fb^{-1} of 2 TeV proton-antiproton data
    - May prove useful in the future to disentangle a more complex theory

Conclusions

- Tevatron important at low mass 115-120 GeV
  - World's best limits at 115 GeV
  - Unique window to Higgs of H→bb
  - Sensitivity continues to improve
- Tevatron important in 130-140 GeV region
  - H→WW analyses sensitive to different signals and backgrounds than LHC
- Tevatron will have 10 fb^{-1} analyzed by spring/summer 2012
  - Even more to say about 115 - 140 GeV

- To claim a Higgs boson discovery
  - Requires consistent picture of SM Higgs boson across multiple signal topologies with different background compositions
  - Tevatron contributes to this picture even after sensitivity is eclipsed by LHC