Tevatron Roadmap for the Higgs

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On behalf of CDF and DØ

July 30th 2010

Where are we?

What can still be done, assuming

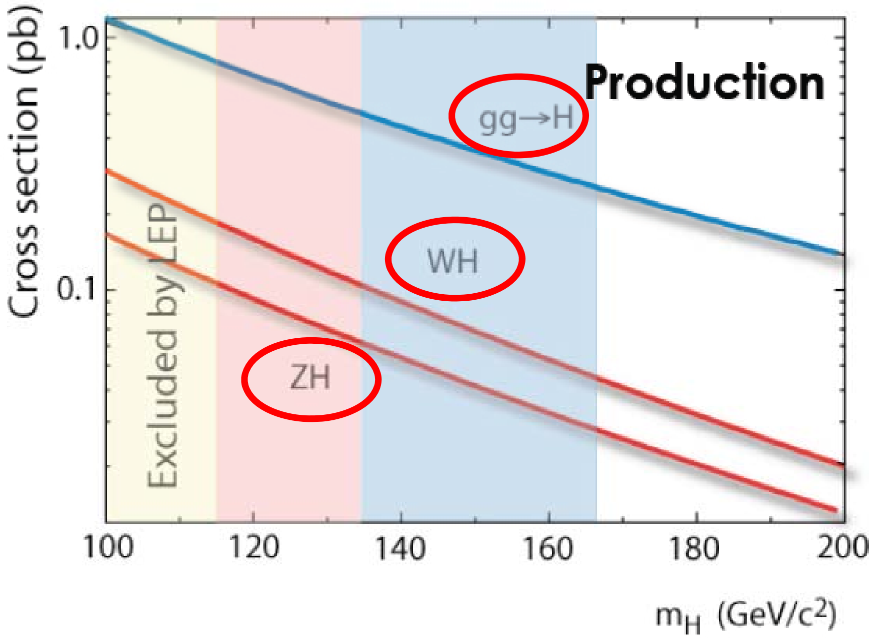
1) Data ends end 2011 / results Moriond 2012

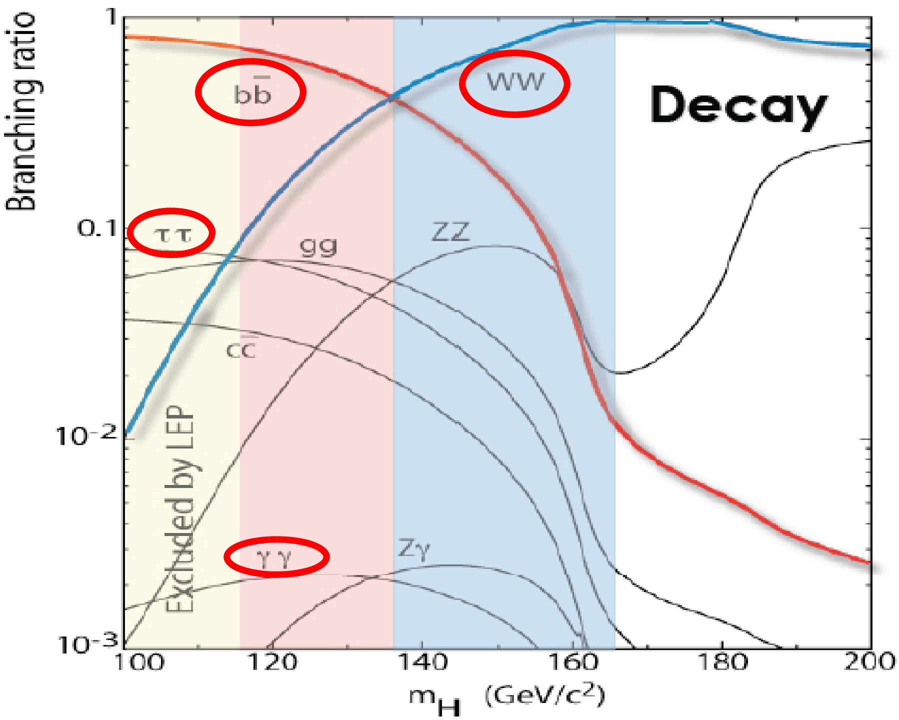
2) Data ends end 2012 / results Moriond 2013

3) Data ends end 2014 / results end 2014

Thanks to Y. Enari, W. Fisher, T. Junk, B. Kilminster, M. Kirby, K. Peters and all cdf & d0 colleagues

Higgs Production and Decay at the Tevatron

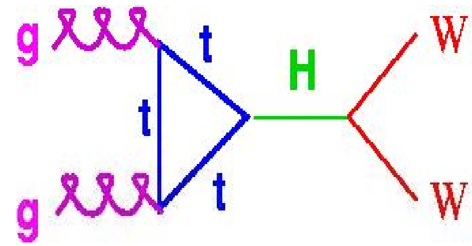




High mass (m_H > 135 GeV) dominant decay:

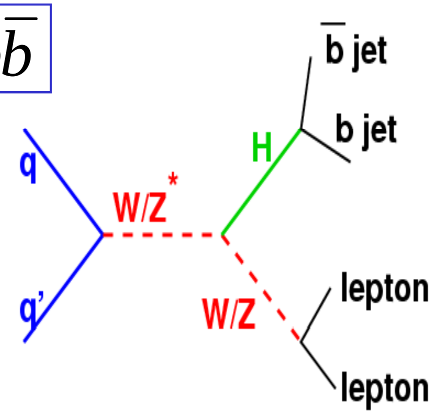
$H \to WW^{(*)}$

$WW \to \ell\nu\ell'\nu'$



Low mass (m_H < 135 GeV) dominant decay:

$H \to b\bar{b}$



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

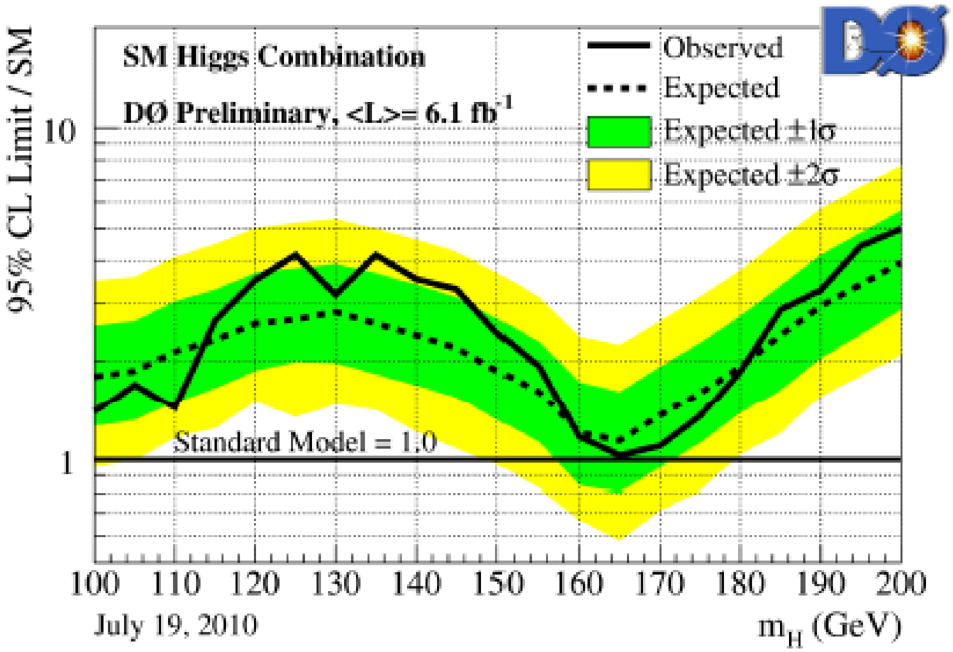
$ZH \to \ell^+\ell^- b\bar{b}$

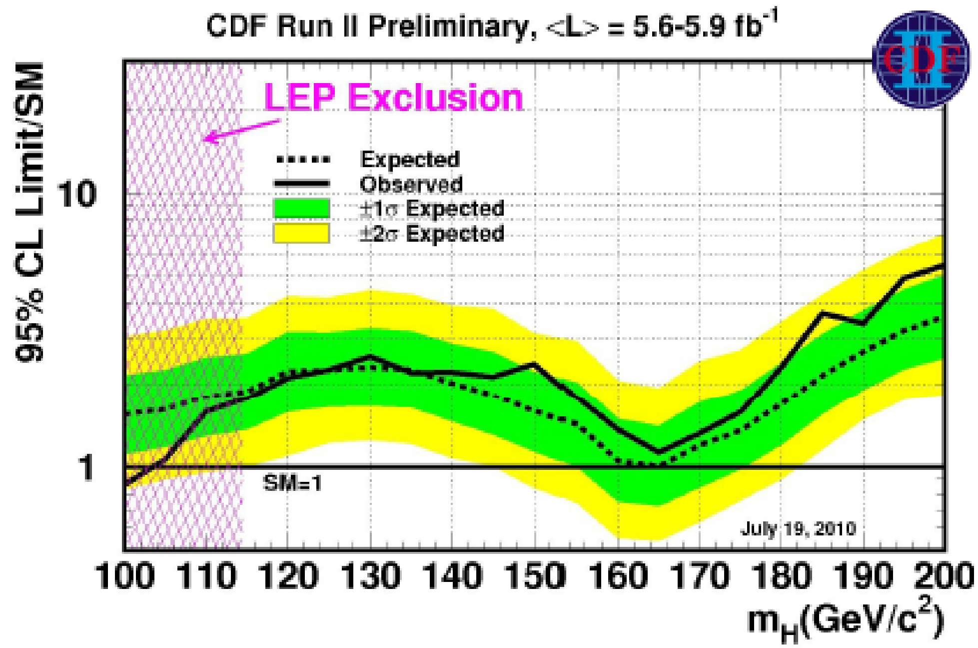
$ZH \to \nu\bar{\nu} b\bar{b}$

use associated production modes to get better S/B

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

CDF and D0 limits





New Milestones achieved for ICHEP 2010:
CDF expected limit reaches exclusion level
Dzero observed limit reaches exclusion level

M_H=165 GeV: DØ 1.0 (1.1) observed (expected)

M_H=165 GeV: CDF 1.1 (1.0) observed (expected)

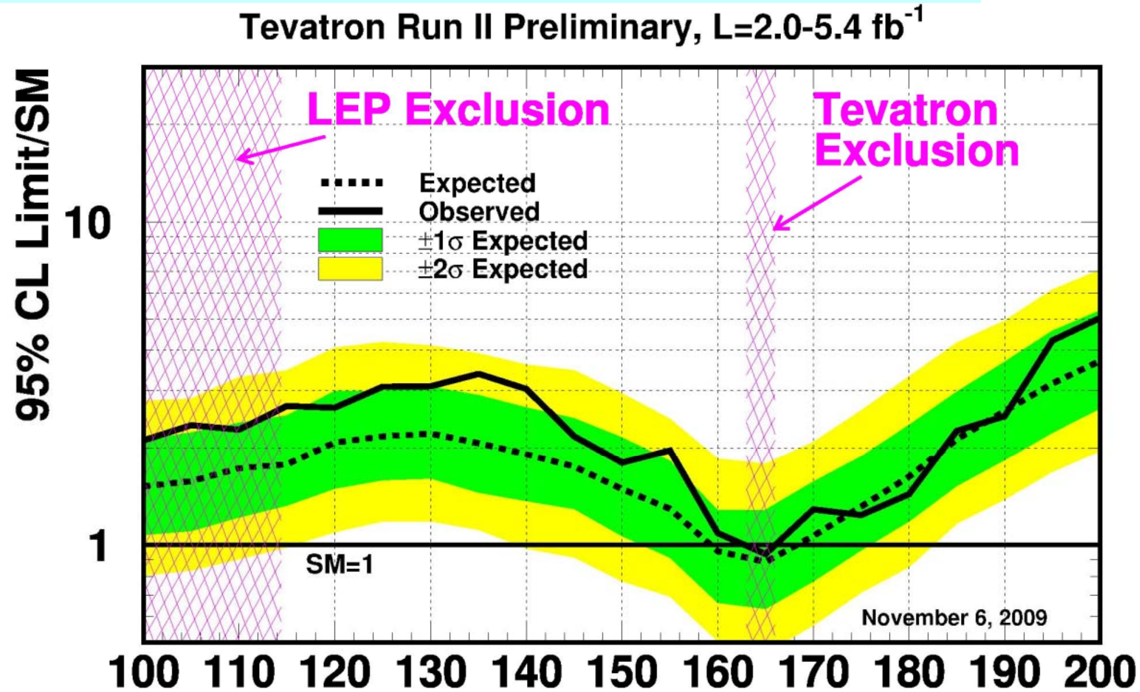
SM combined Higgs Limits, 8 months later

Joint CDF/DØ publication on 1st Higgs exclusion above the limit set by LEP

First time also an expected exclusion range ➔ from **159 to 168 GeV**

Better than **2.2 x σ_{SM}** sensitivity for all mass points **below 185 GeV**

1.8 x σ_{SM} sensitivity @ **m_H = 115 GeV** (average lumi ~3.6/fb)



