Evidence for a particle produced in association with weak bosons and decaying to a bb pair in SM Higgs boson searches at the Tevatron,

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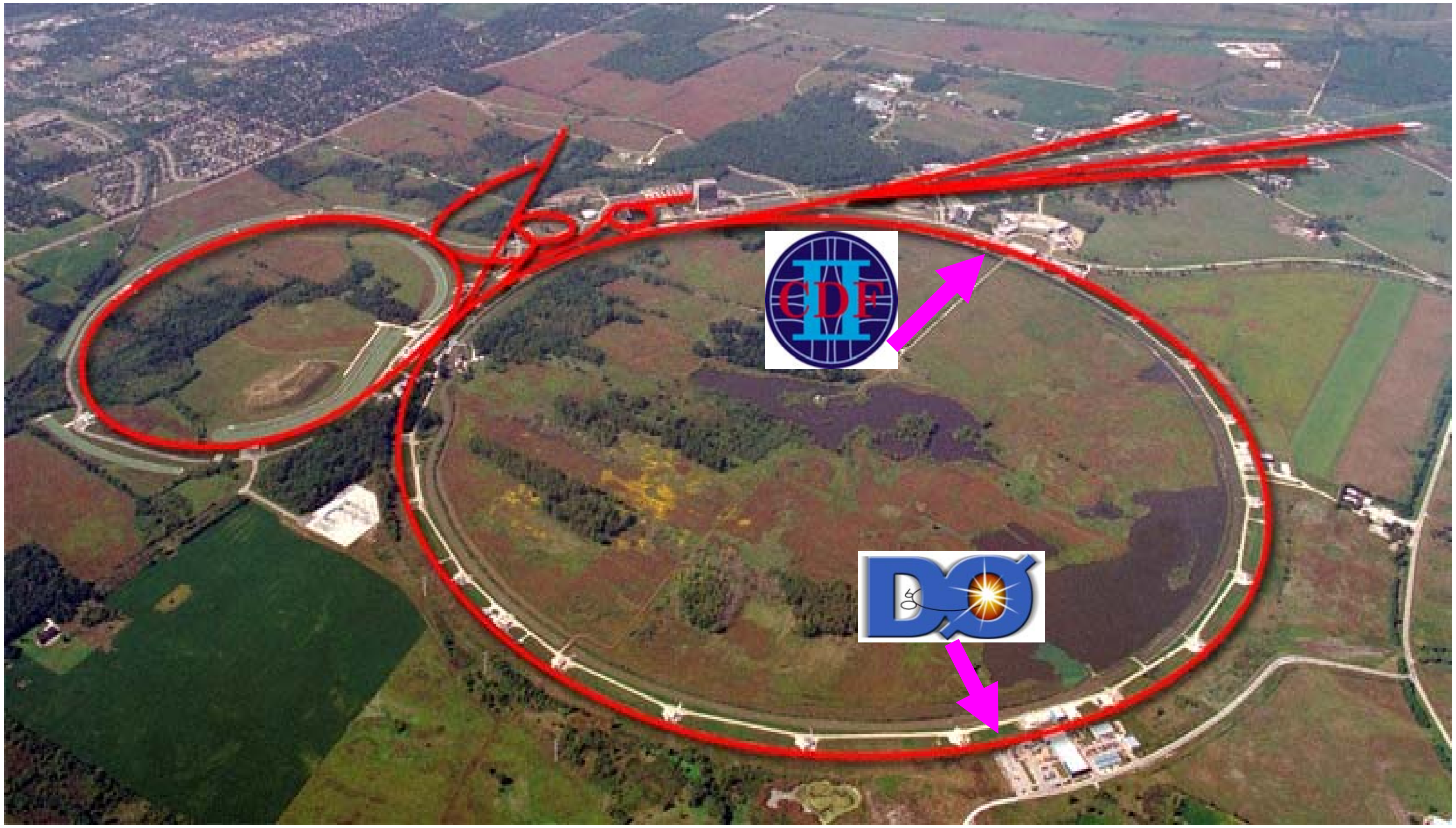
On behalf of CDF and DZero

GGI Higgs focus week, October 10nd 2012

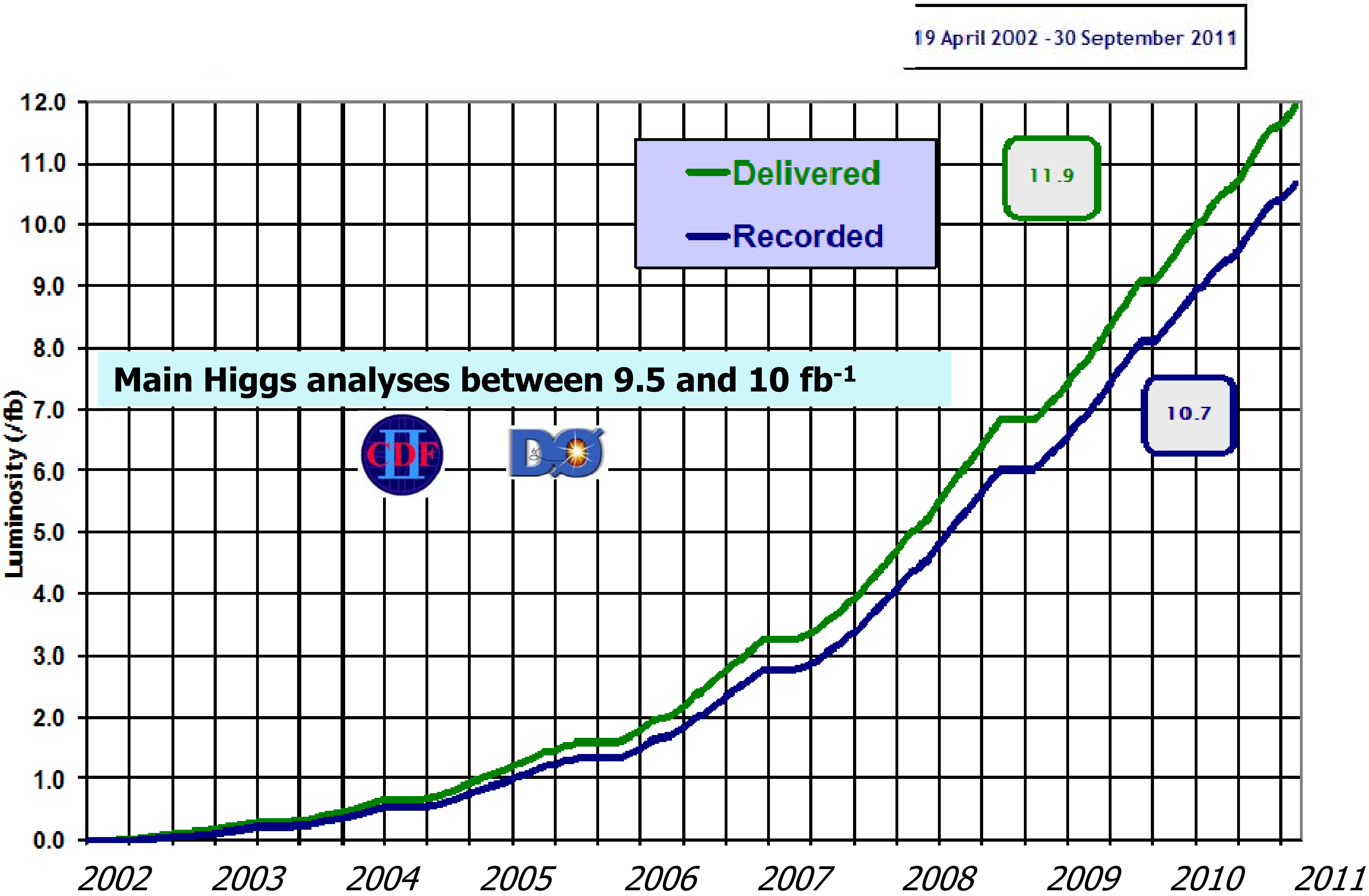
Thanks to all CDF & DZero colleagues



Outline

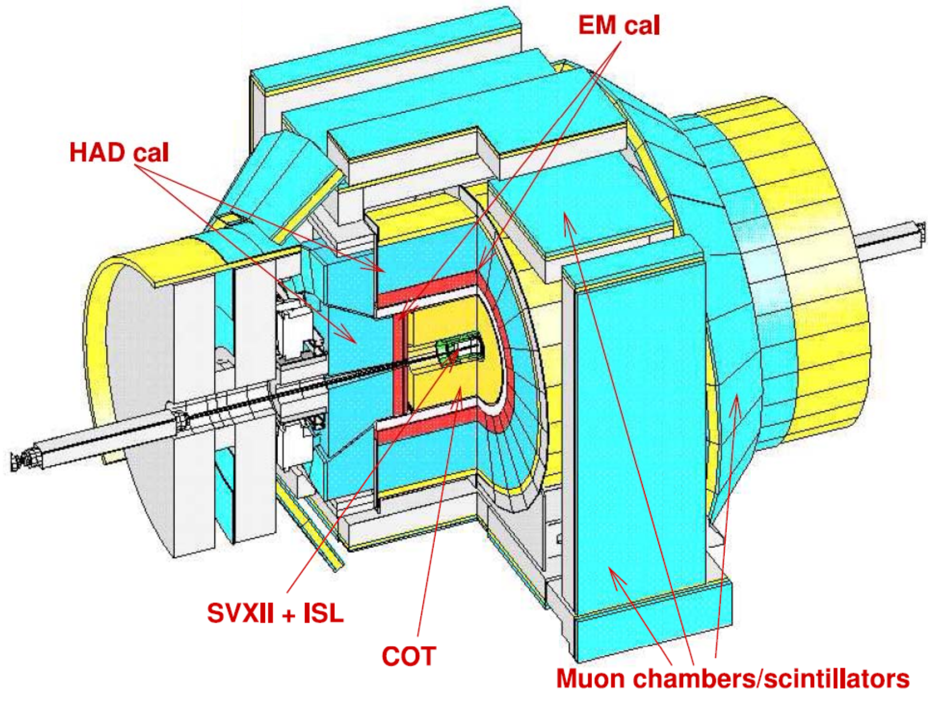
- The Tevatron performance
- Low mass Higgs searches
- Validation using diboson to HF processes
- Combinations of Standard Model searches
- Evidence for H→bb, in WH/ZH production
- Prospects

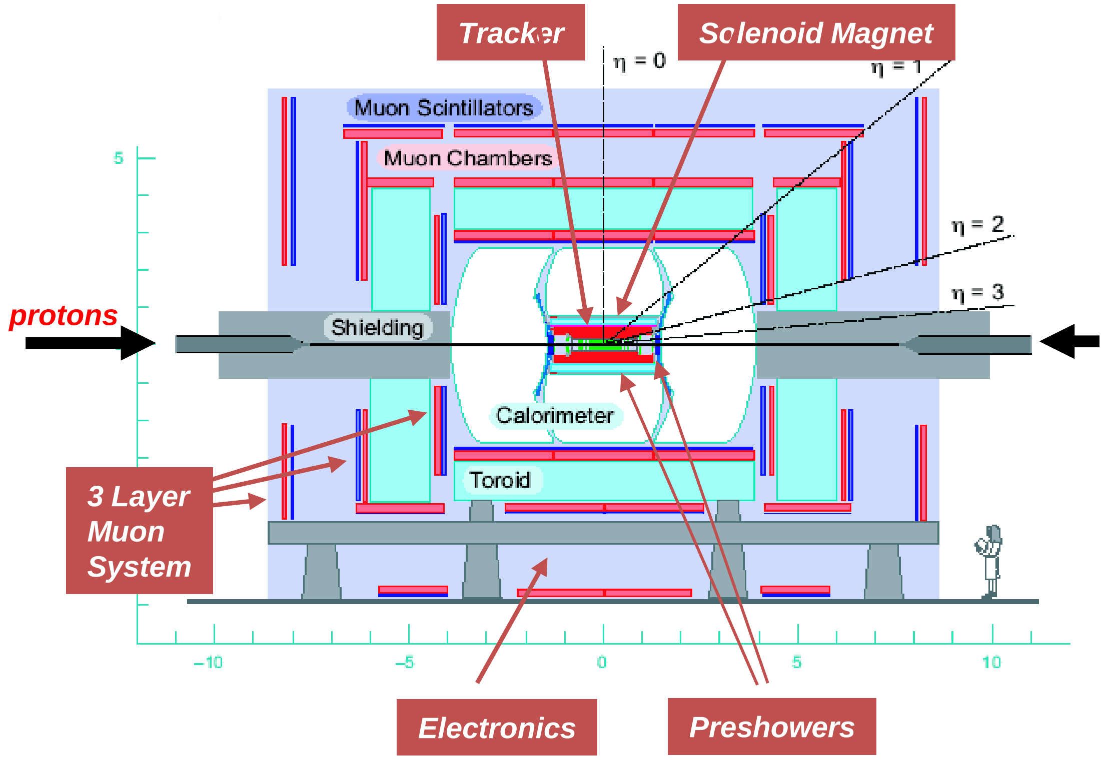
Tevatron Luminosity



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 (up to ~10 interactions)

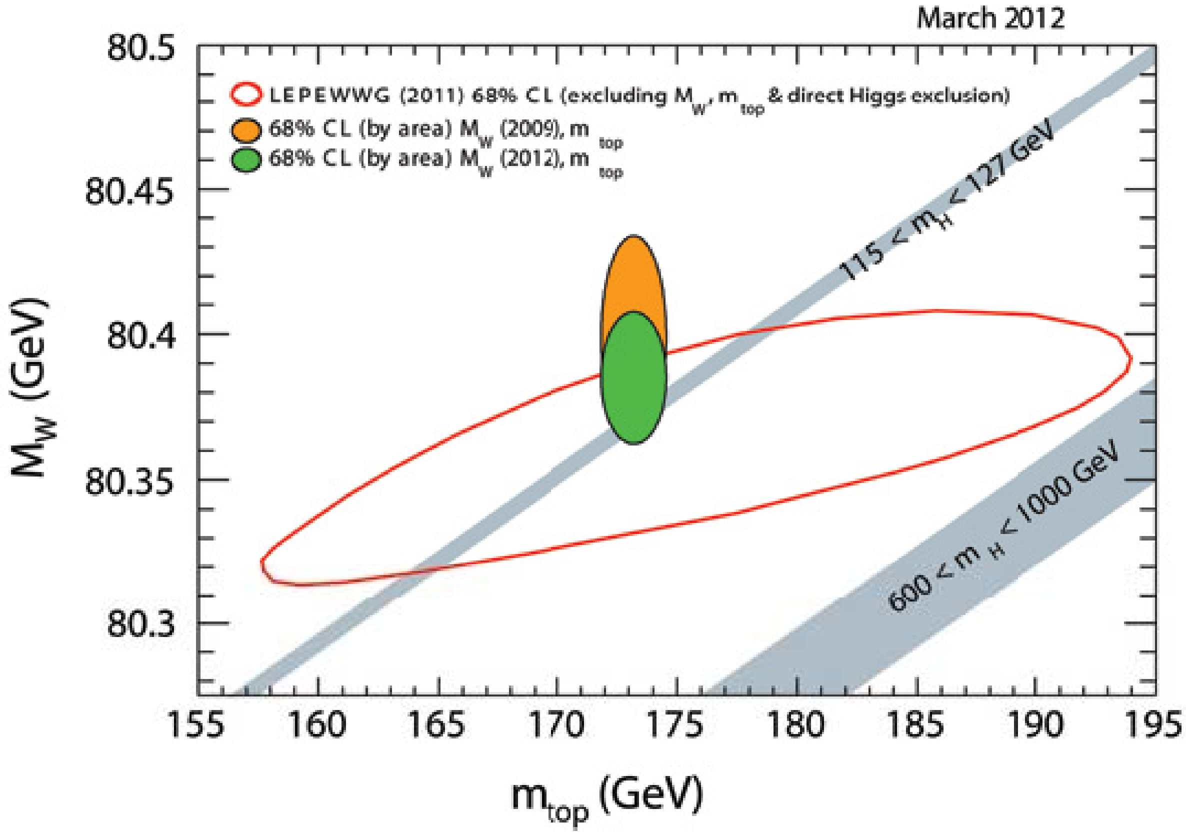
	Rapidity coverage	
	CDF	Dzero
Track	2.0	2.5
Calorimeter	3.6	4.2
Muon	1.0	2.0
B-field	1.4 T	2.0 T

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 particle discovered at the LHC looks like the SM Higgs from the indirect point of view

Is it the SM Higgs?

Strong evidence of H→ gamma-gamma (ATLAS, CMS)
somewhat higher rates but still compatible

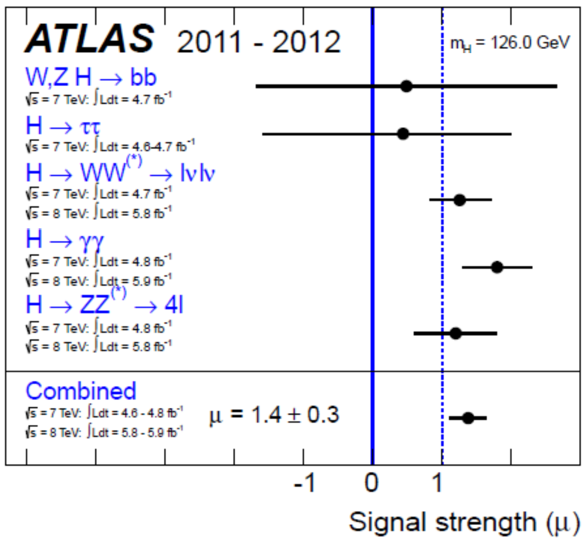
Evidence of H → ZZ (ATLAS, CMS)

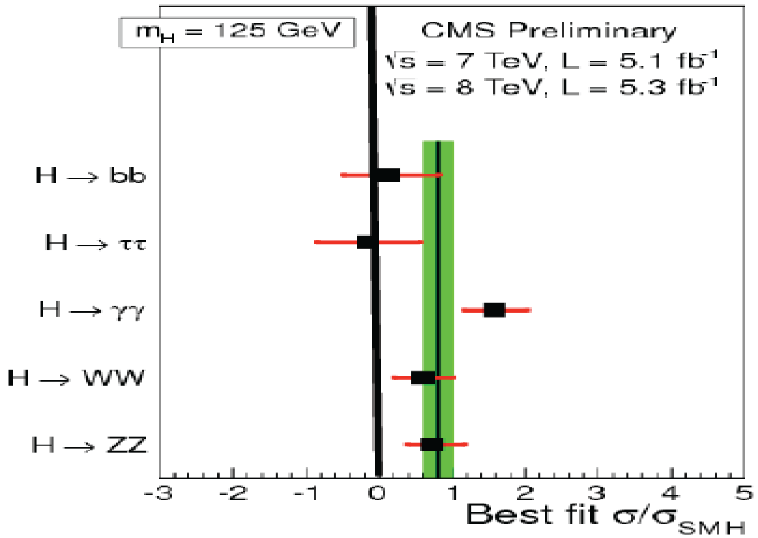
Weak Evidence of H→ WW (ATLAS, CMS)

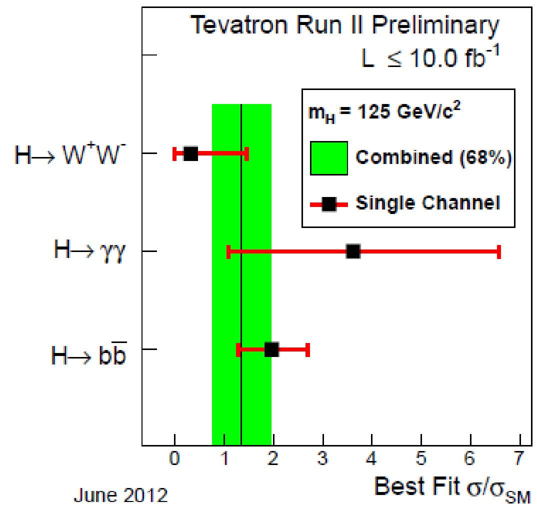
No evidence so far of fermionic decays at LHC:

H→bb sensitivity ~1.5 sigma @ CMS 2011+2012 (10 fb^{-1})
Tau channels are data deficit (sensitivity ~1.5 sigma with 10 fb^{-1})

Indications of H→bb presented at Moriond 2012 (2.6 sigma) (Tevatron)



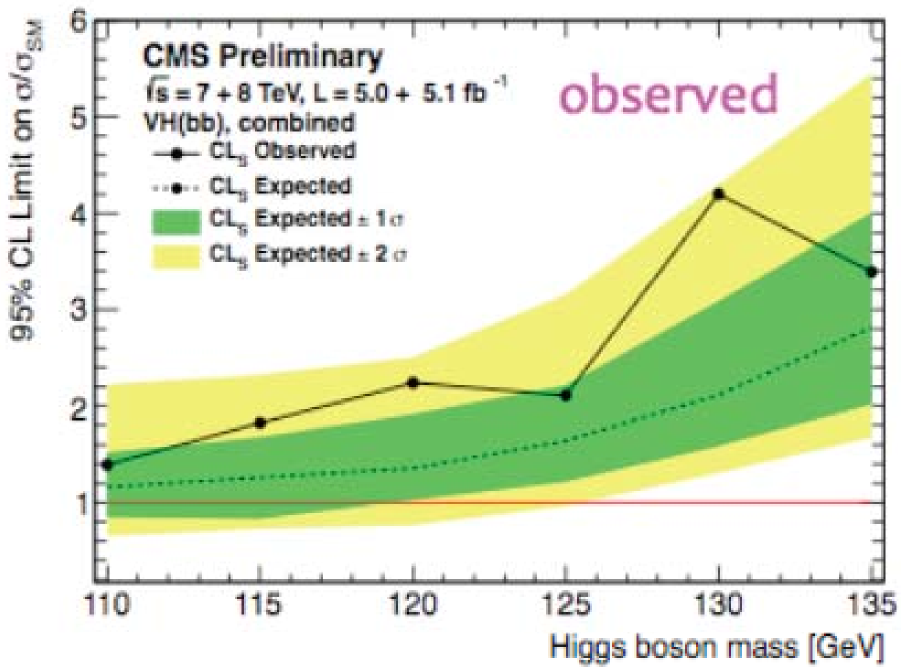




H→ bb at LHC

Strong complementarity on H→ bb
between LHC and Tevatron until 2015 run

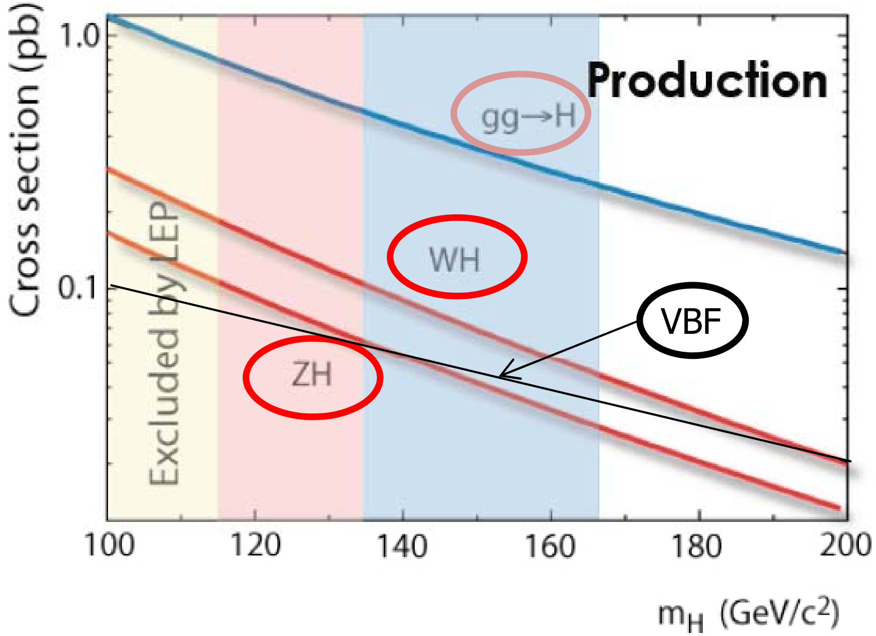
Difficult channel, different s+b, different methods.

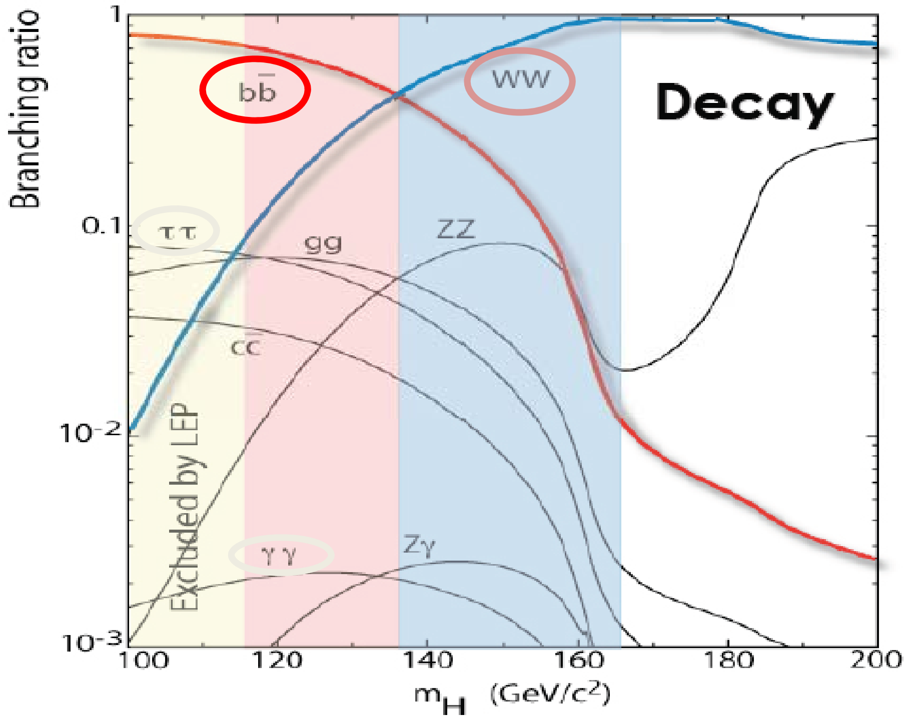


Consistent with S or S+B
slight excess looks like expected for S+B

ATLAS sensitivity with 7 TeV sample ~ 4*SM

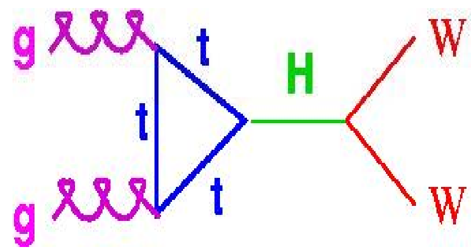
Higgs Production and Decay at the Tevatron





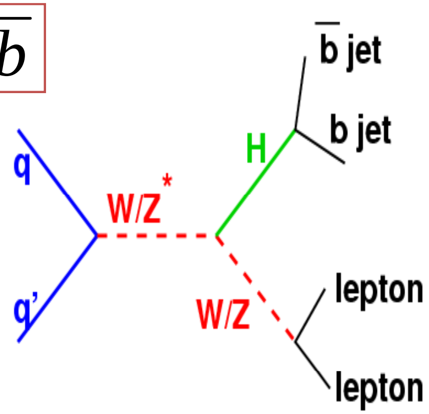
"High" mass (m_H > 135 GeV) dominant decay:

$\boxed{H \to WW^{(*)}}$ $\quad gg \to H \to WW \to \ell\nu\ell'\nu'$



Low mass (m_H < 135 GeV) dominant decay:

$\boxed{H \to b\bar{b}}$



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

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

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

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

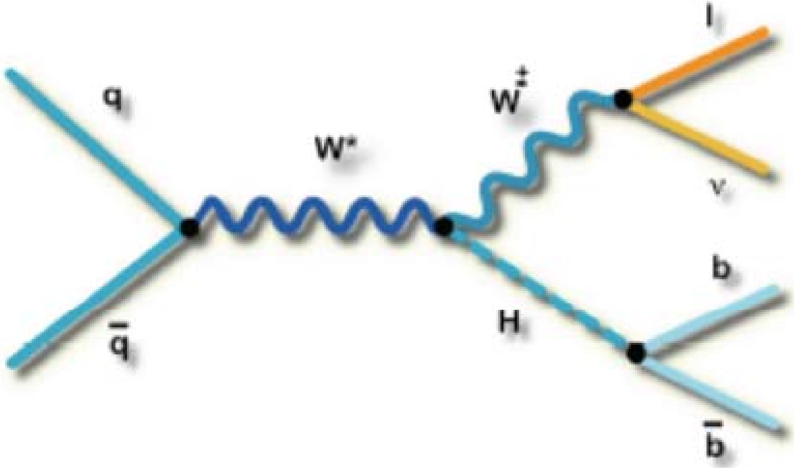
SM Higgs Event Yield expectation

Expected number of events available for selection to CDF + DZero with the full Tevatron Run II data set (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

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, or llbb as lνbb, we consider here l=e,mu)

Low Mass Higgs Channels



WH→lvbb: MET+l+bb

Large production cross section

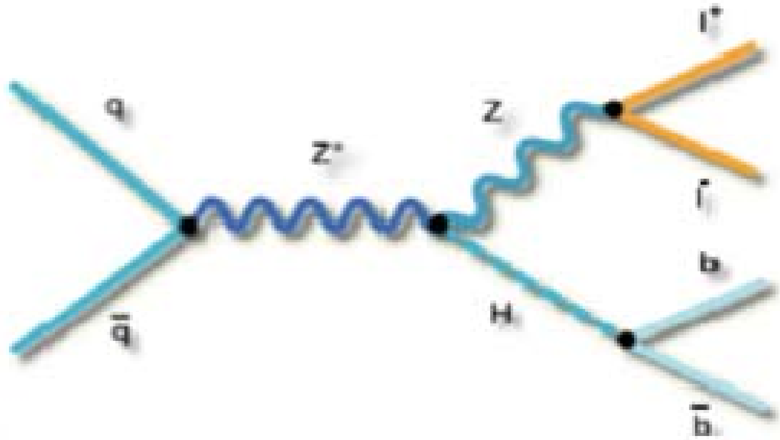
Higher backgrounds than in ZH→llbb

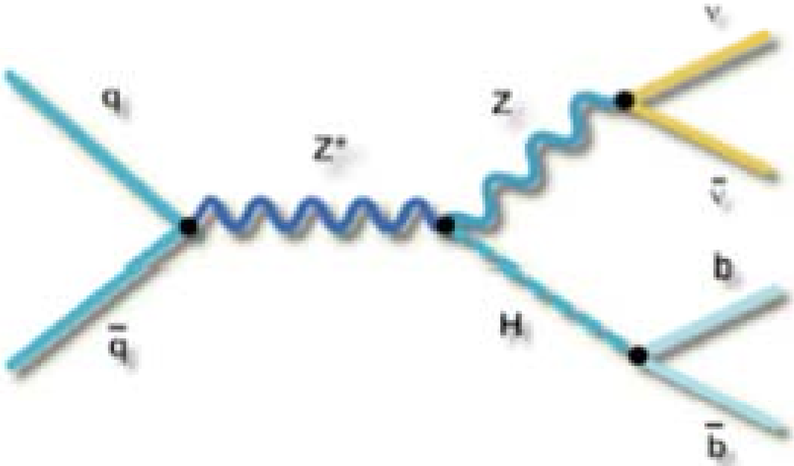
ZH→llbb: ll+bb

Low background

Fully constrained

Small Signal





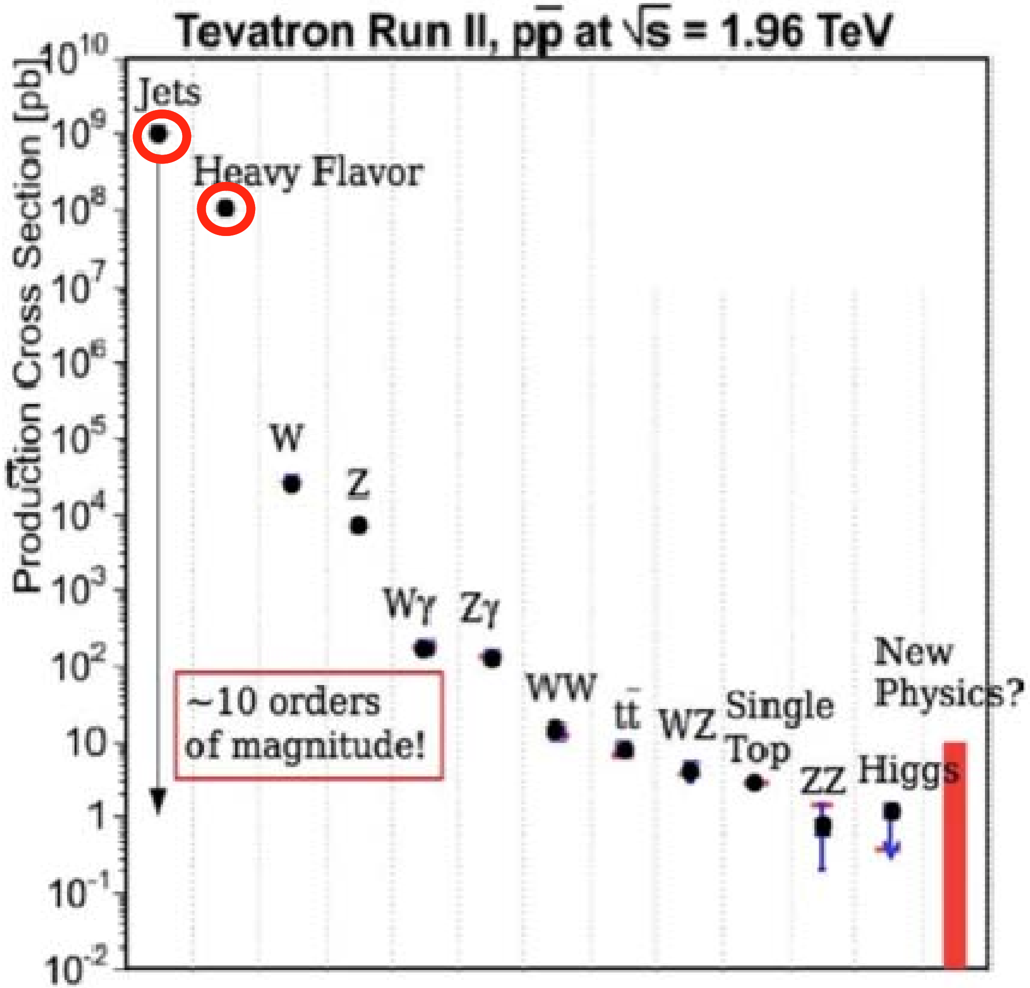
ZH→vvbb: MET+bb

signal 3x larger than ZH→llbb

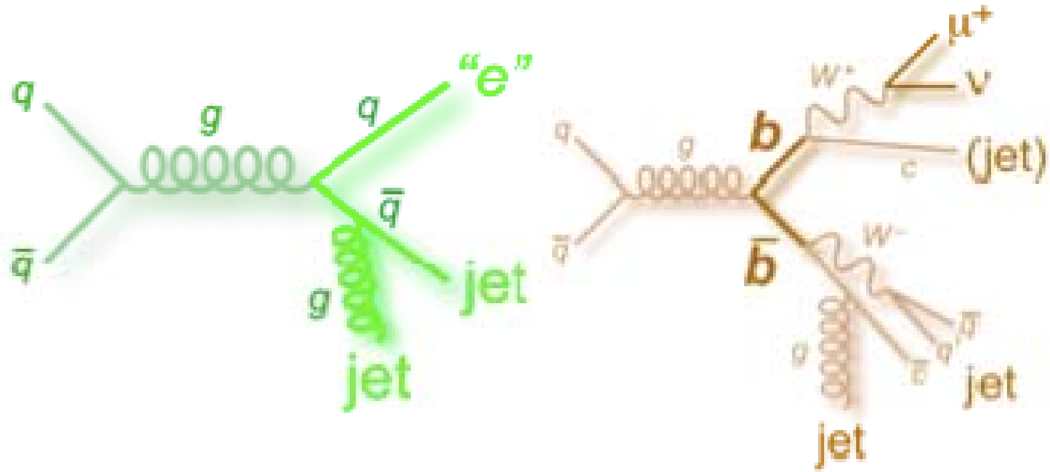
(+ contributions from WH)

difficult backgrounds

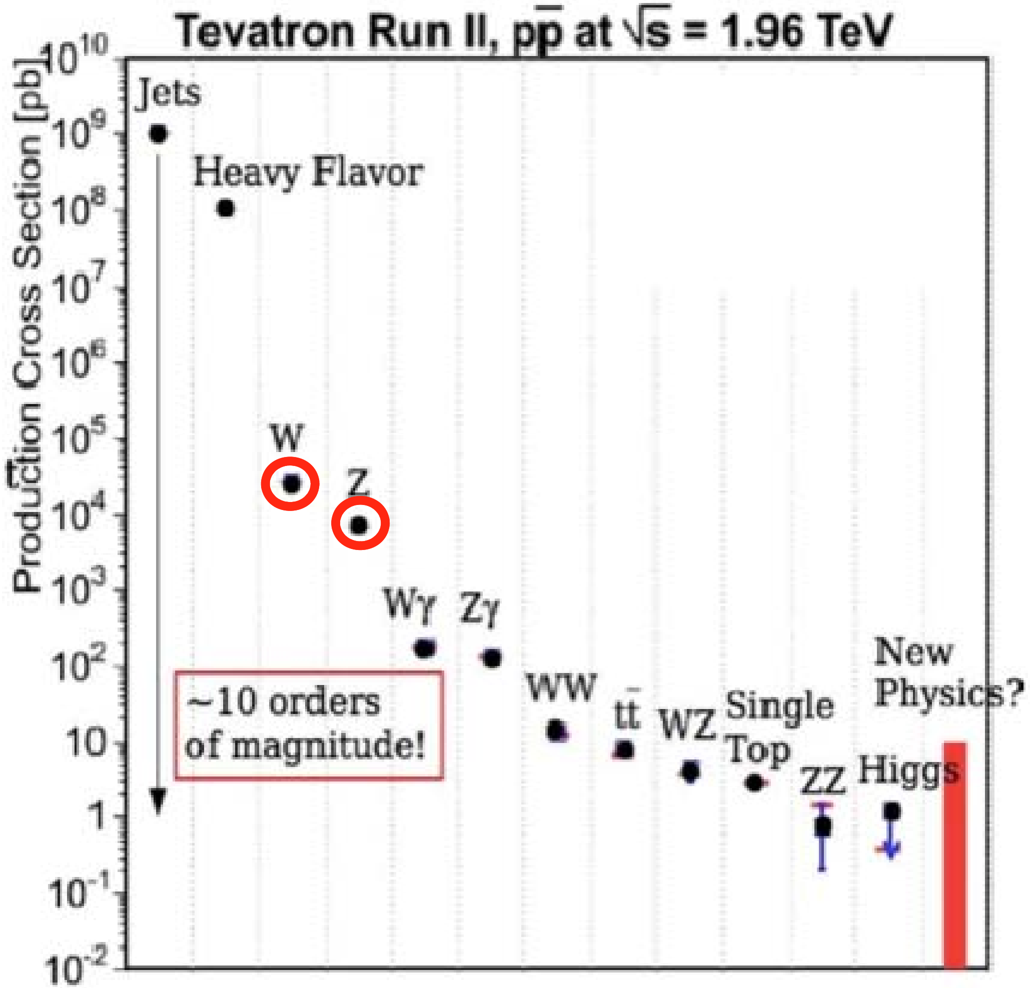
Backgrounds at low mass



- Instrumental backgrounds QCD multijet (e.g faking lepton)Derived from (sidebands) data