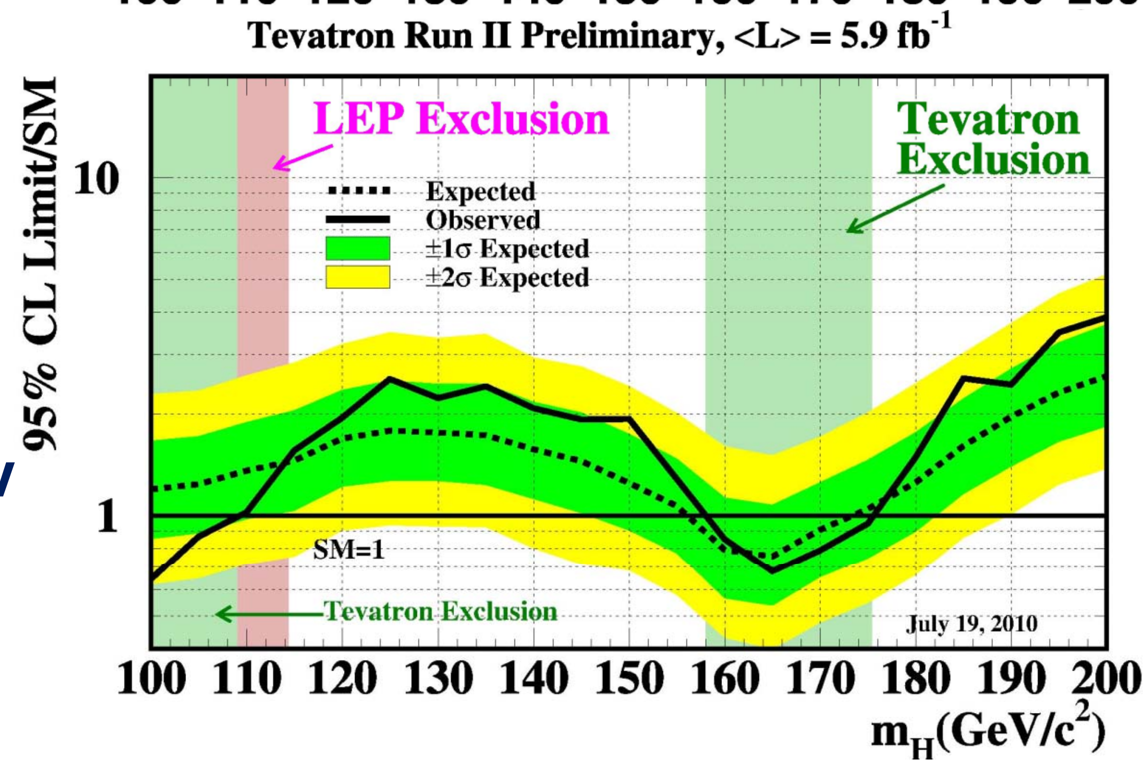
Lumi/improvements expected exclusion now ➔ from **156 to 173 GeV**

Better than **1.8 x σ_{SM}** sensitivity for all mass points **below 185 GeV**

1.45 x σ_{SM} sensitivity @ **m_H = 115 GeV** (average lumi ~5.8/fb)

New: exclusion at low mass <109 GeV

ALL 6 LOW mass channels have more lumi, sometimes significantly more



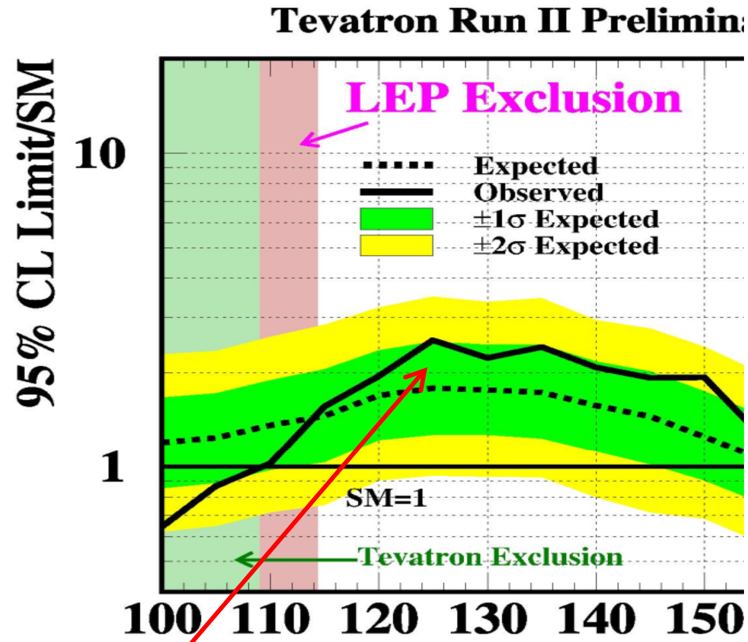
Luminosity increases

- CDF

nu nu bb 5.7 fb-1 (60% more luminosity)
L L bb 5.7 fb-1 (40% more)
WH 5.7 fb-1 (30% more)
H→WW 5.9 fb-1 (25% more)

- D0

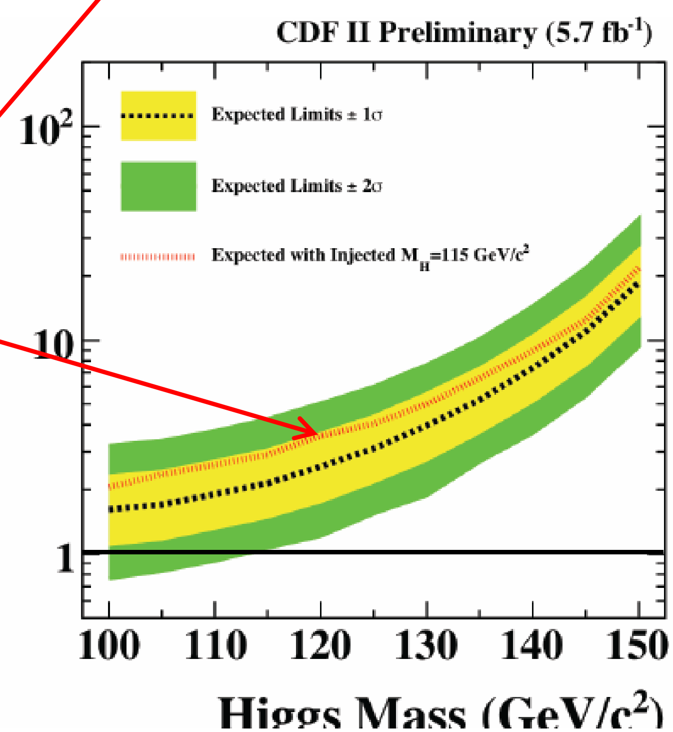
nu nu bb 6.4 fb-1 (25% more luminosity)
L L bb 6.2 fb-1 (45% more)
WH 5.3 fb-1 (5% more)
H→WW 6.7 fb-1 (25% more)



+ improvements in analysis techniques.

We still observe DATA EXCESS at low mass (115-155 GeV)

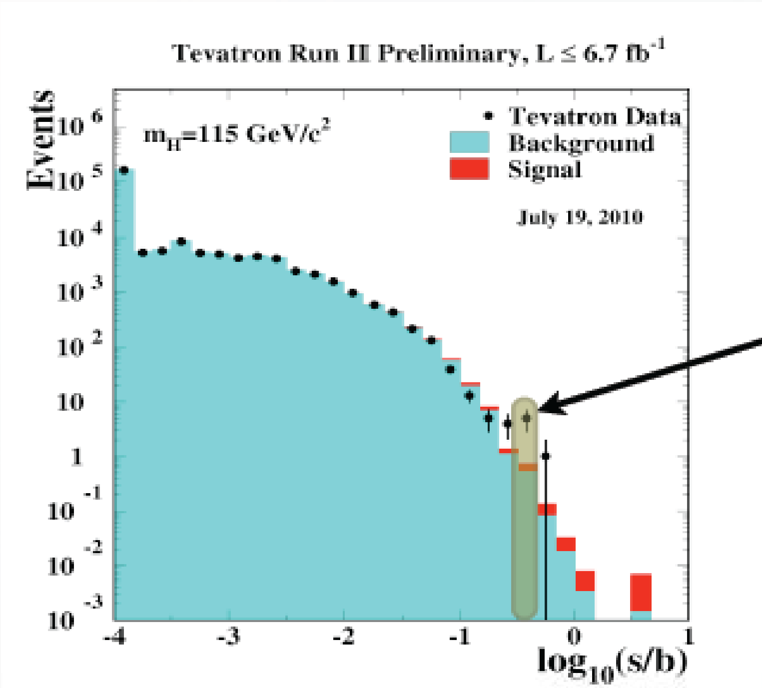
Is this consistent with a 115 GeV signal, as injected here



Difficult to compare: no high mass channels in the Comparison, CDF only (half stat), 1sigma fluctuations are not uncommon from point to point

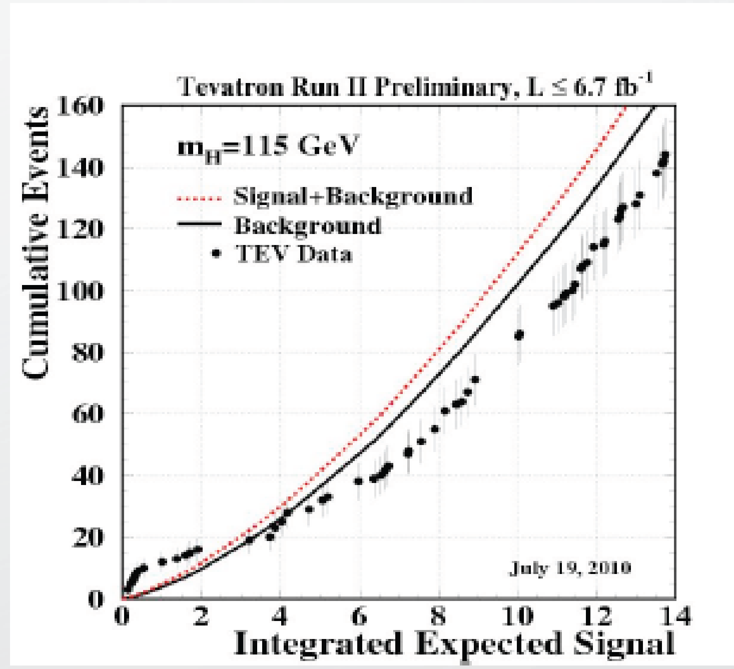
What happens at 115?

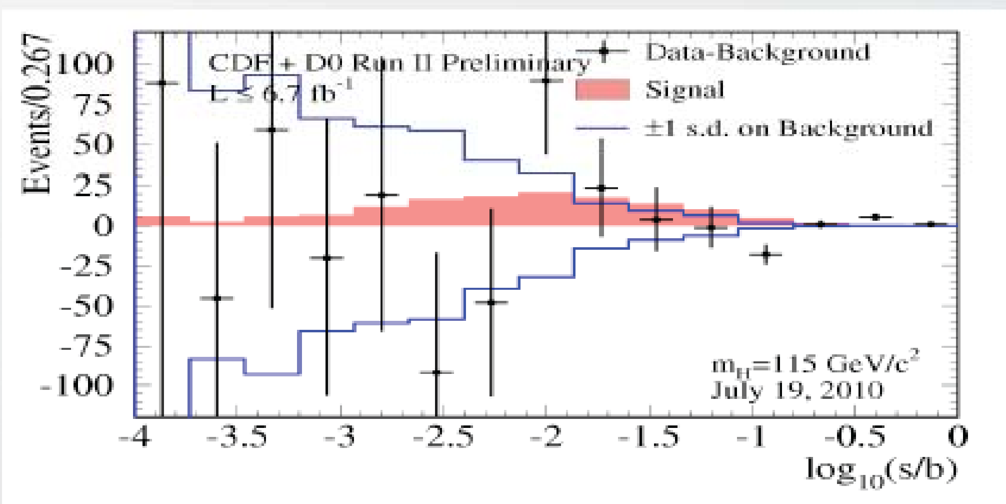
Tevatron Candidate Summary, m_H=115 GeV



Data: 5 events
Backgnd: 0.8 events
S:B ~ 1:2

But must integrate all bins!

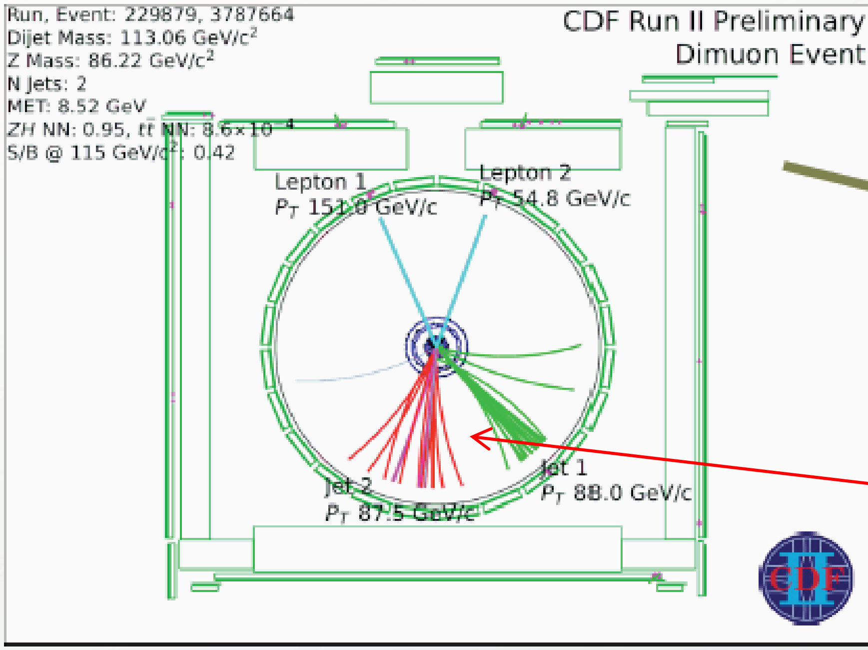




Fluctuations: Excess and deficit average out :
Expected limit 1.45*SM
Observed limit 1.56*SM

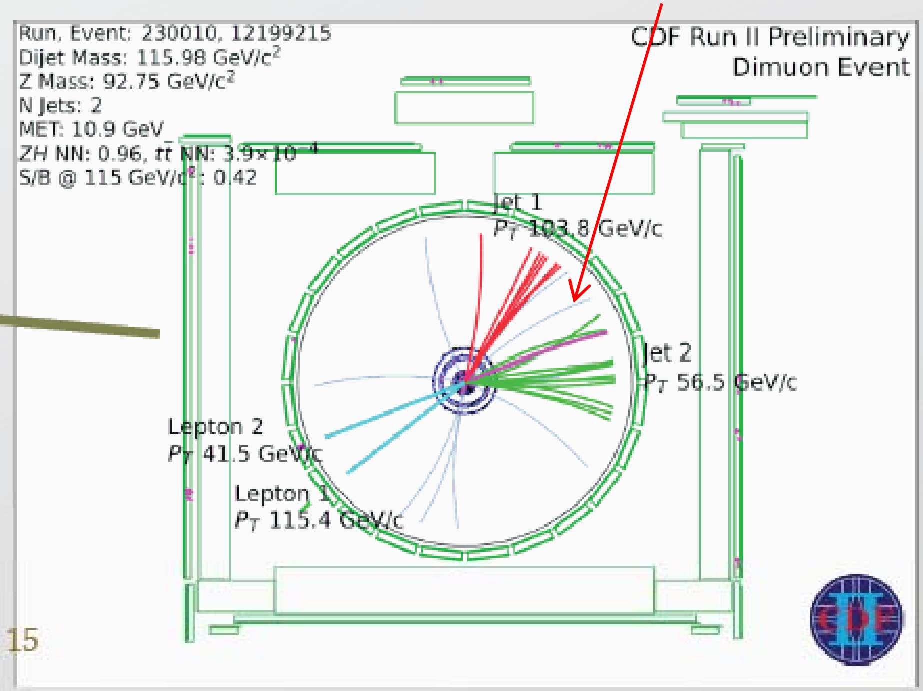
Events

$ZH \to \ell\ell b\bar{b}$ Event Displays



Dijet Mass = 113 GeV / c^2
Z Mass = 86.2 GeV / c^2
MET = 8.5 GeV

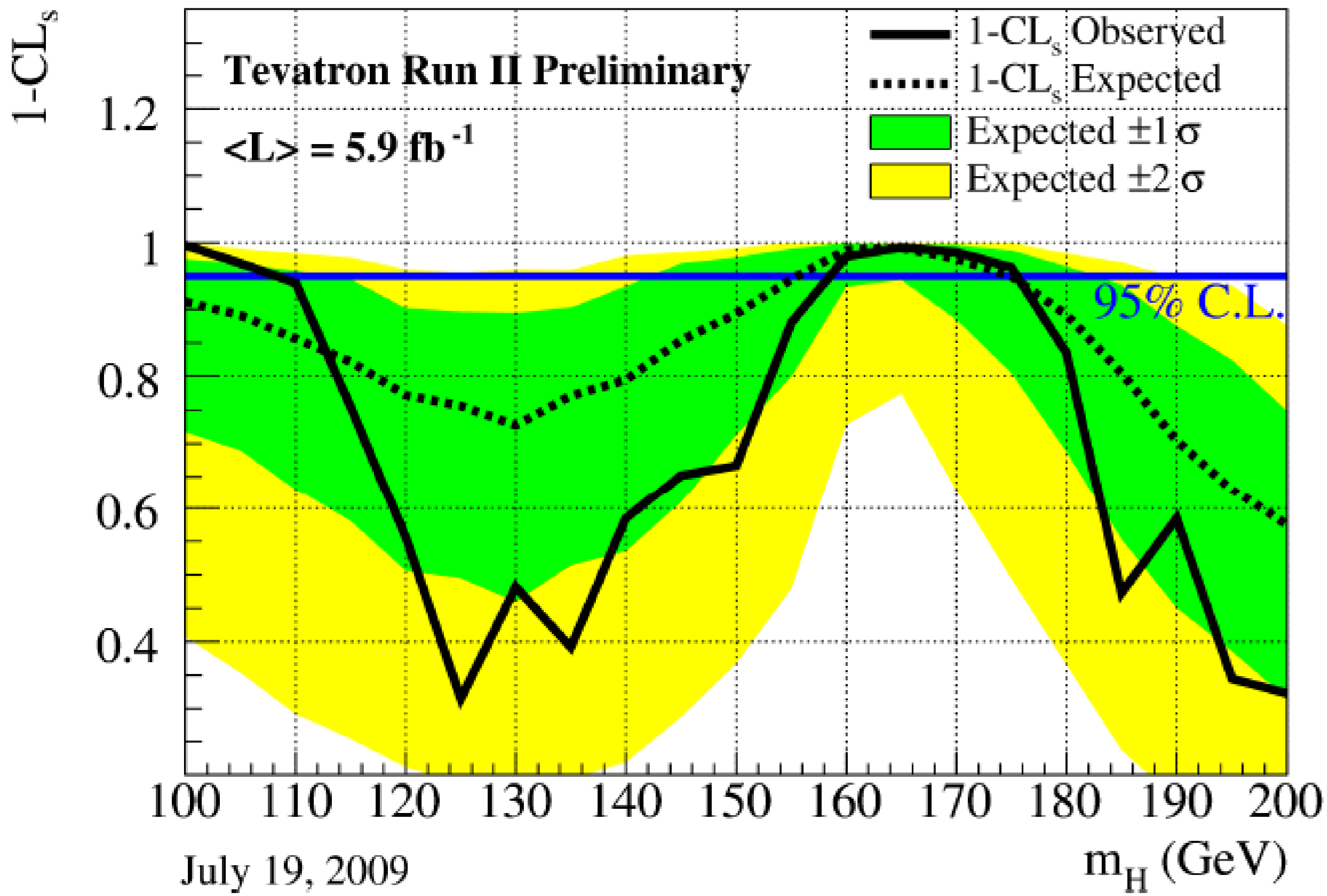
Use color flow between jets to enhance signal



Dijet Mass = 116 GeV / c^2
Z Mass = 92.8 GeV / c^2
MET = 10.9 GeV

15

Confidence Level for Exclusion



Tevatron has already >70% C.L. expected exclusion from 100 to 190 GeV

We exclude 165 GeV at 99.3% C.L !!!

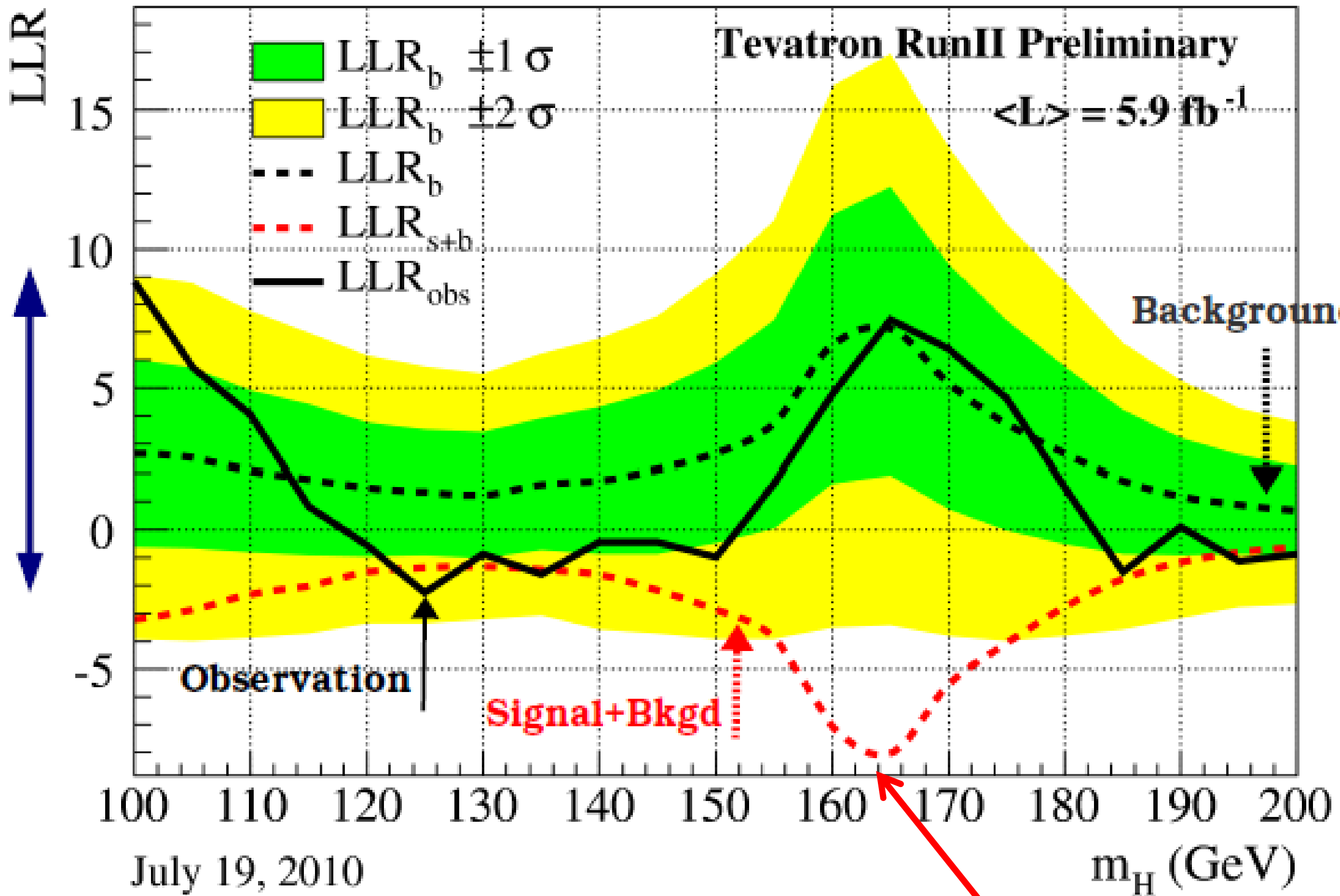
Current Sensitivity

The Log-Likelihood Ratio:

Basic test statistic of the Frequentist statistical method used here.

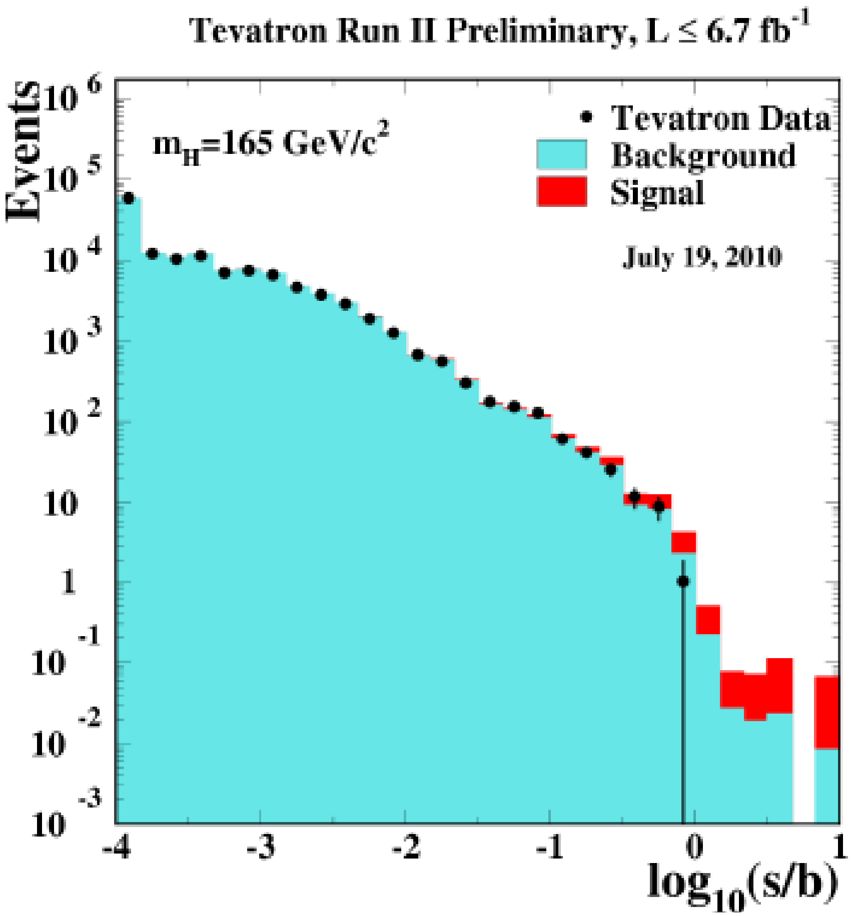
Arise from the ratio of Poisson likelihoods for TEST & NULL hypotheses.