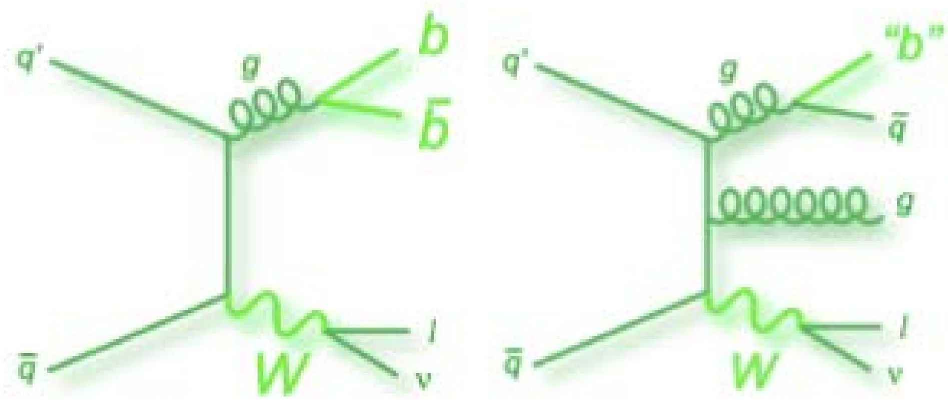


Backgrounds at low mass

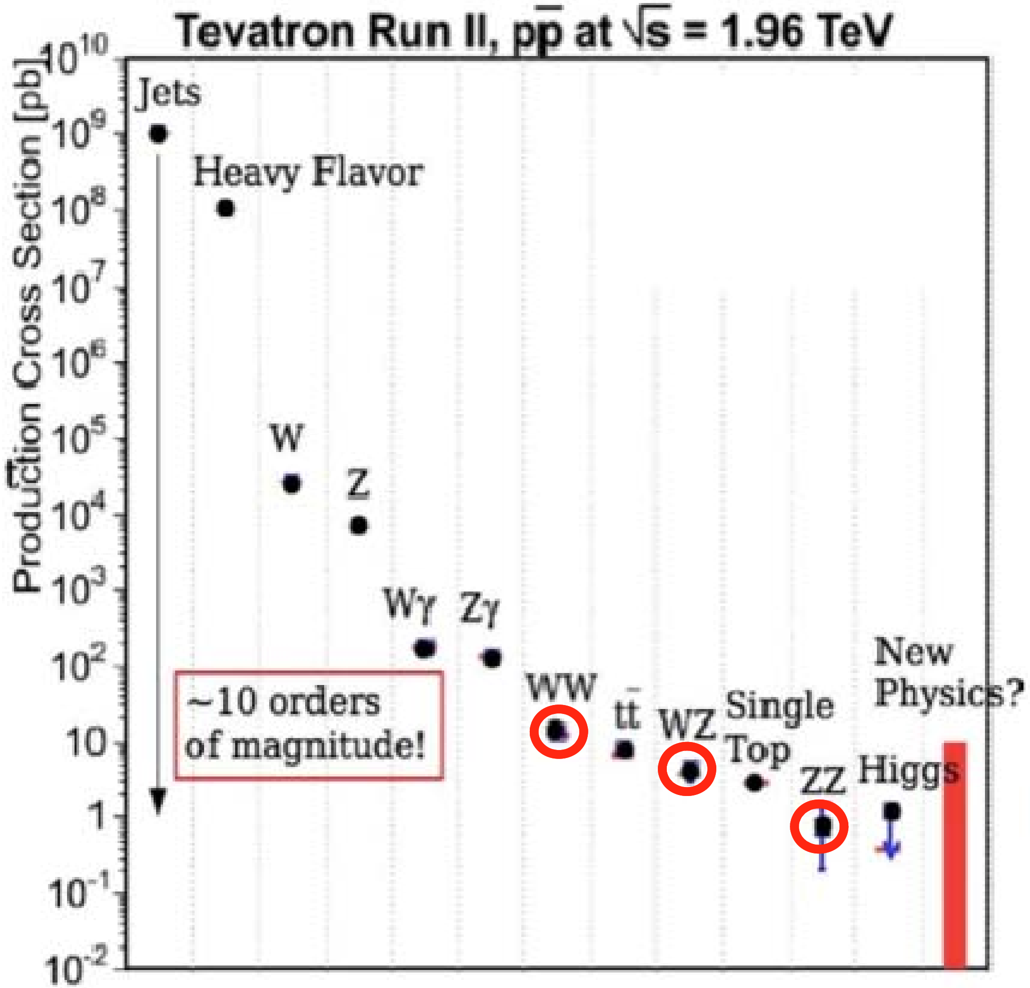


- Instrumental backgrounds QCD multijet (e.g faking lepton)Derived from (sidebands) data

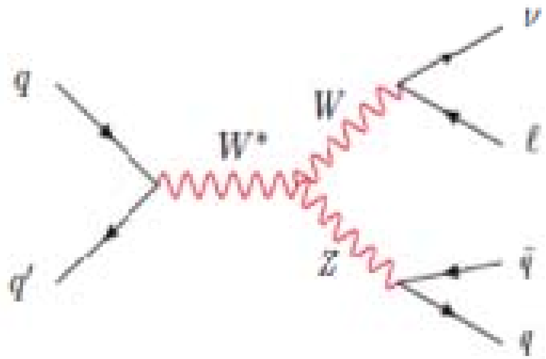
- Physics backgrounds: W/Z+jets with real / misidentified heavy flavour

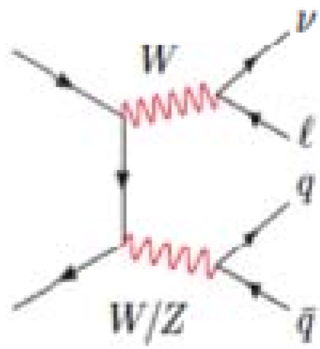


Backgrounds at low mass

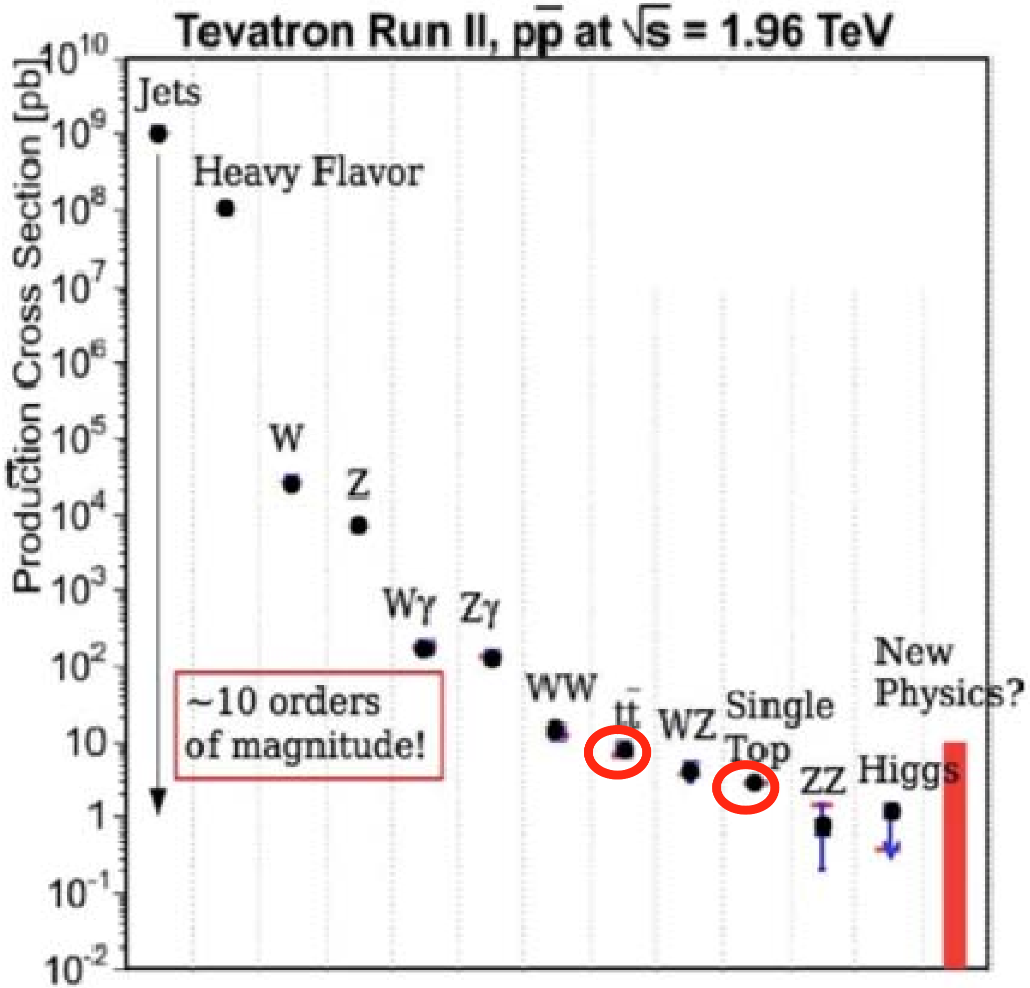


- Instrumental backgrounds QCD multijet (e.g faking lepton)Derived from (sidebands) data
- Physics backgrounds: W/Z+jets with real / misidentified heavy flavour
- Dibosons

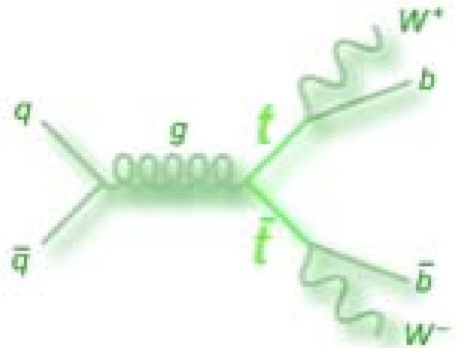


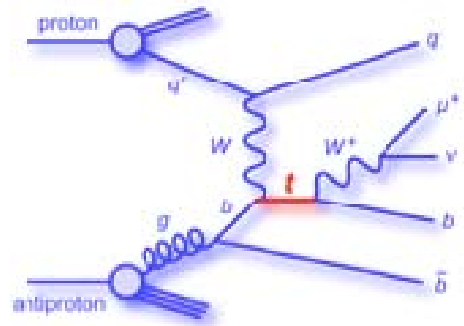


Backgrounds at low mass



- Instrumental backgrounds QCD multijet (e.g faking lepton)Derived from (sidebands) data
- Physics backgrounds: W/Z+jets with real / misidentified heavy flavour
- Dibosons
- ttbar and Single Top

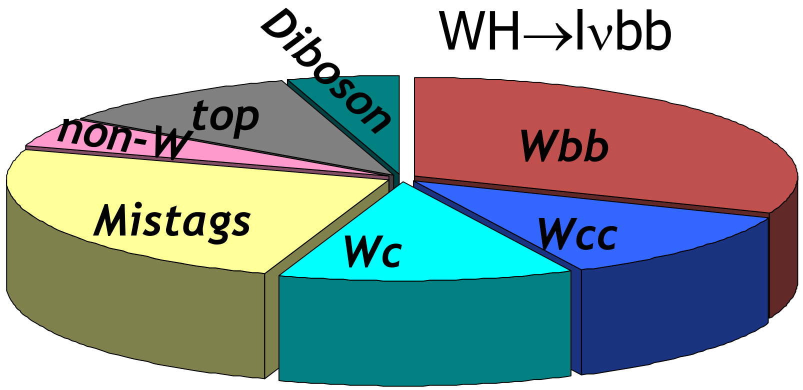




Low Mass Higgs Searches

Increase lepton reconstruction and selection efficiencies

Understand background

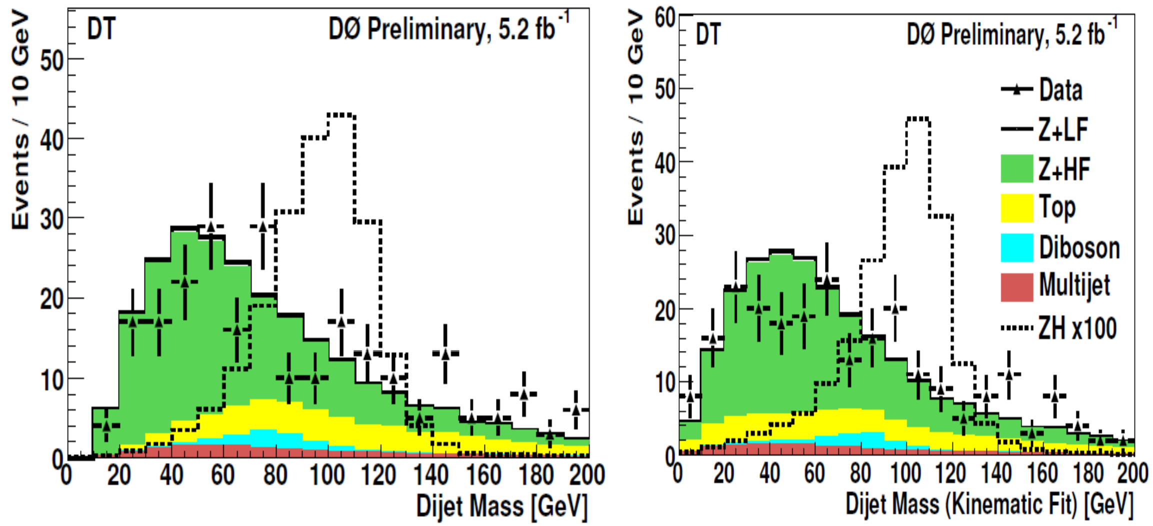


Specific to low mass analyses:

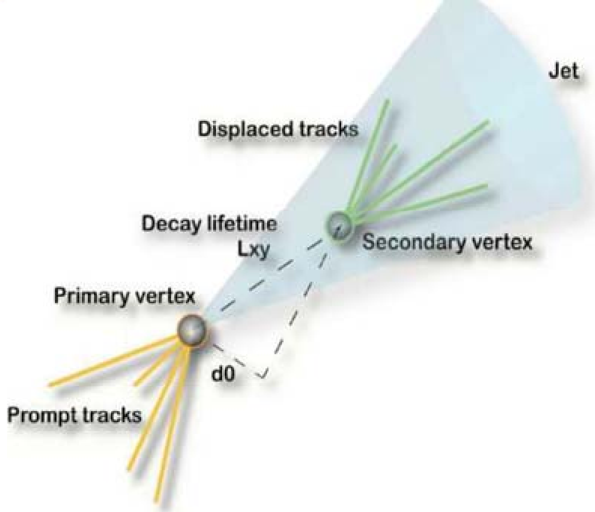
B-tagging (next slides)

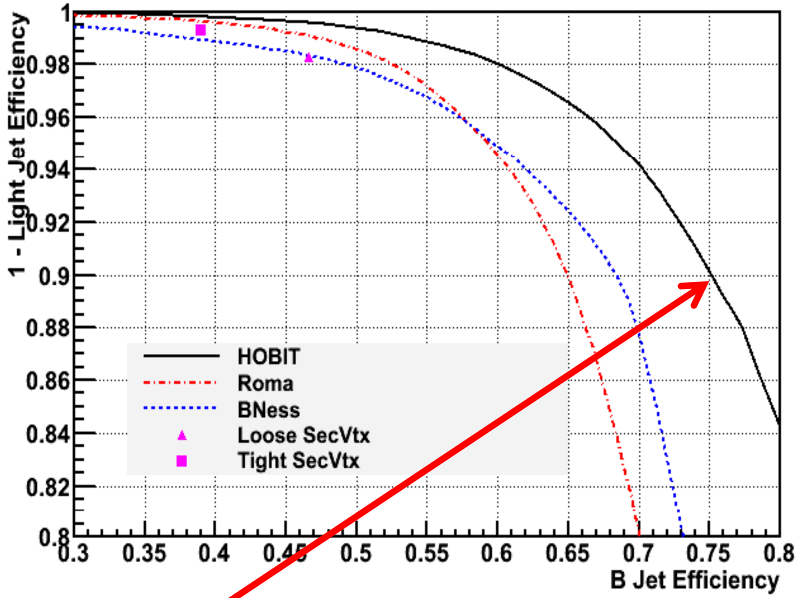
Optimize dijet mass resolution
➔ needs precise calibration and resolution for gluon and quark jets separately
➔ new techniques explored (NN, tracks + calorimeter cells) we are not done yet!

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



Low Mass Higgs Searches





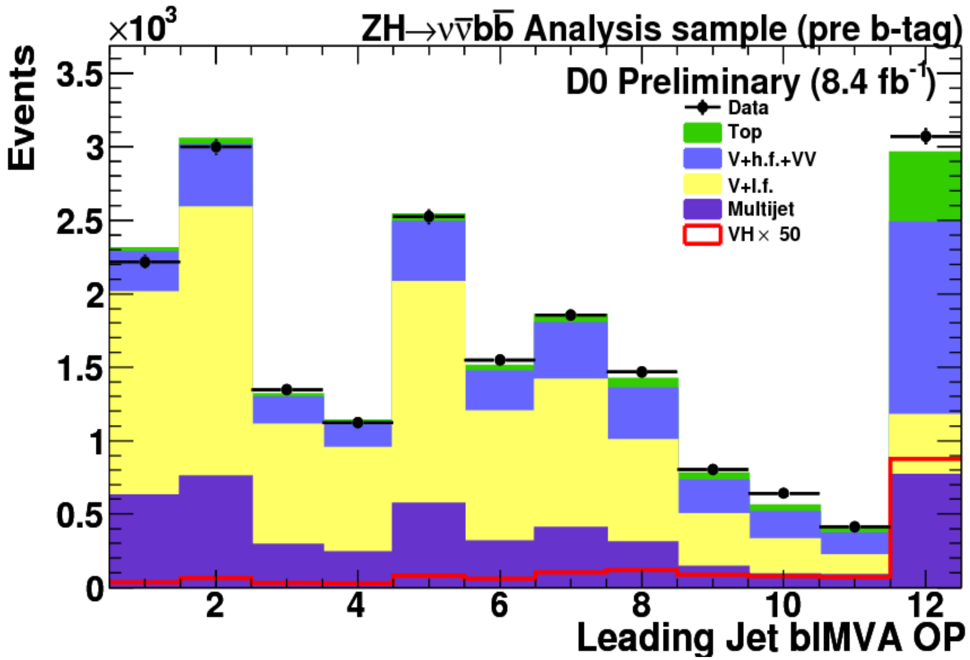
75% eff. for 10% mistag
42% eff. For 0.9% mistag

Reduce the background by tagging b-quark jets

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

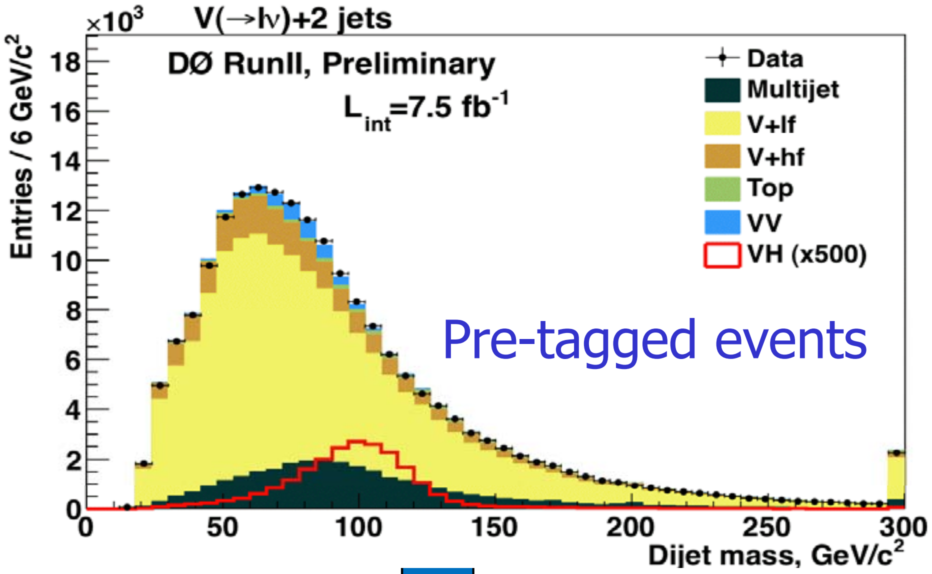
- separate b-jet from light-jets

Multiple operating points →



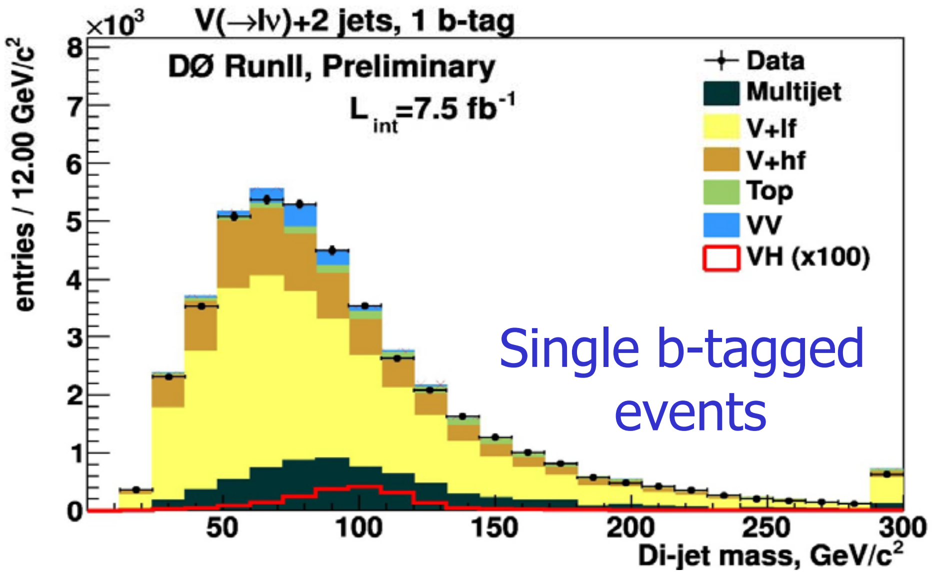
- next step would be to separate b from c with dedicated algorithm

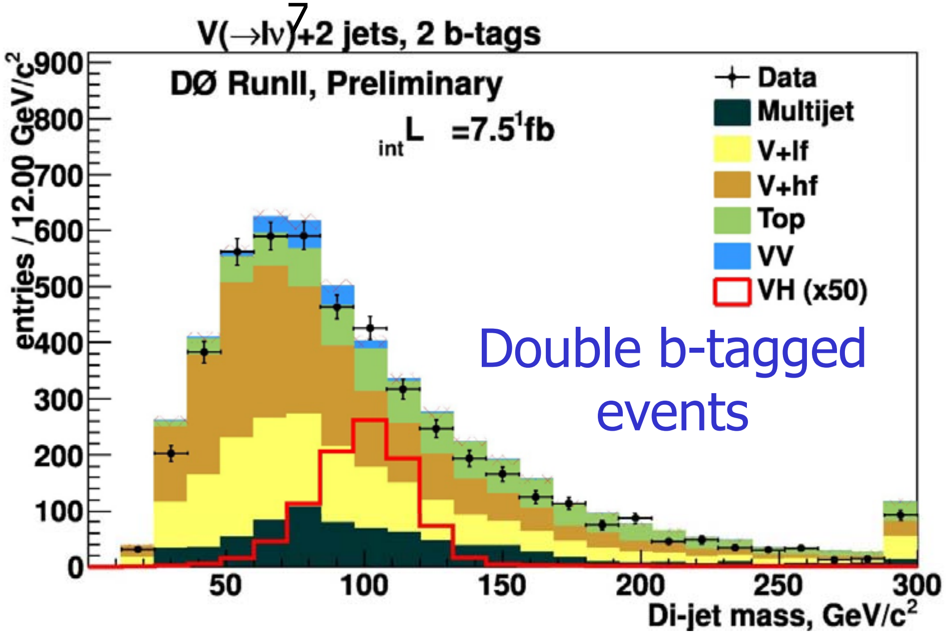
Low Mass Higgs Searches



Strong Reduction of the background by tagging one, then two b-quark jets

Still need to go beyond simple selection approach
➔ Multivariate analysis





From Dijet mass to Multi Variate Analysis

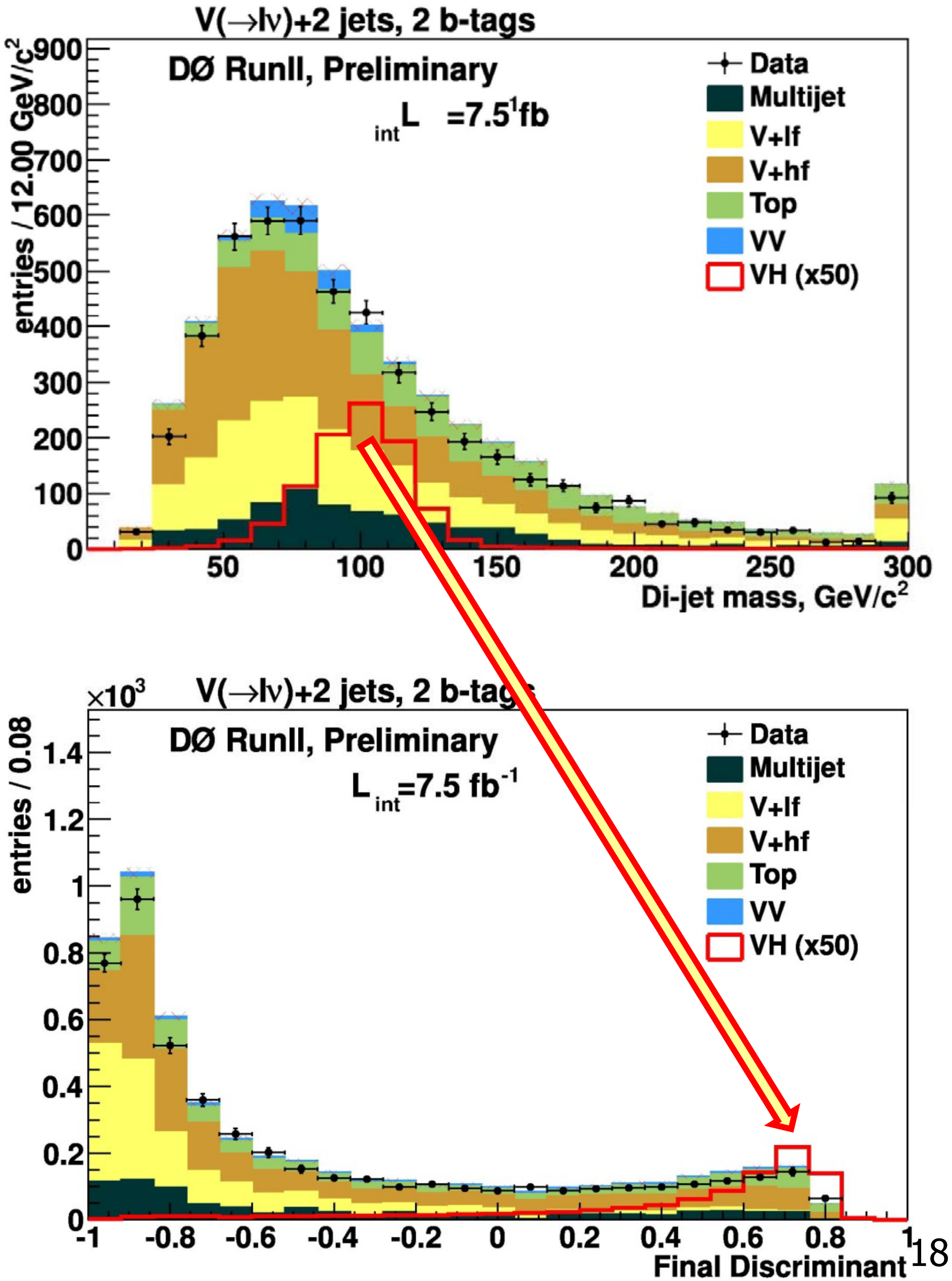
- **To improve S/B → utilize full kinematic event information**

- **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

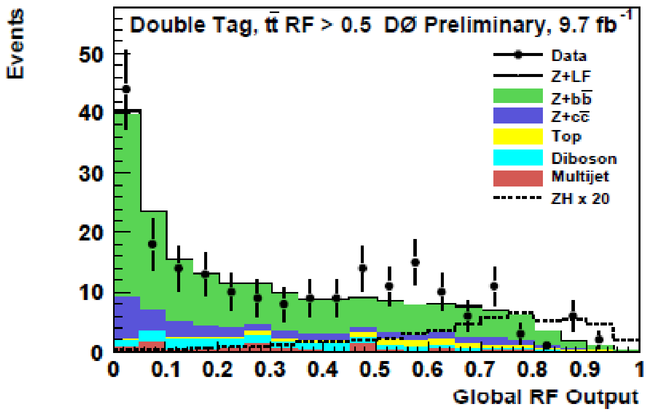
- **Approaches validated in Single Top observation @ Tevatron**
- **Combine these approaches**

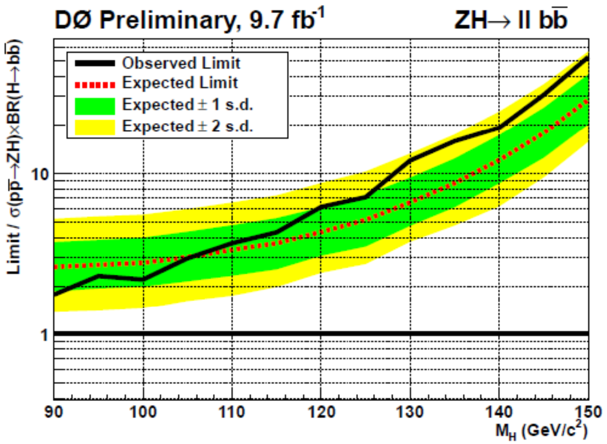
- **Visible gain obtained (~25% in sensitivity)**



Results from DØ

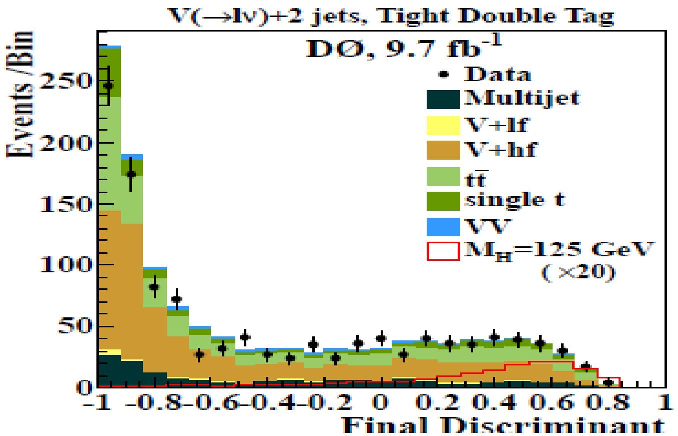
ZH→llbb ∫Ldt=**9.7**fb^{-1}

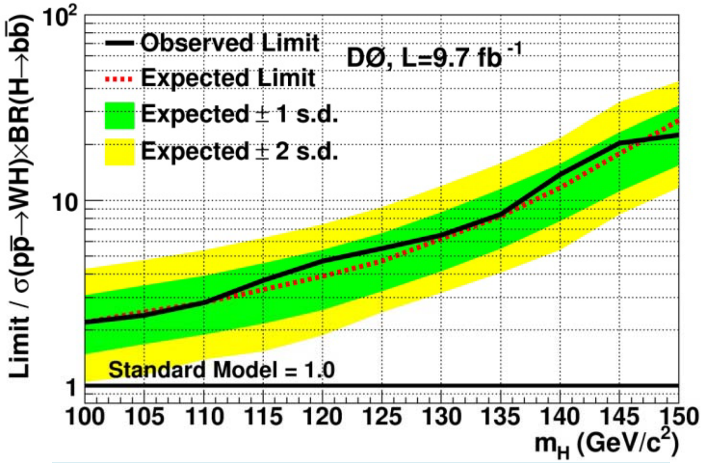




95% CL Exp (obs)
Limit **3.7** (**4.3**) x SM
@ MH=115 GeV

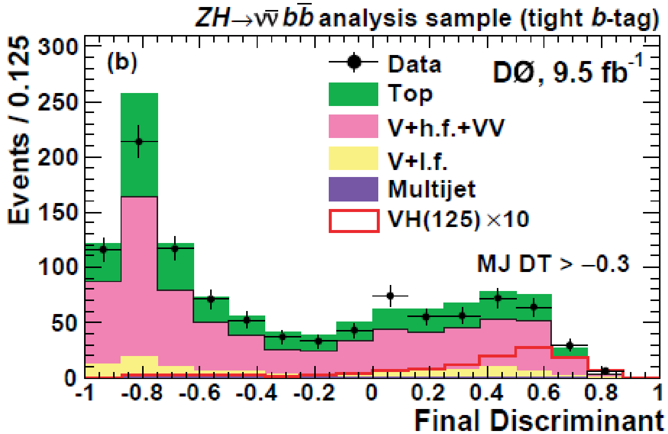
WH→lνbb ∫Ldt=**9.7** fb^{-1}

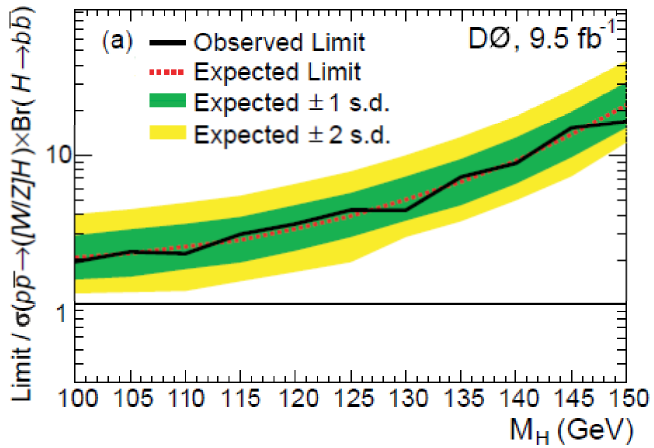




95% CL Exp (obs)
Limit **3.2** (**3.7**) x SM
@ MH=115 GeV

ZH→ννbb ∫Ldt=**9.5** fb^{-1}



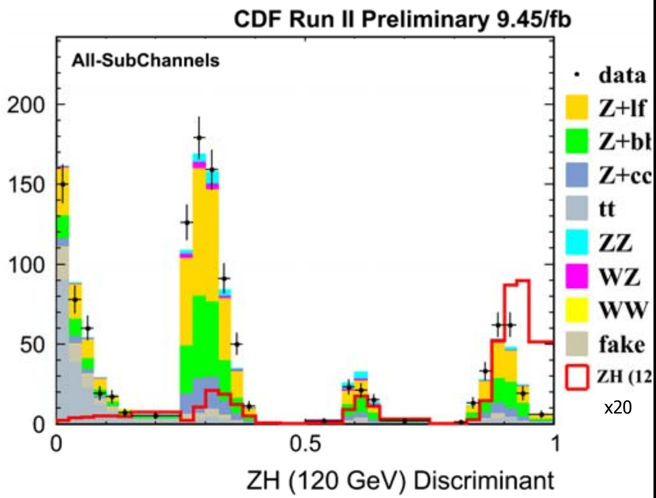


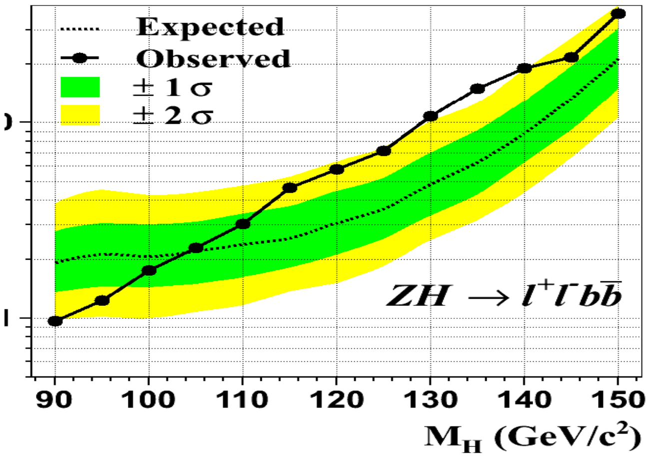
95% CL Exp (obs)
Limit **3.0** (**2.7**) x SM
@ MH=115 GeV

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

Results from CDF

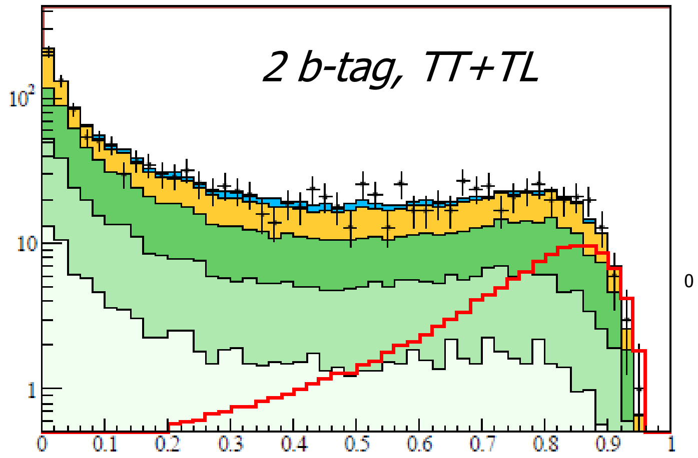
ZH→llbb̄ ∫Ldt=**9.5** fb^{-1}

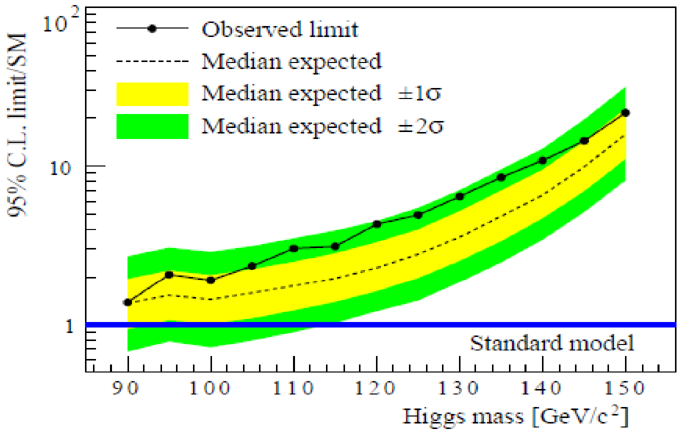




95% CL Exp (obs)
Limit **2.6** (**4.7**) x SM
@ MH=115 GeV

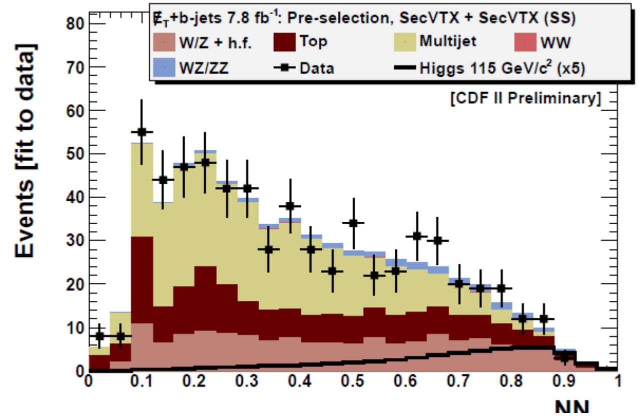
WH→lνbb̄ ∫Ldt=**9.5** fb^{-1}

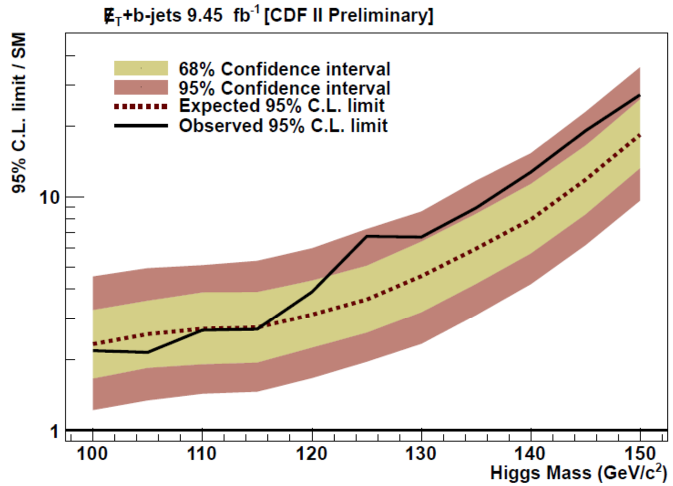




95% CL Exp (obs)
Limit **2.0** (**3.1**) x SM
@ MH=115 GeV

ZH→ννbb̄ ∫Ldt=**9.5** fb^{-1}

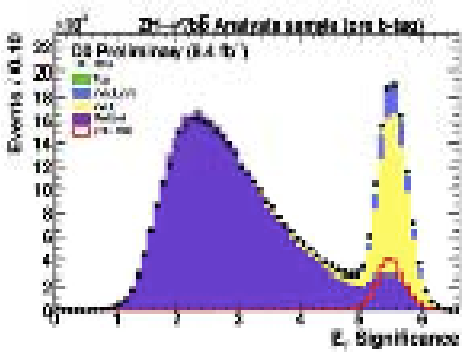




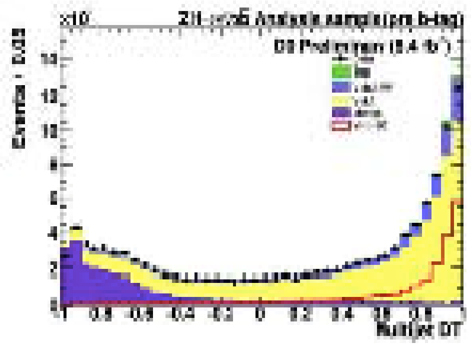
95% CL Exp (obs)
Limit **2.7** (**2.7**) x SM
@ MH=115 GeV

>20% gain on intrinsic sensitivity compared to 2011

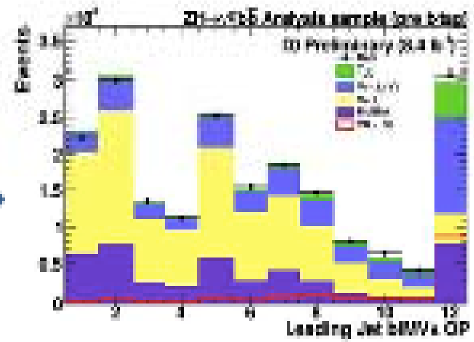
How do we control these techniques?



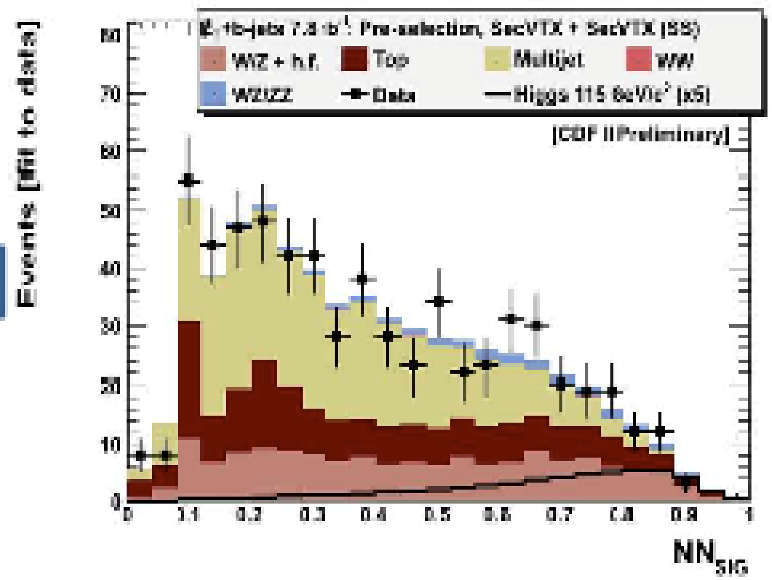
Kinematic event selection



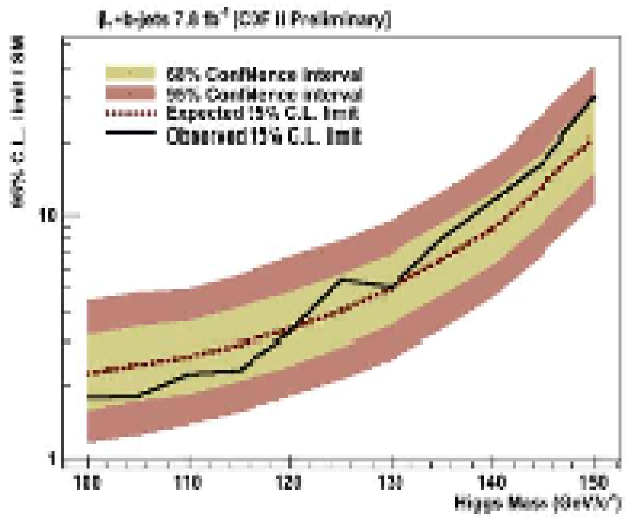
Multijet removal



b-tagging



Final discriminant
SVM, BDT, RF...