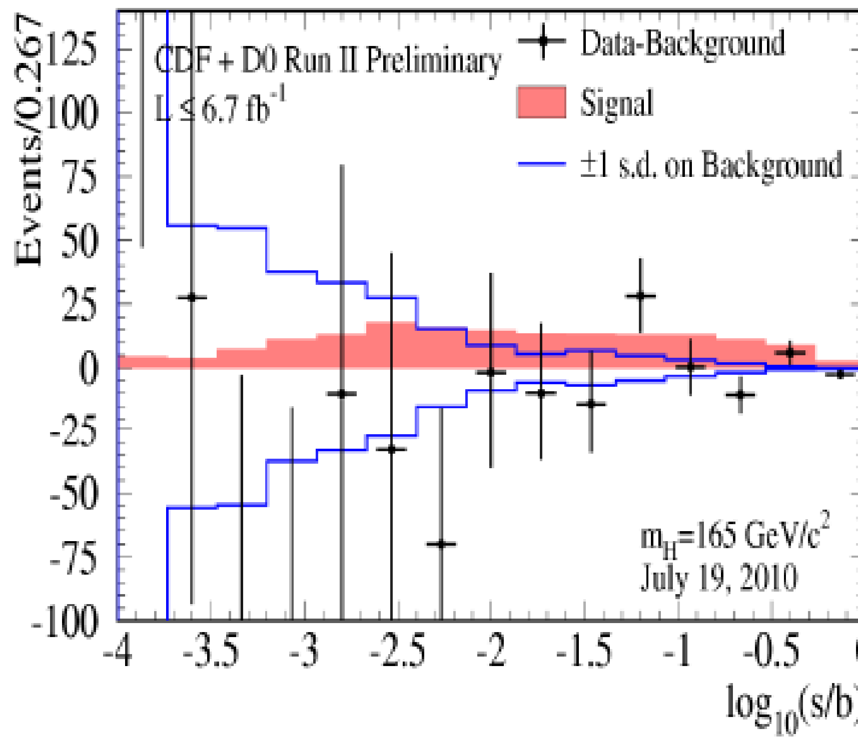
Distances between Points behave like model $\Delta\chi^2$s



If Higgs was at 165 GeV, we could be seeing a ~3 σ excess

S/B at high mass

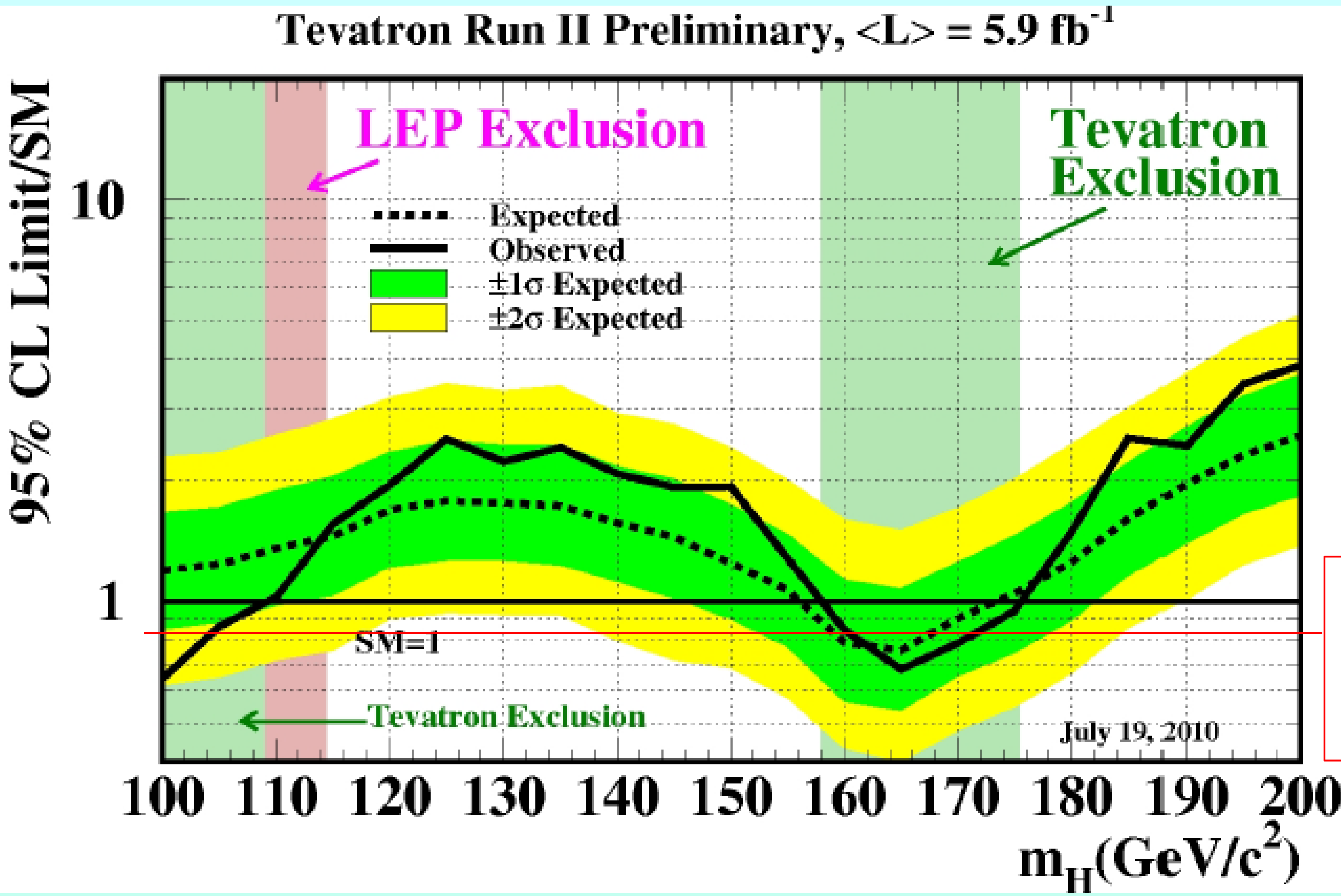




At High Mass, good agreement data/mc at all s/b,

if anything, a small "negative fluctuation" of data for high s/b

ICHEP 2010



Assume (for a test) ~ -20% less on gg→H, don't forget W/ZH,VBF

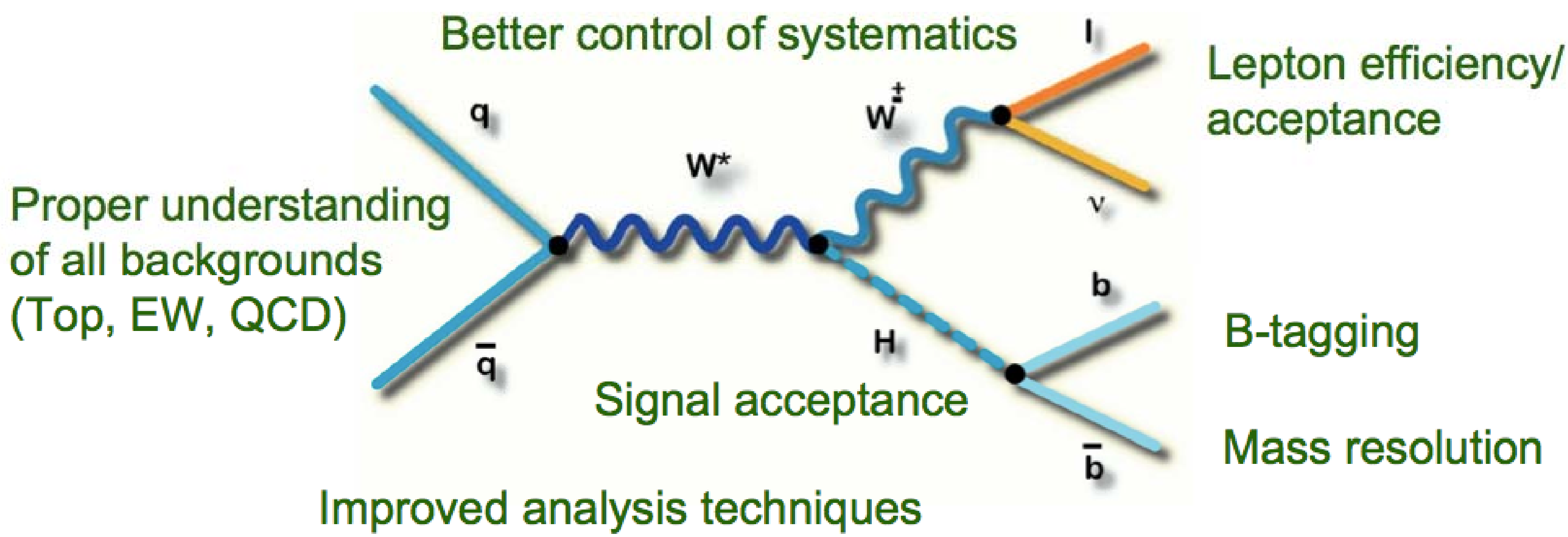
High mass exclusion between 158 and 175 GeV

The dependence on the theoretical x-section is weak: with 20% less on gg→H the exclusion would still be ~ 160-172 GeV, effect of large systematics even weaker.

In any case, no hint of a signal in the 155-175 GeV region where you would expect a > 2 sigma excess

Improvement Perspectives

Continue to make improvements over a wide range of areas

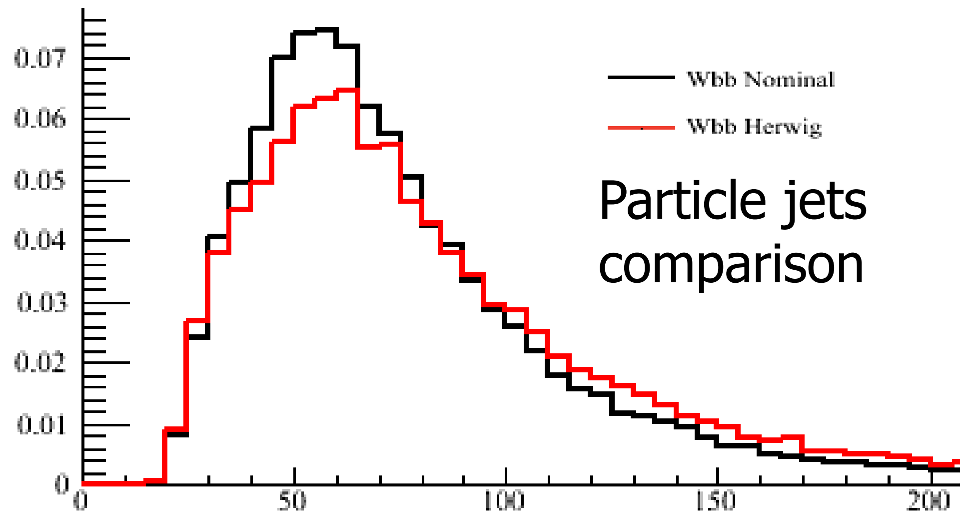


Modeling of V+HF jets

Normalization from MCFM (N)NLO and sideband fit to data

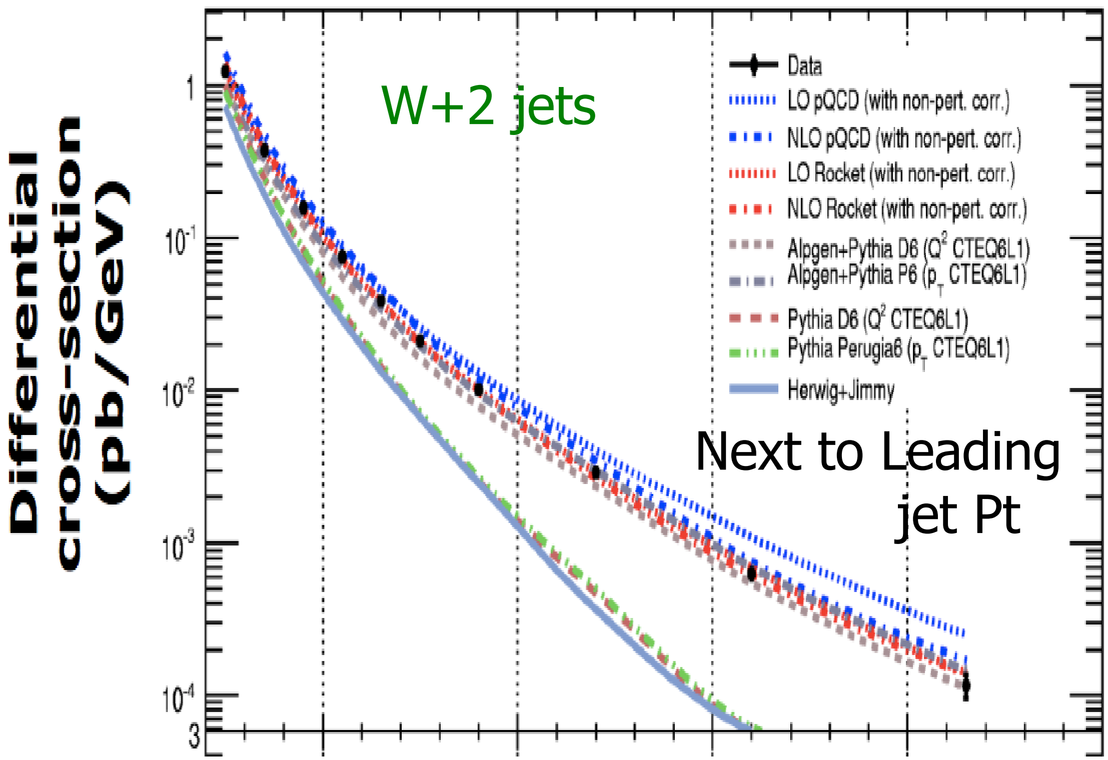
Shapes from MC

-Different choices for scale, underlying event and showering



V+HF cross section measurements

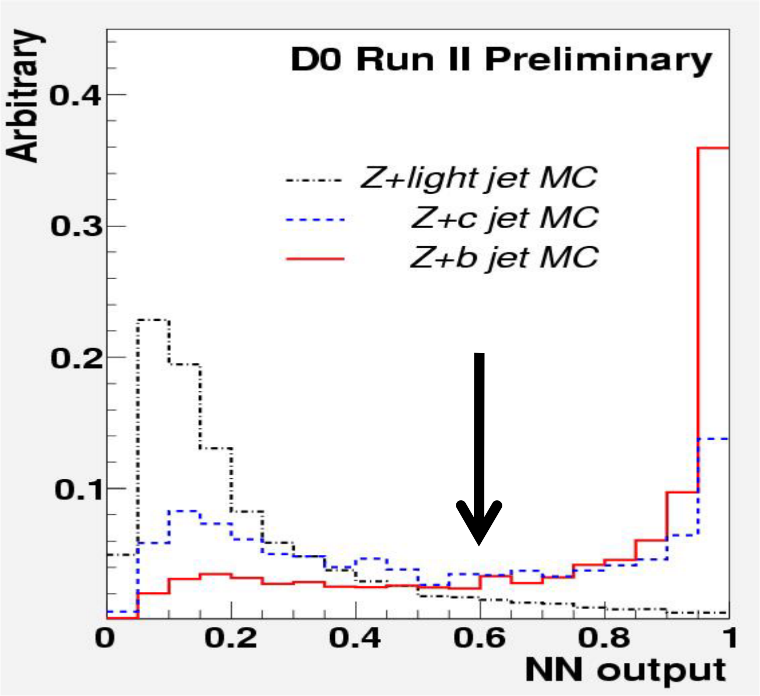
(W+jets, Z+jets, W+c, W+b…) allow to control theoretical models & cross-sections

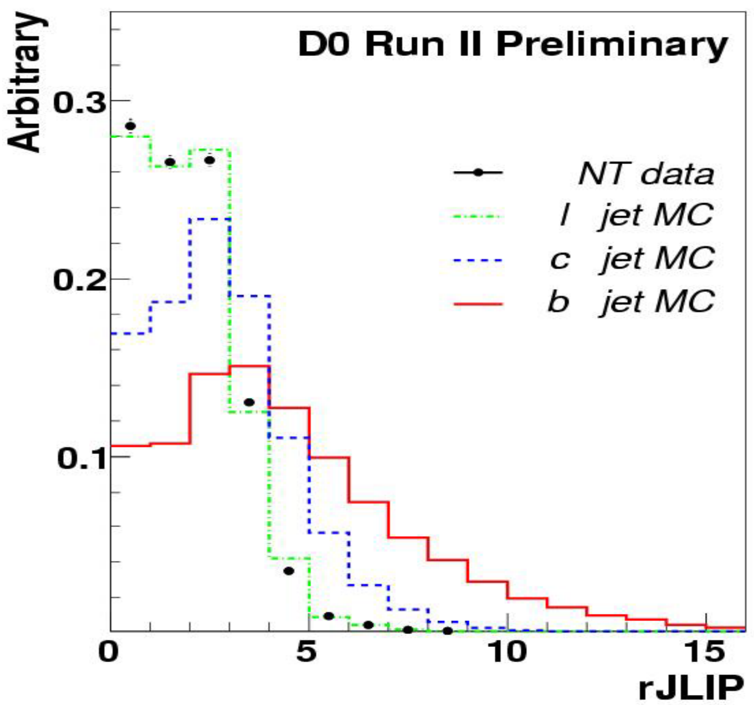


σ(Z+b)/σ(Z+jet) ratio measurement

- **Event Selection:**
  - Dilepton mass 70 ≤ M ≤ 110 GeV
  - At least one jet
    - p_T > 20 GeV; |η| < 1.1
- **Tagged Sample:**
  - Apply Neural Network tagging algorithm on jets to enrich b content
  - Use rJLIP variable to discriminate between b, c and light jets
    - rJLIP calculates probability for a jet to come from the primary vertex
- **Use data for light jet template, Pythia+Alpgen for b, c templates**
- **Use log likelihood fit to extract Z+b fraction**

➔ **Ratio consistent with SM**

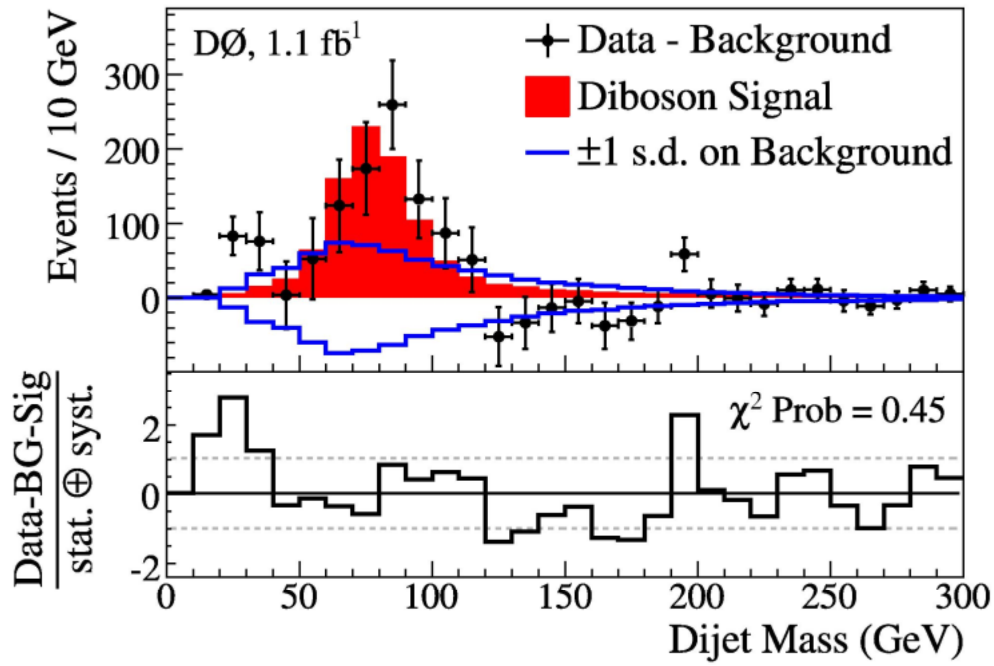




VZ observation by CDF and D0

WV→lvqq provides a benchmark measurement of a dijet mass resonance similar to the Higgs

•But no b-tagging



Main benchmark for our low mass
Higgs searches: observation of WZ(bb)/ZZ(bb)

VZ(bb) = ~4 x VH(115), but more backgrounds. Combine 3 search channels (llbb, vvbb, lvbb)

➔ perfect test if we observe VZ(bb) in the three low mass channels and in combination with CDF (Moriond 2011?).

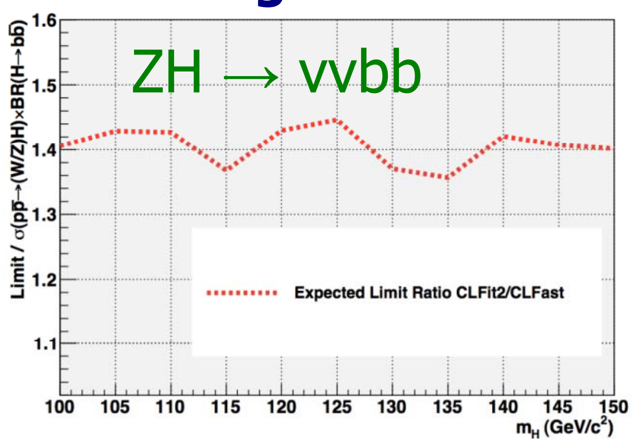
Systematic uncertainties

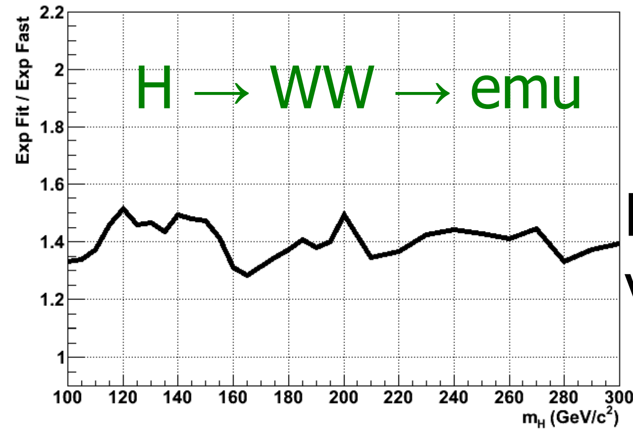
-Play a bigger role as the data sample grows (ie, statistical uncertainty falls) and as we get closer to SM sensitivity

Need to continue improving our understanding of all the relevant systematic

Especially the modeling of our signal and main backgrounds: Higher order corrections, different choices for scale and matching parameters

Significant degradation of sensitivity due to systematic uncertainties





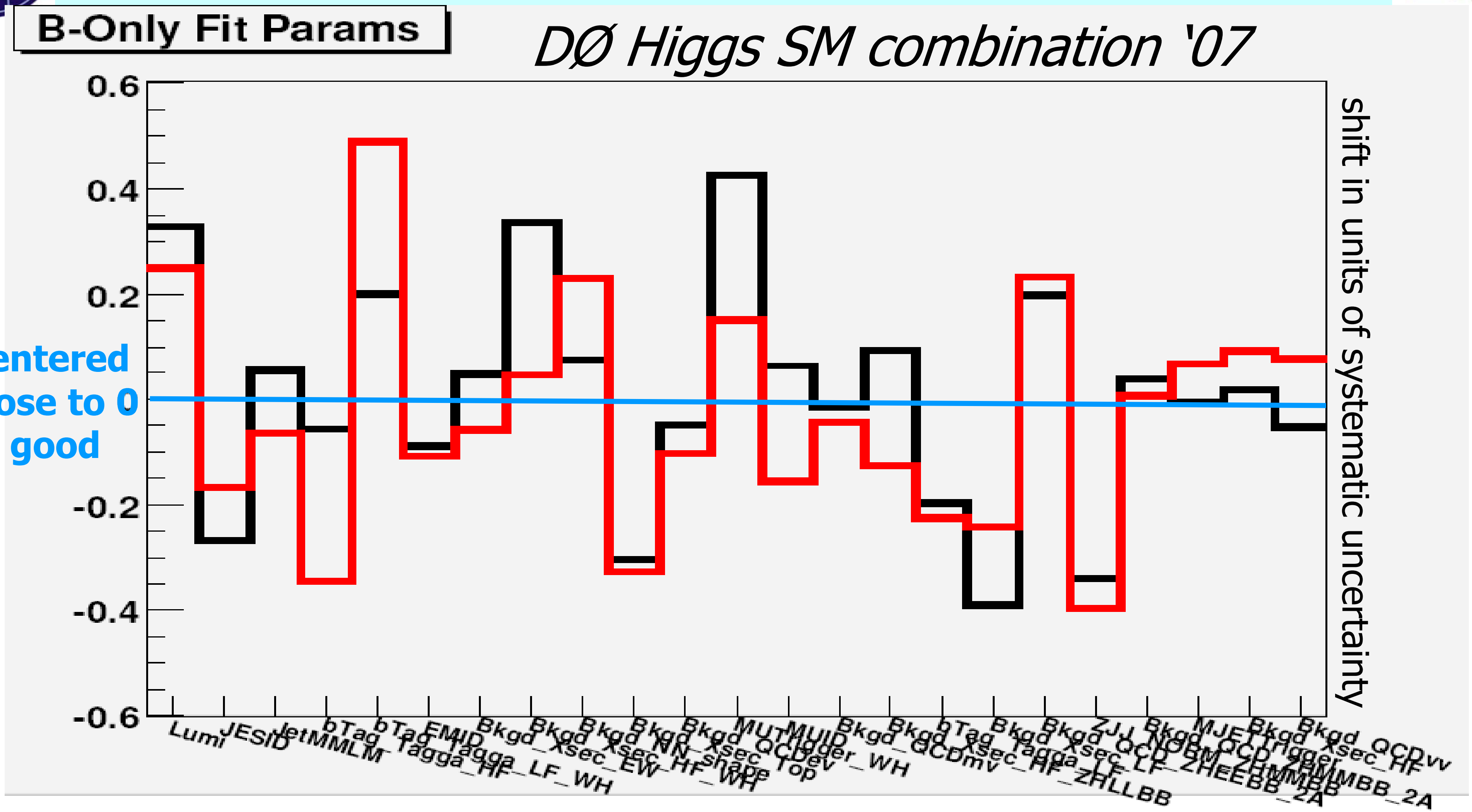
Limit degradation vs Higgs mass

Limiting the degrading effect of systematic uncertainties allows to improve the sensitivity on the 10% level

-Obtain a better understanding of the modeling of our backgrounds instead of using large systematic uncertainties

-An important part of algorithm improvements can be to reduce systematic errors associated to them (i.e. large degradation from b-tagging uncertainties)

Best fit for nuisance parameters



Centered close to 0 → good

- Error correlations between channels and experiments taken into account

-"shape error" used in many background or signal modeling uncertainties, strong impact on the limits.

Algorithm improvements: b-tagging

Improved b-tagging algorithms (b vs light jet discrimination)

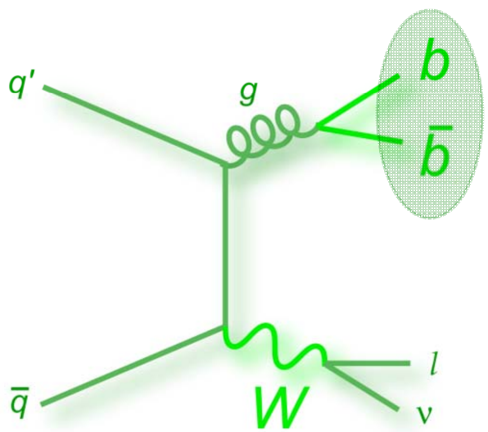
~10% increase in b-jet efficiency at same fake rate