Statistical analysis
Log Likelihood Ratio (LLR)
Marginalization of nuisance parameters

Cross check on Diboson process

Benchmark of H→bb searches with real data.

VZ→leptons + heavy flavor jets

For m_H=115 GeV

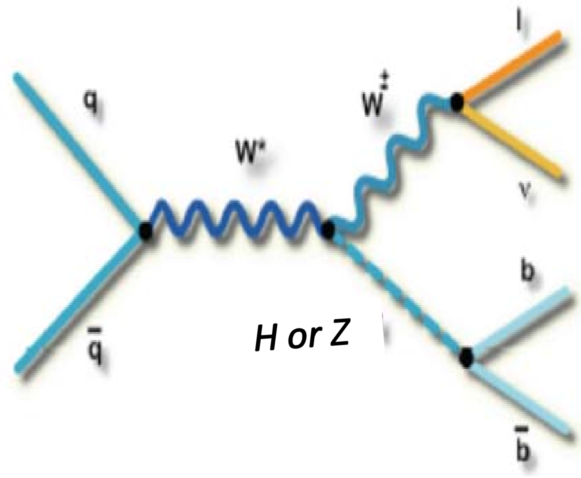
WH→lνbb: σ = 26 fb
ZH→ ννbb:σ = 15 fb
ZH→ llbb: σ = 5 fb

Total VH: σ = 46 fb

Replace H with Z

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

Total VZ: σ = 213 fb

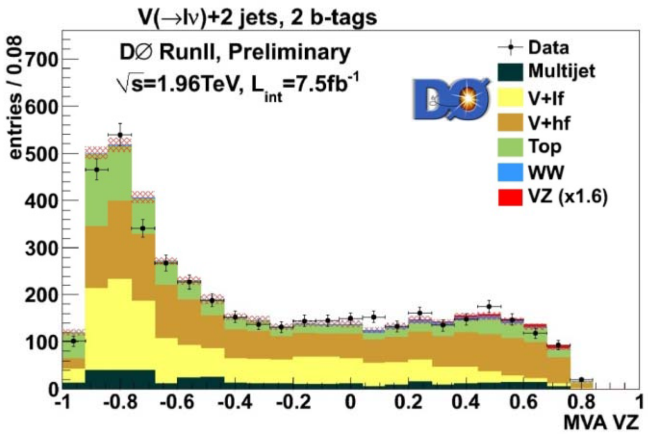


At 115 GeV, Z→bb yields is 5 times larger, but lower BR than H→bb, much more W+jets backgrounds, and difficult background from WW.

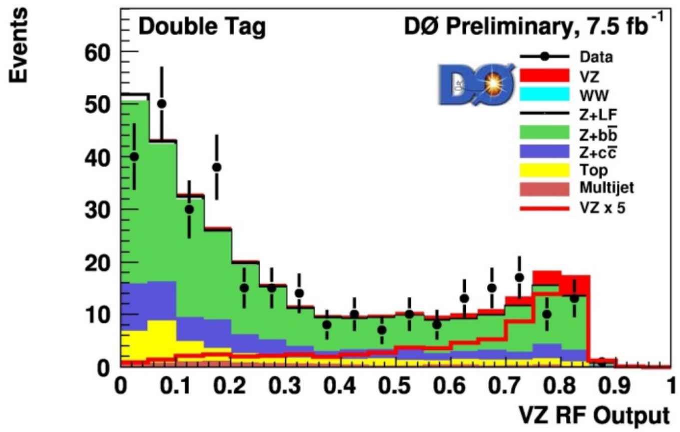
Apply similar analysis as low mass H→bb analysis, and check sensitivity.

Benchmarks : Dibosons to Heavy Flavor

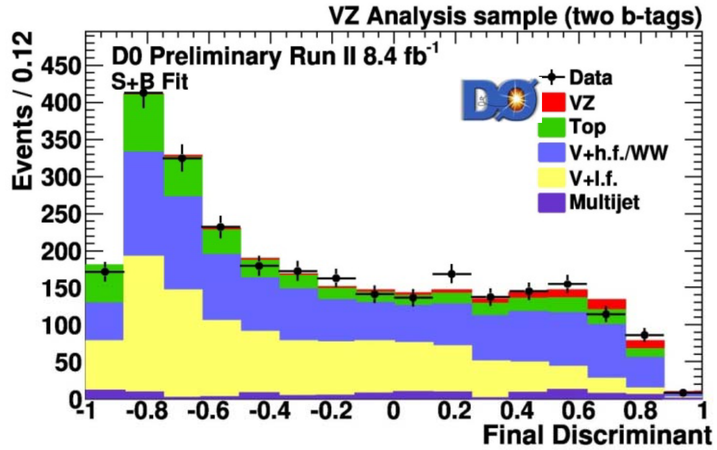
Diboson lvbb



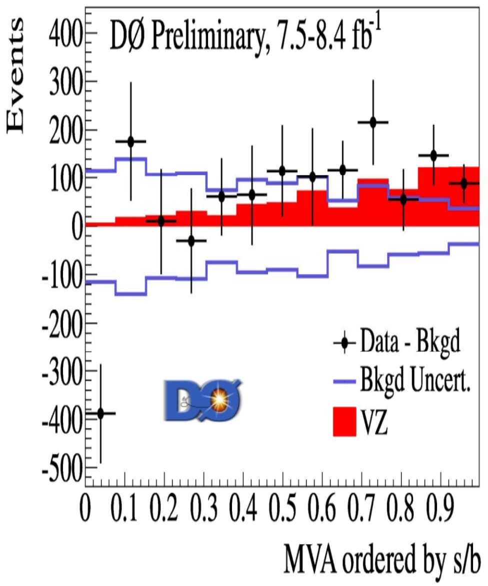
Diboson llbb

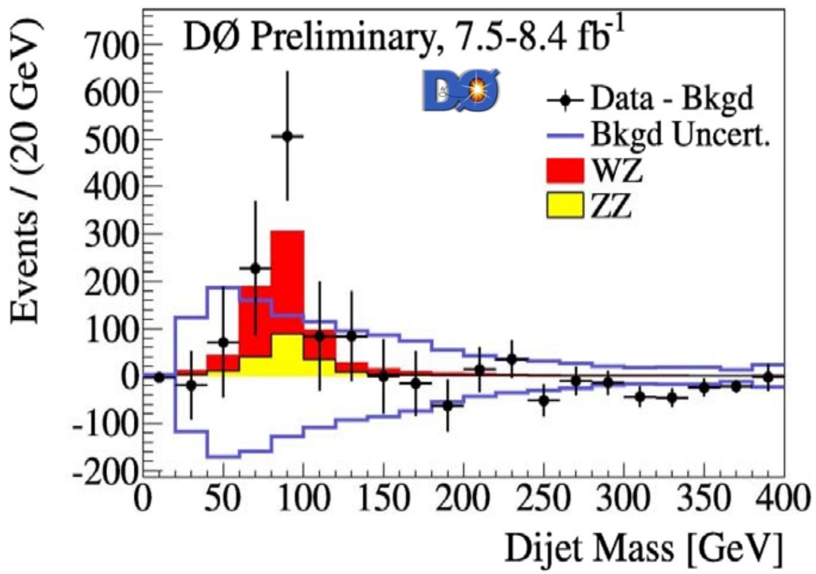


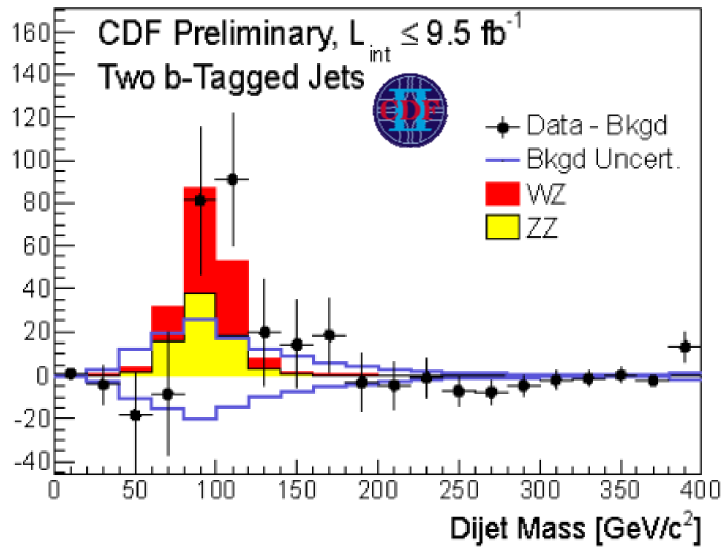
Diboson ννbb



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





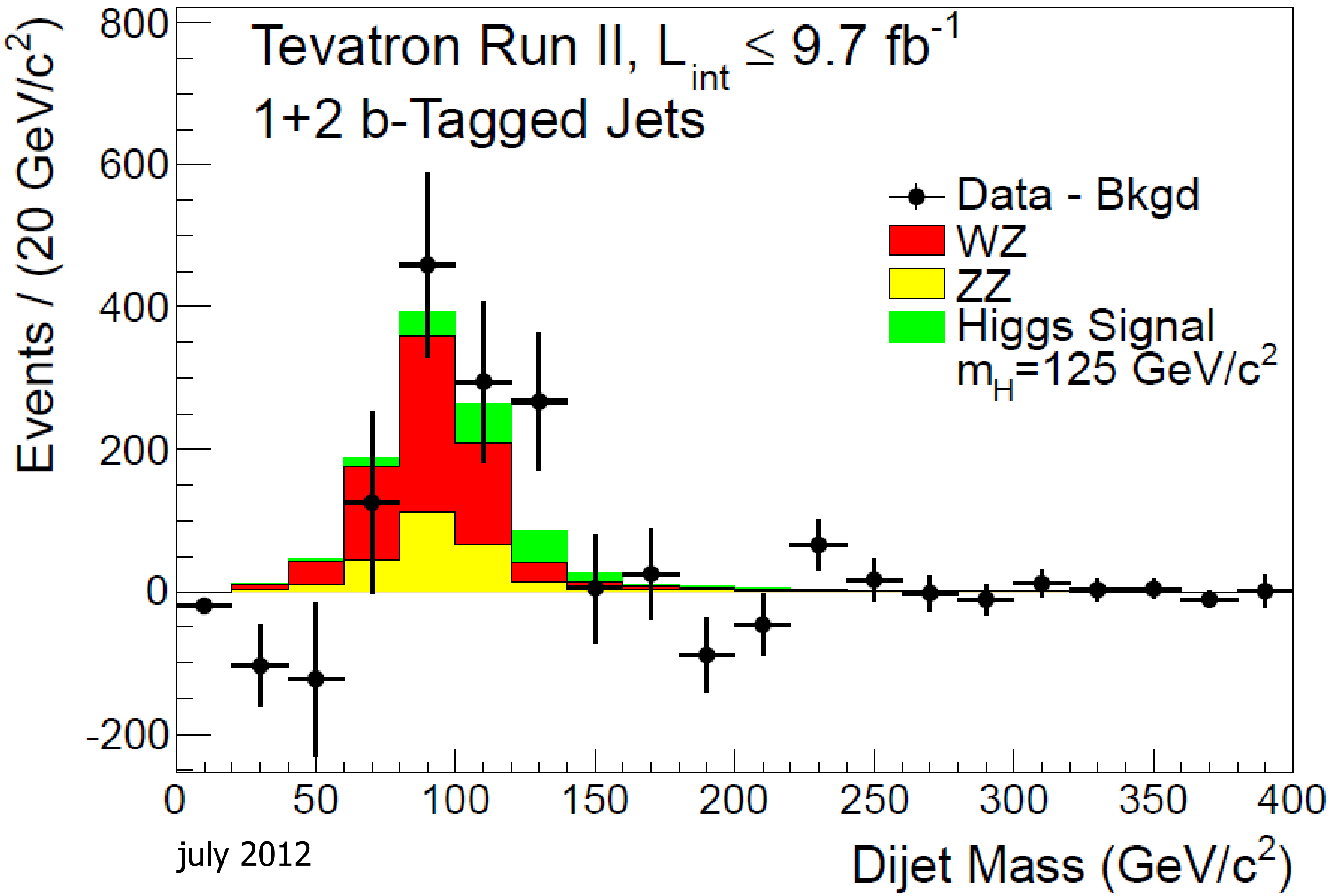


Benchmarks : Dibosons to Heavy Flavor

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)



july 2012

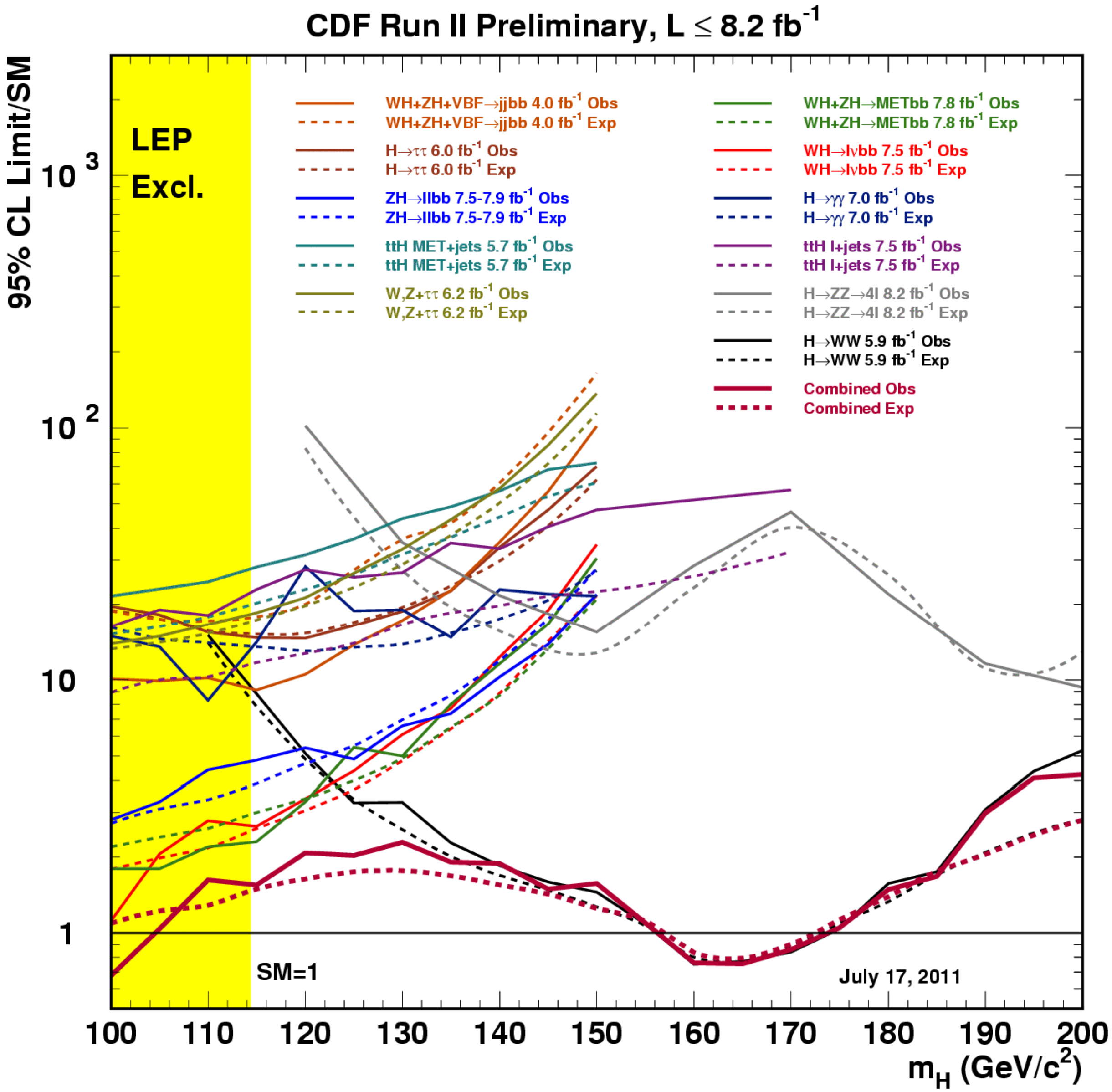
→ **If there is a light SM Higgs, we should “see” it!**

Combining Channels

Best sensitivity → combination of many independent search channels

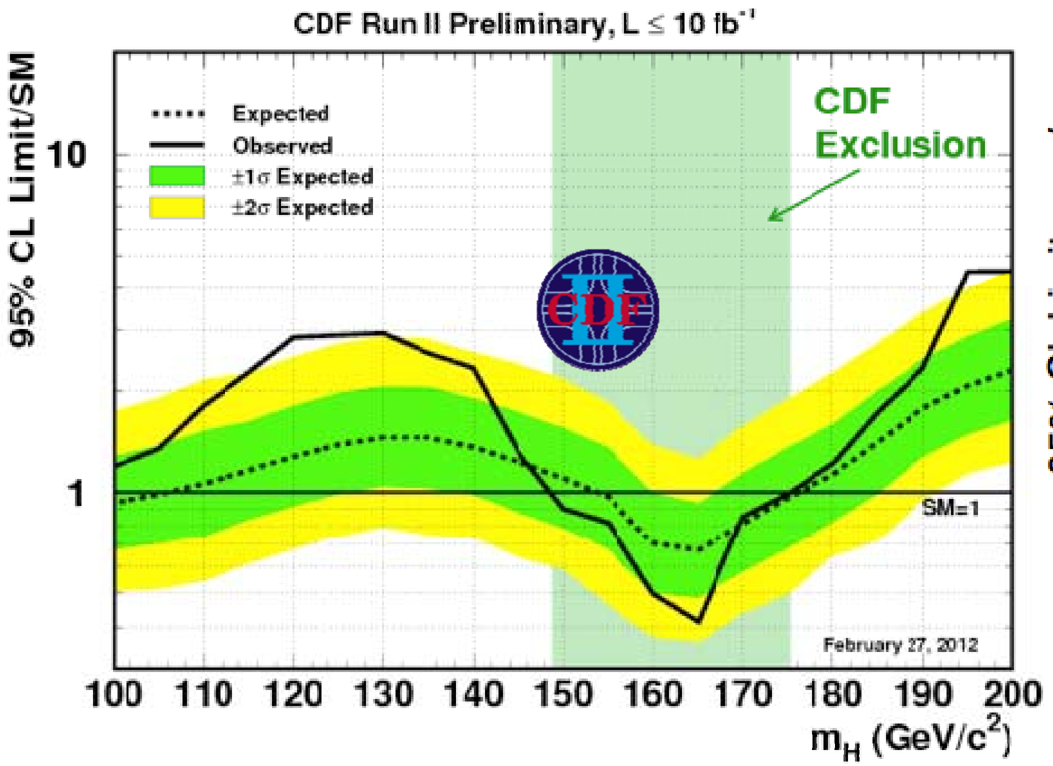
Other analyzed channels are listed here below:

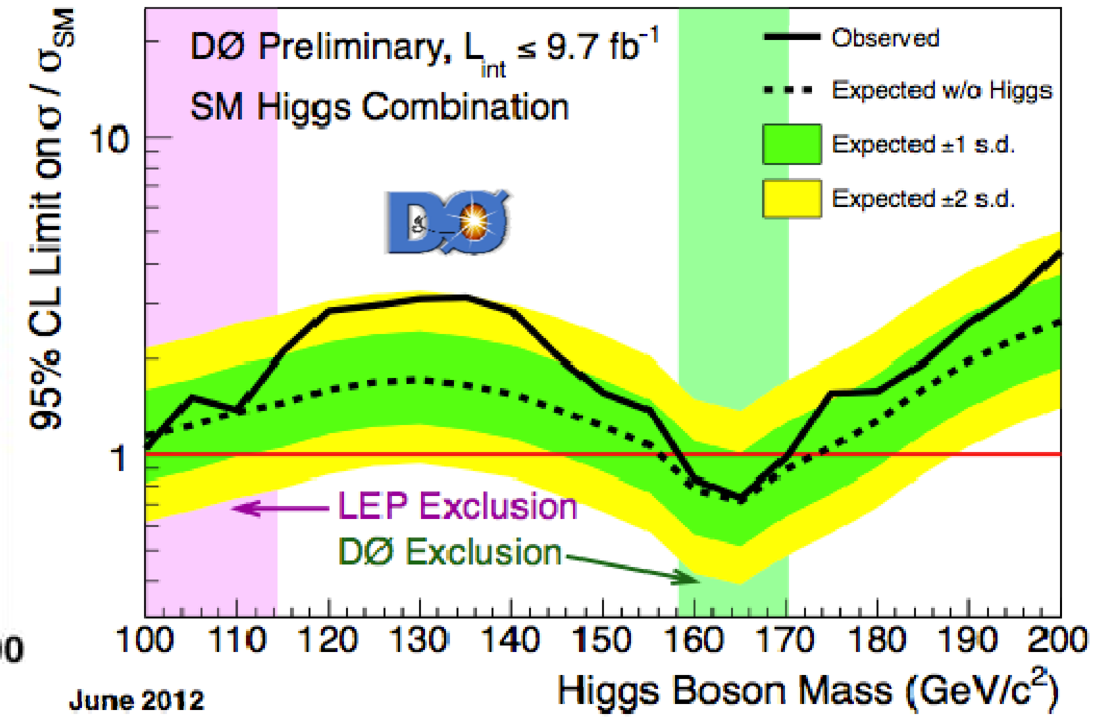
WH→lνbb
ZH→ννbb
ZH→llbb
WH/ZH→jjbb
ttH→WbWbbb
H→γγ
H→ττ
WH→lνττ / ZH→llττ
H→WW→lνlν
H→WW→lνjj
WH→WWW / ZH→ZWW
H→ZZ



Individual Experiment Results

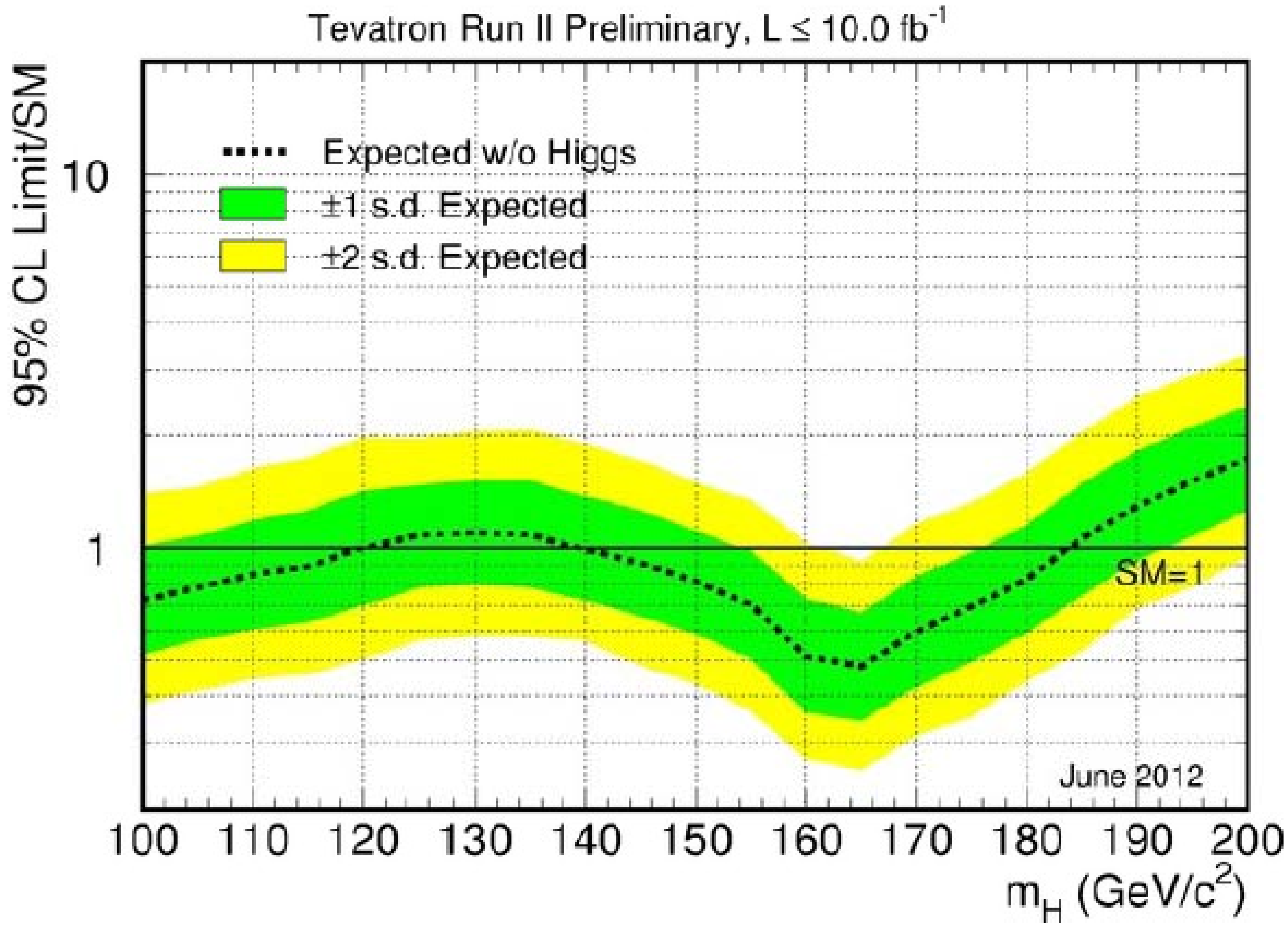
CDF & D0 single-experiment combinations of all SM Higgs search channels ($H \rightarrow WW$, $H \rightarrow bb$, $H \rightarrow \gamma\gamma$ + other modes)





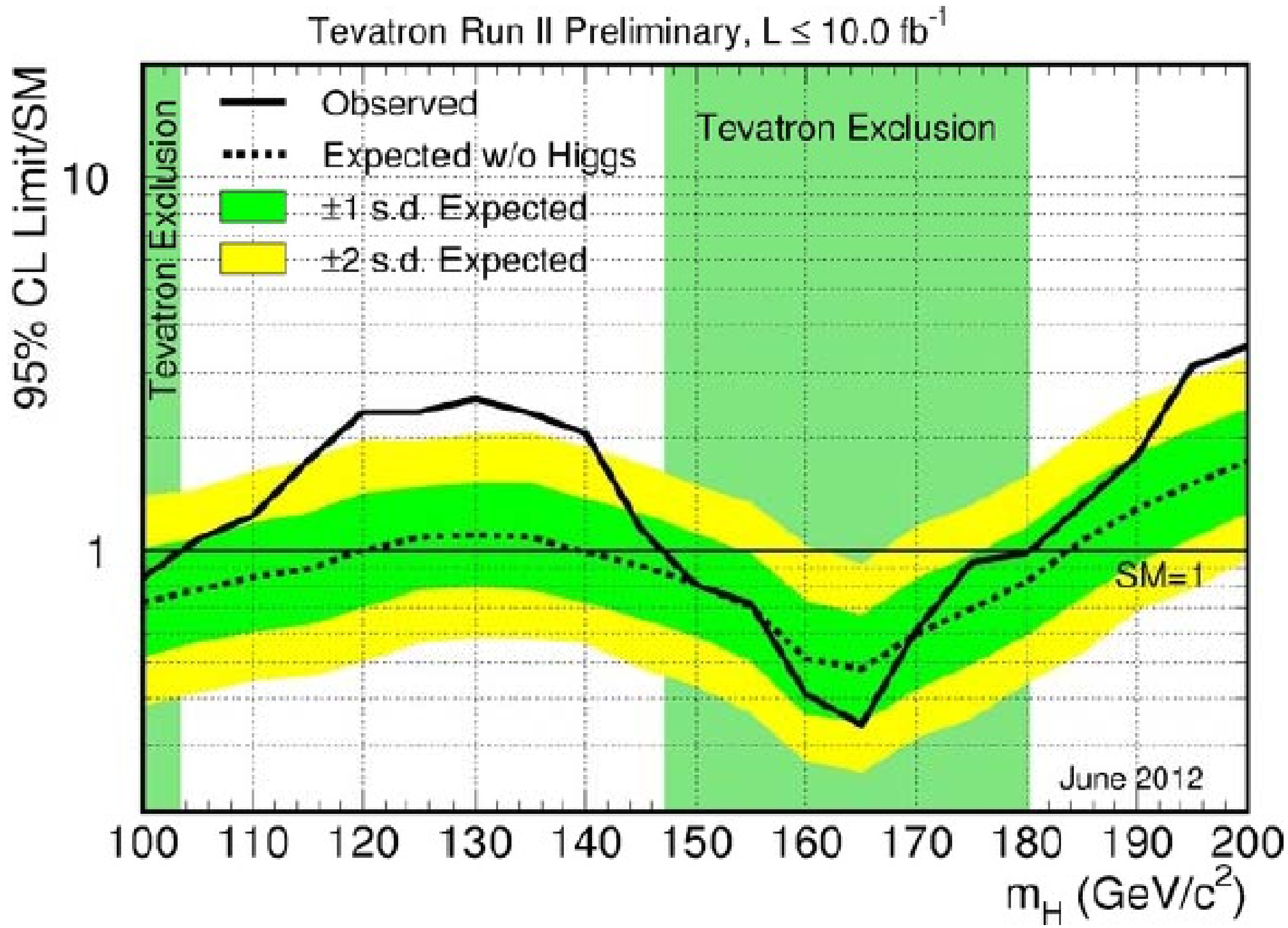
Remarkably similar shapes: within 1 sigma below ~110 GeV,
broad excess around ~120-140 GeV,
exclusion around ~165 GeV
small excess around ~200 GeV

2012 Tevatron combination: expected



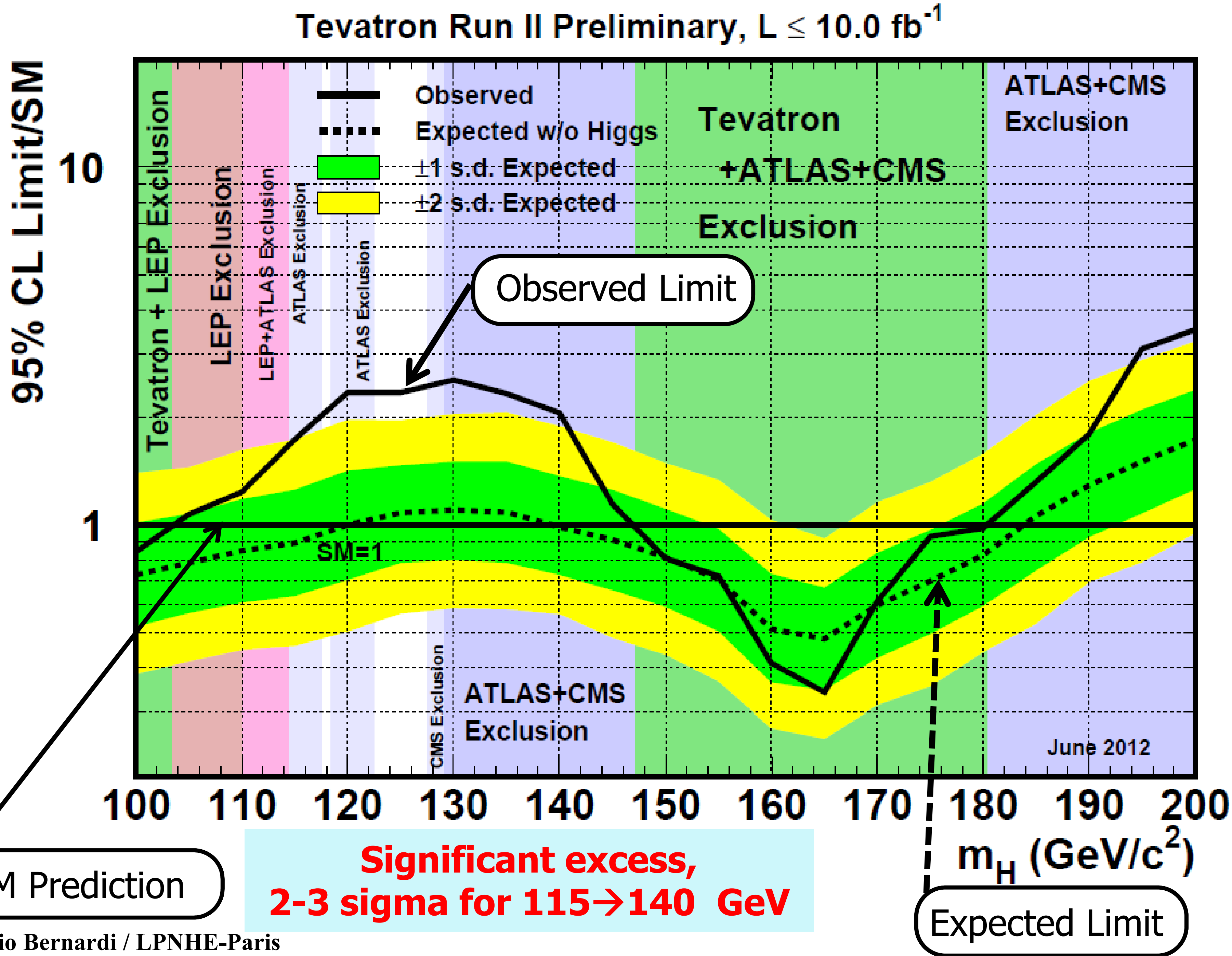
- 95% C.L. upper limits on SM Higgs boson production at the Tevatron
  - Expected exclusion: $100 < M_H < 120$ GeV $139 < M_H < 184$ GeV

Summer 2012 Tevatron combination



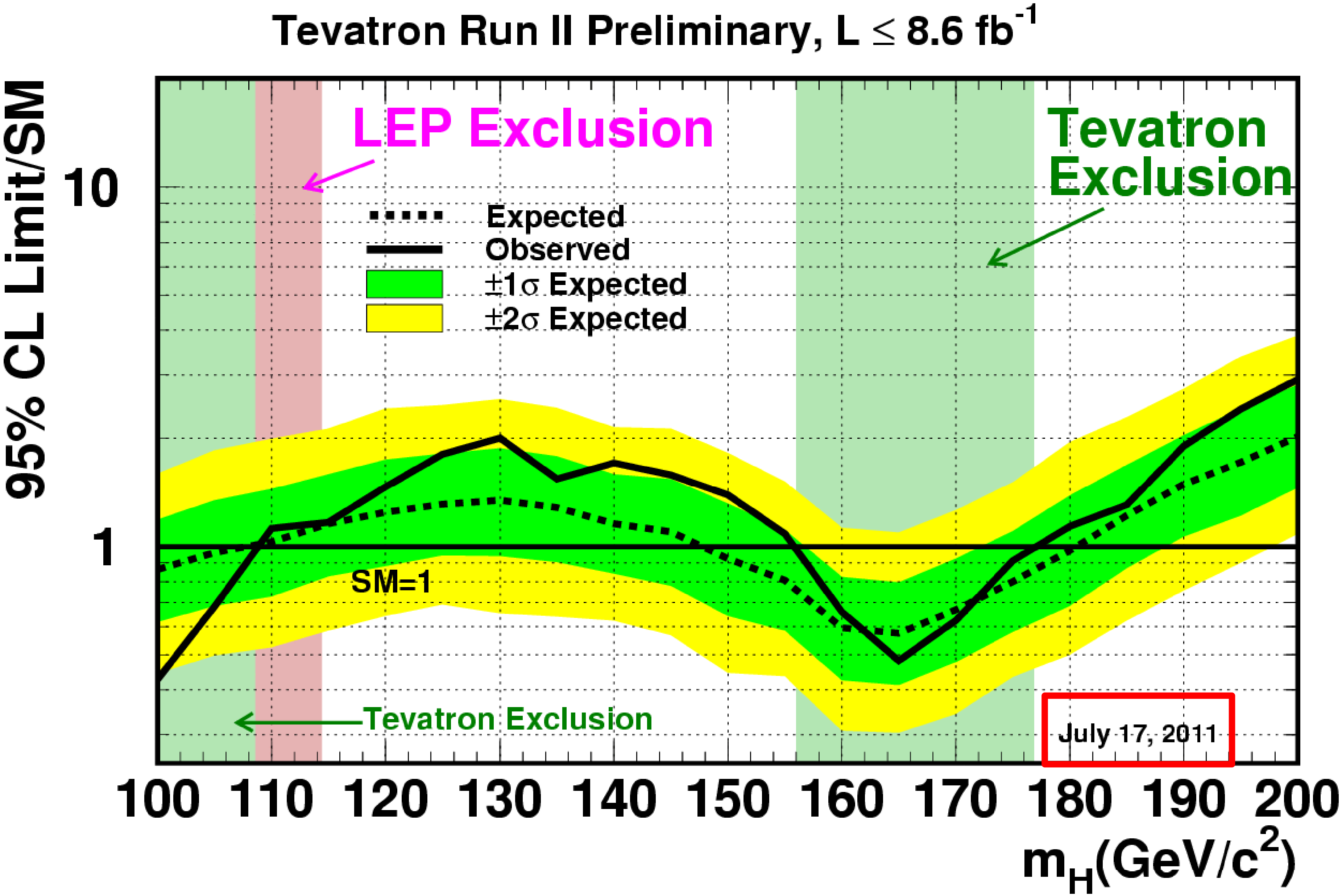
- 95% C.L. upper limits on SM Higgs boson production at the Tevatron
  - Expected exclusion: **100 < M_H < 120 GeV** 139 < M_H < 184 GeV
  - Observed exclusion: **100 < M_H < 103 GeV** 147 < M_H < 180 GeV

Summer 2012 Tevatron Combination



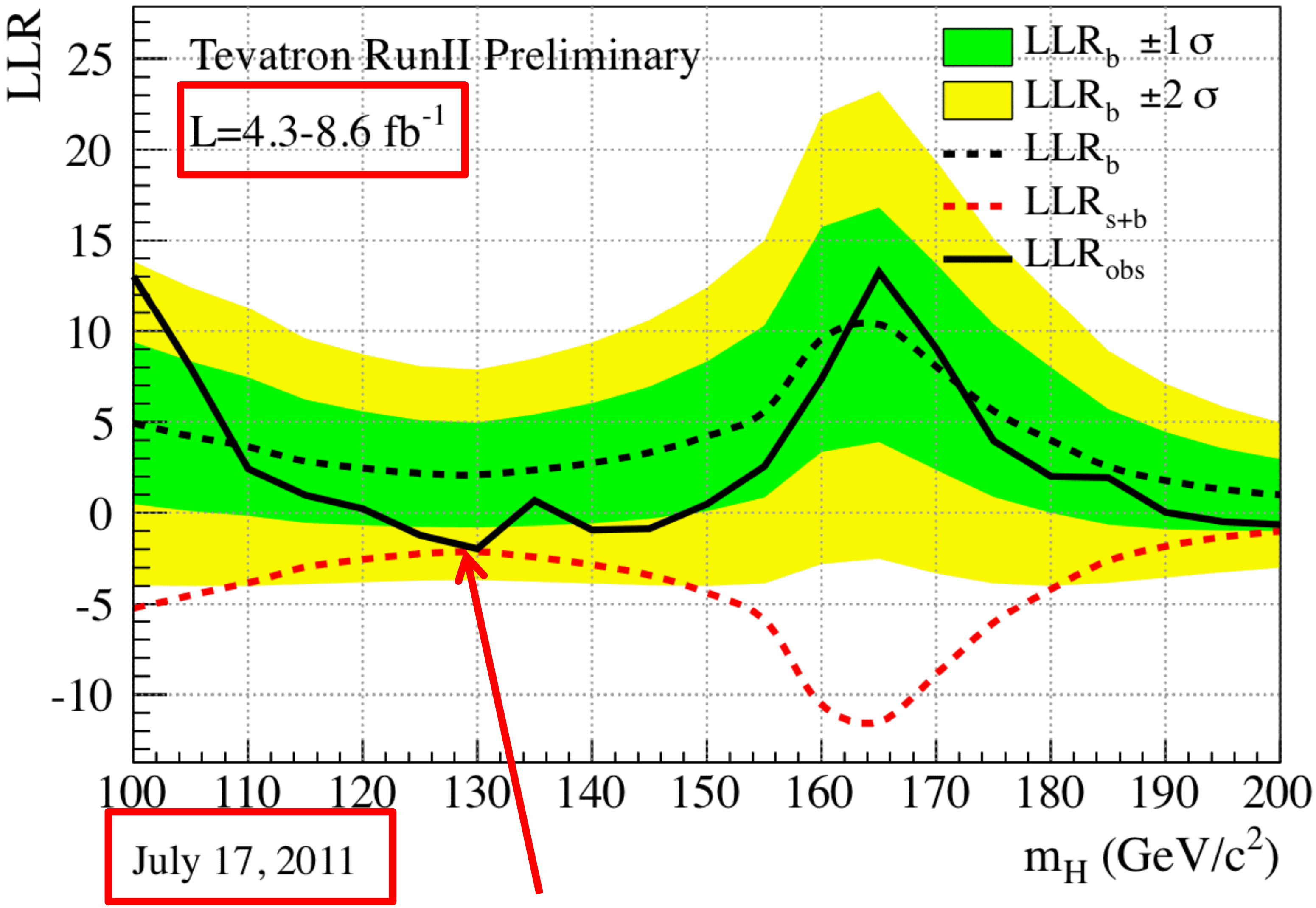
Significant excess,
2-3 sigma for 115→140 GeV