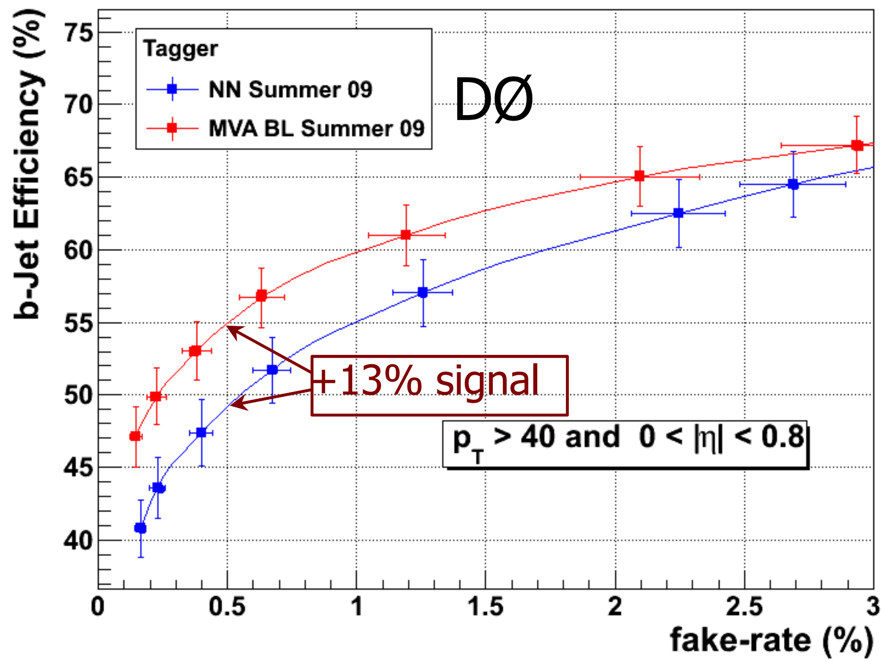
New, additional algorithms

-b vs. c discrimination

-b vs. bb (merged) discrimination

Not yet in recent Higgs results





Jet energy Resolution

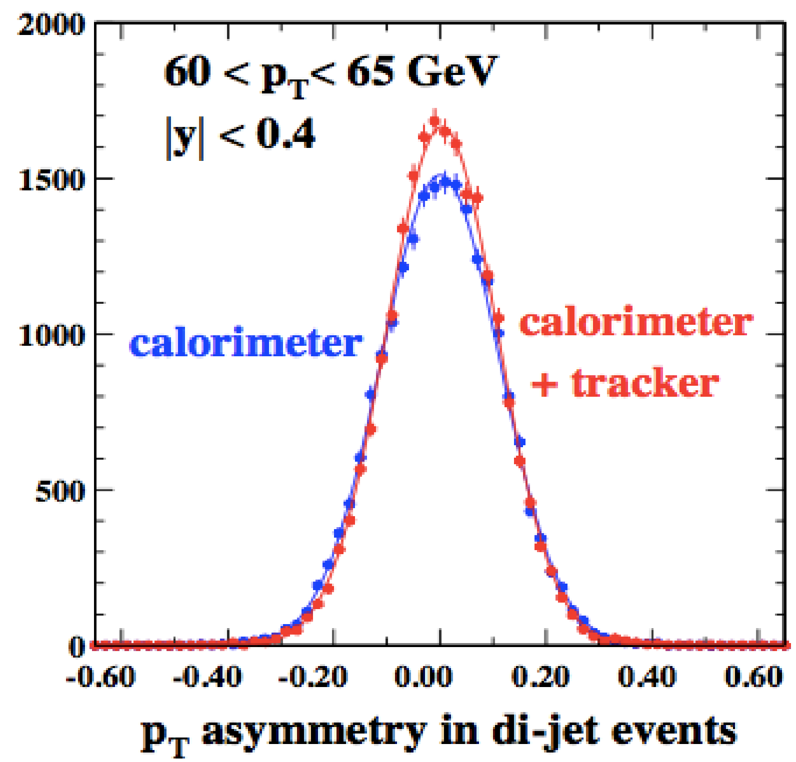
Lots of work in the past years to improve the jet energy resolution,

Still progress is being made

-Preshower correction

-Track-cal jets

-Neural Nets
(using also b-tag information)
-Combined correction



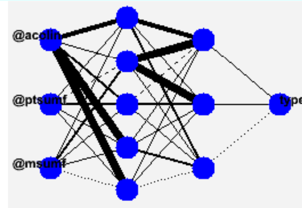
Dijet mass remains the best discriminating variable at low mass

→high priority to maximize the gain from these algorithms

Multivariate Analysis (MVA)

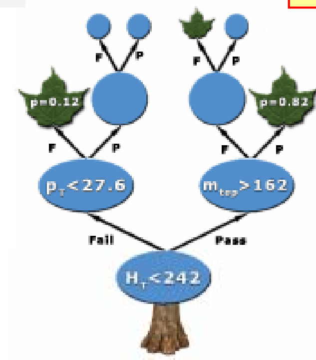
In order to maximize sensitivity

- **Neural Network (NN)**



Main Inputs at low mass:
- Dijet mass, p_T of dijet
- W p_T, Z p_T, Sphericity
- ΔR_{jj} , $\Delta\phi_{jj}$, $\Delta\eta_{jj}$

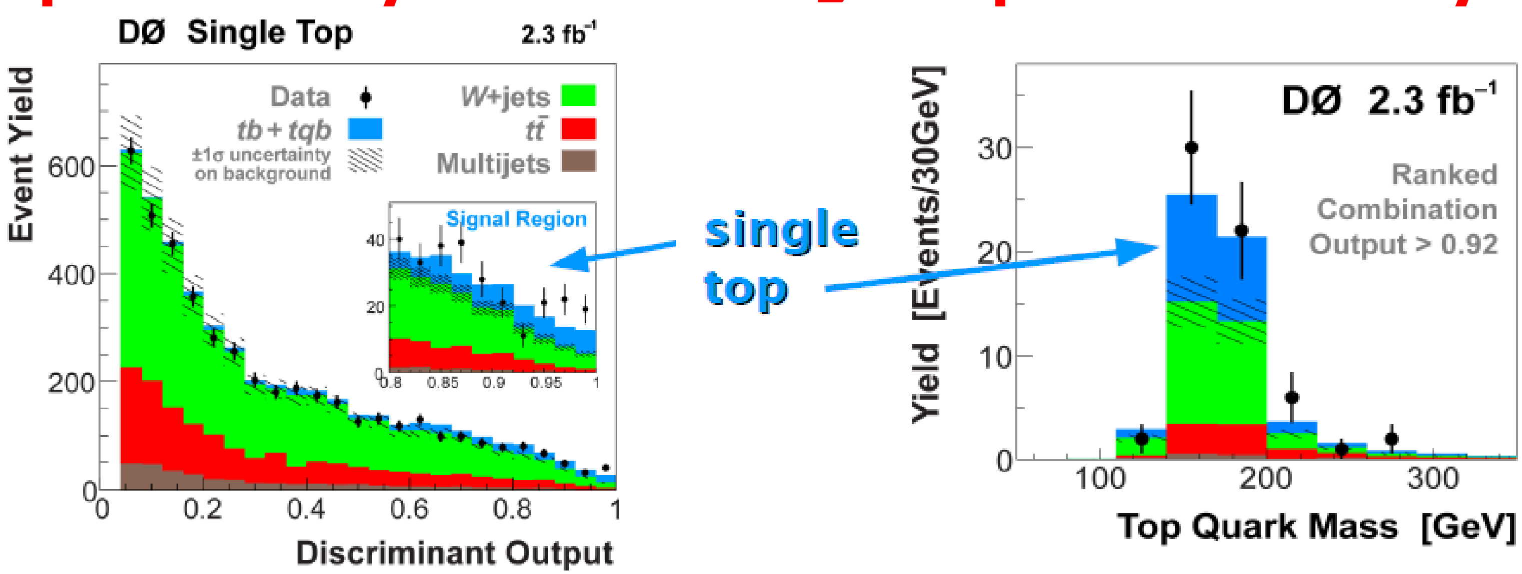
- **Boosted Decision Tree (BDT)**
  - BDT can handle larger number of inputs → less dependent on the selection of input variables



- **Matrix Element (ME)**
  - Event probability can be obtained by integrating ME
  - Input is four-momentum vector of each object

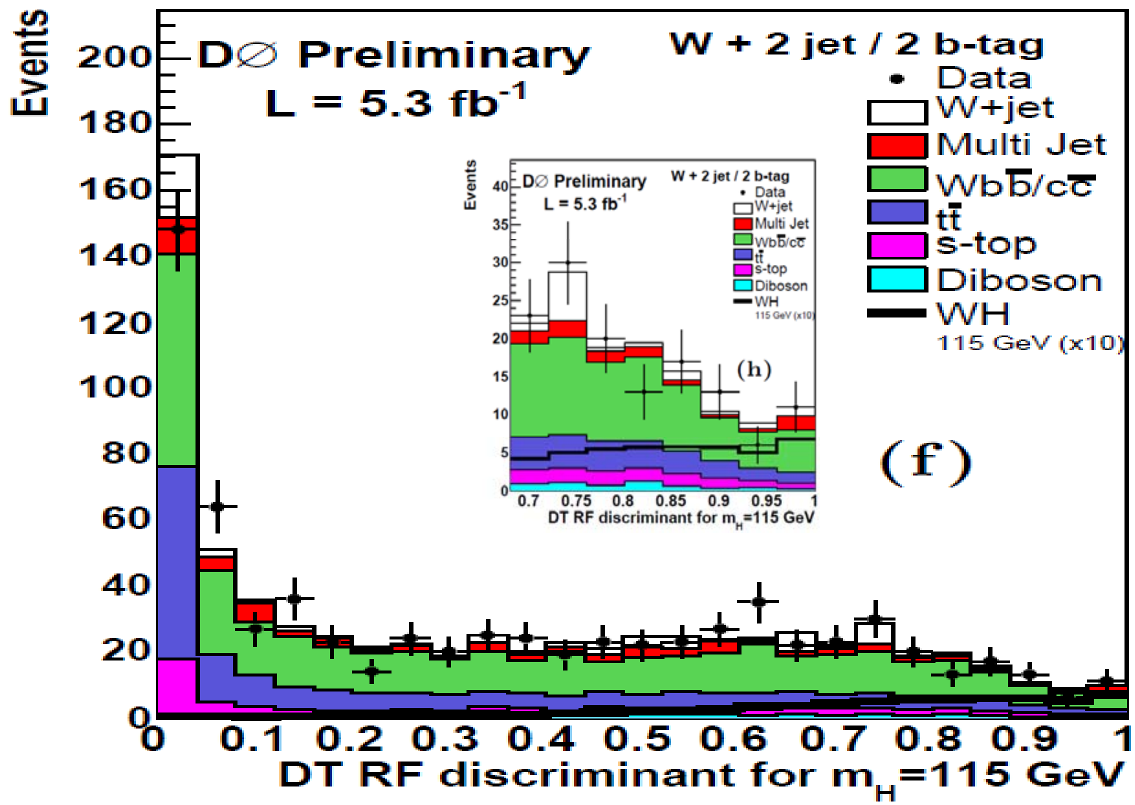
These three approaches are often combined by Neural Net / BDT

→Experimentally tested on Single Top observation by CDF/DØ



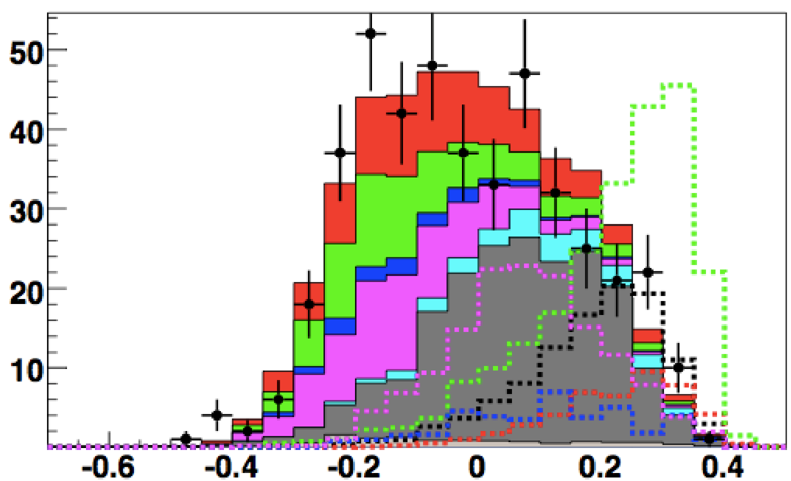
Final Discriminant

Refining the work on final discriminant, leads to sensitivity improvements



Example WH → lνbb:

Upgrading from NN to RF allowed for a ~10% gain in sensitivity



Example ZH → ττjj:

Combine several BDTs instead of cuts gives

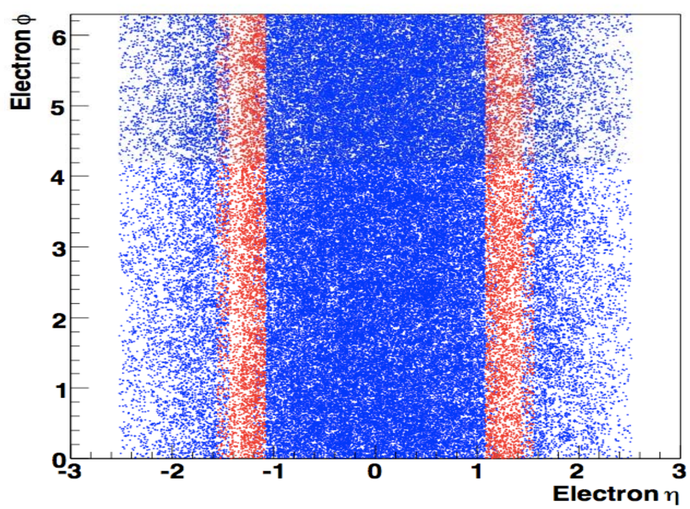
~10% sensitivity gain

Signal Acceptance

Continue to work to maximize signal acceptance

Example: ZH channels

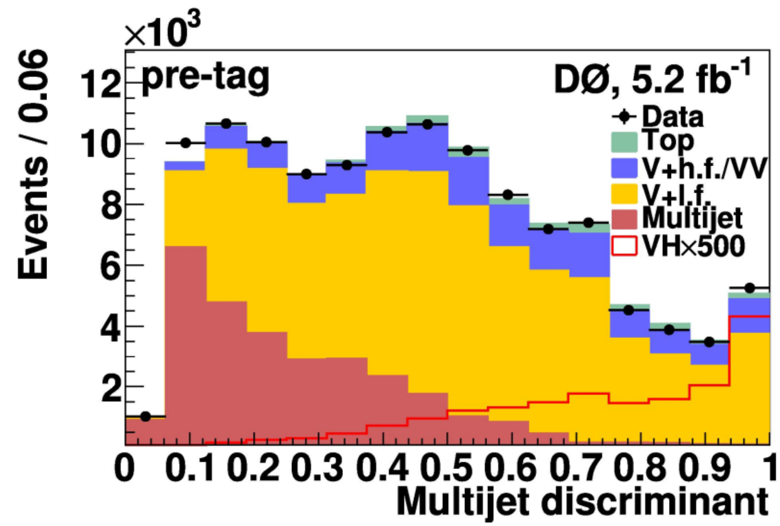
Electrons in inter calorimeter regions



mu+track

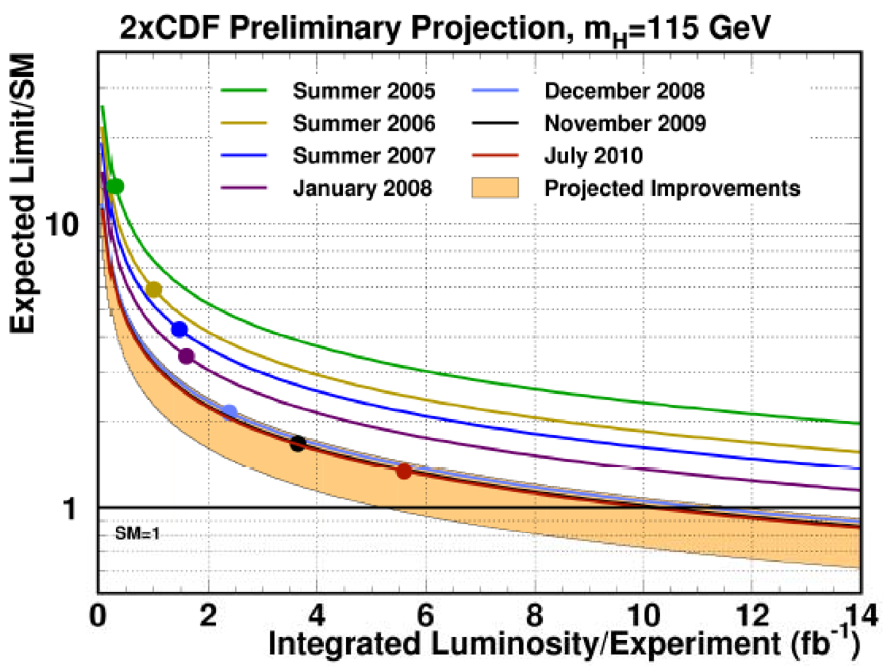
Already got ~8% increase in signal yields per lepton

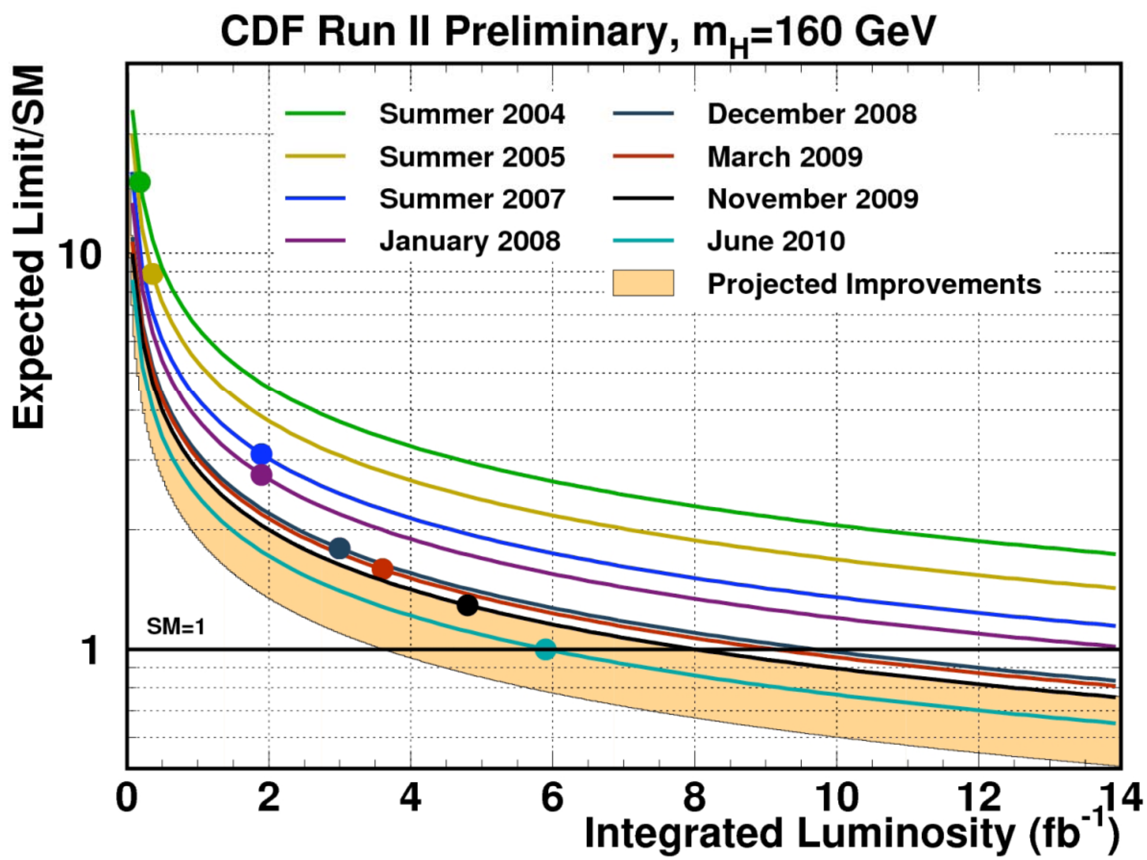
Replace several cuts on kinematic variables by cut on discriminant



➔ sensitivity improvement

Improvements beyond luminosity verified on Data

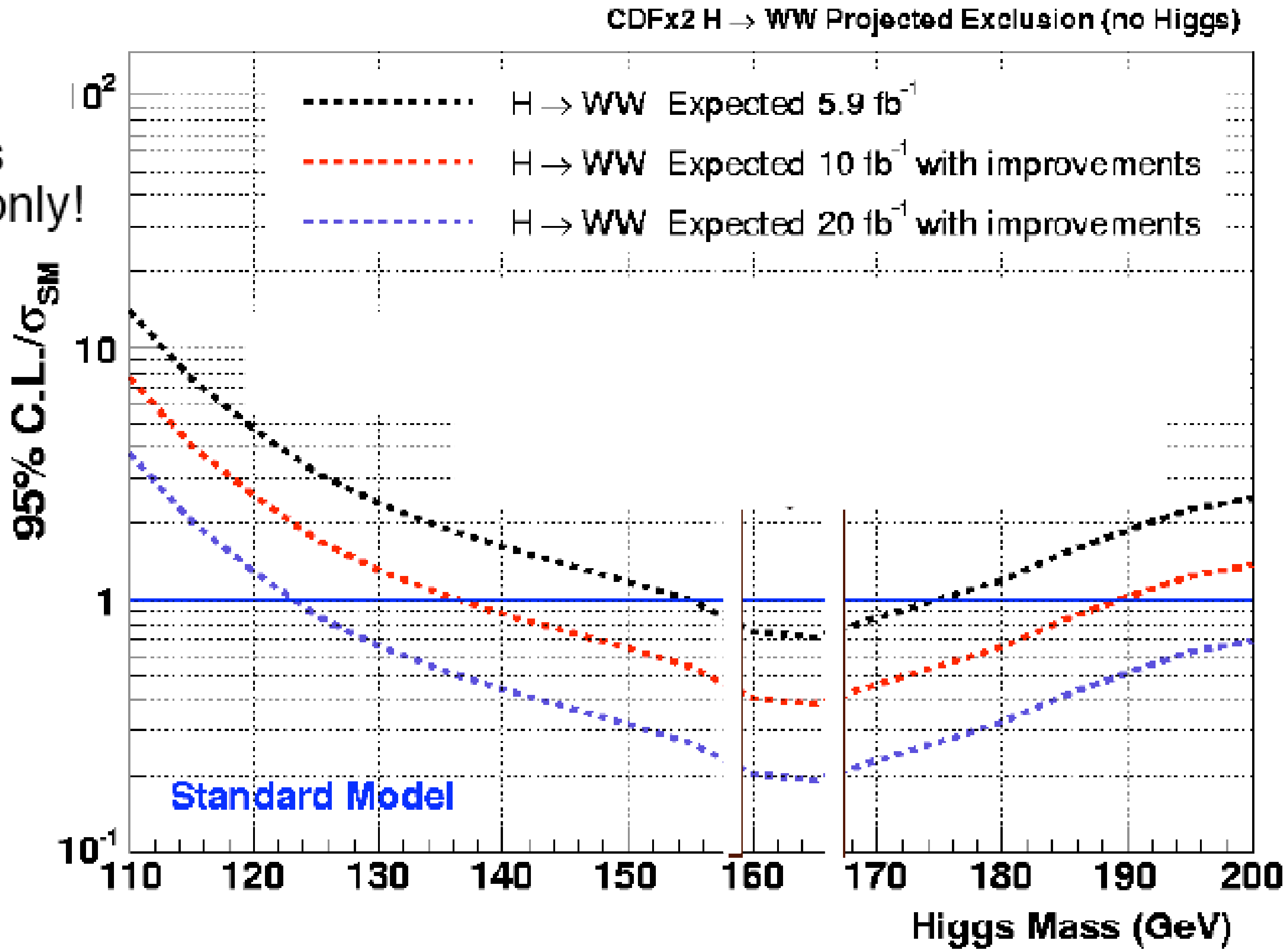




Good progress in particular at high mass →

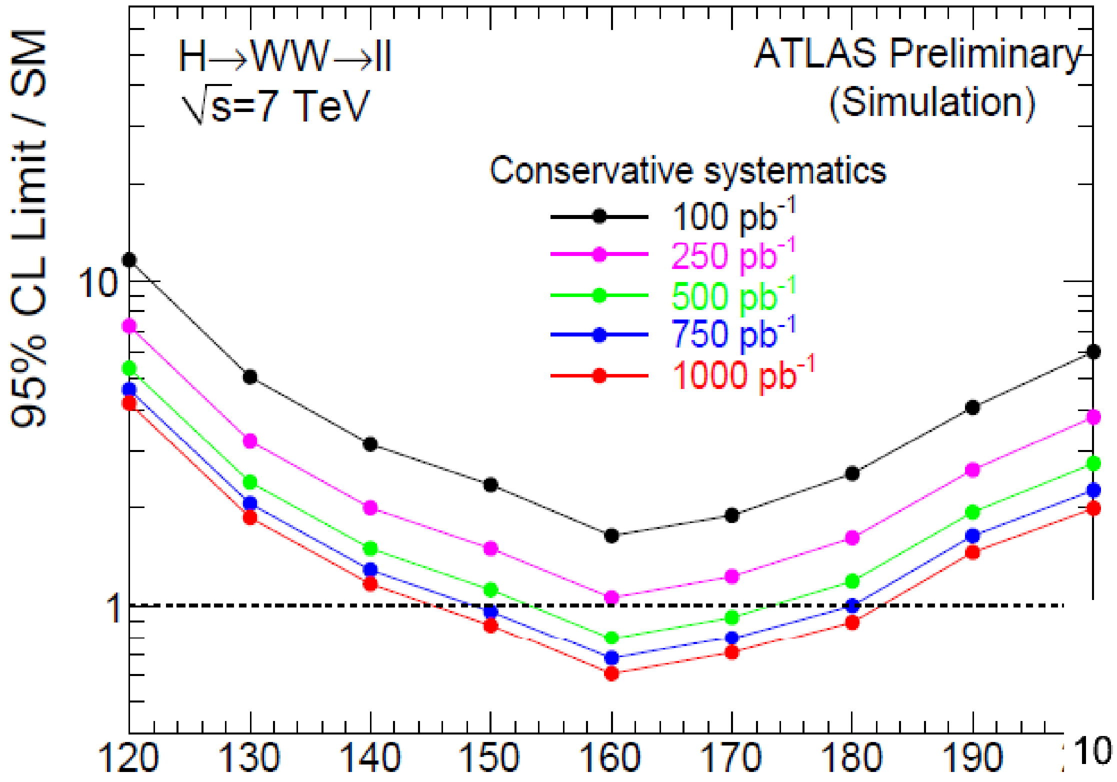
Exclusion at the end of 2011

High Mass
analyses only!



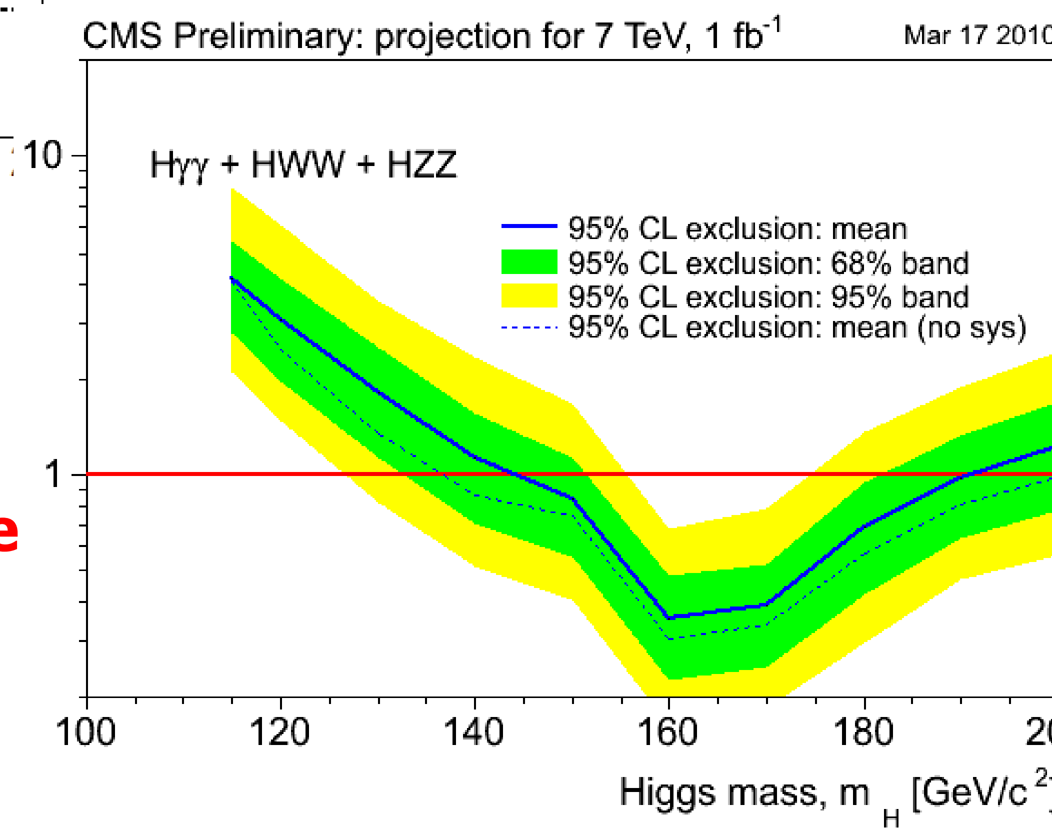
If No SM Higgs, expect exclusion from 140 to 190

LHC first projections shown at ICHEP



Both foresee an exclusion 145-185 GeV with 1 fb^{-1}

→Need to improve and/or combine to be competitive with Tevatron.