One step back:
EPS 2011 Tevatron Combination



Before any LHC hints (EPS 2011)

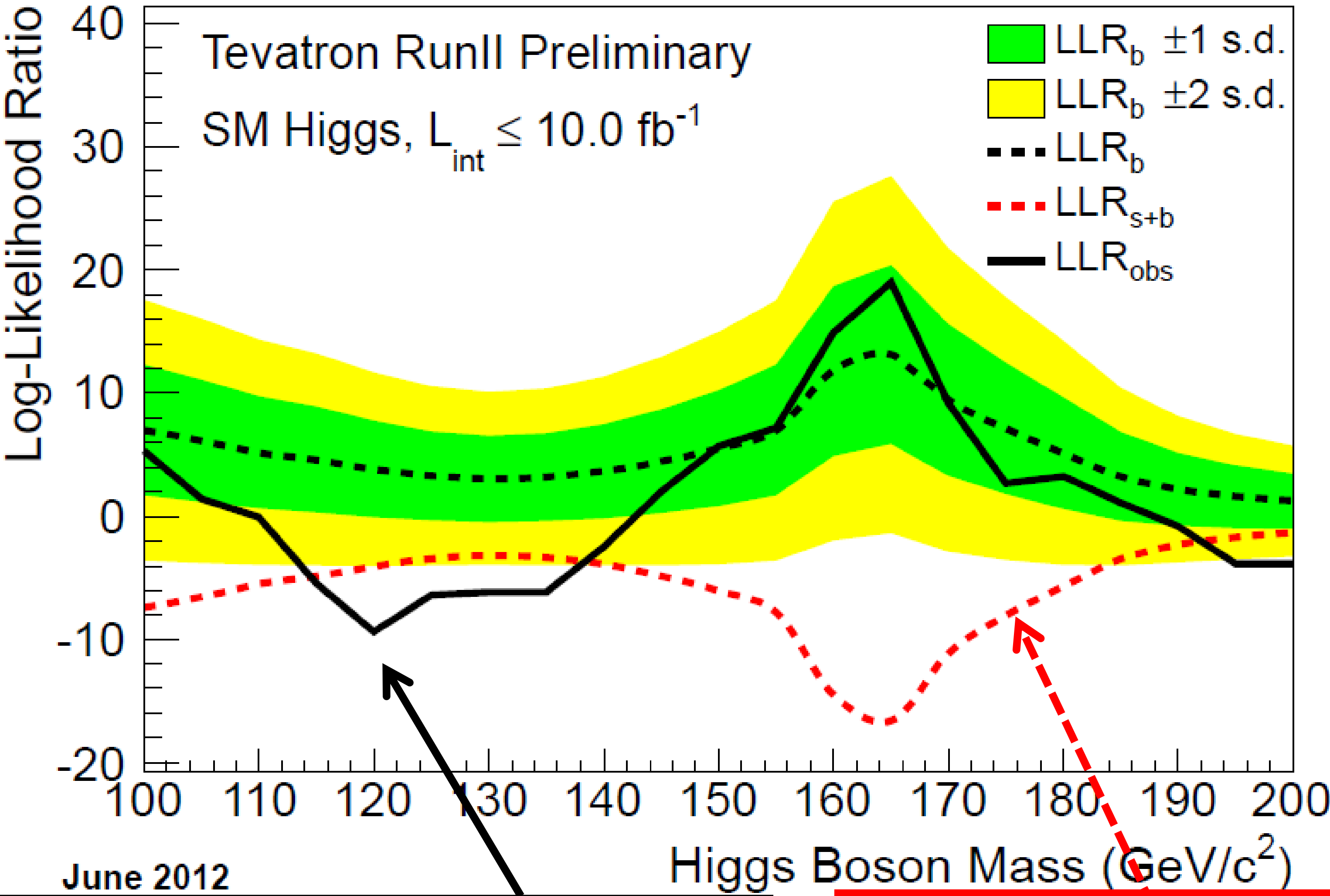
Log-Likelihood ratio plot



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

Back to the present: S+B vs. B-only Hypotheses

Log-Likelihood Ratio plot, 2012



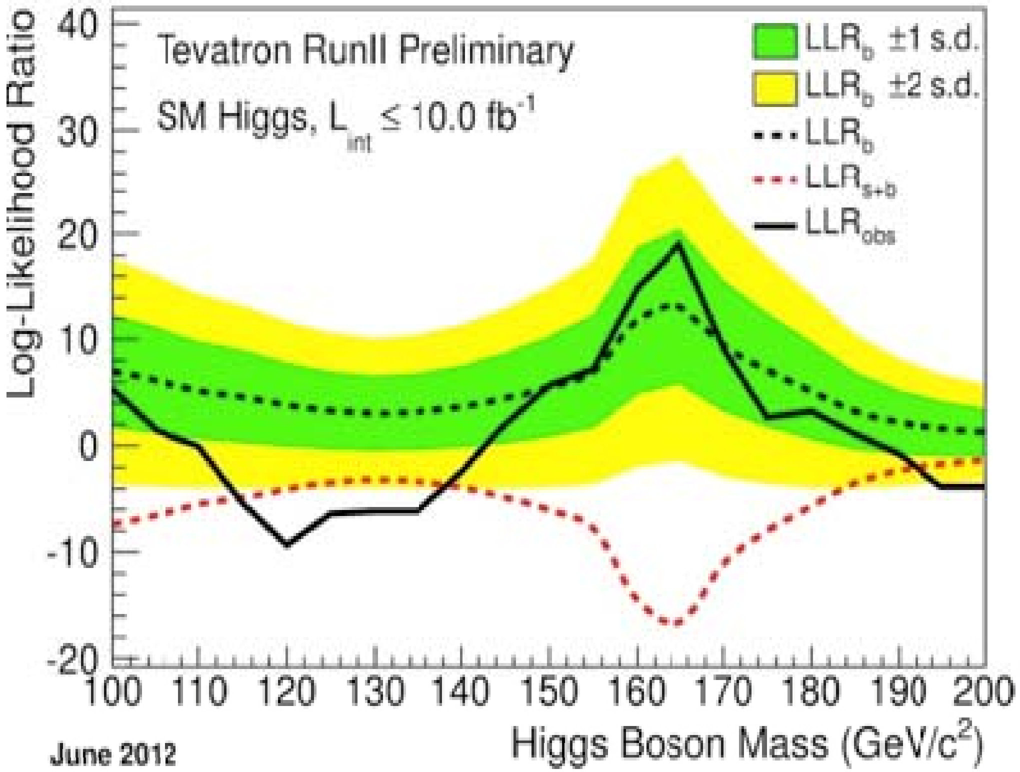
3.0 sigma local excess at 120 GeV, consistent with SM Higgs

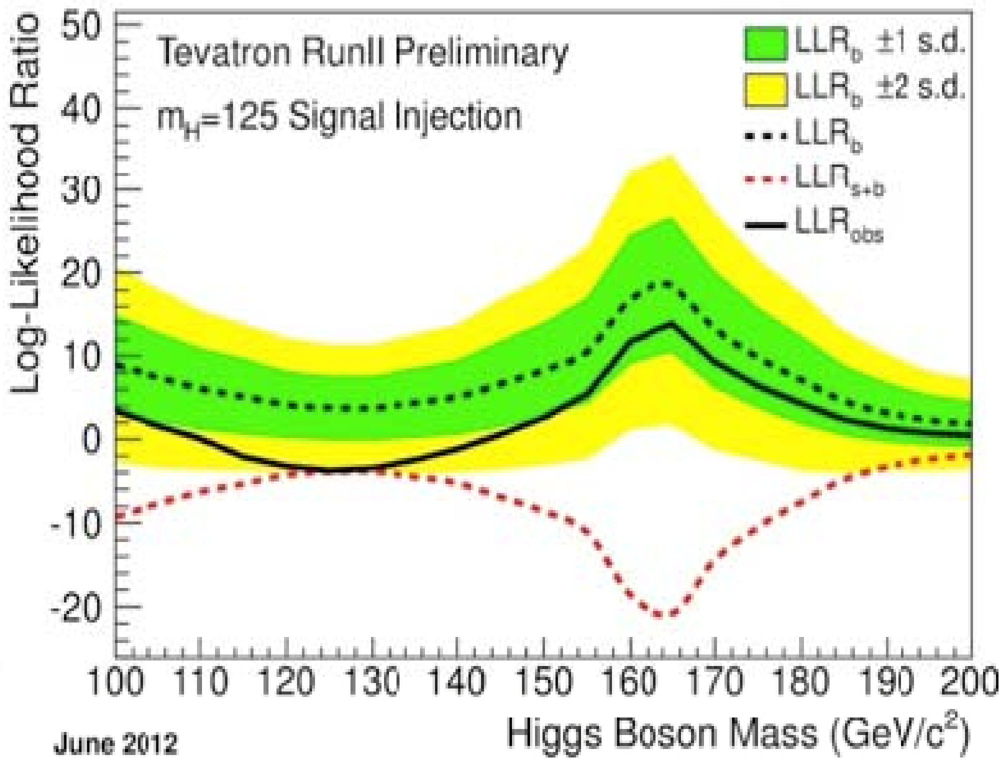
Expected s+b LLR shows good sensitivity up to 185 GeV. Data above Higgs expectation between 115 and 140 GeV

LLR: Signal Injection Comparison

Real Data Analysis

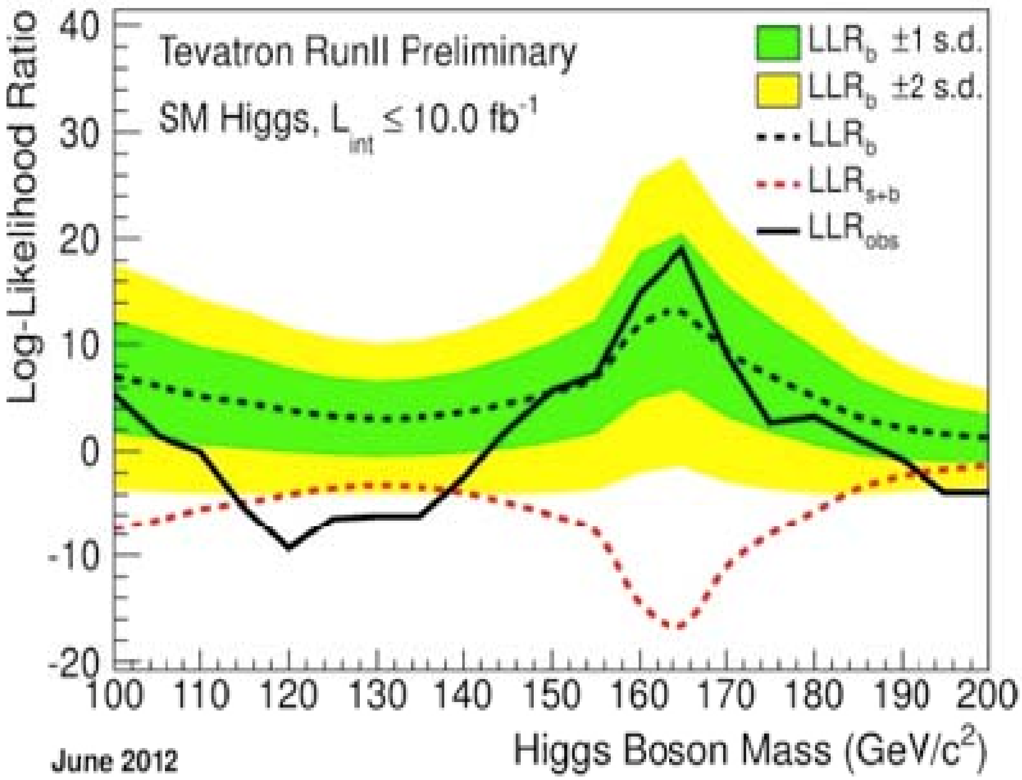
Signal Injection Study



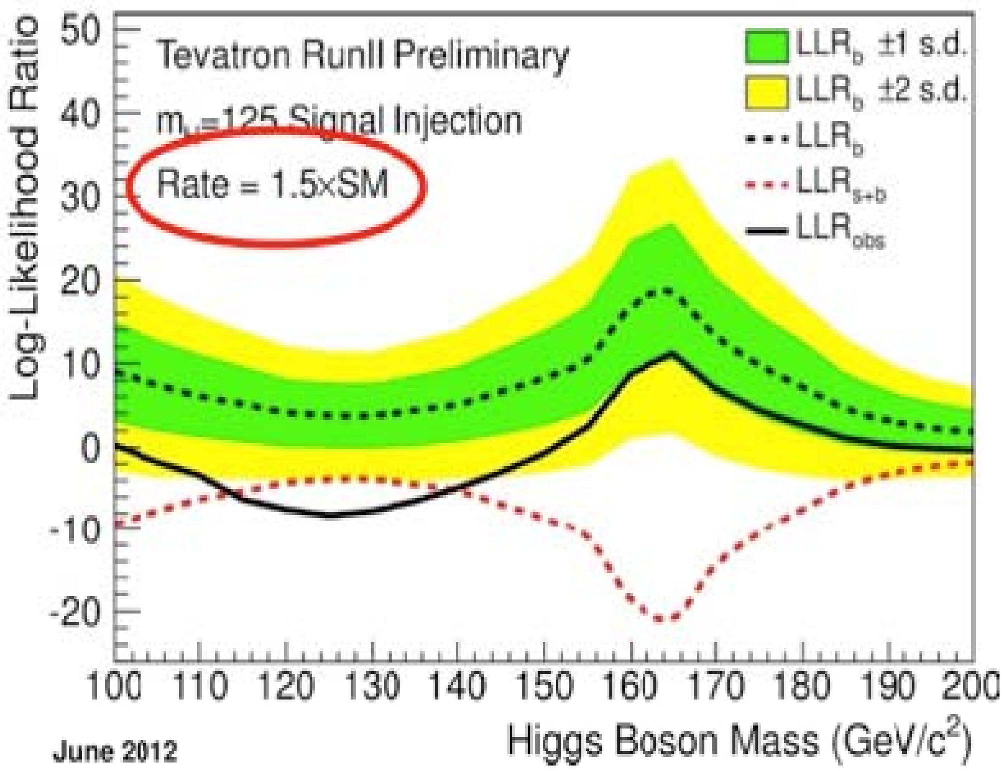


LLR: Signal Injection Comparison

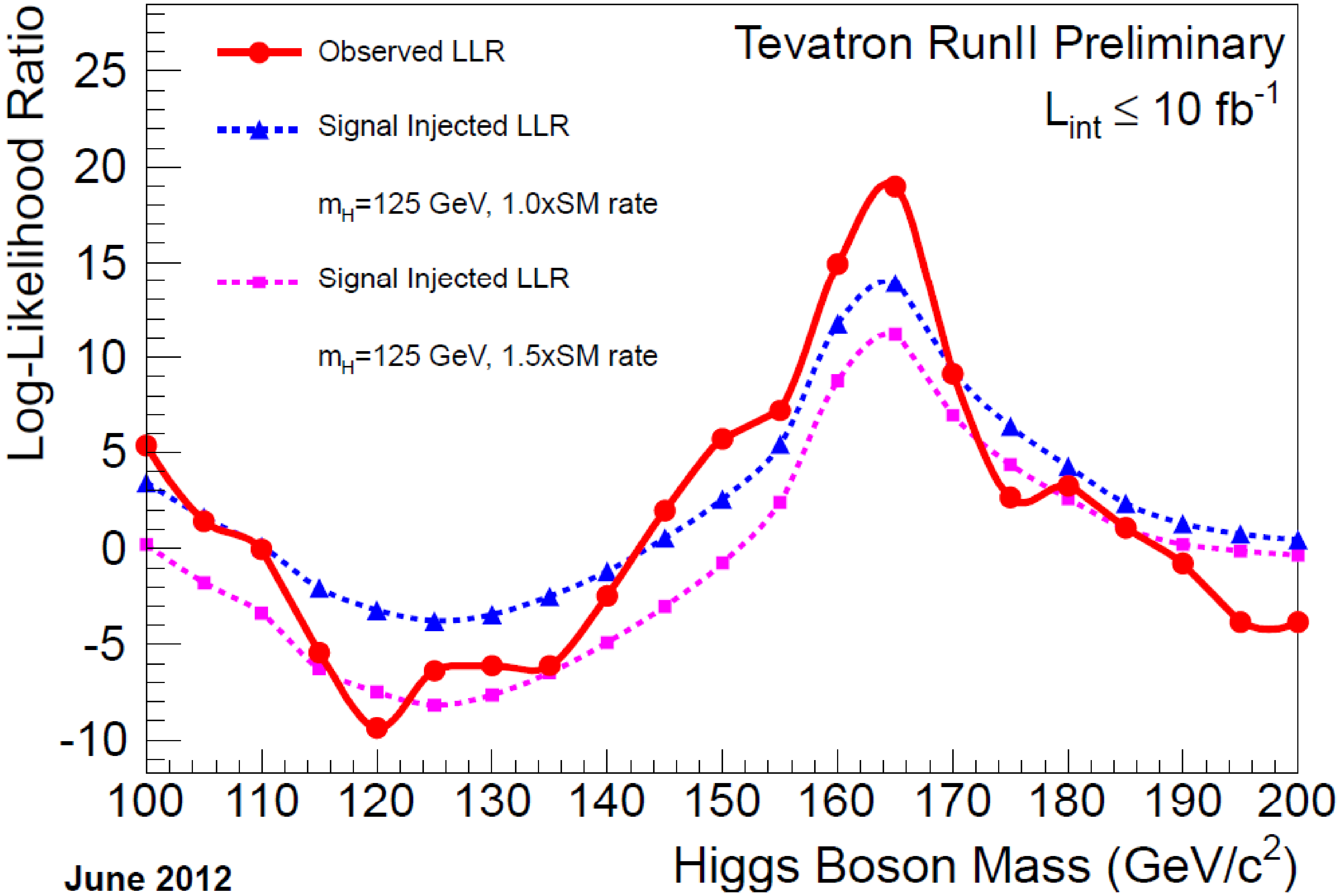
Real Data Analysis



Signal Injection Study



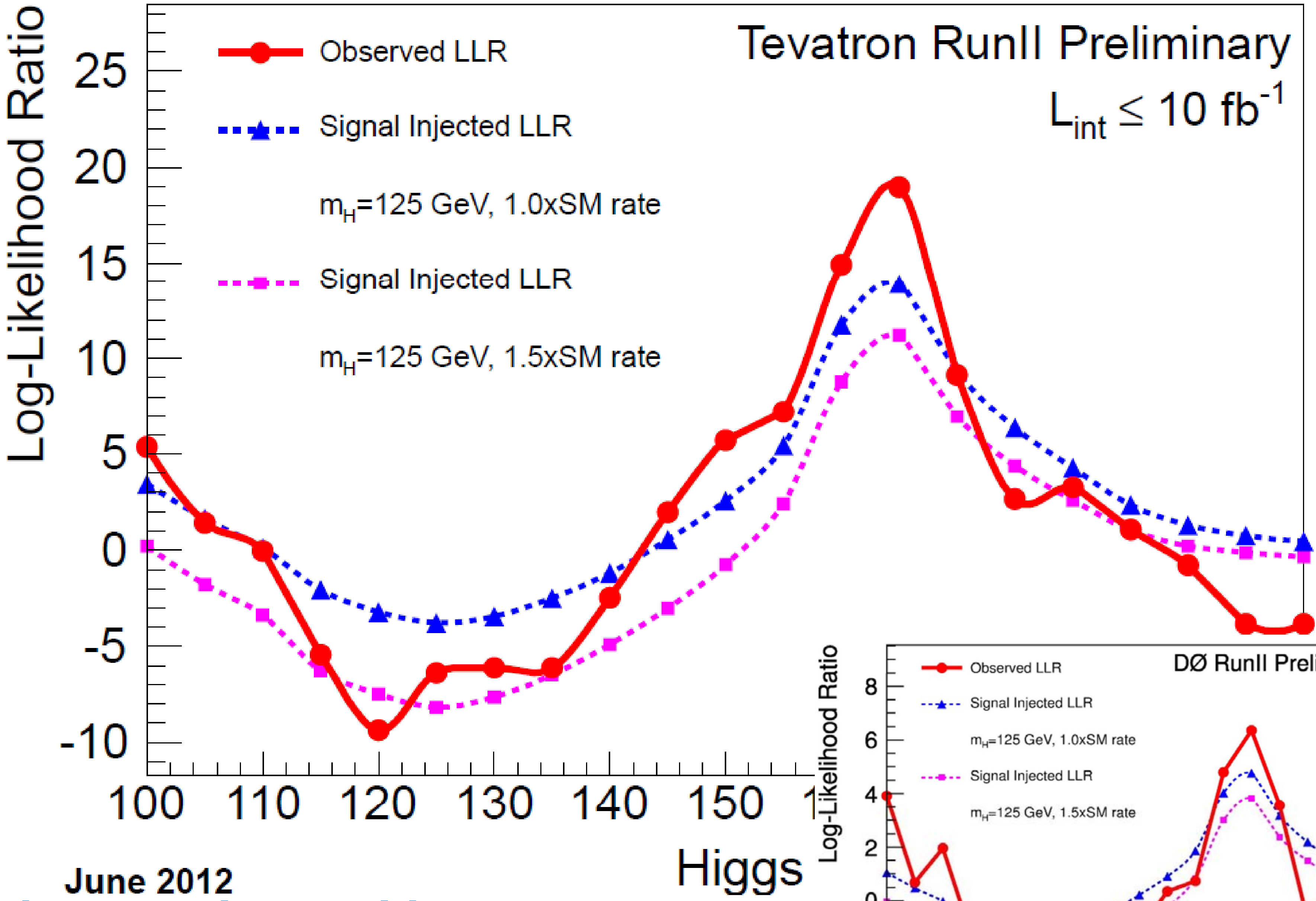
LLR shape compared to m_H=125 GeV

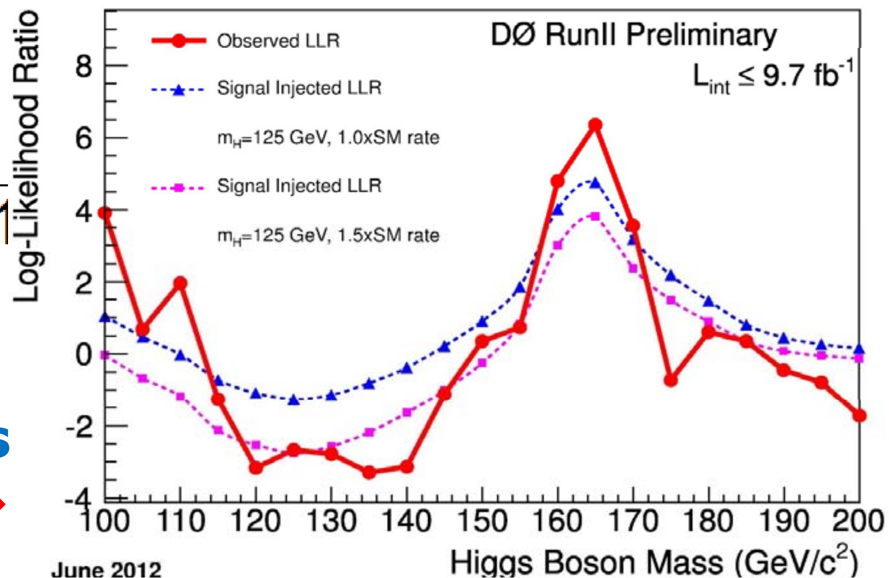


Shape consistent with background + injected 125 GeV SM Higgs.

Significantly higher significance (from LLR, and shape) at low mass

LLR shape compared to m_H=125 GeV

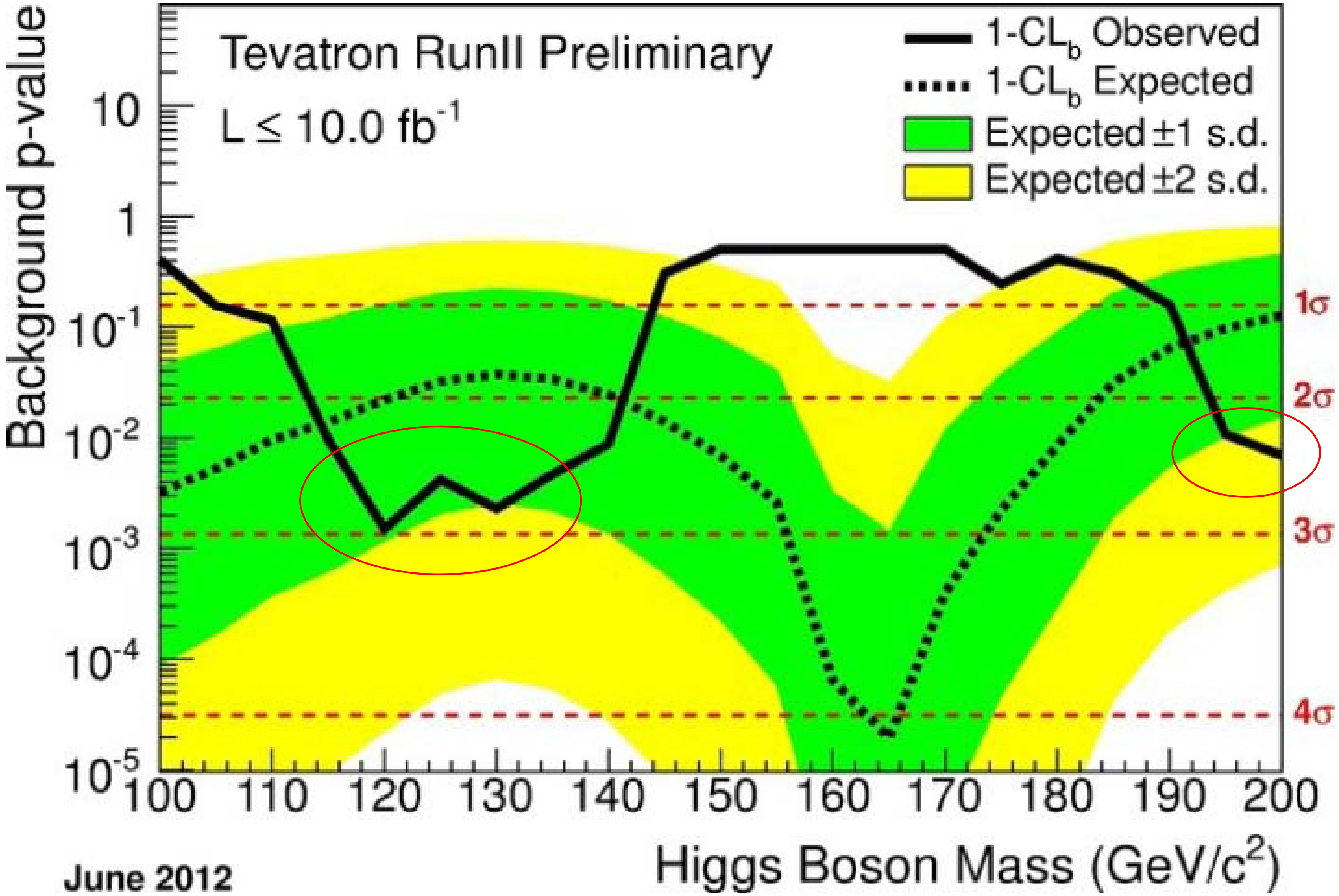




Shape consistent with background + injected 125 GeV SM Higgs

true for both experiments →

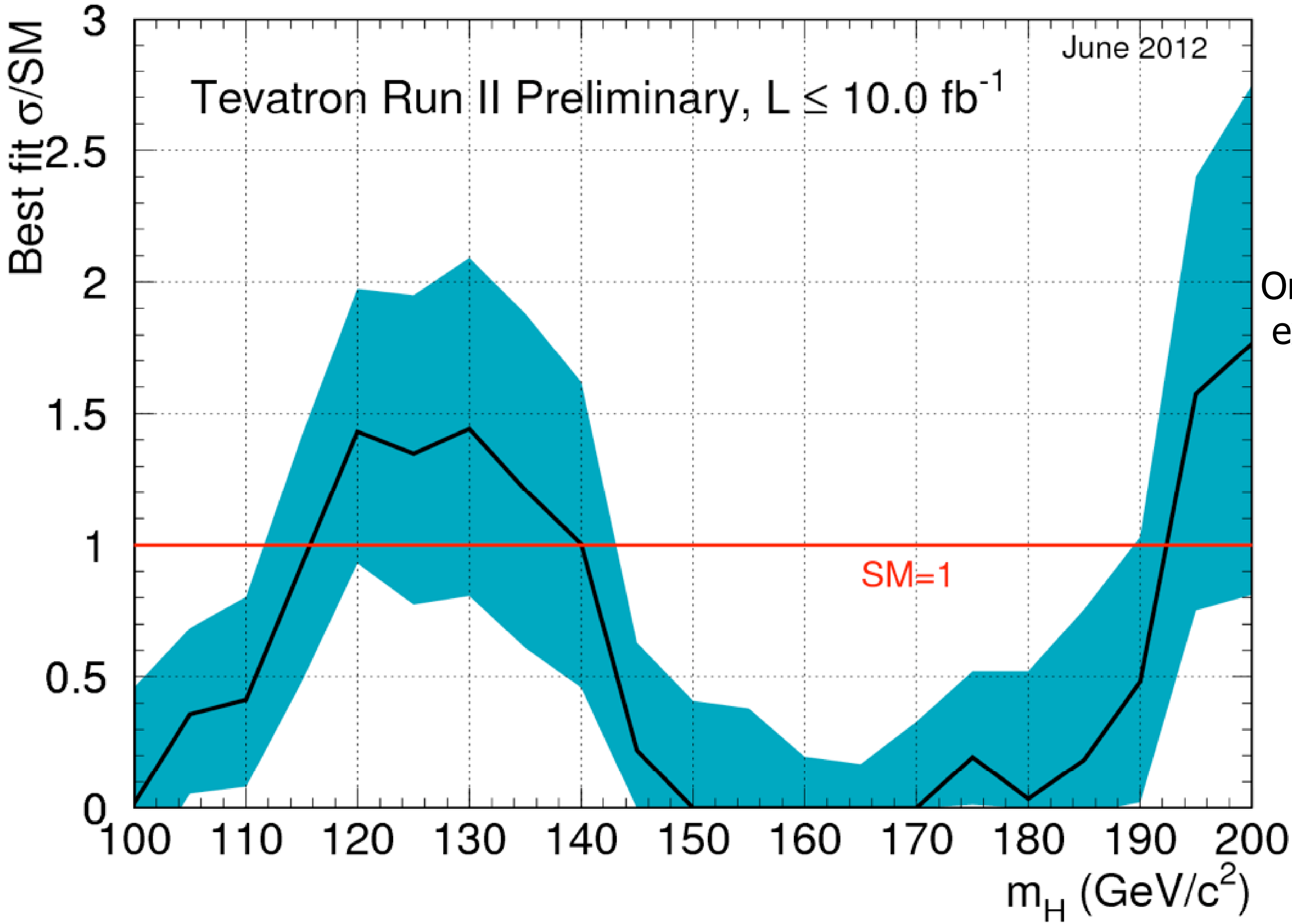
Full combination, p-values



Small excess, incompatible with H→WW resolution

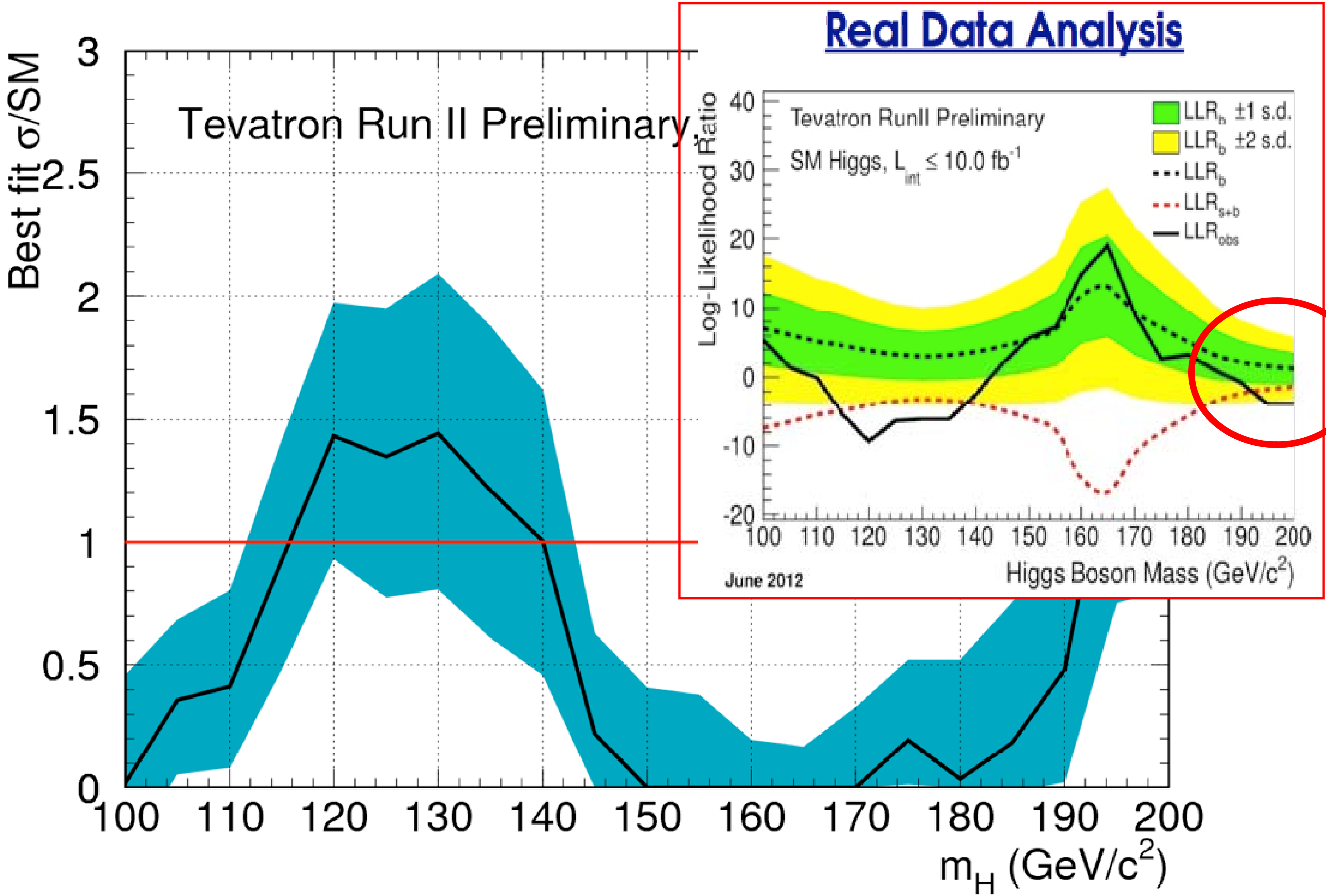
3.0 sigma local excess at 120 GeV,
2.5 sigma global excess,
2.0 sigma expected sensitivity

Tevatron Cross Section Fits

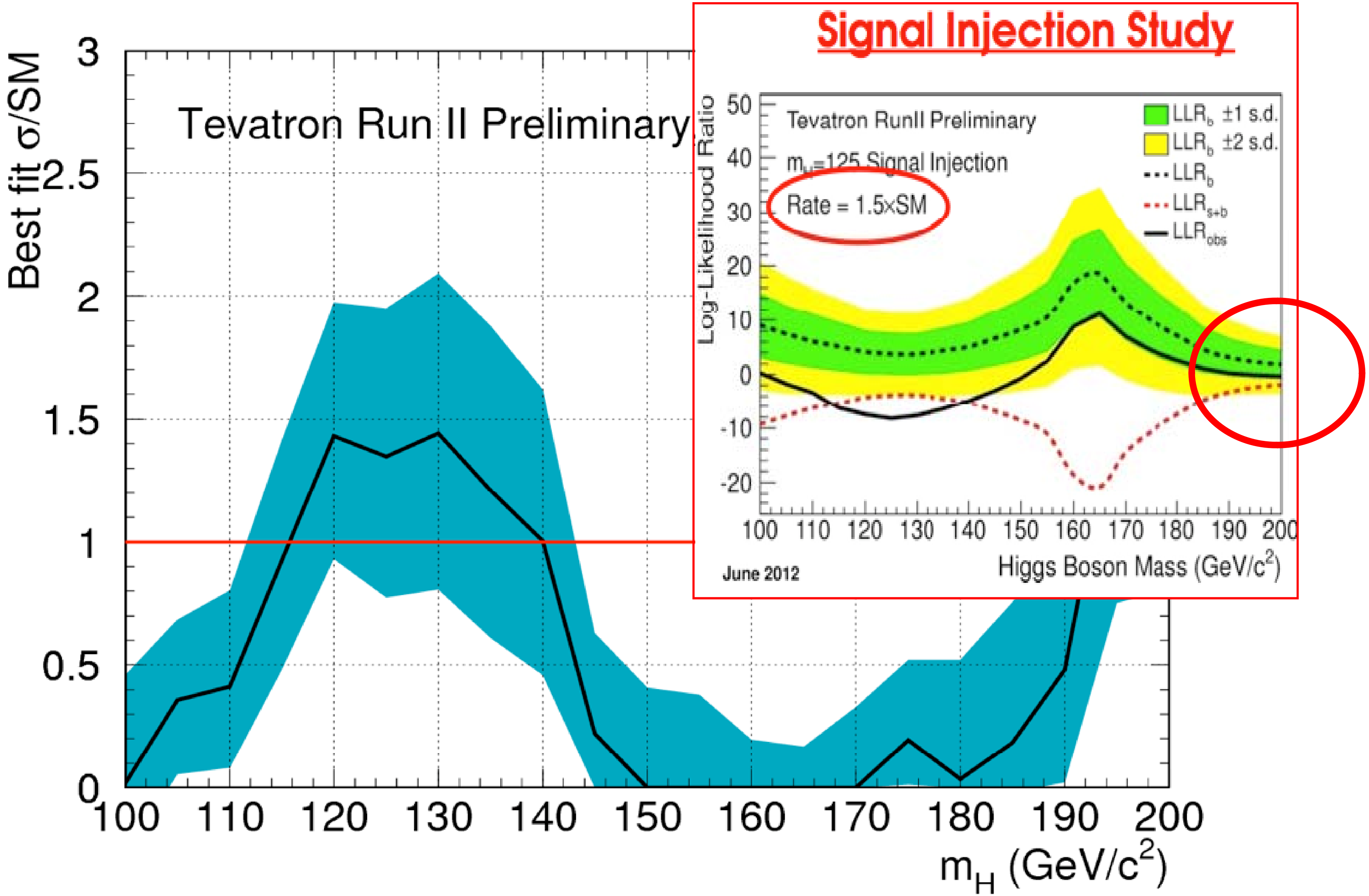


Only small excess in data

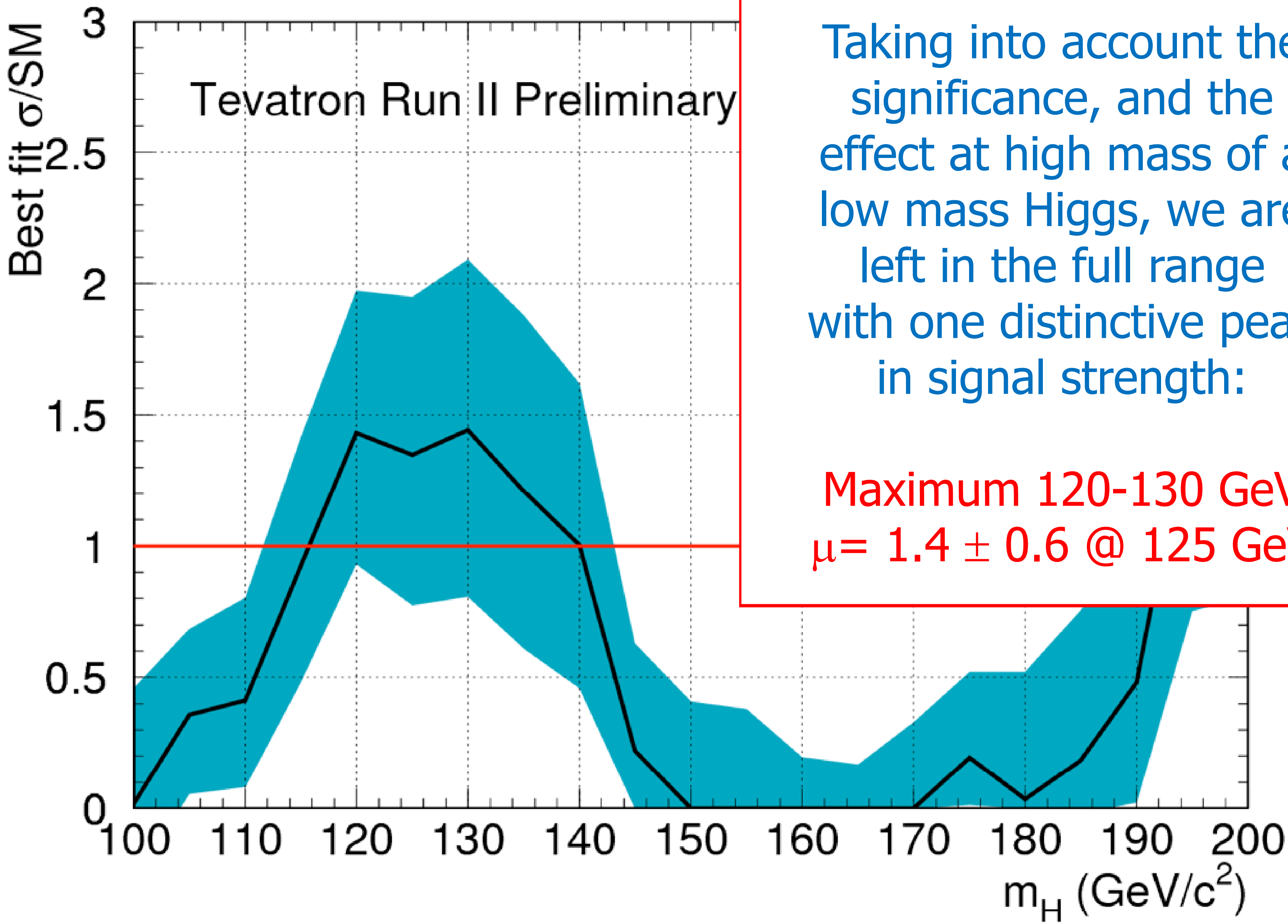
Tevatron Cross Section Fits



Tevatron Cross Section Fits



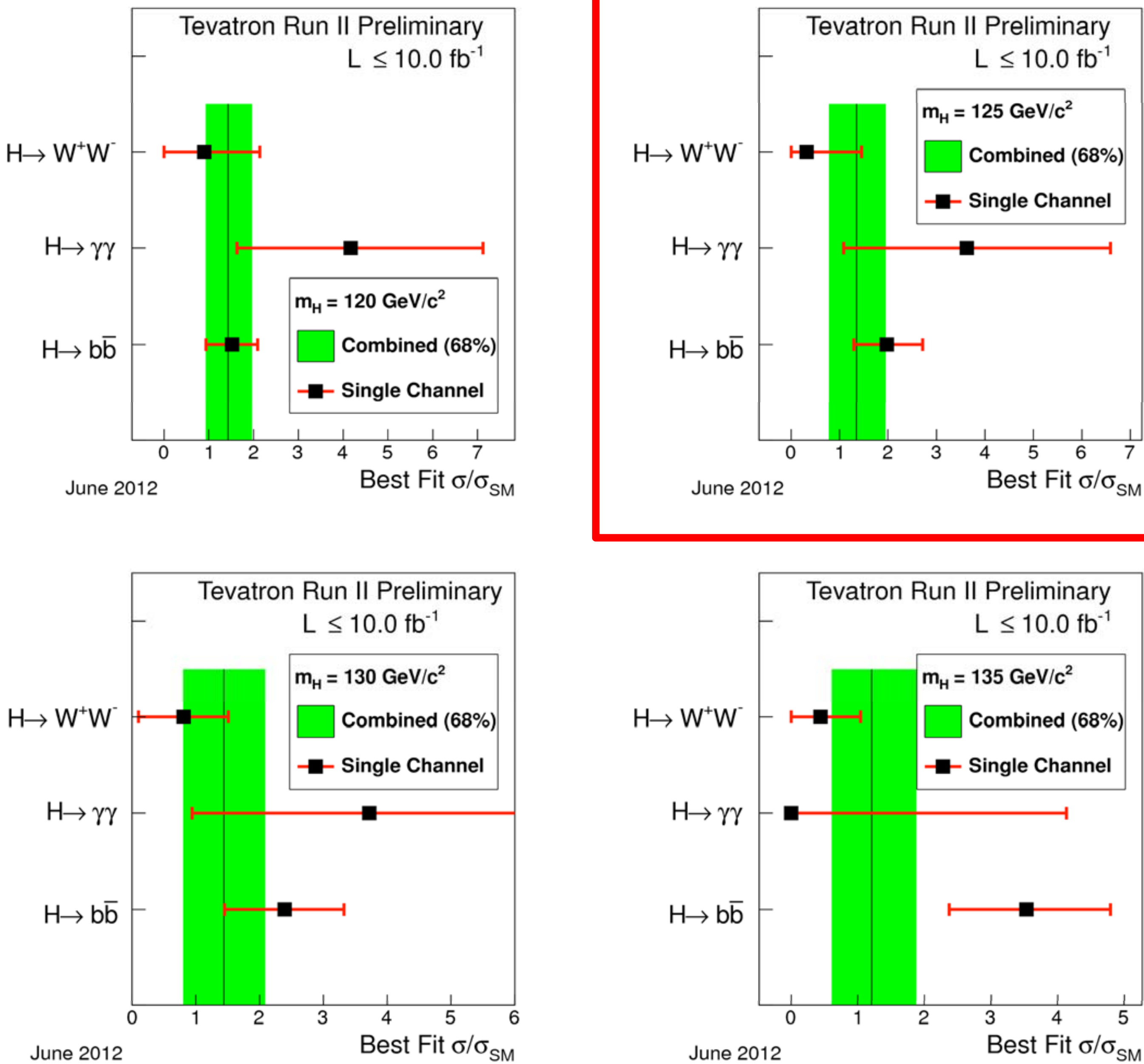
Tevatron Cross Section Fits



Taking into account the significance, and the effect at high mass of a low mass Higgs, we are left in the full range with one distinctive peak in signal strength:

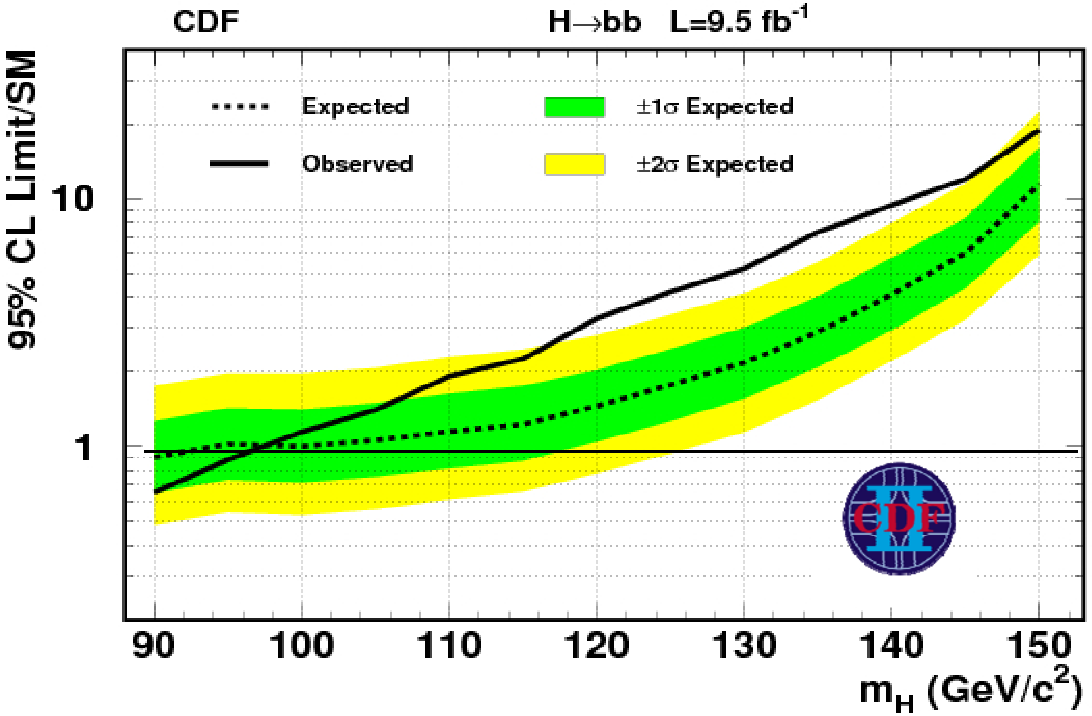
Maximum 120-130 GeV
$\mu = 1.4 \pm 0.6$ @ 125 GeV

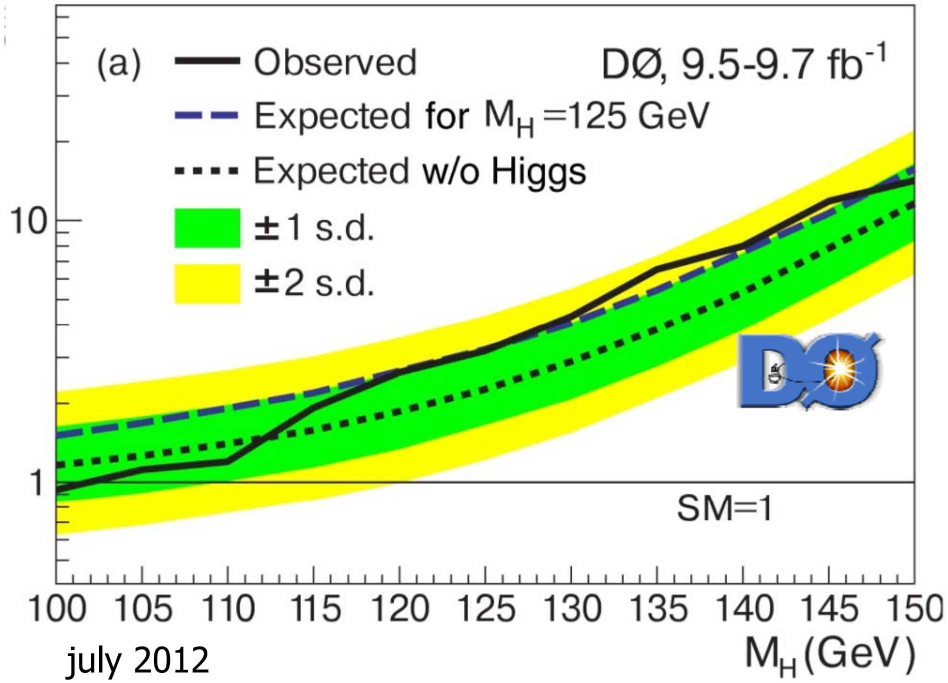
Tevatron Cross Section Fits



H→bb, Individual Experiment Results

Similar broad shapes





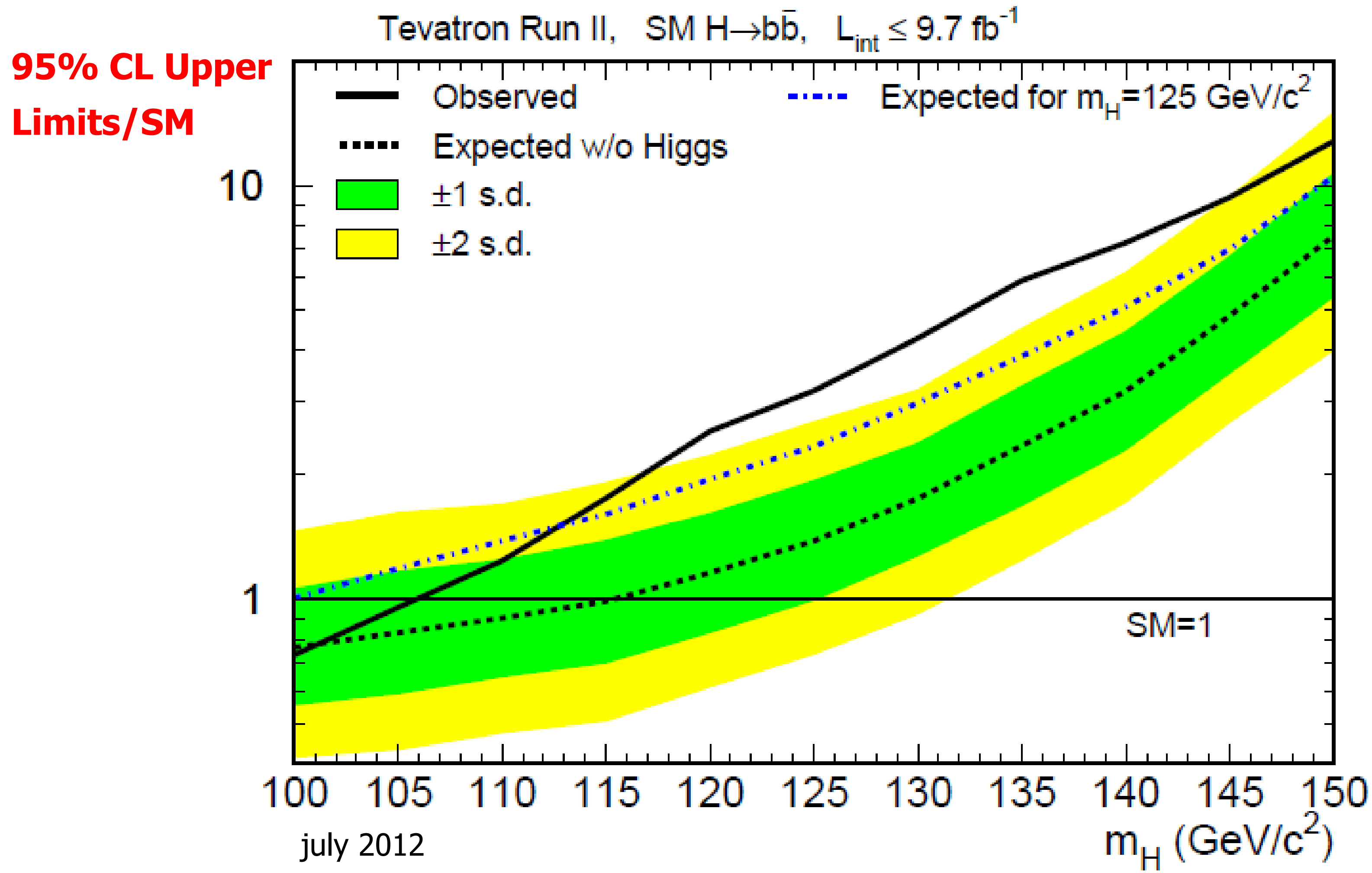
> 2 sigma excess in 120-145 GeV
Global significance **2.5 σ**

> 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

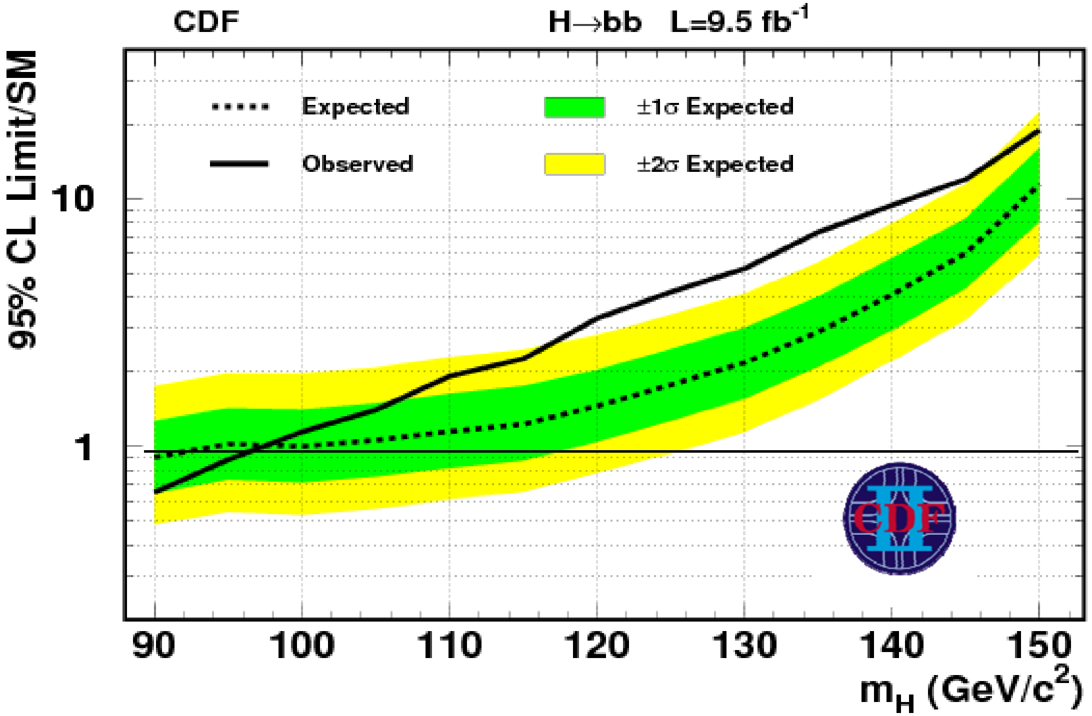
H→bb Combination, Limits

Broad excess, maximum between 120 and 135 GeV

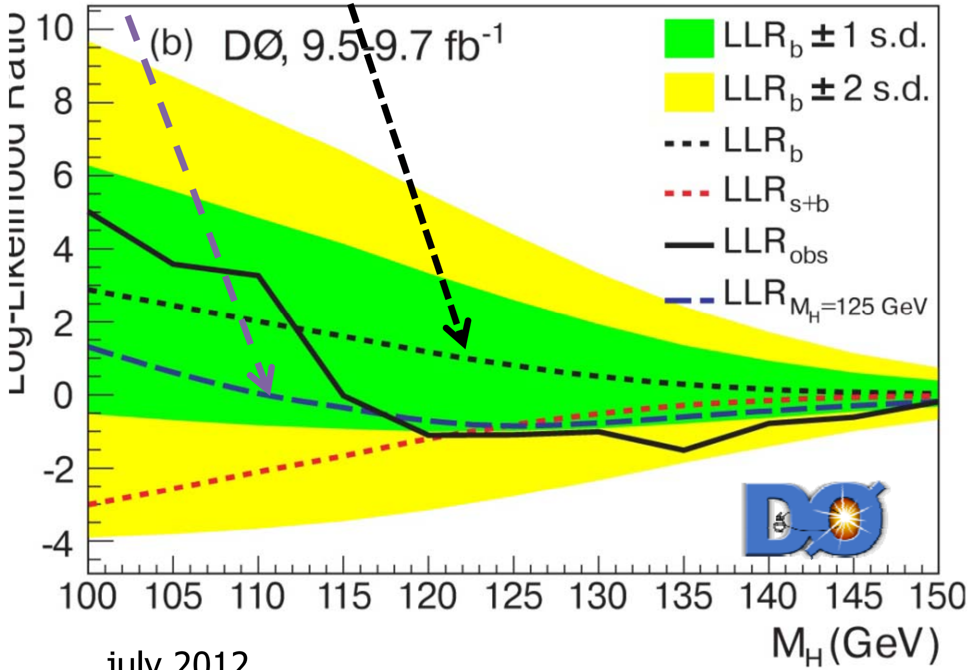


~5% more sensitive than March 2012 result

H→bb, Individual Experiment Results



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



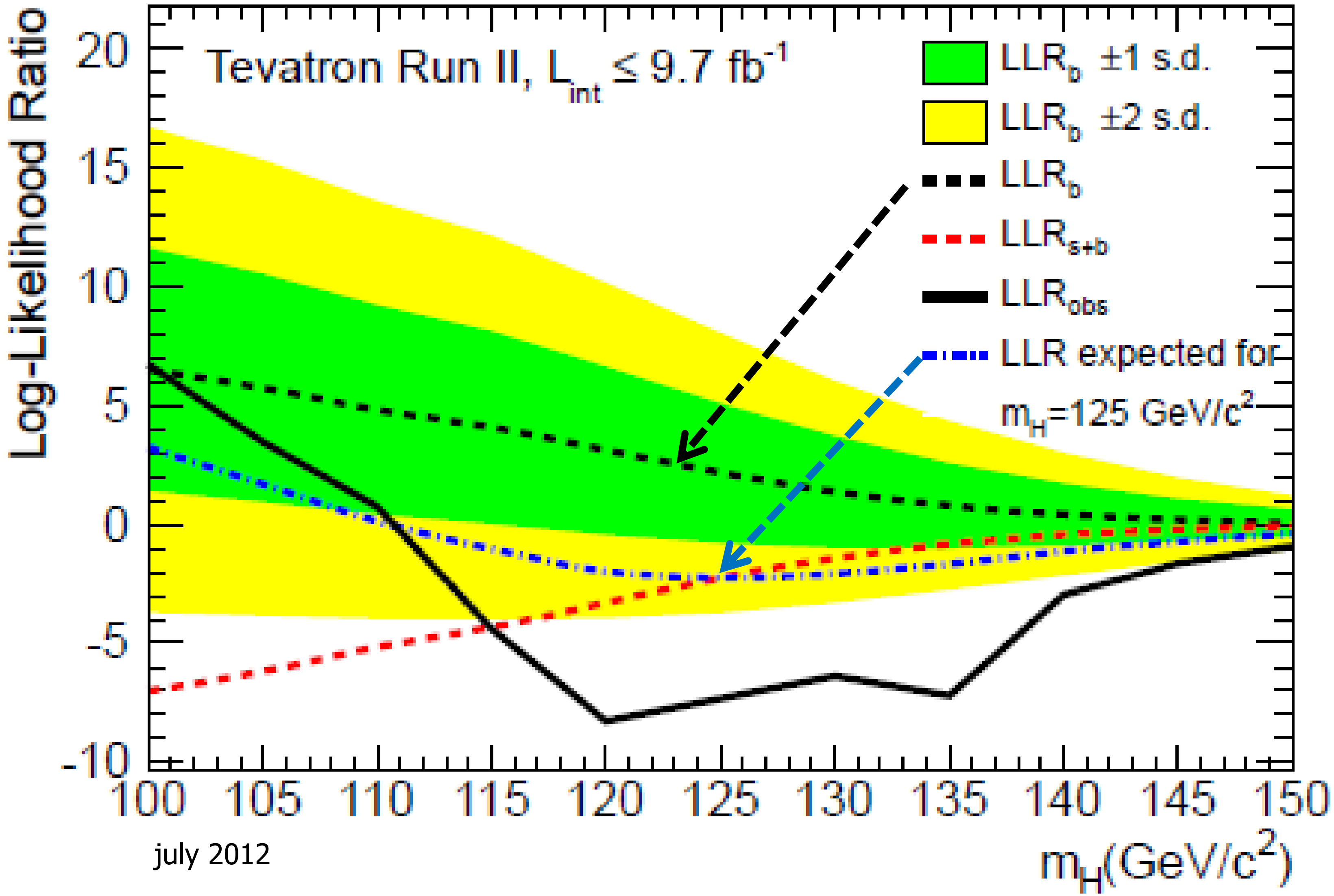
july 2012

> 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

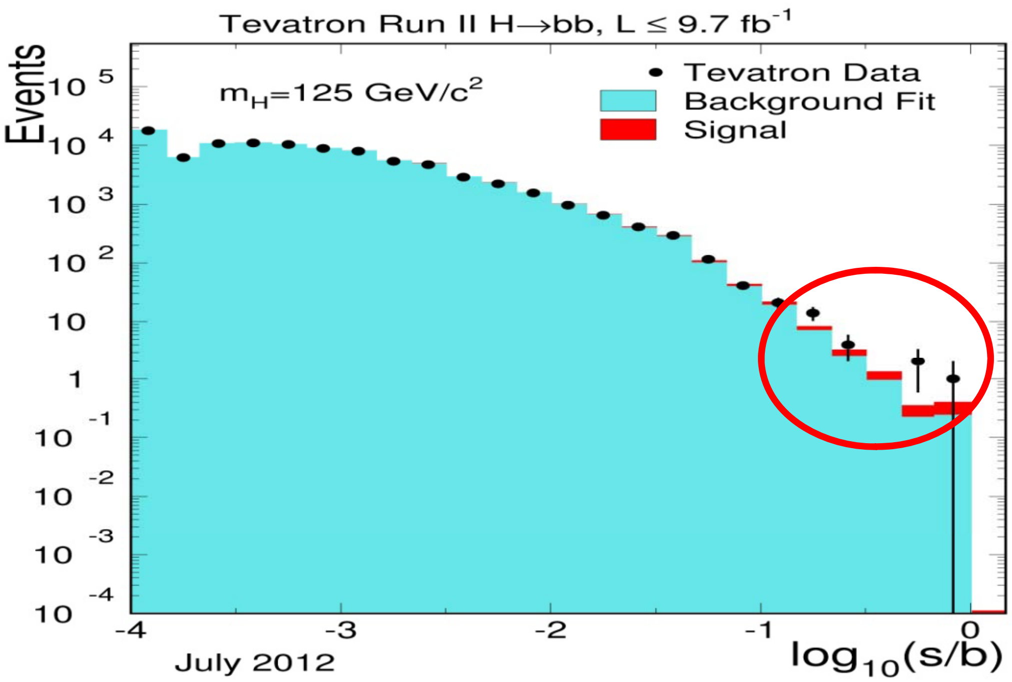
Combined LLR for H→ bb and signal injection

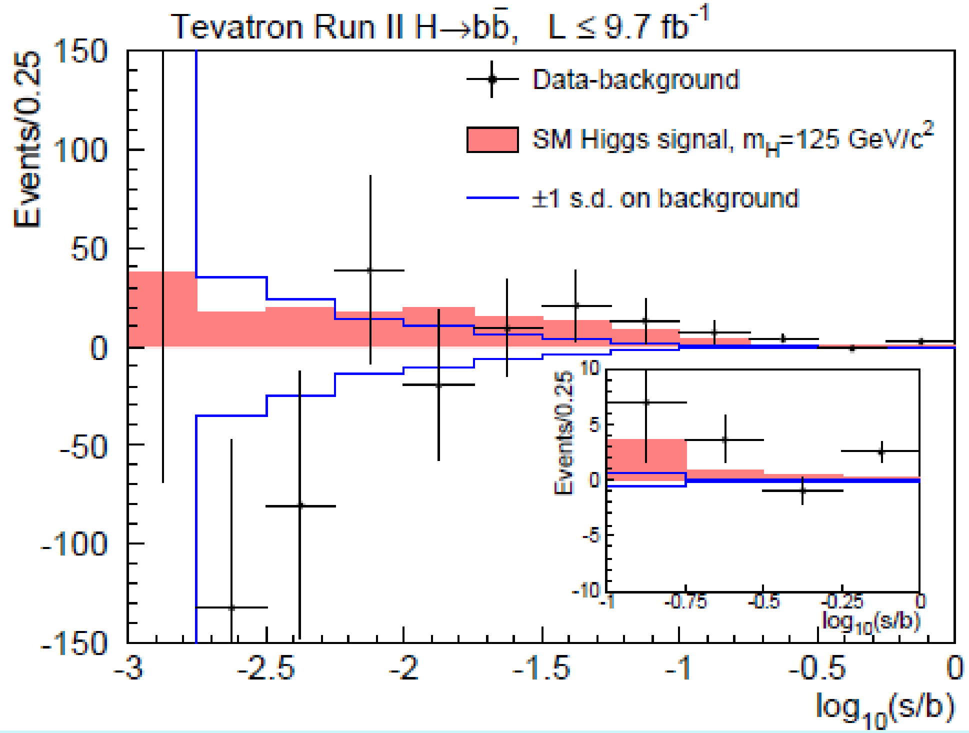


shape is OK, excess more pronounced than expected with a 120-135 GeV SM Higgs

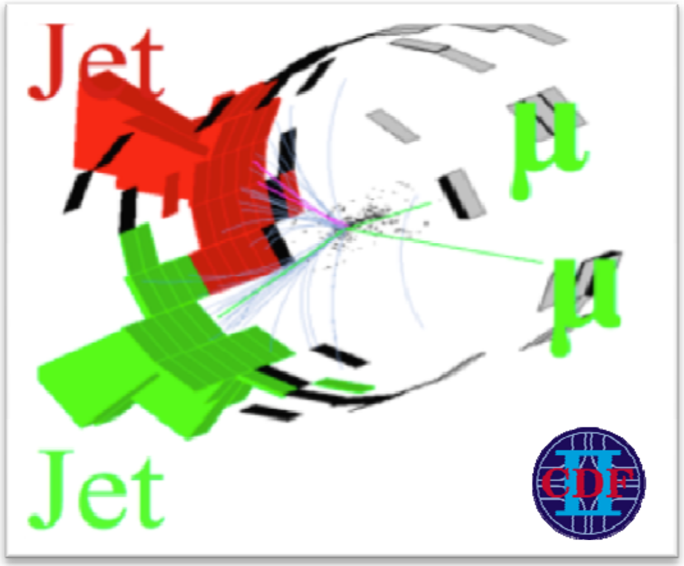
→ Data prefer higher x-section*BR than SM with 125 GeV Higgs

H→bb, final discriminant, events



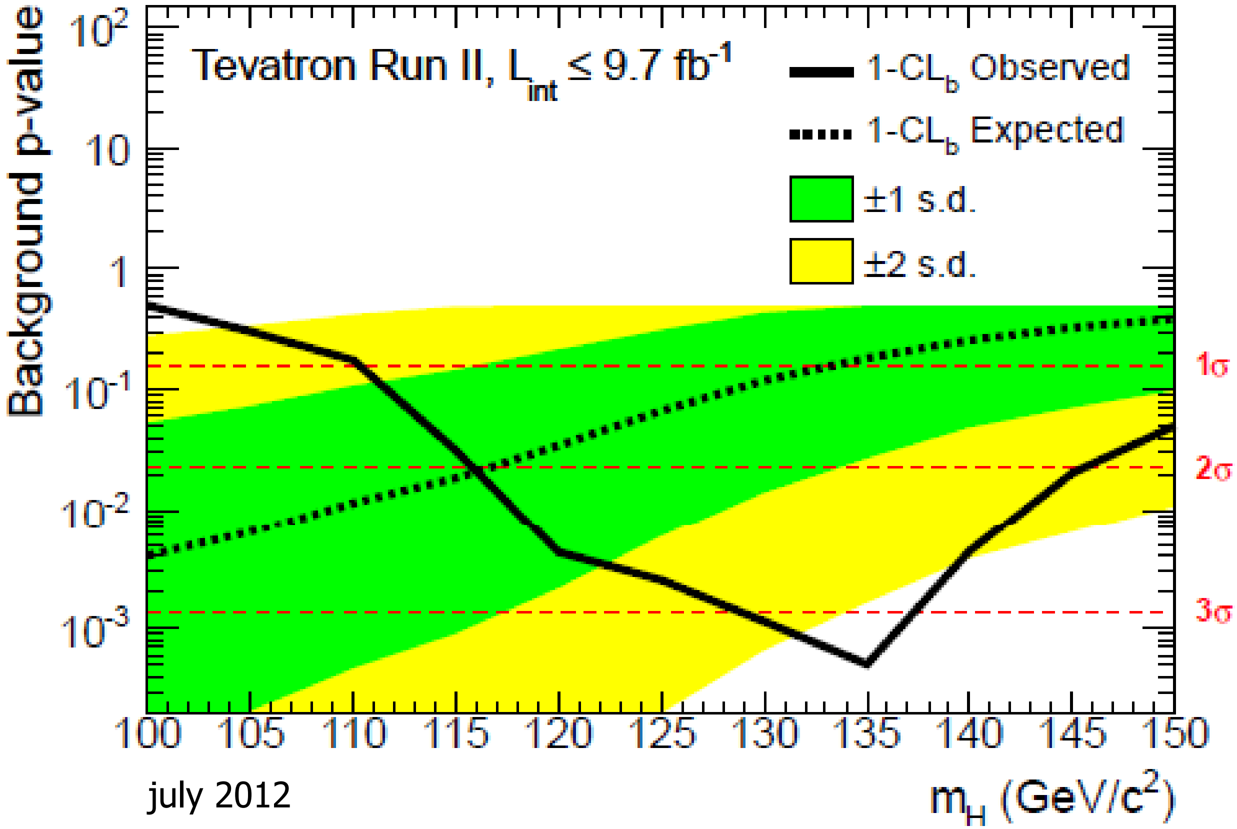


Clear excess in the high S/B region. Those events have indeed the WH/ZH topology:



H→bb combination, p-values

What is the likelihood of the background producing an excess at least as large as what we see in the data?

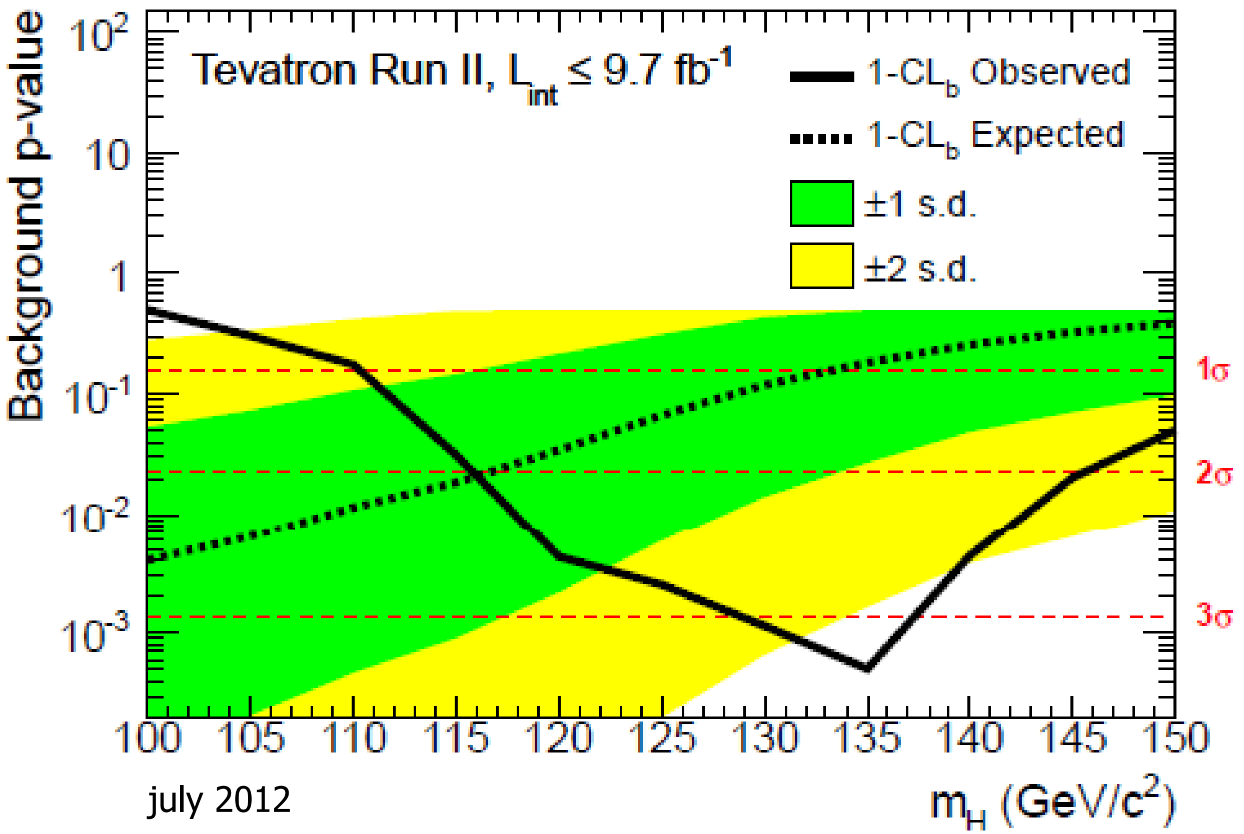


Maximum local significance **3.3 σ** at 135 GeV
(compatible with 125 GeV given our resolution
After LEE of 2, the global p-value is **3.1 σ**

@ 125 GeV, significance is **2.8 σ**
(using 2011 LHC limits, LEE=1)

H→bb, p-values

What is the likelihood of the background producing an excess at least as large as what we see in the data?



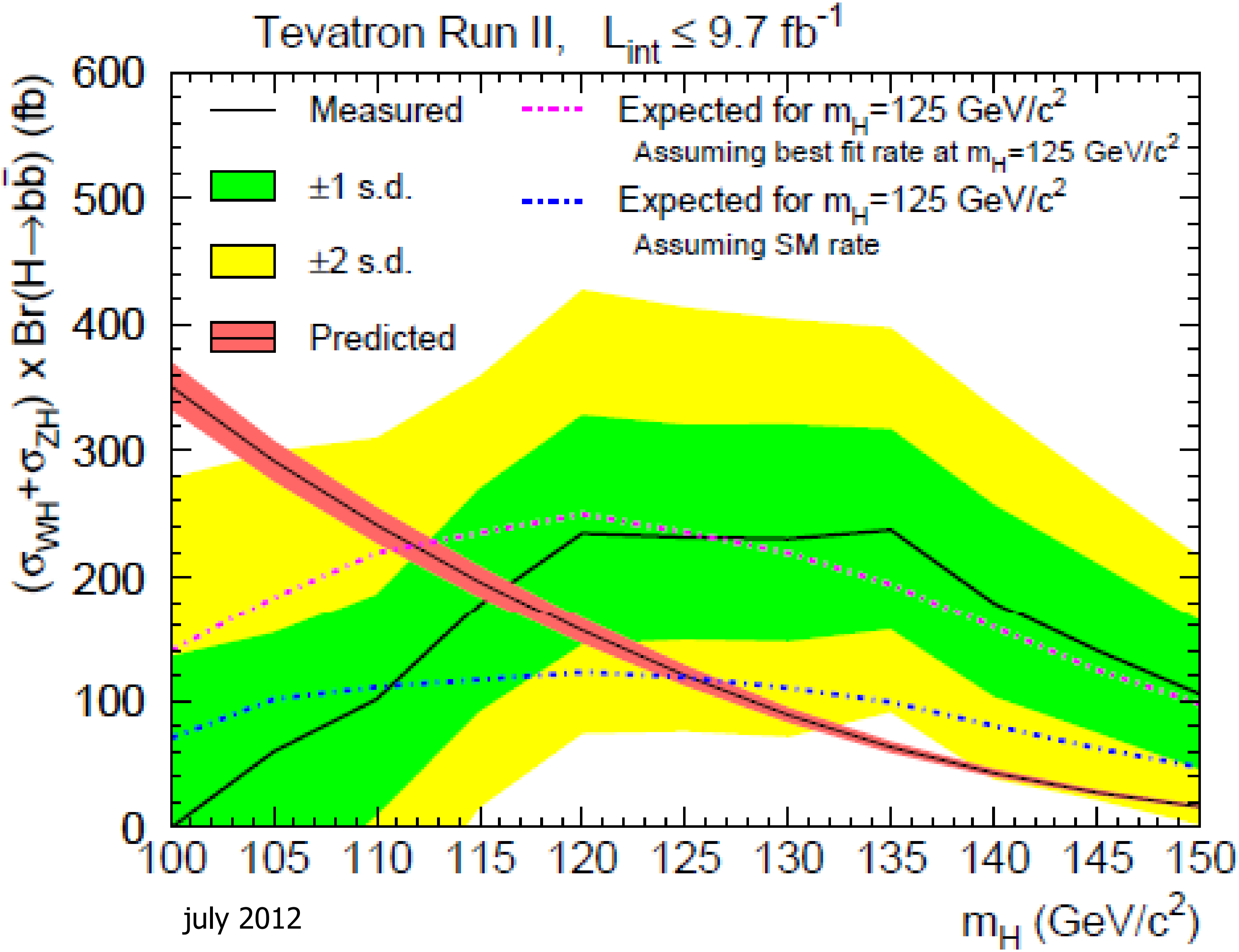
Reminder: Significance of observed excess:

Channels	Local	Global
All Tevatron	3.0 σ	2.5 σ
H→bb	3.3 σ	3.1 σ

preliminary

accepted for publication (PRL)

Cross section * BR measurement

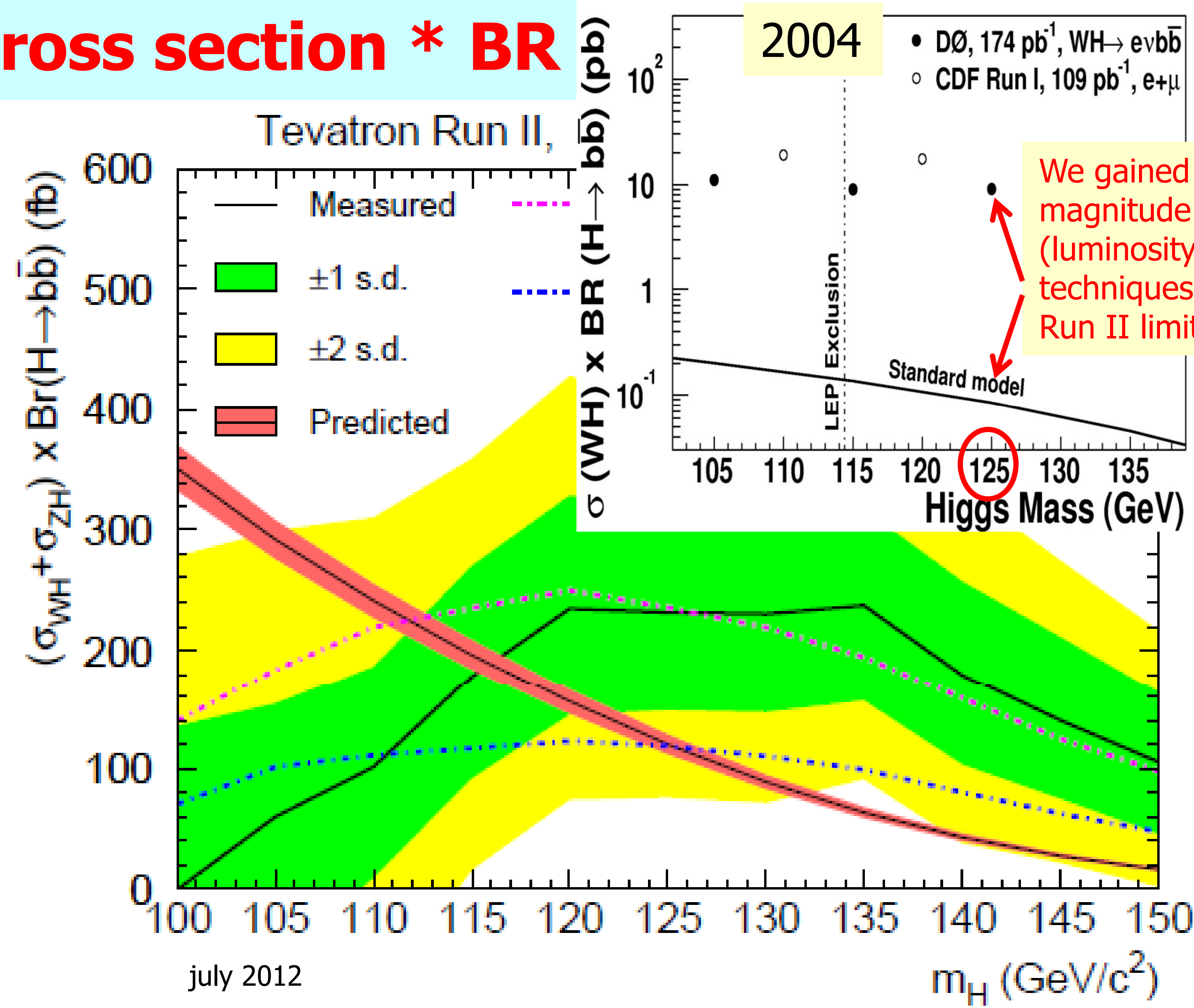


july 2012

$$(\sigma_{WH} + \sigma_{ZH}) \times \mathcal{B}(H \to b\bar{b}) = 0.23^{+0.09}_{-0.08}\ (\mathrm{stat} + \mathrm{syst})\ \mathrm{pb}$$

SM Higgs @ 125 GeV: 0.12 ± 0.01 pb

Cross section * BR

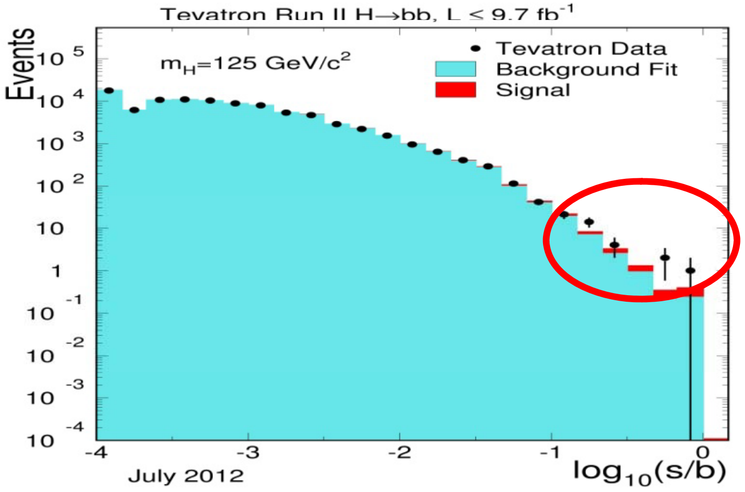


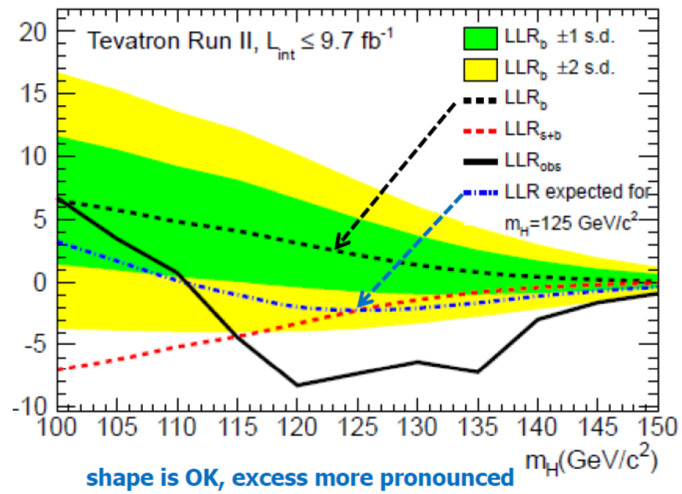
We gained two orders of magnitude in sensitivity, (luminosity,more channels, techniques) since that first Run II limit !!

$$(\sigma_{WH}+\sigma_{ZH}) \times \mathcal{B}(H \to b\bar{b}) = 0.23^{+0.09}_{-0.08}\ (\text{stat}+\text{syst})\ \text{pb}$$

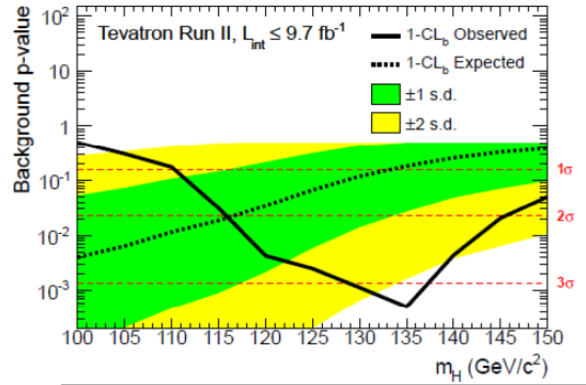
SM Higgs @ 125 GeV: 0.12 ± 0.01 pb

Evidence for WH/ZH with H→bb





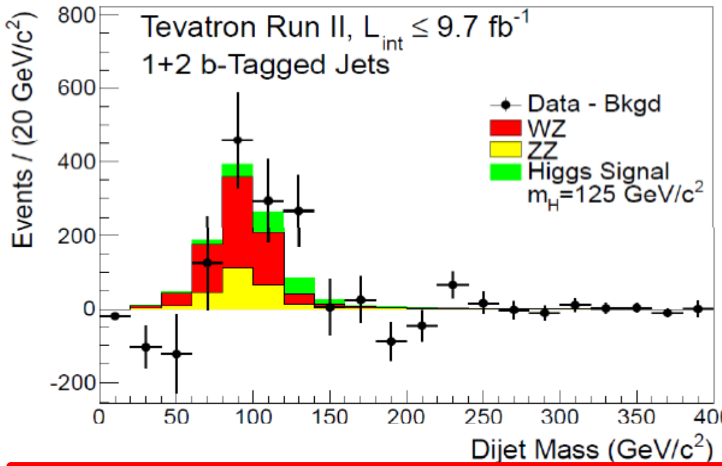
shape is OK, excess more pronounced than expected with a 120-135 GeV SM Higgs

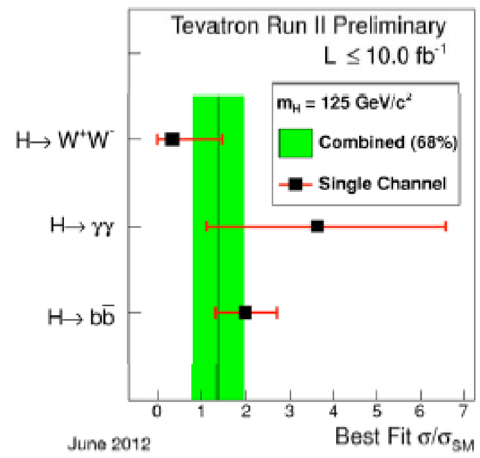


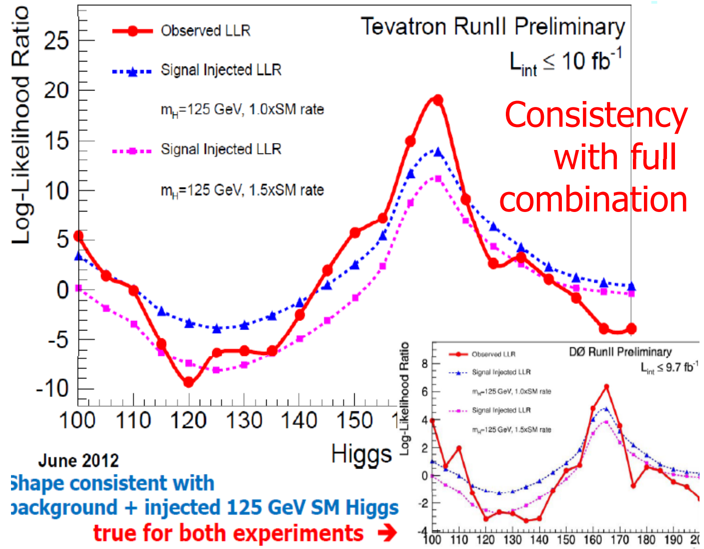
Channels	Local	Global
All Tevatron	3.0 σ	2.5 σ
H→bb	3.3 σ	3.1 σ

- Diboson combination ~ 4.5 sigma significance

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







Consistency with full combination

Shape consistent with background + injected 125 GeV SM Higgs true for both experiments →

We interpret these results as evidence for the presence of a new particle, consistent with the standard model Higgs boson, produced in association with a weak vector boson and decaying to a bottom-antibottom quark pair

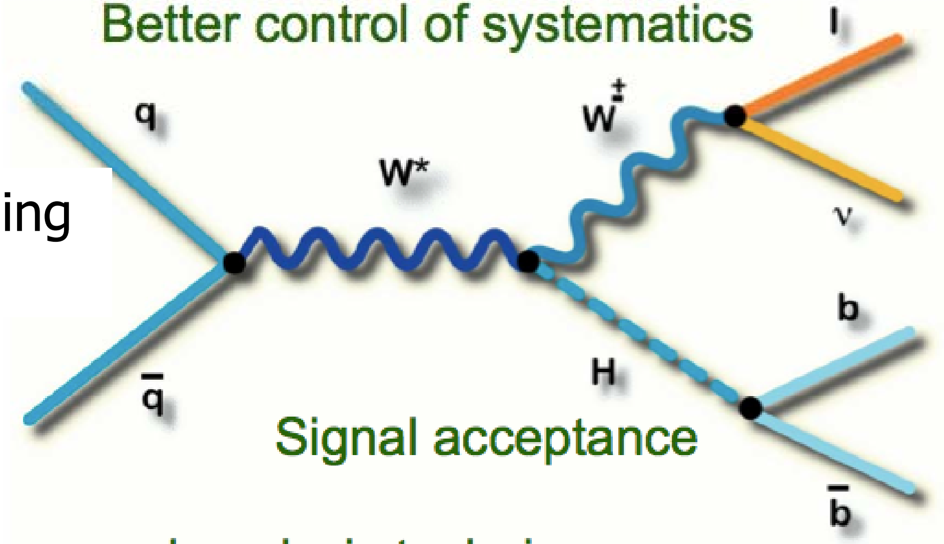
$$(\sigma_{WH} + \sigma_{ZH}) \times \mathcal{B}(H \to b\bar{b}) = 0.23^{+0.09}_{-0.08}\ (\mathrm{stat + syst})\ \mathrm{pb}$$

Perspectives

Aiming at making small improvements over a wide range of areas

Better control of systematics

Improved understanding of all backgrounds (Top, EW, QCD)



Lepton efficiency/ acceptance

B-tagging

Mass resolution

Signal acceptance

Improved analysis techniques

We now also use m_H=125 GeV to improve our constraints and study couplings. Update at HCP.

H→ bb remains a difficult channel also at LHC. Impressive progress, but difficult to imagine observation by one experiment alone with the 2011+2012 run, we'll see.

→ we look forward to LHC+Tevatron combinations during LHC shutdown

Conclusions

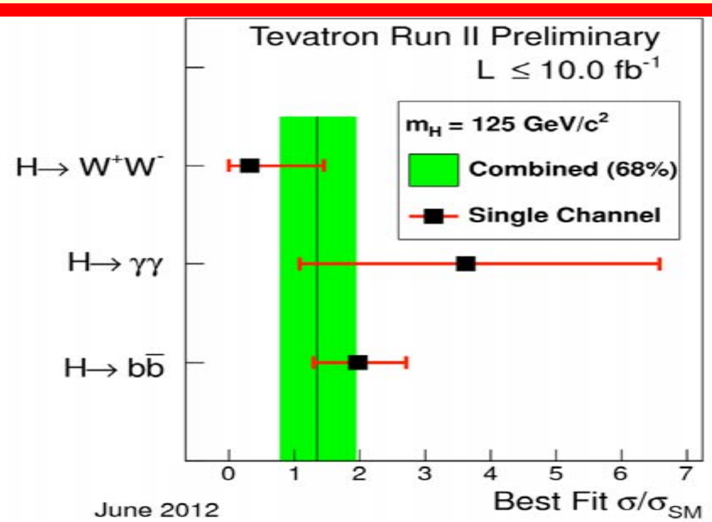
We presented evidence for WX/ZX production with X→bb, in 10 fb^{-1} of Tevatron data, where X is consistent with a SM Higgs boson of 125 GeV, as the newly discovered particle by ATLAS and CMS. The maximum local significance is 3.3 sigma, 3.1 sigma global

$$(\sigma_{WH} + \sigma_{ZH}) \times \mathcal{B}(H \to b\bar{b}) = 0.23^{+0.09}_{-0.08} \text{ (stat + syst) pb}$$

SM Higgs @ 125 GeV: 0.12 ± 0.01 pb

The combination of all our search channels also support this interpretation, with a 3.0 sigma local maximum at 120 GeV, 2.5 sigma global significance and a signal strength of 1.4+/-0.6

These results bring direct evidence that this new particle couples to fermions, as expected in the Standard Model.
We look forward to LHC results at HCP-2013/Kyoto



Backup Slides

References / Congrats

This seminar is based on results presented in: arXiv: 1207.0449
(which also include the full combination which is still preliminary)

Since then, we have submitted for publication 8 papers on H→bb to document these results

CDF-D0, H→ bb Evidence, accepted in Phys. Rev. Letters, arxiv:1207.6436

CDF lvbb:	arXiv:1207.1703, submitted to Phys. Rev. Lett.
CDF METbb:	arXiv:1207.1711, submitted to Phys. Rev. Lett.
CDF llbb:	arXiv:1207.1704, submitted to Phys. Rev. Lett.
CDF Comb. Hbb:	arXiv:1207.1707, submitted to Phys. Rev. Lett.
D0 lvbb:	arxiv:xxxx.xxxx, to be subm. to Phys. Rev. Lett.
D0 METbb:	arXiv:1207.5689, submitted to Phys. Lett. B.
D0 llbb:	arXiv:1207.5819, submitted to Phys. Rev. Lett.
D0 Comb. Hbb:	arXiv:1207.6631, submitted to Phys. Rev. Lett.

CDF and D0 thank the Tevatron for high quality Data

CDF and D0 extend their Warmest Congratulations to CERN, ATLAS, and CMS for their outstanding discovery

Cross Sections & BR

We use the following references for our cross sections and branching ratios. The citations below include only those papers which contain numbers that we use. Further citations are available in our conference note.

•The WH and ZH cross sections are from Baglio and Djouadi: arXiv:1003.4266v2, which is published as JHEP 1010:064 (2010). We have obtained from the authors an extension of Table 3 to include test mass range down to 100 GeV and predictions with more digits. The VBF production cross sections were computed with VBF@NNLO, and we multiply these by $(1+\delta_{EW})$ from the HAWK program, which amounts to a roughly 2% to 3% downward correction.

•The gg → H production cross section is calculated at NNLL in QCD and also includes two-loop electroweak effects. For details, see C. Anastasiou, R. Boughezal and F. Petriello, "Mixed QCD-electroweak corrections to Higgs boson production in gluon fusion", arXiv:0811.3458 [hep-ph] (2008), which is published as JHEP 0904:003 (2009), and D. de Florian and M. Grazzini, "Higgs production through gluon fusion: updated cross sections at the Tevatron and the LHC", arXiv:0901.2427v1 [hep-ph] (2009), which is published as Phys.Lett.B674:291-294 (2009). These cross were updated with the full m_{top} dependence in the calculation.

•We follow the BNL Accord to assign scale uncertainties separately in the 0, 1, and 2 or more jet bins. Details can be found in arXiv:1107.2117.
•PDF uncertainties follow the prescription of the PDF4LHC working group.

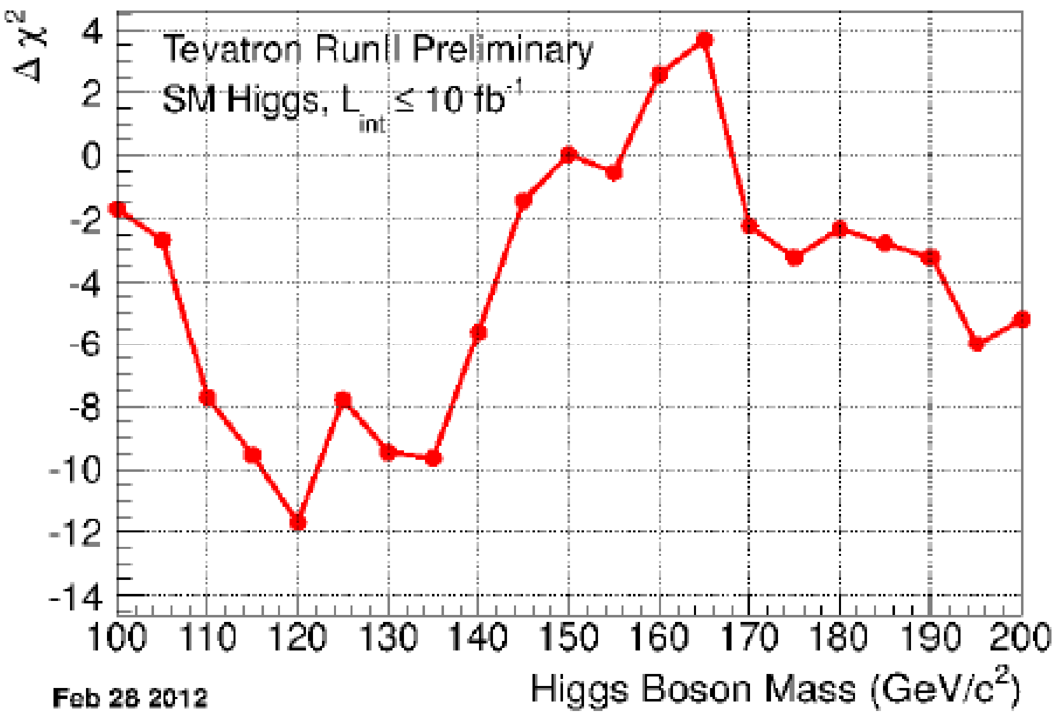
•The Higgs boson decay branching ratios are those reported in the Handbook of LHC Cross Sections: 1. Inclusive observables, arXiv:1101.0593v2.
•Higgs boson decay branching ratio uncertainties from m_b, m_c, and α_s are computed by Baglio and Djouadi in arXiv:1012.0530, which is published as JHEP 1103:055 (2011).

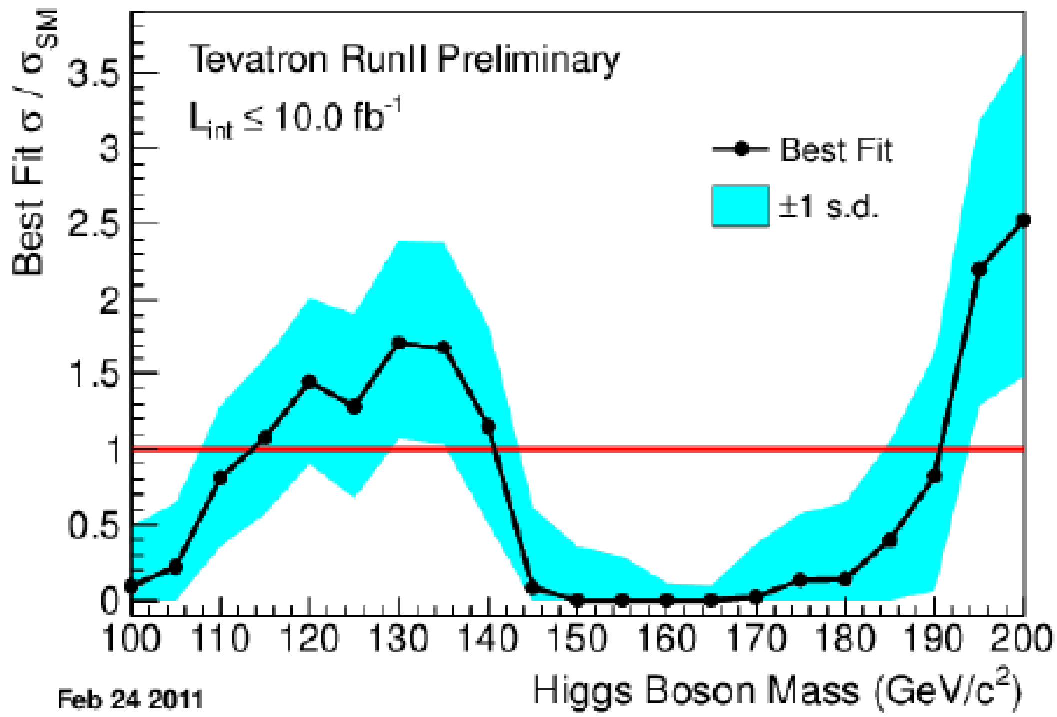
Cross Sections & BR

m_H (GeV/c^2)	$\sigma_{gg\to H}$ (fb)	σ_{WH} (fb)	σ_{ZH} (fb)	σ_{VBF} (fb)	$\sigma_{t\bar{t}H}$ (fb)	$B(H\to b\bar{b})$ (%)	$B(H\to c\bar{c})$ (%)	$B(H\to\tau^+\tau^-)$ (%)	$B(H\to W^+W^-)$ (%)	$B(H\to ZZ)$ (%)	$B(H\to\gamma\gamma)$ (%)
100	1821.8	281.1	162.7	97.3	8.000	79.1	3.68	8.36	1.11	0.113	0.159
105	1584.7	238.7	139.5	89.8	7.062	77.3	3.59	8.25	2.43	0.215	0.178
110	1385.0	203.7	120.2	82.8	6.233	74.5	3.46	8.03	4.82	0.439	0.197
115	1215.9	174.5	103.9	76.5	5.502	70.5	3.27	7.65	8.67	0.873	0.213
120	1072.3	150.1	90.2	70.7	4.857	64.9	3.01	7.11	14.3	1.60	0.225
125	949.3	129.5	78.5	65.3	4.279	57.8	2.68	6.37	21.6	2.67	0.230
130	842.9	112.0	68.5	60.5	3.769	49.4	2.29	5.49	30.5	4.02	0.226
135	750.8	97.2	60.0	56.0	3.320	40.4	1.87	4.52	40.3	5.51	0.214
140	670.6	84.6	52.7	51.9	2.925	31.4	1.46	3.54	50.4	6.92	0.194
145	600.6	73.7	46.3	48.0	2.593	23.1	1.07	2.62	60.3	7.96	0.168
150	539.1	64.4	40.8	44.5	2.298	15.7	0.725	1.79	69.9	8.28	0.137
155	484.0	56.2	35.9	41.3	2.037	9.18	0.425	1.06	79.6	7.36	0.100
160	432.3	48.5	31.4	38.2	1.806	3.44	0.159	0.397	90.9	4.16	0.0533
165	383.7	43.6	28.4	36.0	1.607	1.19	0.0549	0.138	96.0	2.22	0.0230
170	344.0	38.5	25.3	33.4	1.430	0.787	0.0364	0.0920	96.5	2.36	0.0158
175	309.7	34.0	22.5	31.0	1.272	0.612	0.0283	0.0719	95.8	3.23	0.0123
180	279.2	30.1	20.0	28.7	1.132	0.497	0.0230	0.0587	93.2	6.02	0.0102
185	252.1	26.9	17.9	26.9	1.004	0.385	0.0178	0.0457	84.4	15.0	0.00809
190	228.0	24.0	16.1	25.1	0.890	0.315	0.0146	0.0376	78.6	20.9	0.00674
195	207.2	21.4	14.4	23.3	0.789	0.270	0.0125	0.0324	75.7	23.9	0.00589
200	189.1	19.1	13.0	21.7	0.700	0.238	0.0110	0.0287	74.1	25.6	0.00526

Reminder: Moriond 2012

Quantifying the Excess

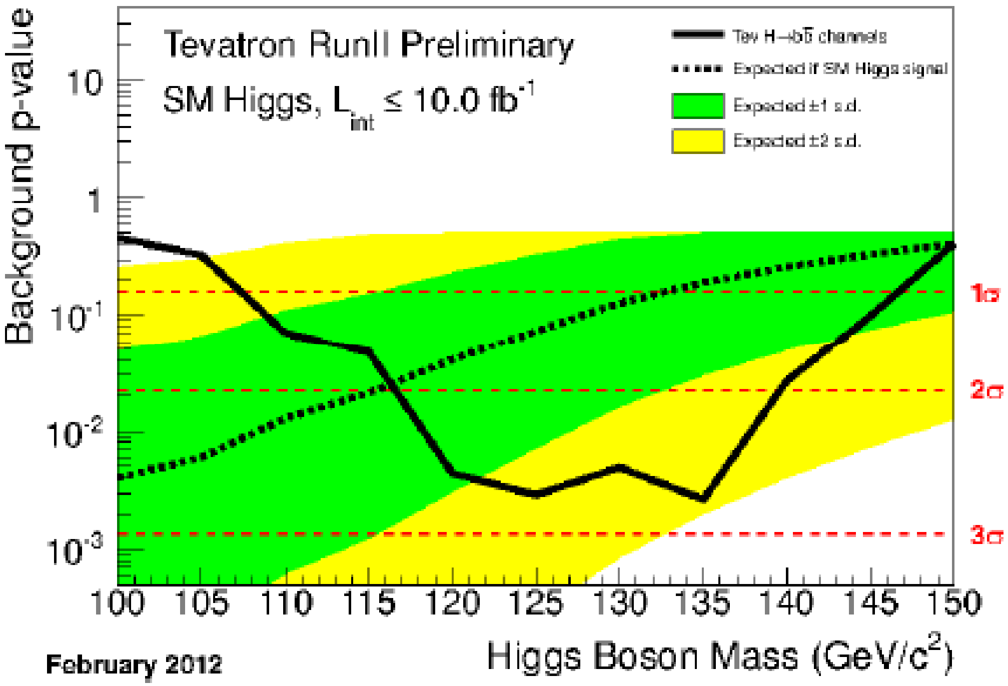


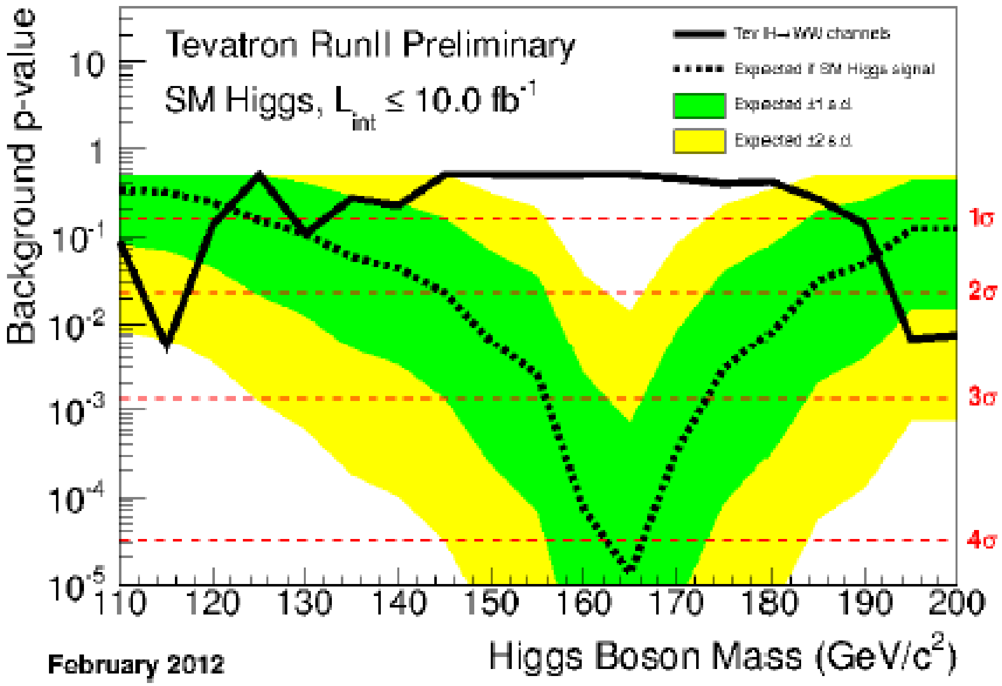


$\Delta\chi^2$ test with fixed signal prediction from SM theory agrees well with freely floating signal rate estimation

- $\Delta\chi^2$ minimum in the region $115 < M_H < 135$ GeV
- Region above M_H=150 never falls below $\Delta\chi^2$ = -6

Reminder: Moriond 2012 Quantifying the Excess

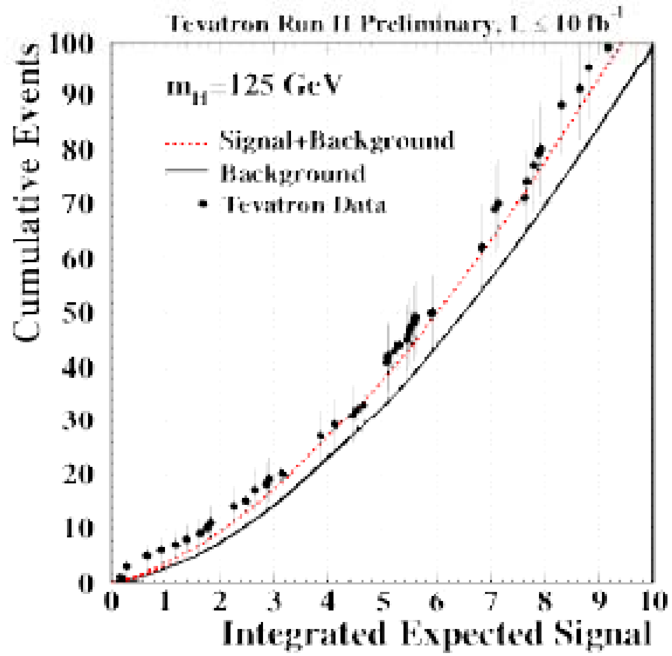


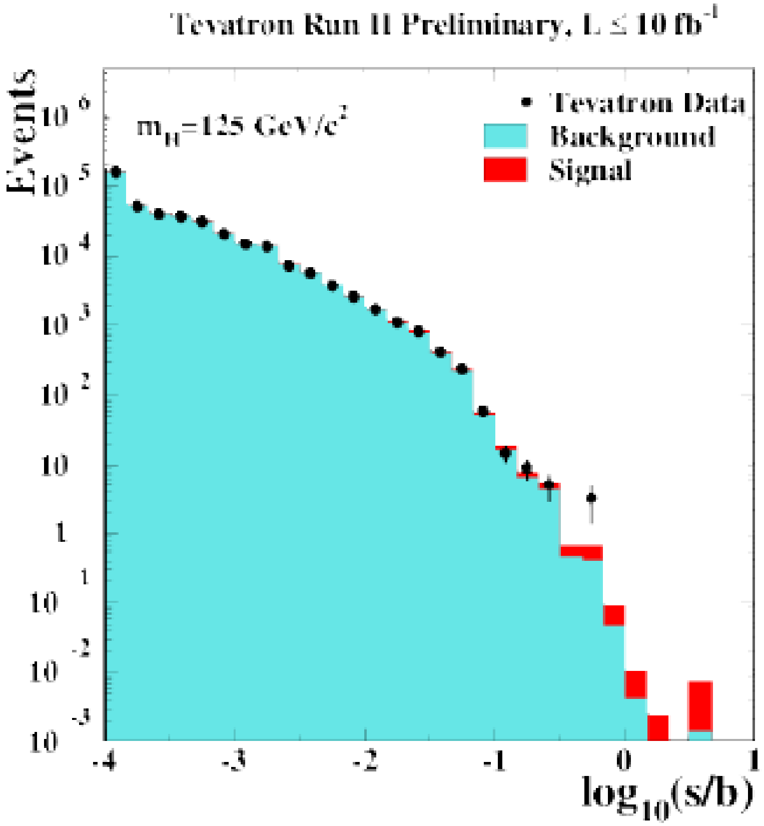


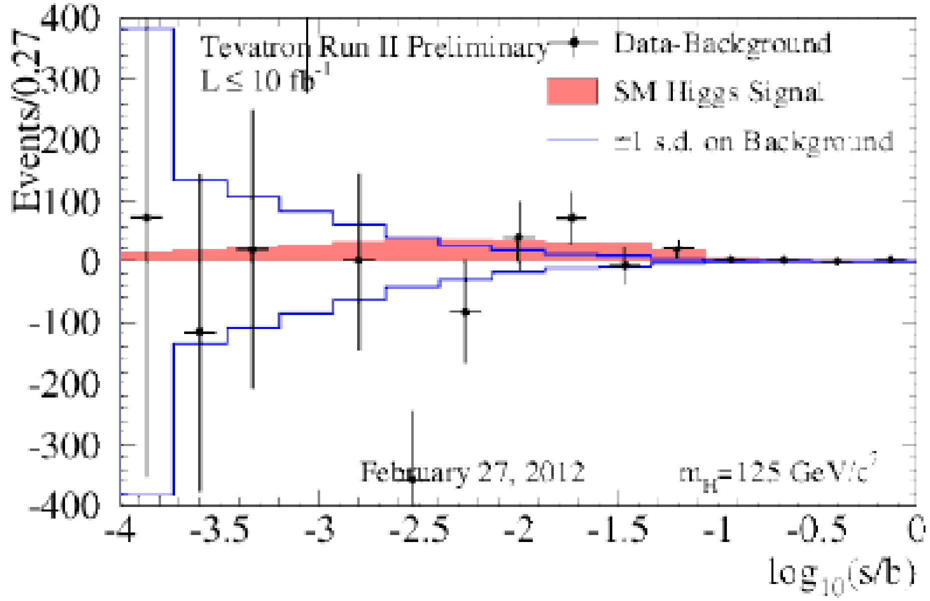
- **Considering separately the H→bb and H→WW channels**
  - Local p-value distribution for background-only expectation.
    - Minimum H→bb local p-value: 2.8 standard deviations
    - Global H→bb p-value with LEE factor of 2: **2.6 standard deviations**

Reminder: Moriond 2012 — Quantifying the Excess

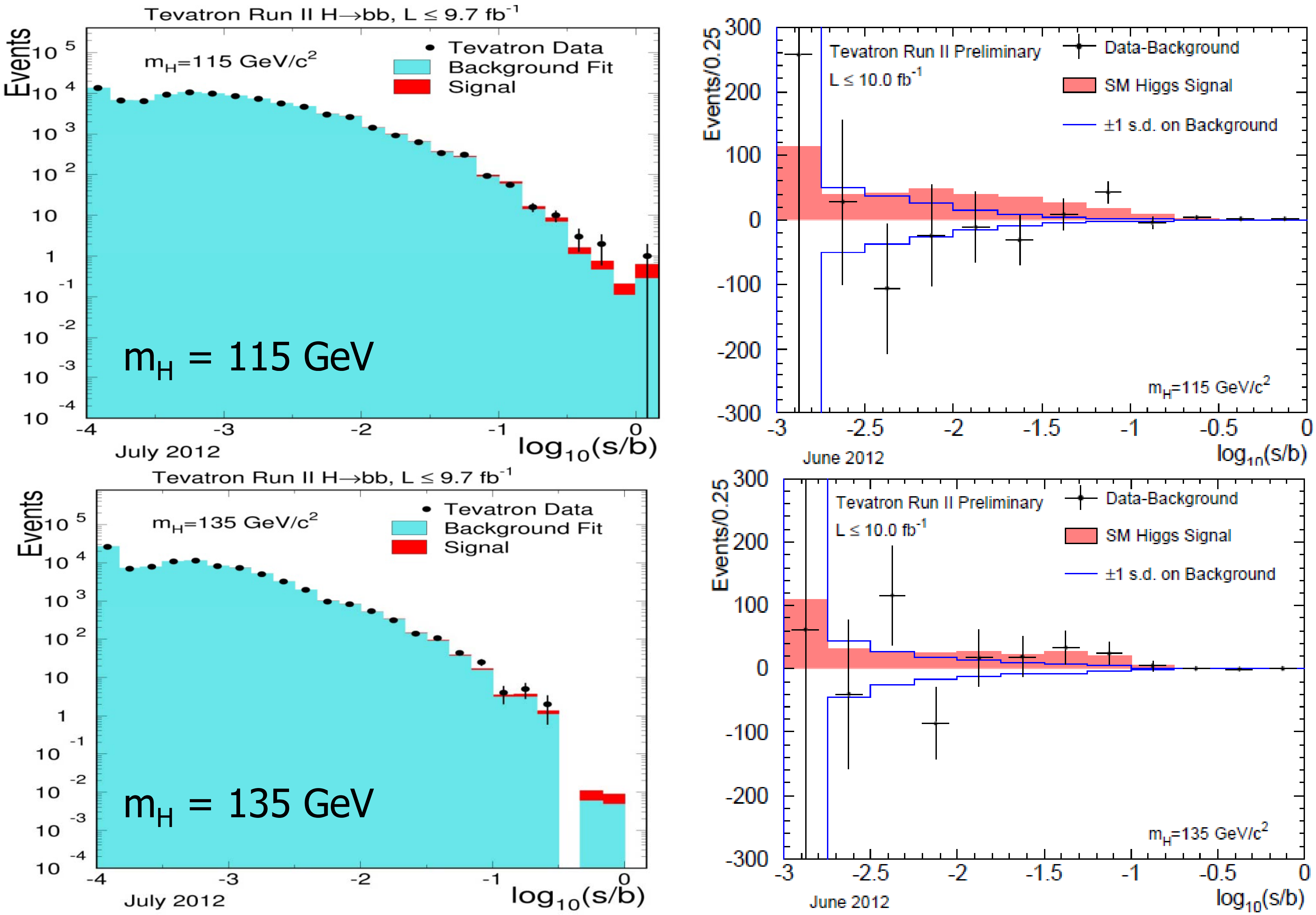
- Revisit s/b rebinned distribution plot for M_H=125 GeV
  - Cumulative distribution seems to prefer S+B model
  - Background-subtracted plot illustrates several interesting candidate events





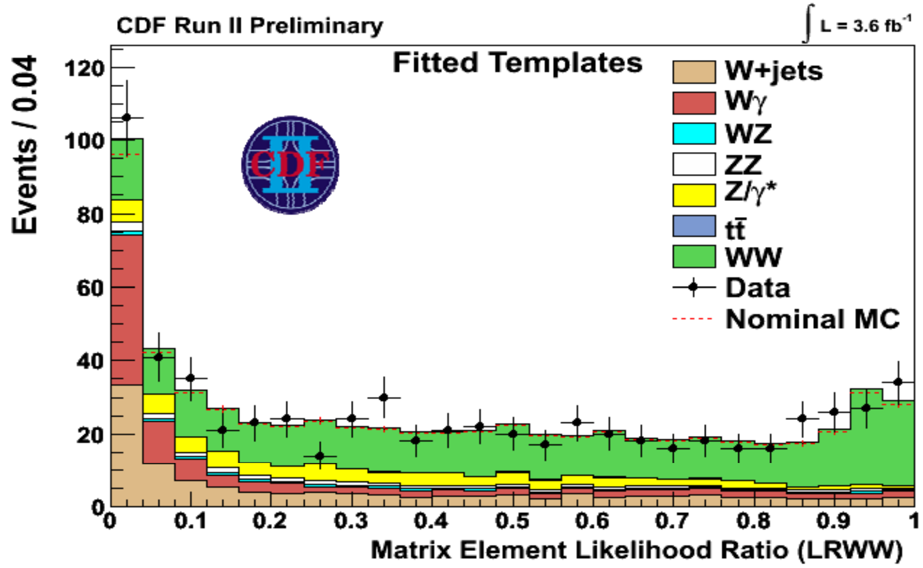


H→ bb, Discriminants, s/b ordering



WW and ZZ measurements

Diboson cross section measurements are based on the same tools and data samples used for the H→WW→lνlν search ➔ important cross check on background modeling and analysis techniques

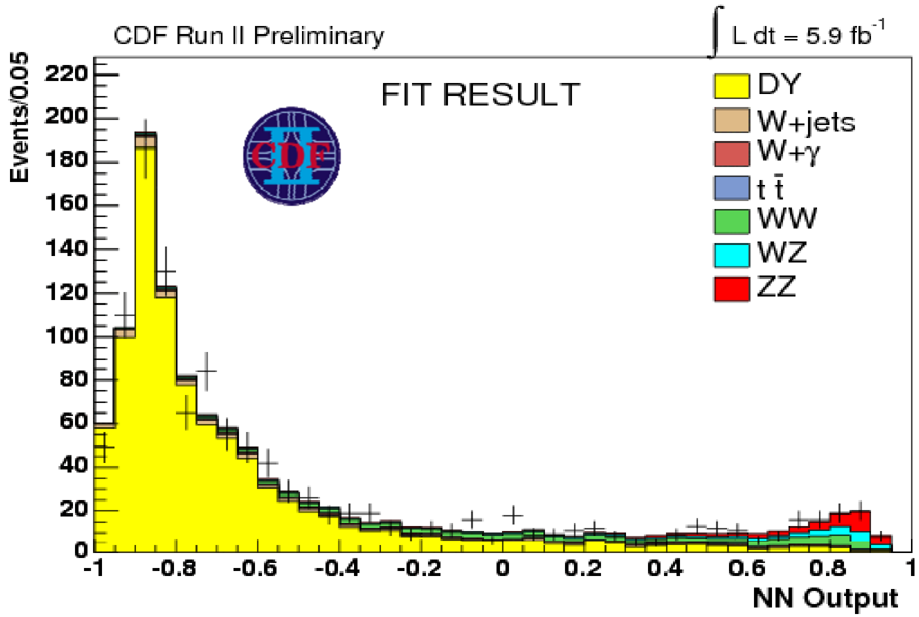


$$WW \to l\nu l\nu : \sigma(WW) = 12.1^{+1.8}_{-1.7} \text{ pb}$$

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

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

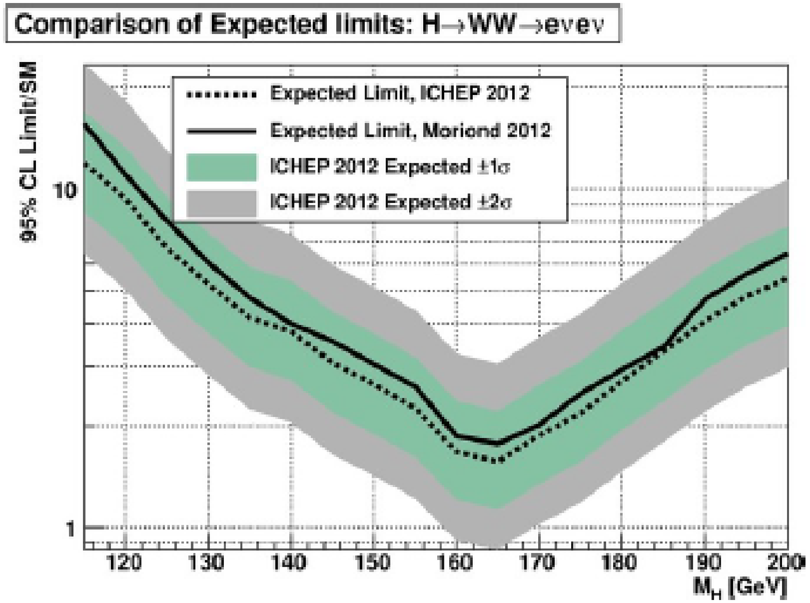
$$\text{NLO QCD}: \sigma(ZZ) = 1.4^{+0.1}_{-0.1} \text{ pb}$$



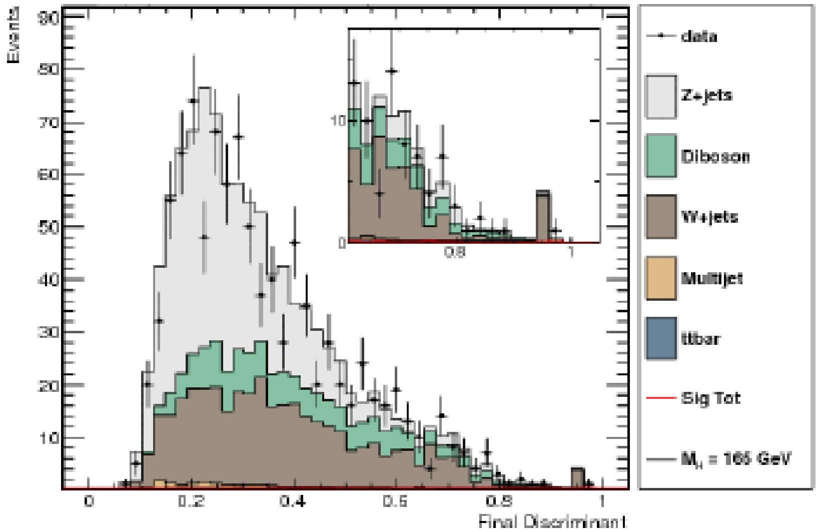
VV cross sections with bb final states are analyzed separately

Recent improvements: H→WW→ lvlv

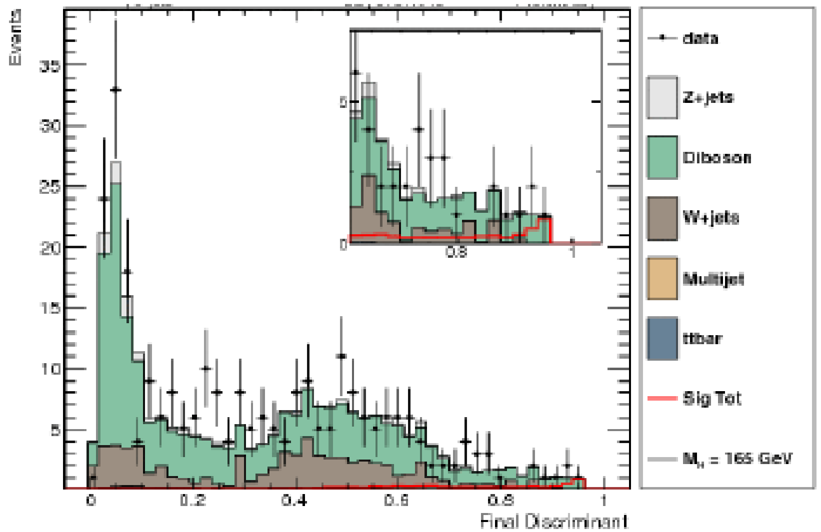
- More data & refined analysis technique
  - Di-electron channel adds 12% more data & improves electron identificiation efficiency
  - Di-muon and di-electron channels now split search sample into regions dominated by Diboson and W/Z+jet backgrounds
  - Technique improves expected limits by **5-10%**



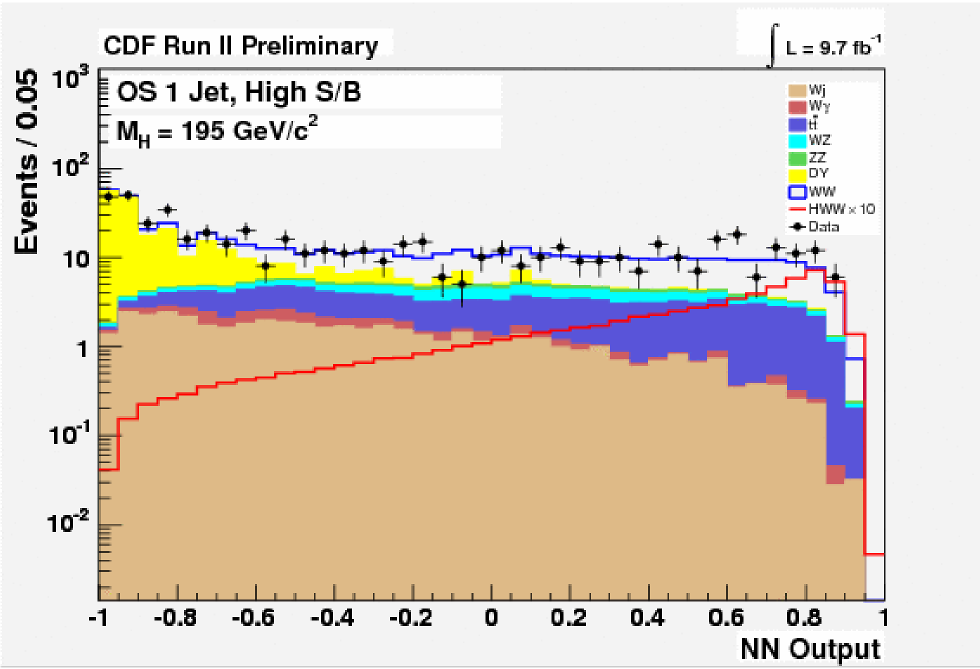
W/Z+jet Dominated

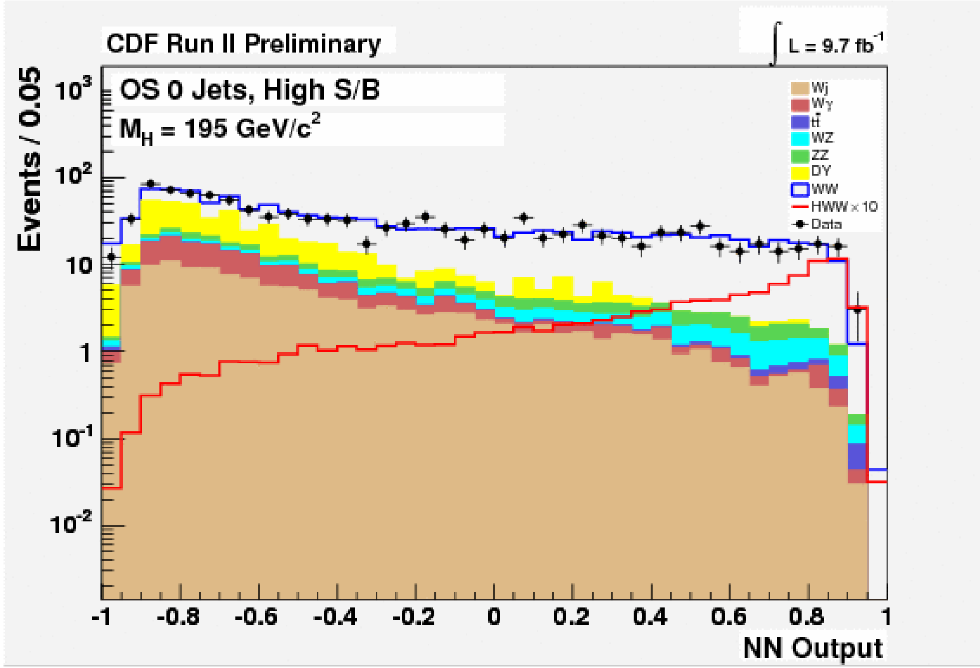


Diboson-Dominated



High Mass Excess ?

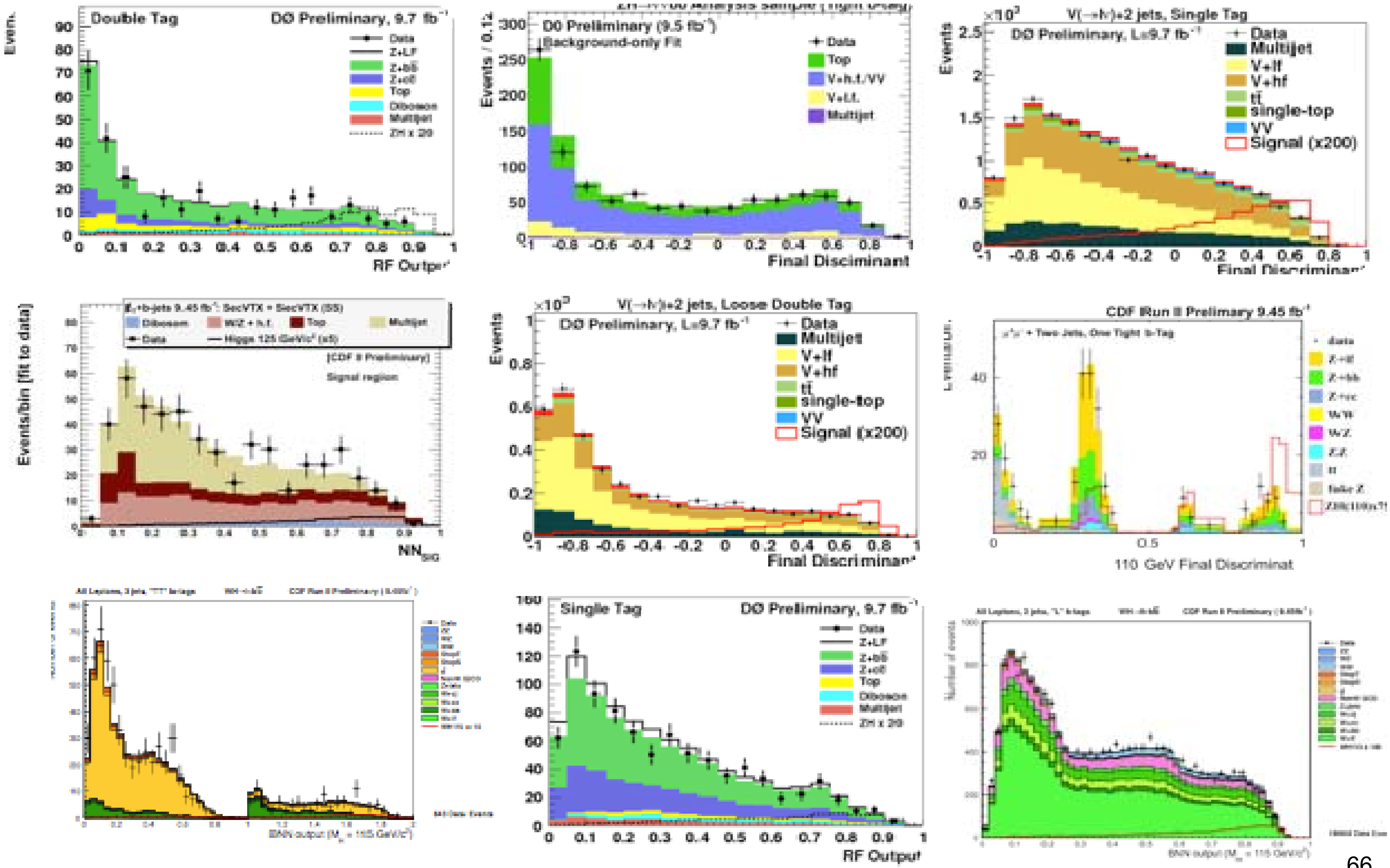




- Behavior of observed limits driven by small event excesses in the high S/B regions of opposite-sign dilepton 0 and 1 jet channels
- Nothing peculiar in the modeling of these distributions
- Of course, ATLAS and CMS have ruled out a m_H = 195 GeV SM Higgs based primarily on equivalent searches in H->WW

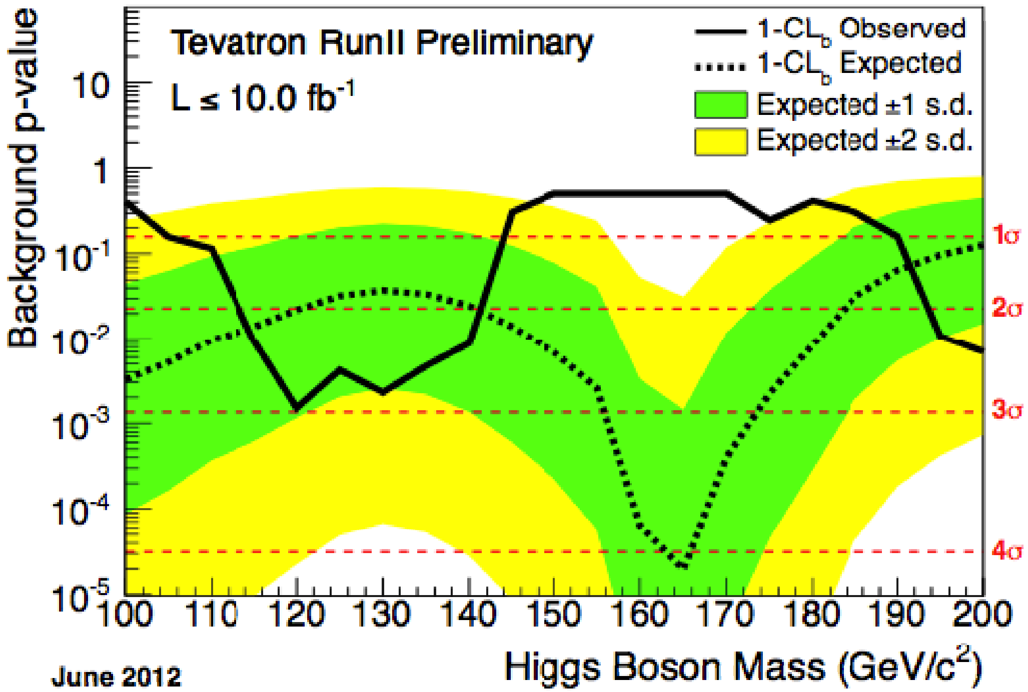
More H→ bb discriminants

Challenging due to the large number of H→bb search channels (showing a fraction here!)

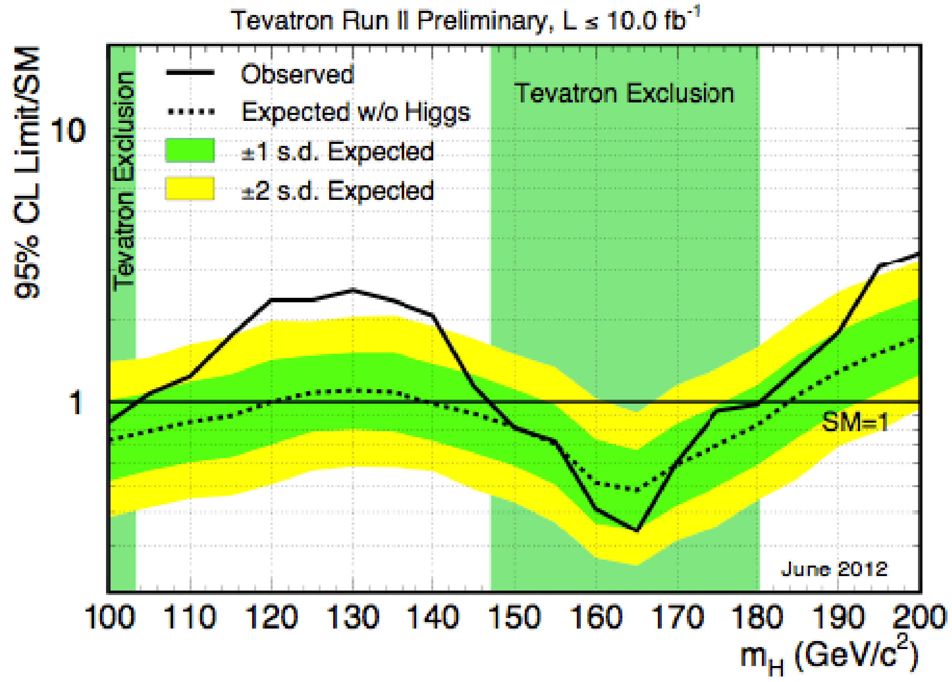


Combined Tevatron Result, p-values

Background p-values



95% CL Upper Limits / SM



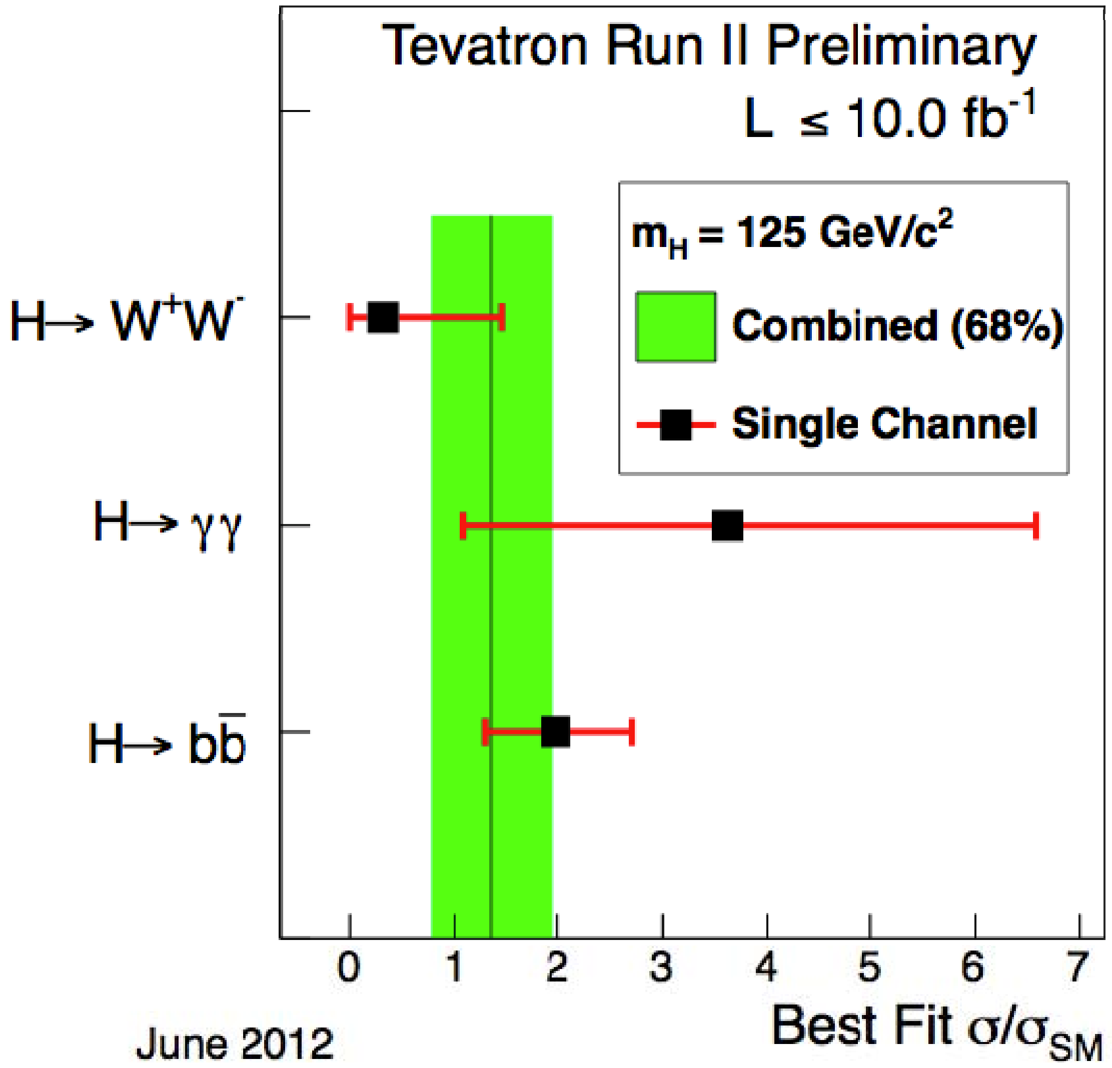
- max significance (local) **3 σ**
- max significance (global) **2.5 σ** after LEE of 4

Signal Strength

Perform fit of S+B model to data

Compare combined best fit Higgs production cross section to result from individual production modes

Consistent with SM values within the uncertainties



More on CL_S and LLR

- In the absence of signal, we set limits on Standard Model Higgs boson production
  - We calculate limits via the CLs prescription:

$$CL_s = \frac{CL_{s+b}}{CL_b}$$

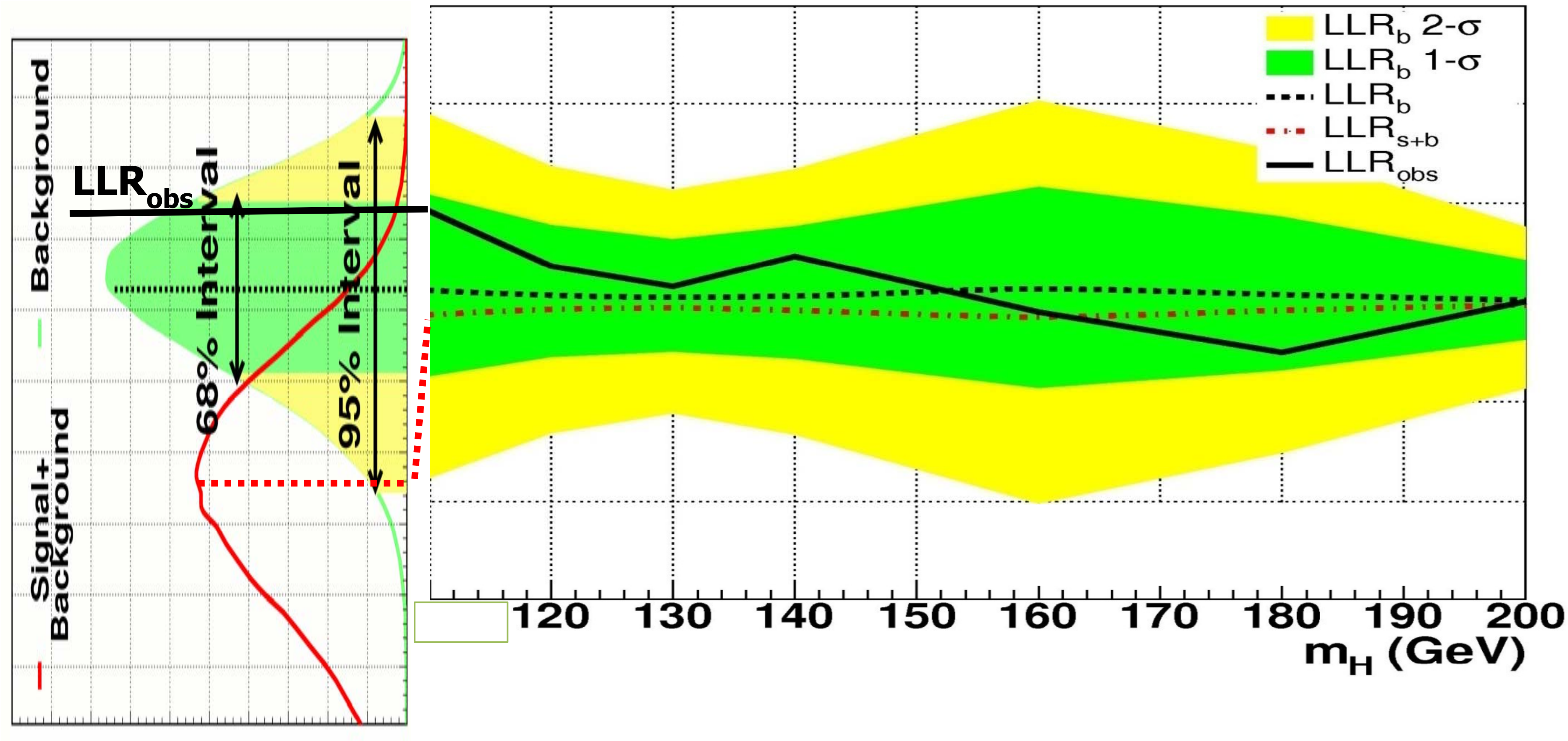
  - Using a Log-Likelihood Ratio test statistic:

$$Q(\vec{s},\vec{b},\vec{d}) = \prod_{i=0}^{N_{Chan}} \prod_{j=0}^{N_{bins}} \frac{(s+b)_{ij}^{d_{ij}} e^{(s+b)_{ij}}}{d_{ij}!} / \frac{b_{ij}^{d_{ij}} e^{b_{ij}}}{d_{ij}!} \qquad LLR = -2 \times Log Q$$

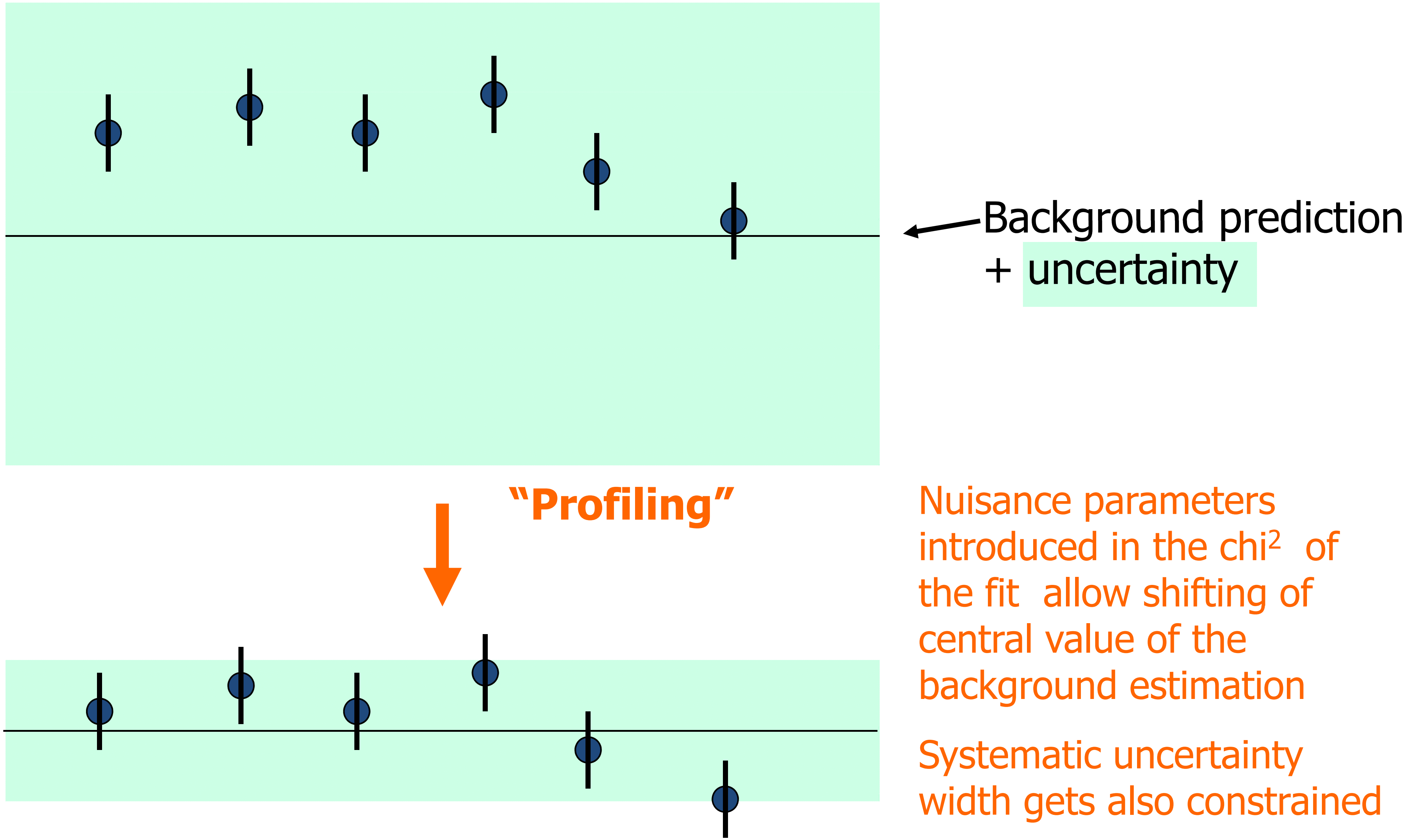
d_{ij} refers to "data" for model being tested **Observed events, or expected Background or Signal+Background**

- Distributions of simulated outcomes are populated via Poisson trial with mean values given by B-only or S+B hypotheses
  - Systematics are folded in via Gaussian marginalization
  - Correlations held amongst signals and backgrounds

CL_b and CL_{s+b} projections vs Mass



Constraining Systematics Uncertainties with Data



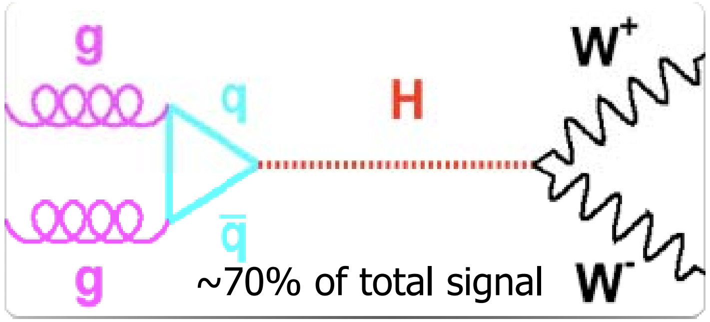
Nuisance parameters introduced in the chi^2 of the fit allow shifting of central value of the background estimation

Systematic uncertainty width gets also constrained

Shape of the systematics is also taken into account

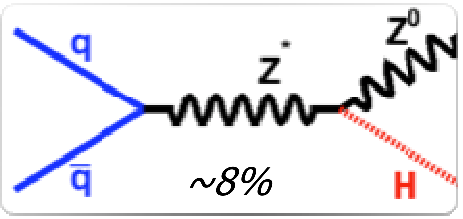
Searches for $H \to W^+W^-$

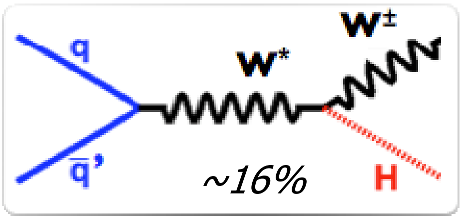
Primary Signal :

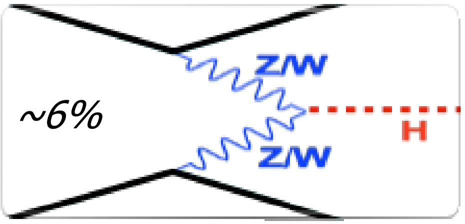


- Selection ($W \to l^{\pm}\nu$) : high P_T leptons + significant missing E_T
- Separate searches in 0, 1 and ≥2 jet final states
- Background & Signal vary with number of jets

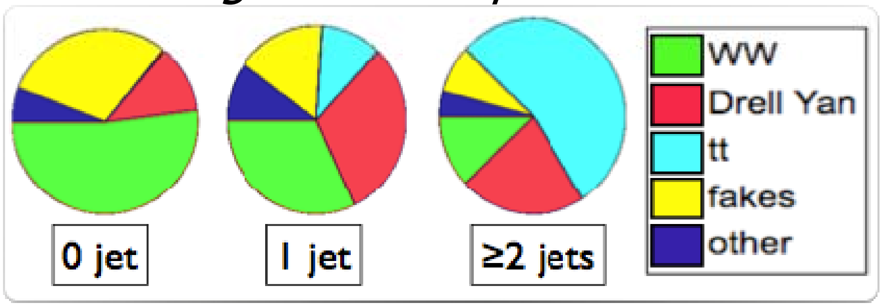
Additional sensitivity gained by including contributions from :



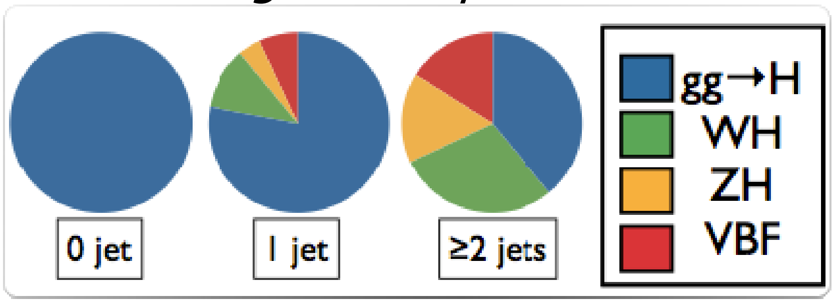




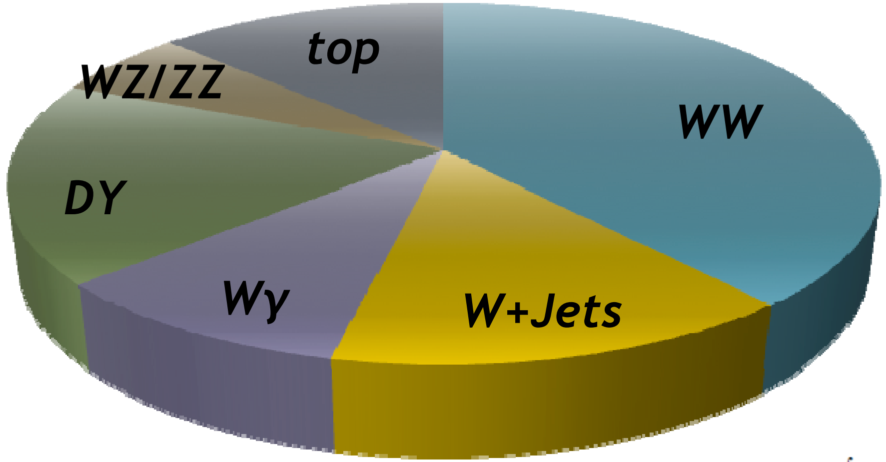
Background Composition



Signal Composition



SM Backgrounds to H→WW



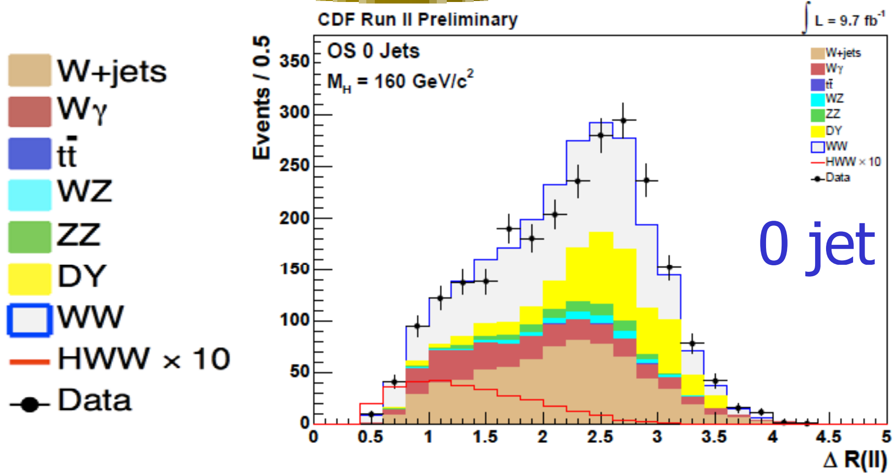
- Need to separate small potential signal from large SM background in our search channels

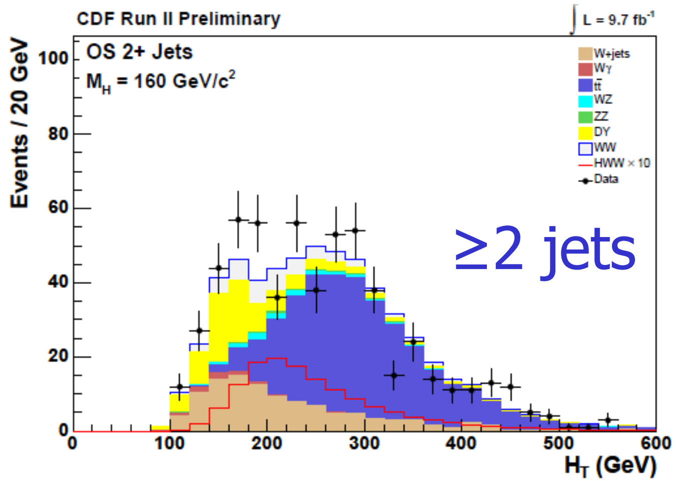
- After inclusive selection S/B ~ 0.02 in the most sensitive search channels

→ Need to model well ALL backgrounds, in particular those dominating for measurements at low m_H

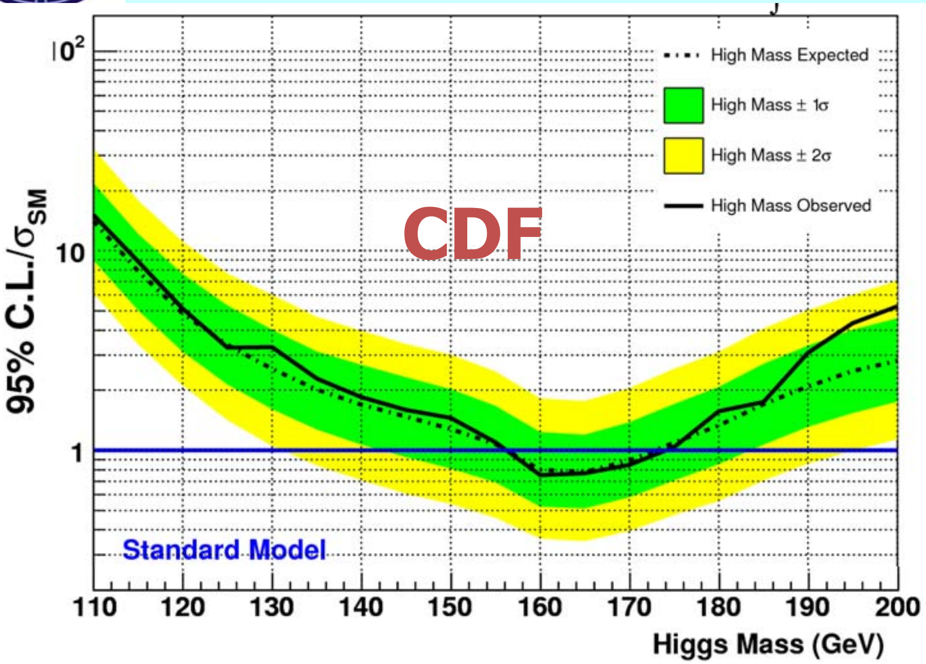
- Define specific control regions to test modeling for each individual background (whenever possible)

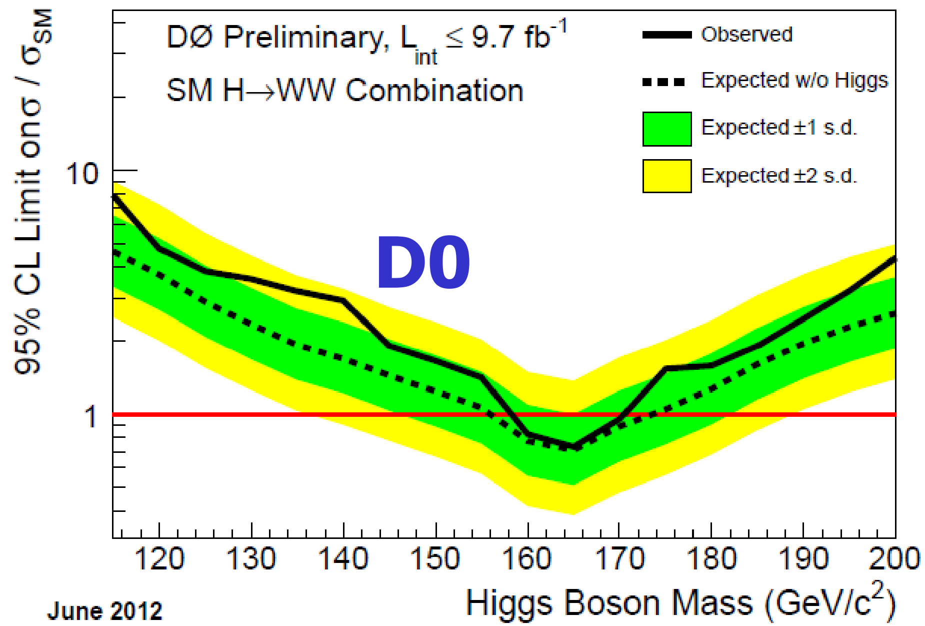
- In the case of dibosons (WW/Z, ZZ) there are no control regions so we measure them to check their modeling



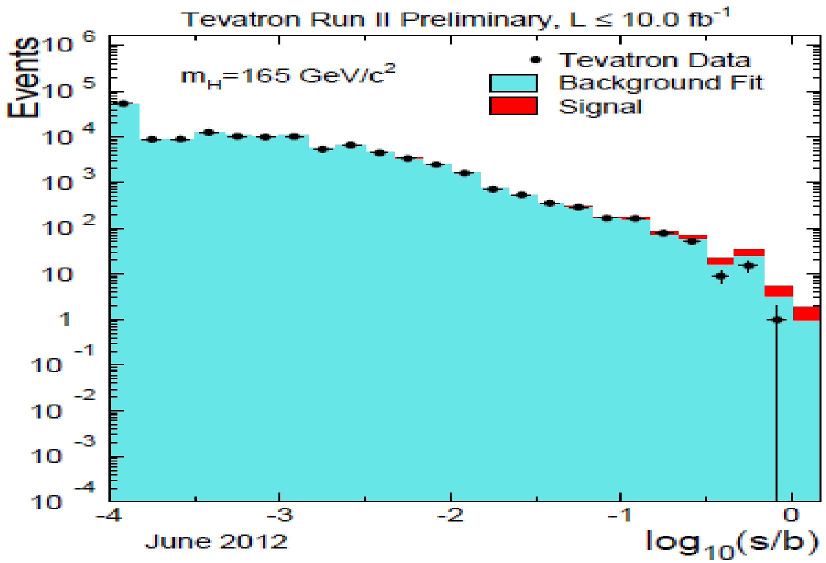


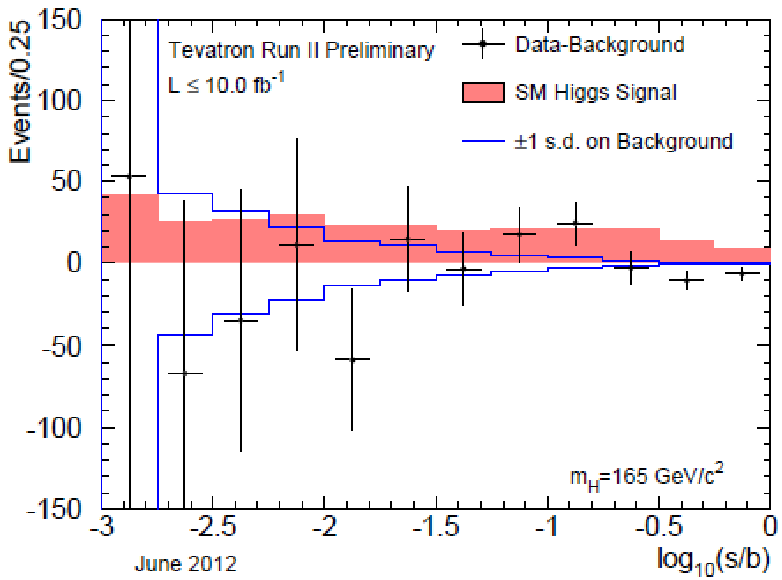
CDF/D0 H→WW→lνlν Limits





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

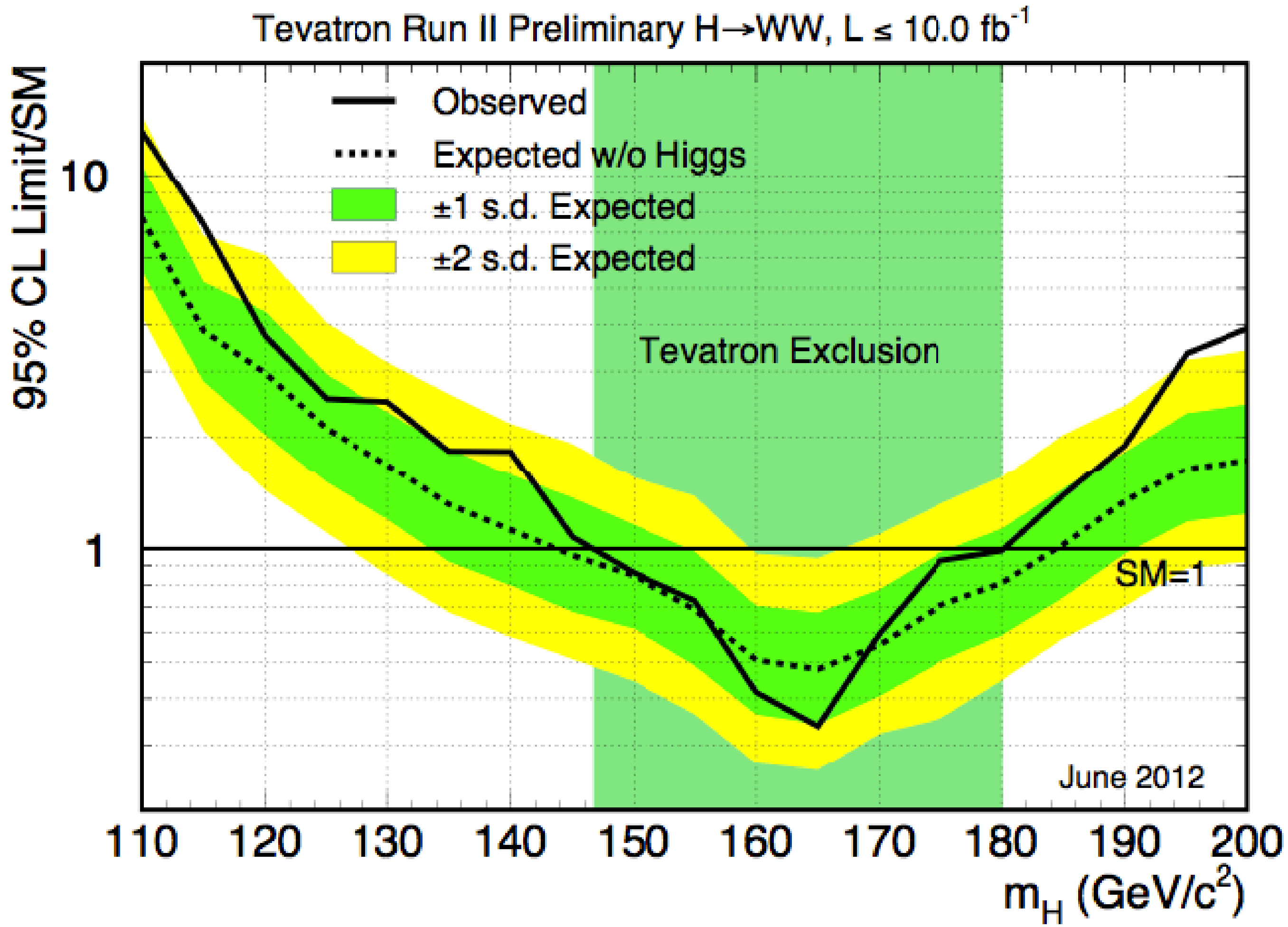




Similar limit behavior, sort events in s/b, no excess around 165 GeV

$H \to W^+W^-$ Combination

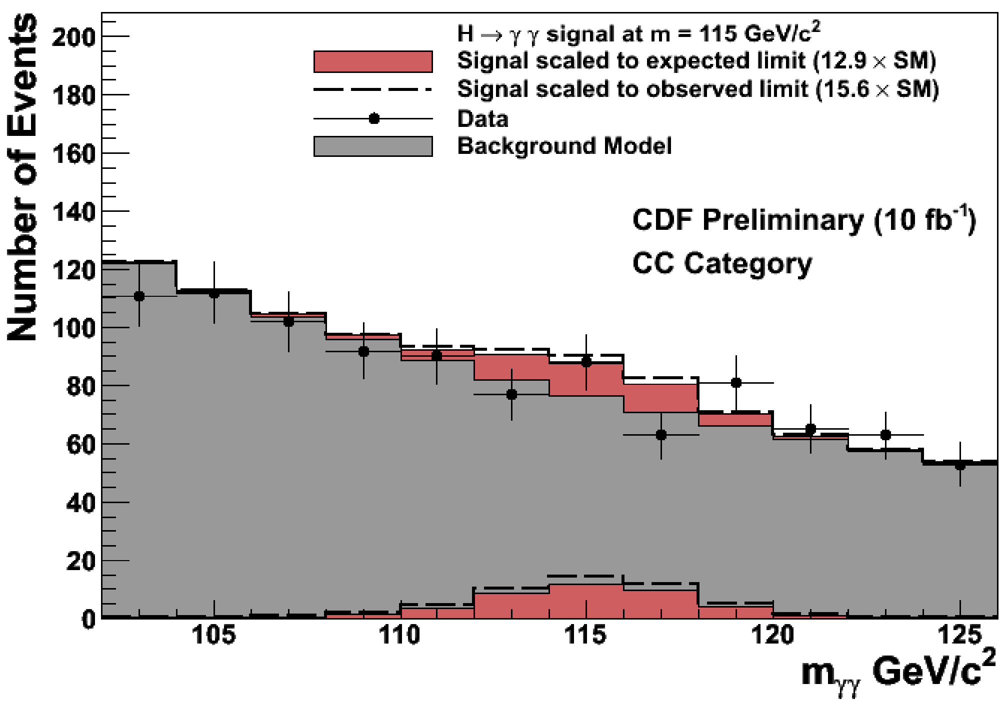
Exclude 147< M_H < 180 GeV @ 95% CL

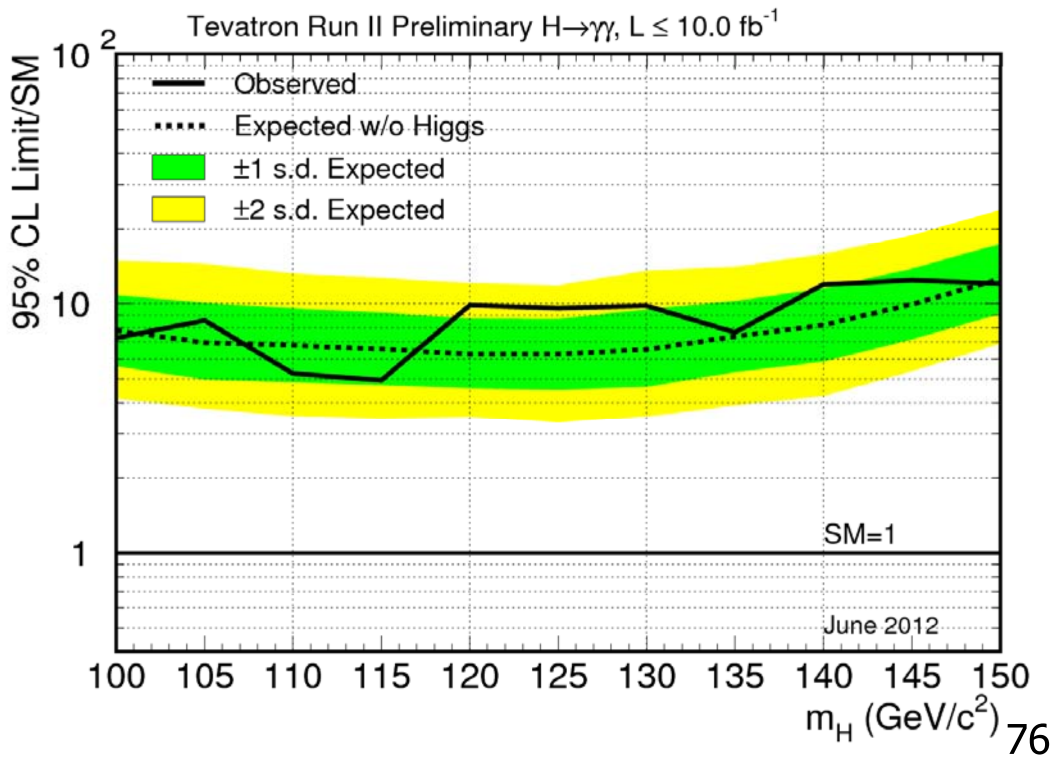


No significant excess, let's move to low mass!

H→γγ / Tevatron Combination

- Very small BR in SM, clean signature
- Main challenge is instrumental background (fakes)
- Data-driven methods for both CDF and D0 to estimate background from jets faking photons
- Use of multivariate methods for background estimation and final discriminants
- Now completely superseded by LHC. Fermiophobic limits resisted until this year (not discussed here, since we will learn later that H seems to like fermions a lot ;))

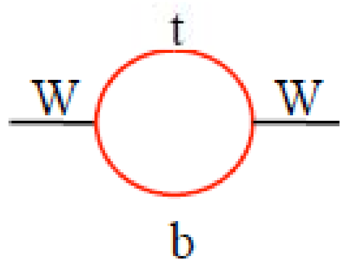




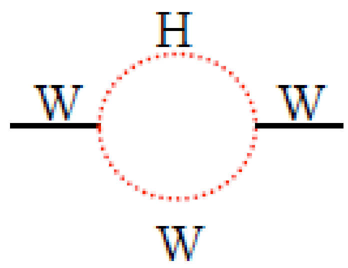
Indirect SM Higgs constraints

- SM Higgs boson mass is a free parameter of the theory
- Constrained indirectly through precision measurements
- In particular, self-energy corrections to the W mass depend on the mass of the top quark and Higgs boson

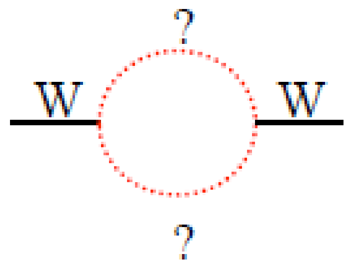
$\Delta M_W \propto M^2_{top}$



$\Delta M_W \propto \ln M_H$



New Physics



Updates for Summer 2012

Search Mode	Changes
$H \to W^+W^-$	DØ (technique + new data)
$H \to \gamma\gamma$	DØ (technique)
$ZH \to l^+l^-bb$	DØ (technique) CDF (minor changes)
$WH \to l\nu bb$	DØ (technique)
$VH \to \nu\nu bb$	DØ (technique) CDF (minor changes)

~10-15% gain in sensitivity for channels with improved technique since last update in Moriond 2012

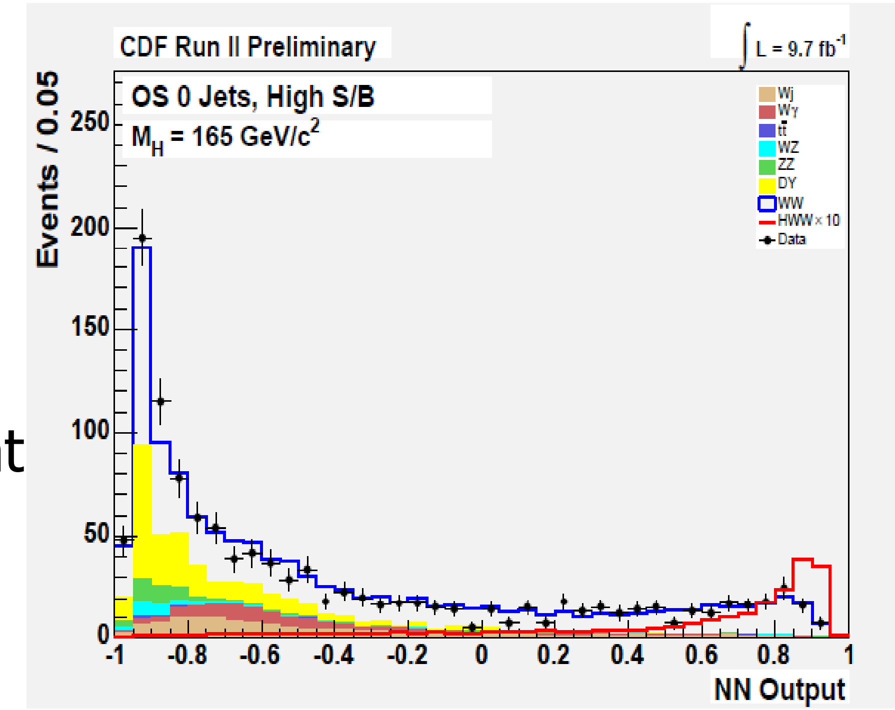
MVA (neural networks, boosted decision trees..) provide a gain of ~25% in sensitivity beyond that obtained from optimized, cut-based analysis

Backgrounds

Signal

Event Kinematics → **MVA (nn, bdt..)** → Final Discriminant

Training ➔correlate multiple input variables

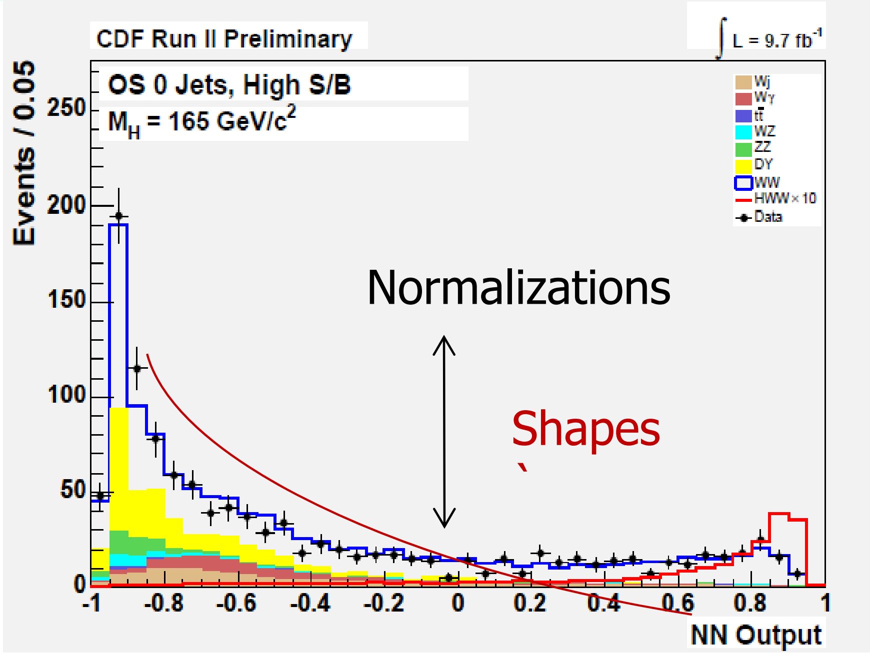


Discriminants / Systematic Uncertainties

Event Kinematics → **MVA (nn, bdt..)** ← Backgrounds, Signal

→ Final Discriminant

Training ➔correlate multiple input variables



MVA (neural networks, boosted decision trees..) provide a gain of ~25% in sensitivity beyond that obtained from optimized, cut-based analysis

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

- 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

Limit Settings / LLR

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

Limits are derived using

Bayesian and CLs methods →

Look-Elsewhere-Effects (LEE)

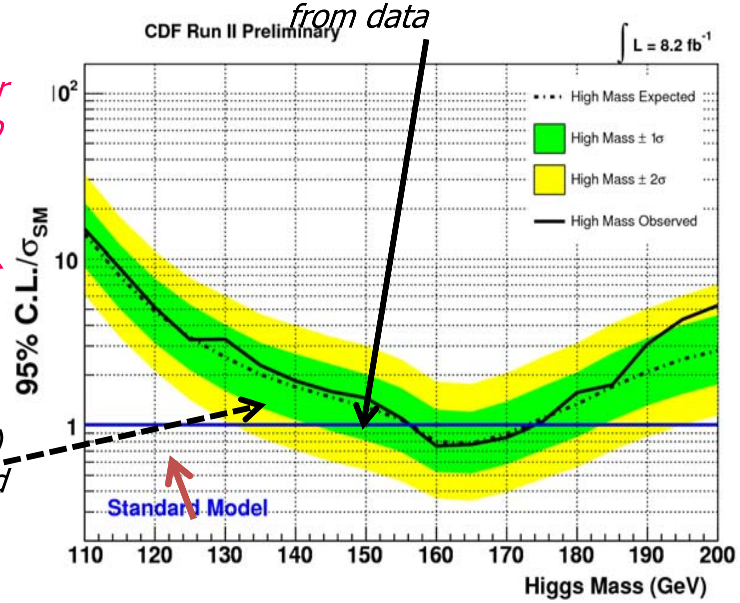
LEE = 4 for full combination (100-200 GeV),

LEE = 2 for H→bb combination (115-150 GeV)

Upper cross section limit for Higgs production relative to SM prediction

Observed limit (solid line) from data

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

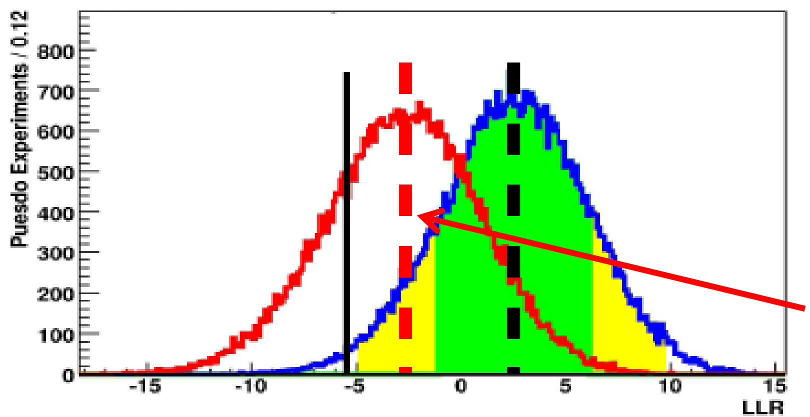


The Log-Likelihood Ratio (LLR) allows to check the data/expectation agreement on background or signal +backgrnd models. Distributions are populated with pseudoexp'ments to get an estimate of the significance

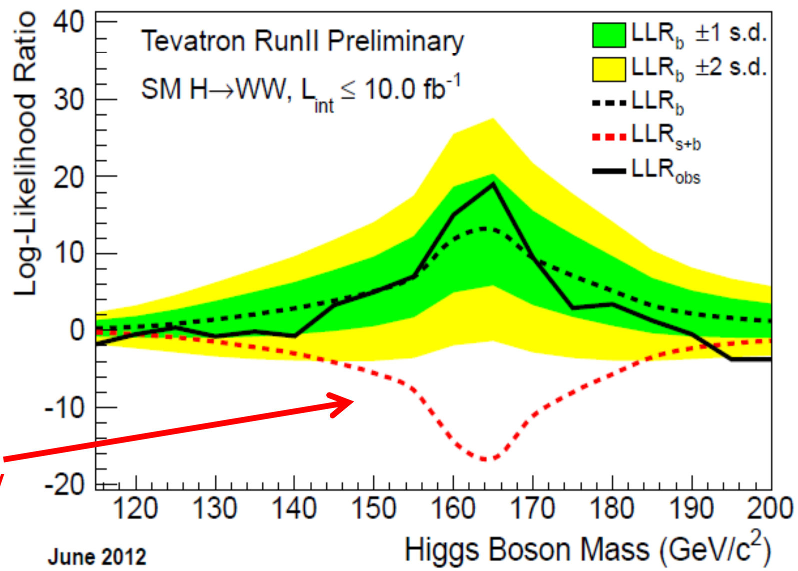
Background-Only Pseudo-Experiments

Signal+Bkgd Pseudo-Experimentss

Observed LLR

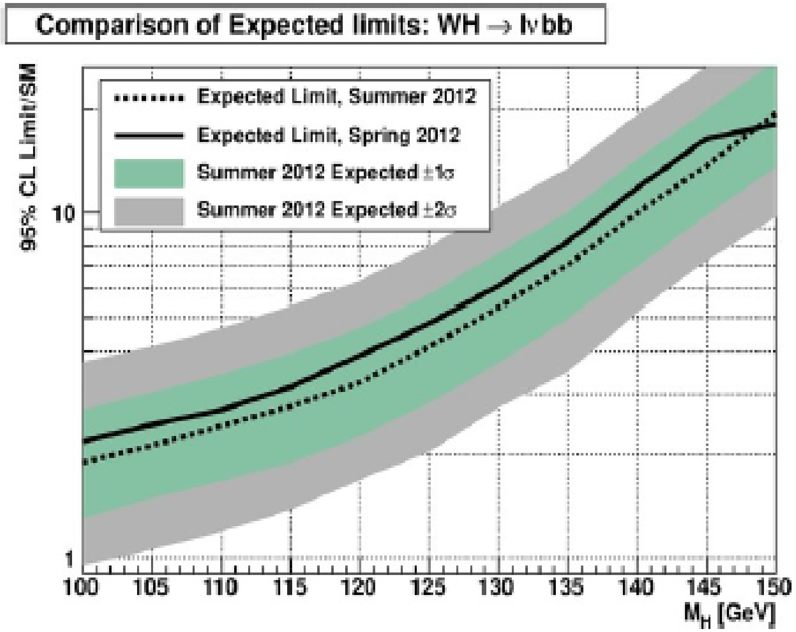


expected LLR from signal +background



Recent improvements: WH →lvbb

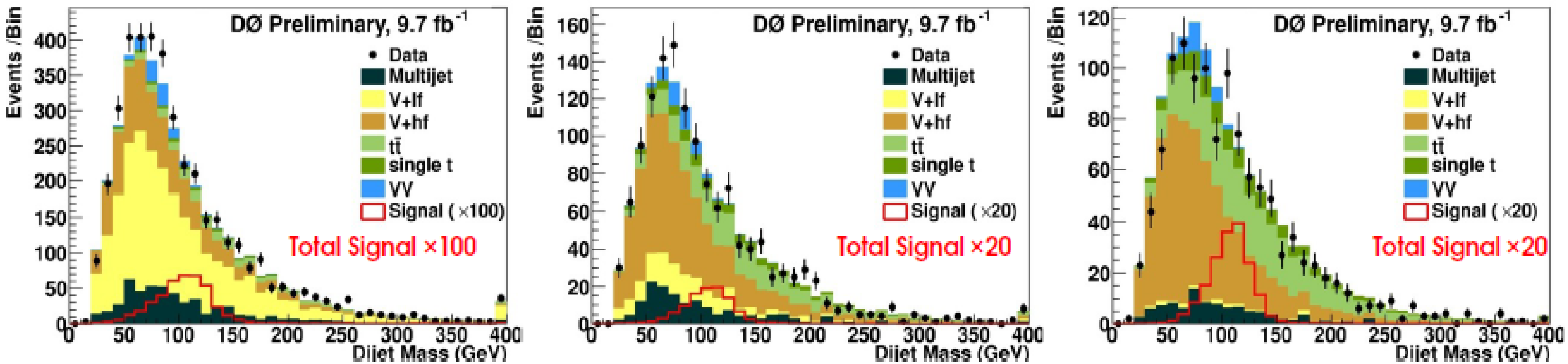
- Updates to the WH→lνbb Higgs search
  - Additional muon triggers
  - Improved multijet modeling & rejection
  - Improved signal isolation via separation into 3 double b-tagged final states (vs 2 previously)
  - Bottom line: **10-17%** improvements in expected limits



2 Loose b-tags

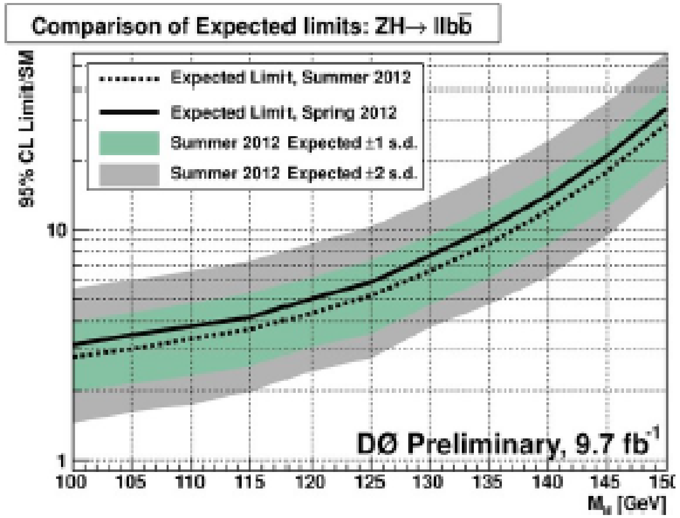
2 Medium b-tags

2 Tight b-tags

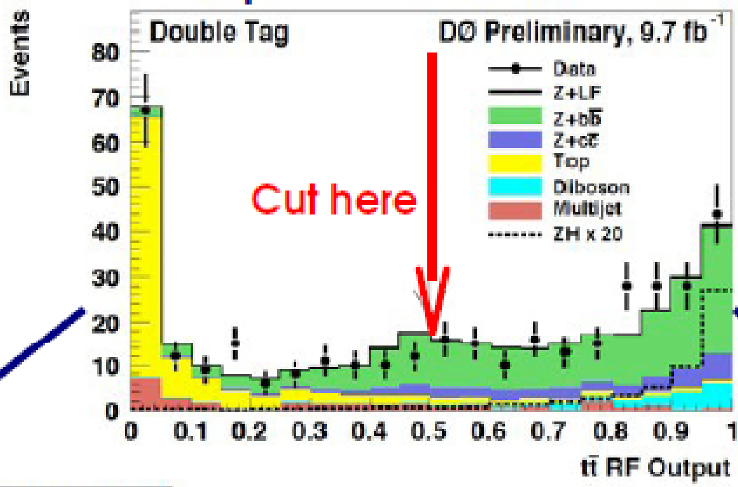


Recent improvements: ZH →llbb

- Updates to the ZH→llbb Higgs search
  - Selection requirements relaxed
  - Isolation of top quark backgrounds represents largest change

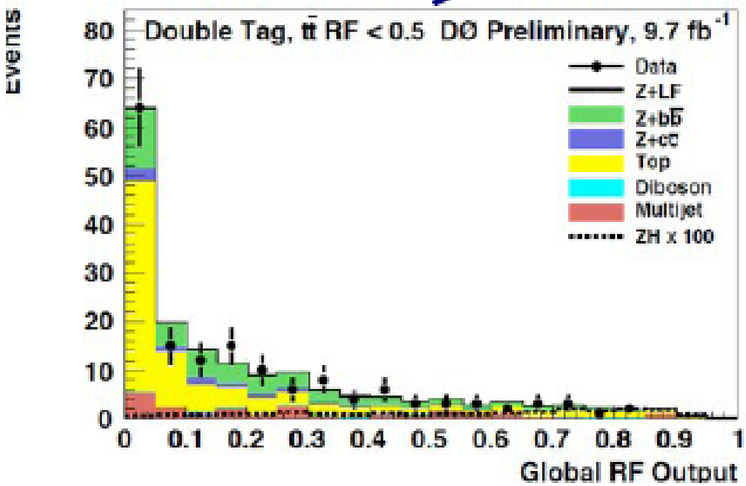


Top Quark Classifier



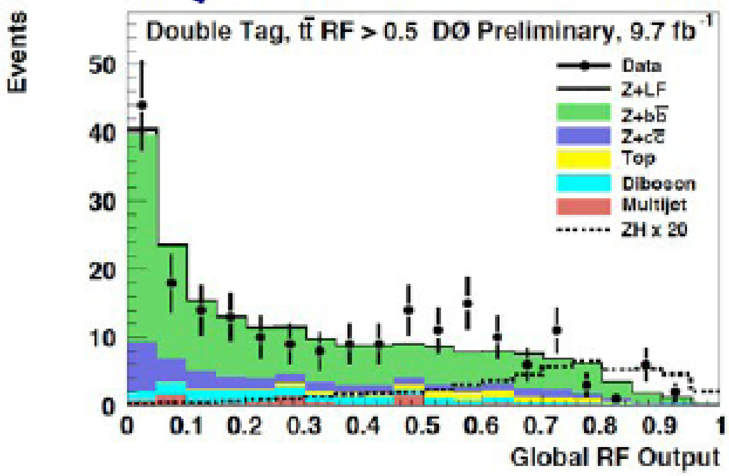
Region dominated by top quark backgrounds

Region dominated by Z+heavy flavor quark backgrounds

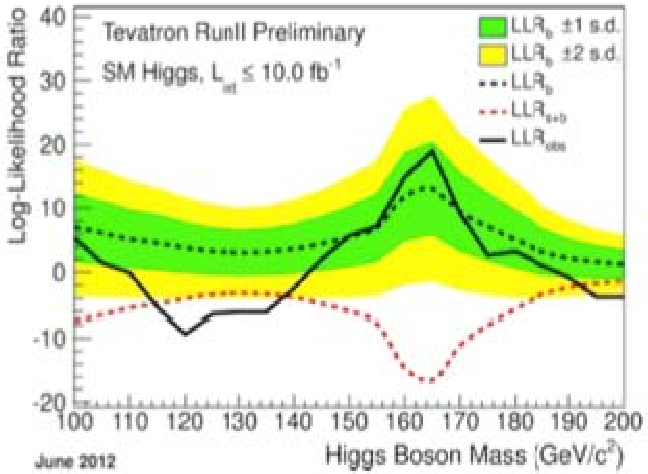


Bottom line:

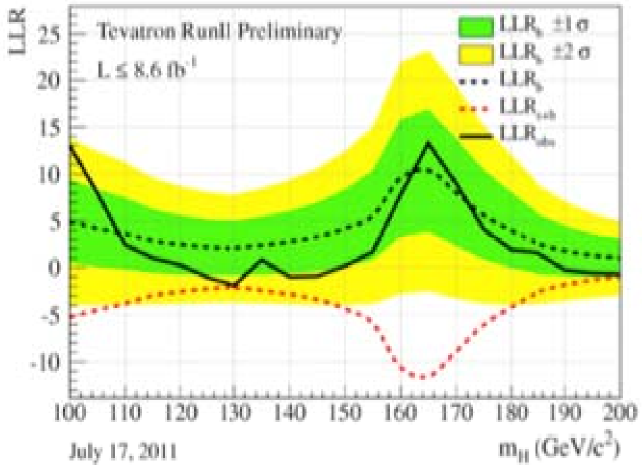
10-15% improvement in expected limits



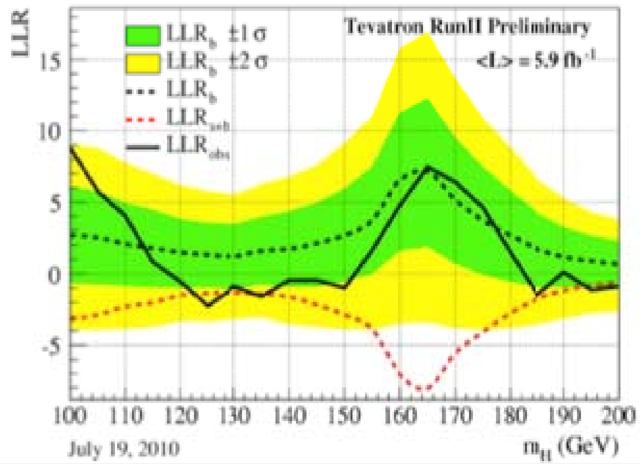
Many steps back: LLR time evolution 2007-2012



2012

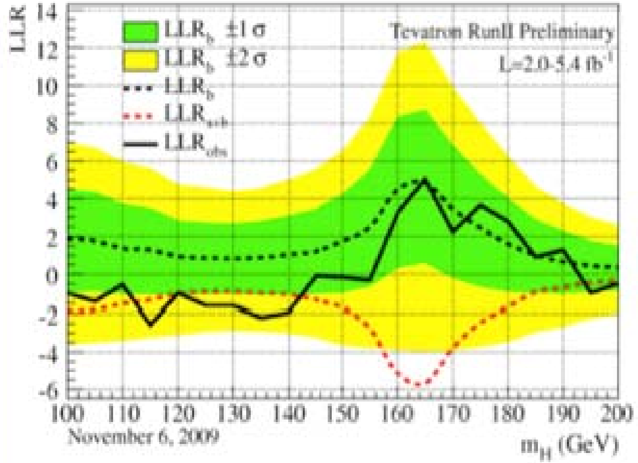


2011

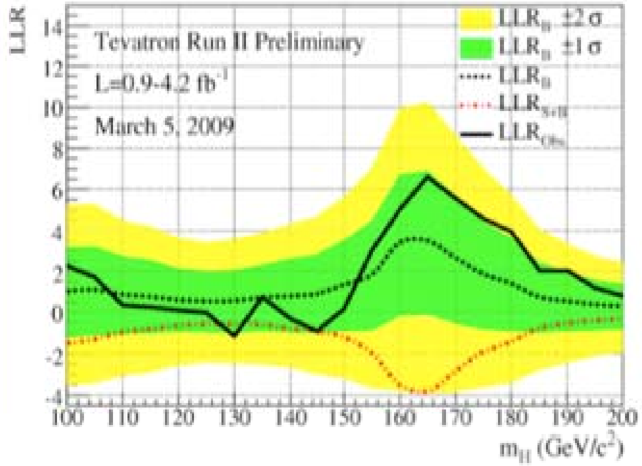


2010

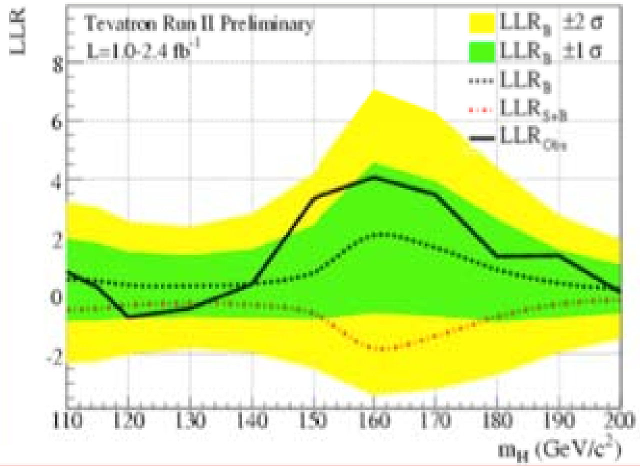
2009



2008



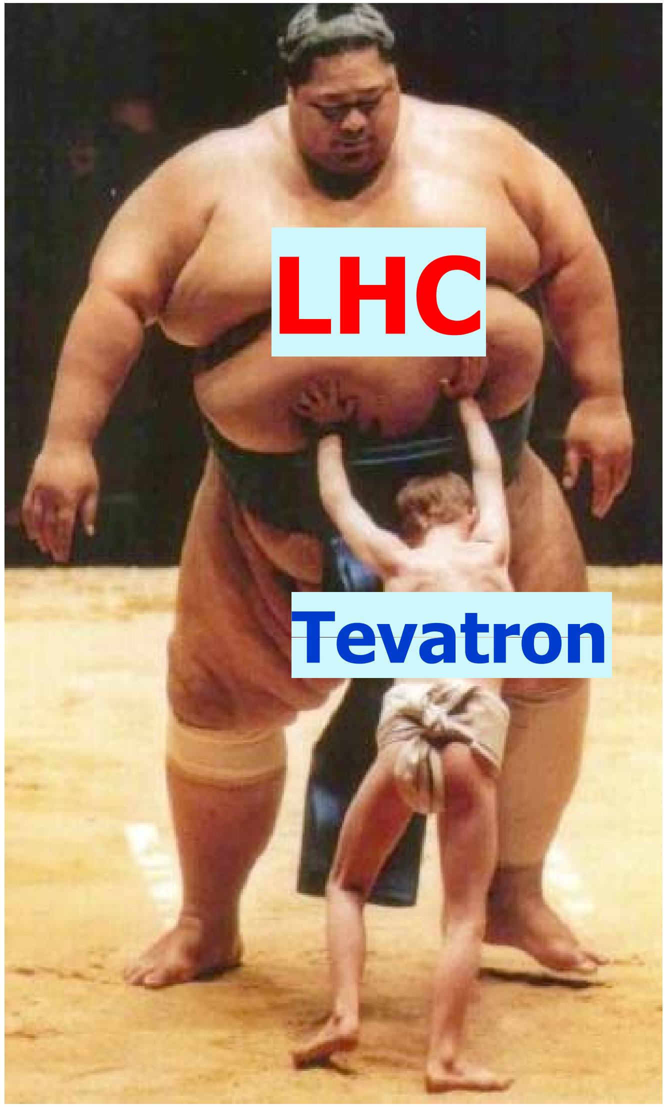
2007



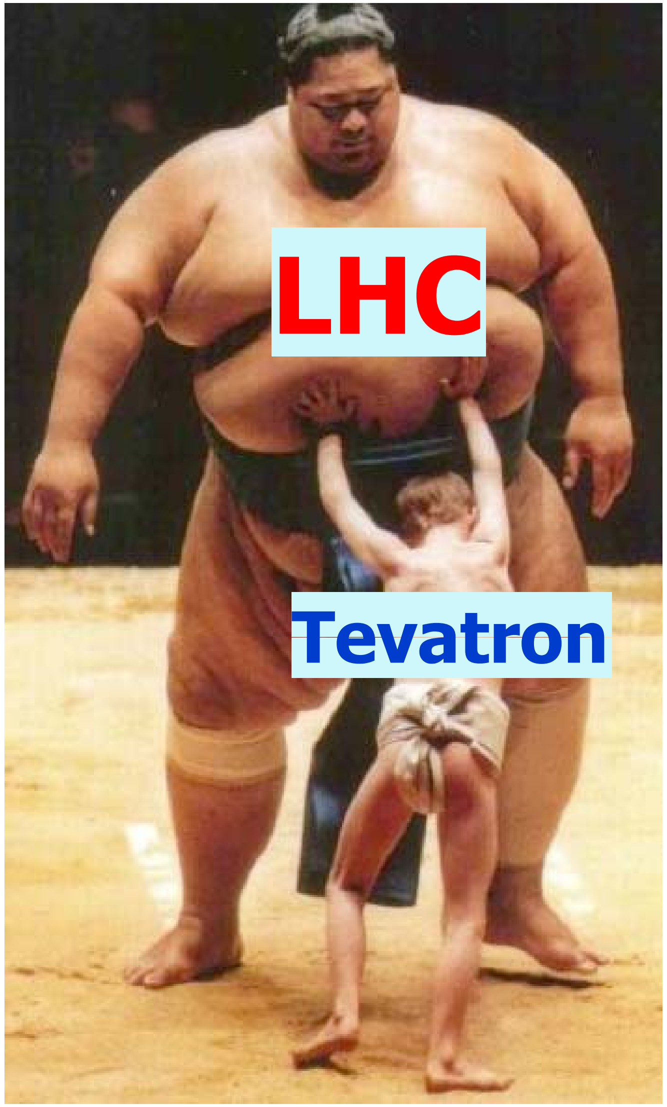
Higgs Search Strategy @ Tevatron

- 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 sub-channels of different S/B, to improve the sensitivity.
- Model all backgrounds using simulation and data, with detailed verifications in independent control regions in data
- Use advanced multivariate analysis tools to separate signal from background using the full event kinematics (tested on data)
- Derive systematic uncertainties from independent measurements, both in normalization and on the shape of their distributions.
- Use two standard statistical approaches and constrain the systematic uncertainties to the data, to obtain the best sensitivity.

Higgs @ Tevatron



Rumors of my death were greatly exaggerated



Rumors of my death were greatly exaggerated

But this young LHC giant, is running really fast!