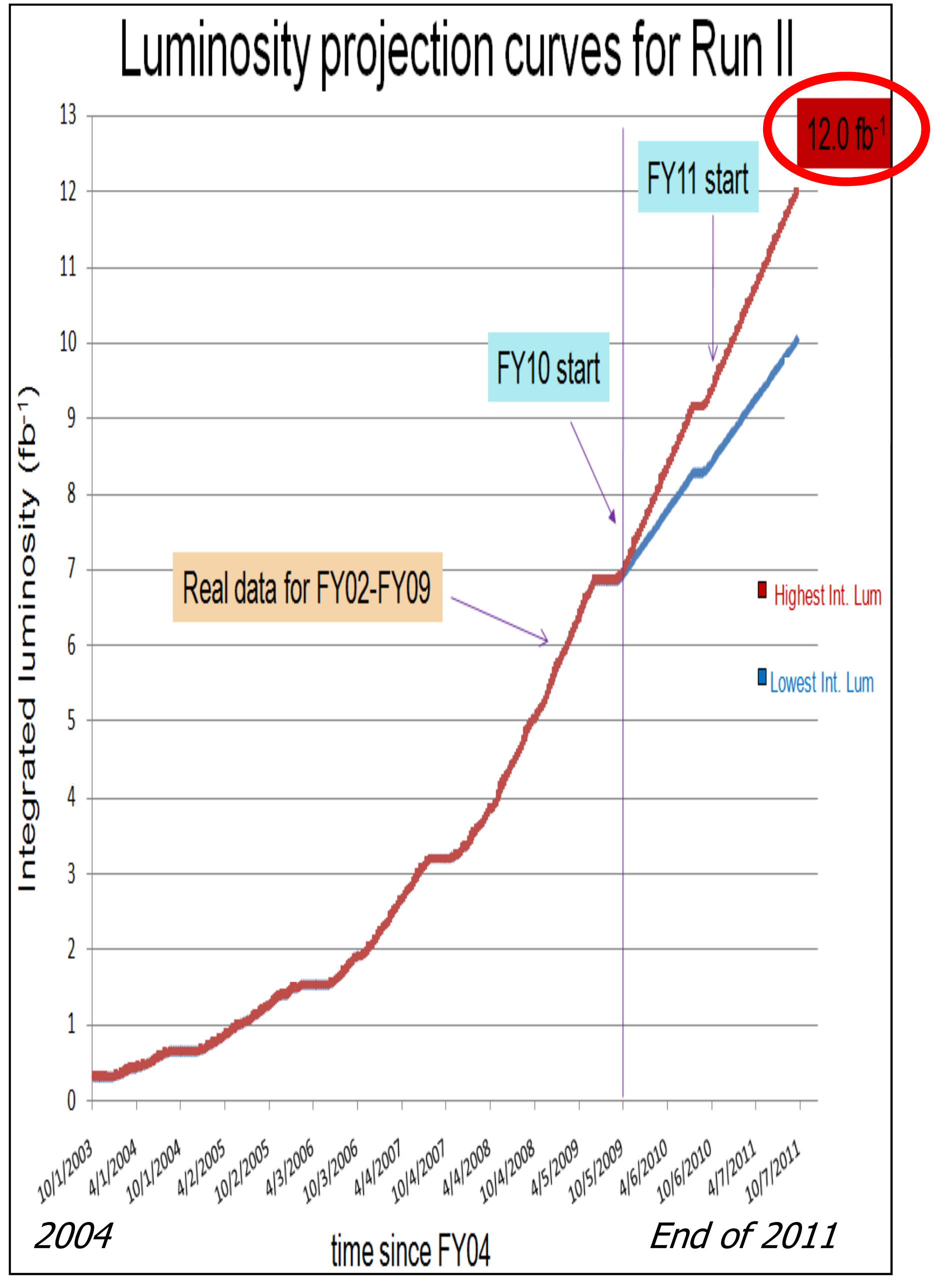


From 2011 to 2014 @ Tevatron

- **Expect 2 fb-1 of recorded data for each year after 2011**

➔ **12 fb-1 analyzed end of 2012**

➔ **16 fb-1 analyzed end of 2014**

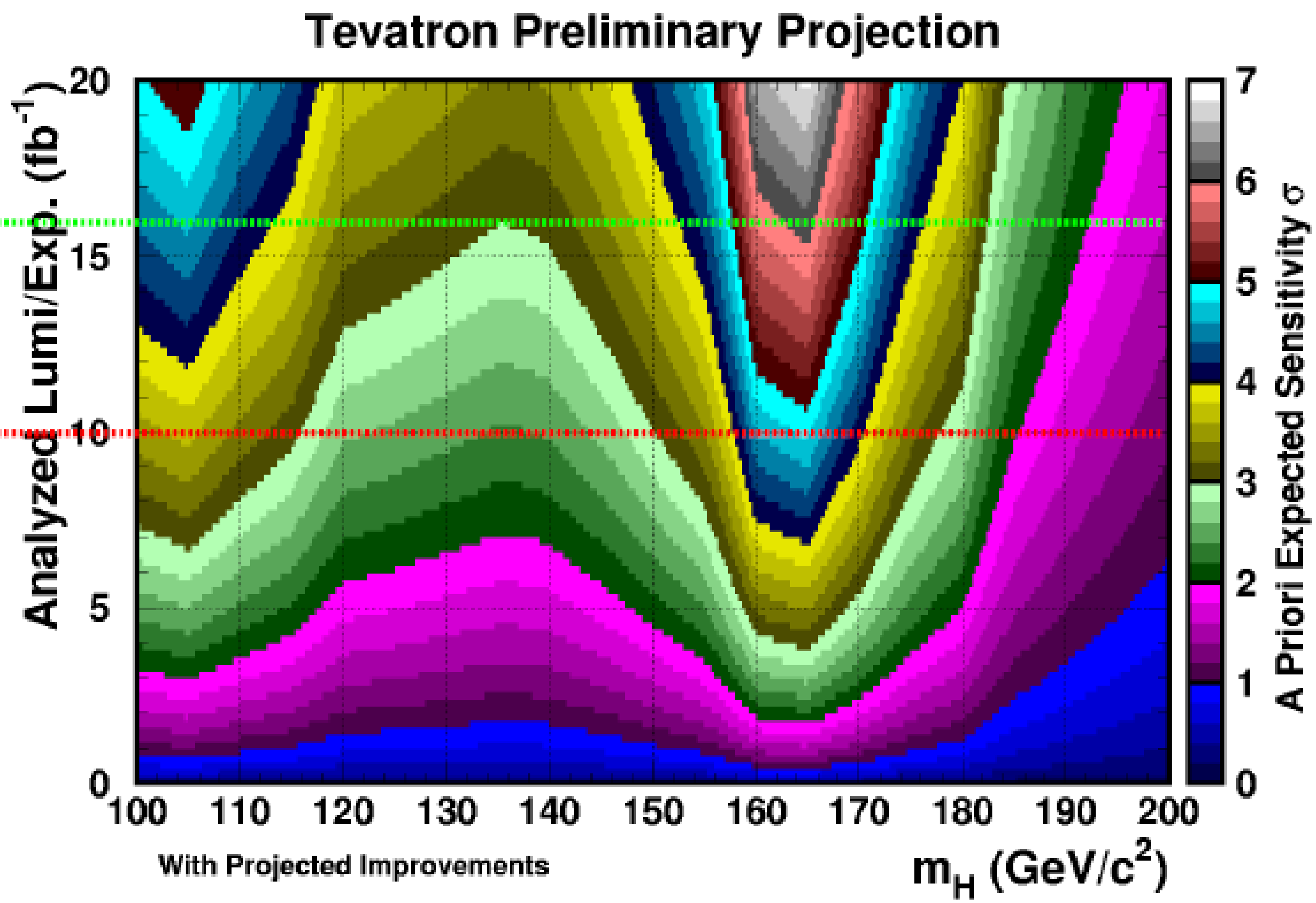


Sensitivity projections

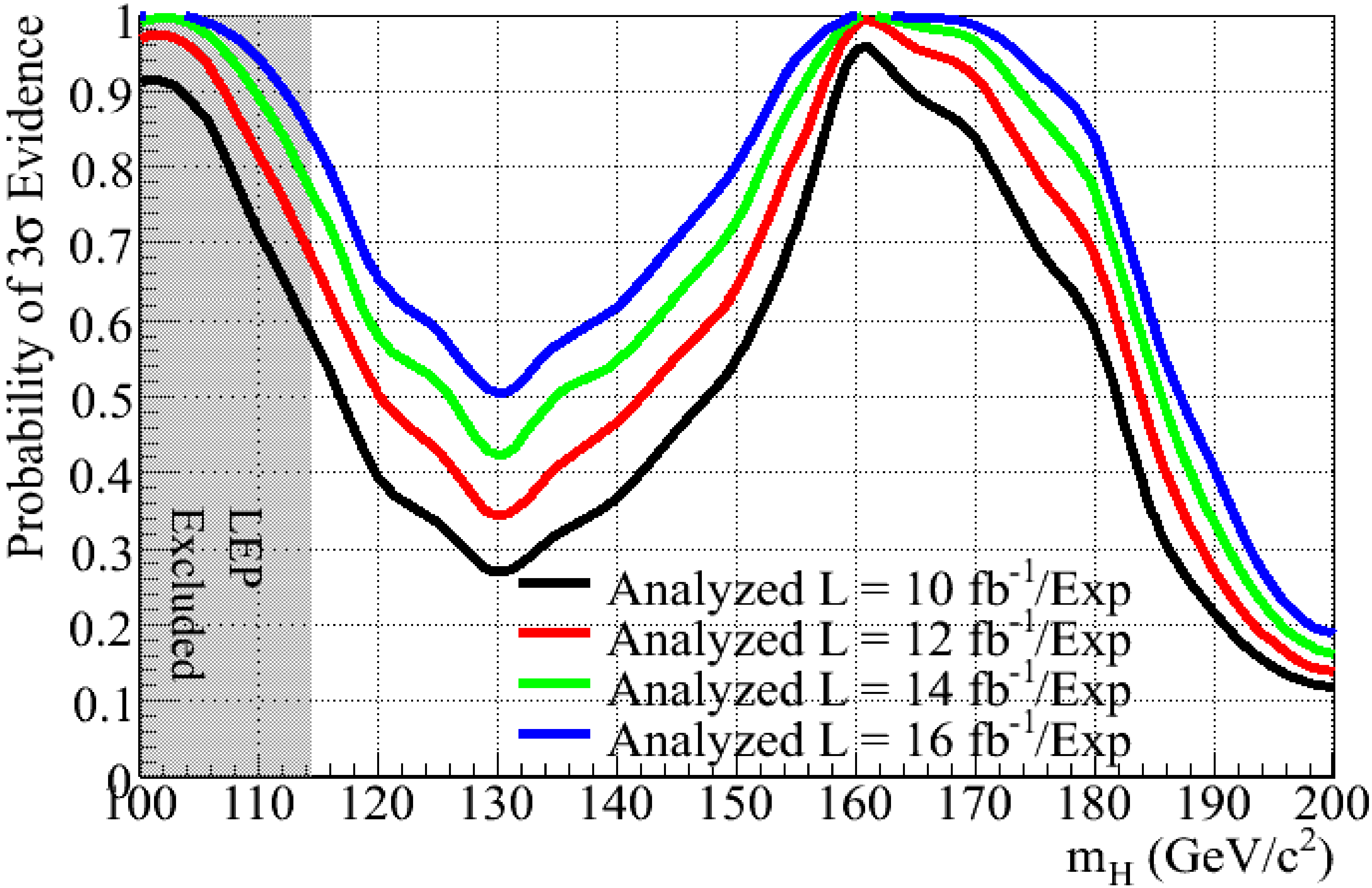
16 fb^{-1}:
3σ expected from
100-180 GeV

~4σ at 115 GeV

End of 2011:
>2.4σ expected over
entire mass range



Projections in Higgs Sensitivity



Using P5 plots we extended combined projected Tevatron Higgs sensitivity for 3 sigma evidence to luminosities above 10 fb^{-1}

5 SM Scenarios (personal view)

- **Heavy SM Higgs (above 185 GeV)**

➔ good for LHC run II (>2013), Tevatron can try up to ~200 GeV
not likely scenario though given E-W fits.

- **145 GeV SM Higgs**

➔ ~ 50% probability to have 3 σ evidence @ Tevatron-2011

➔ similar at LHC with 1 fb^{-1} (combining or improving)

- **130 GeV SM Higgs**

➔ ~ 25% probability to have 3 σ evidence @ Tevatron-2011

➔ ~ 50% probability to have 3 σ evidence @ Tevatron-2014

➔ LHC needs > 2 fb^{-1} (even combining and barring significant improvements)

- **115 GeV SM Higgs**

➔ ~ 50 (80)% (probability to have 3 σ evidence @ Tevatron-2011 (2013),
good chances to reach 4 σ (if lucky and 2014, 5 σ observation!)

➔ LHC needs significant time in Run II

- **No SM Higgs**

➔ Tevatron exclude 115-185 GeV @ Tev-2011, LHC confirms down to 140 GeV

Gregorio Bernardi / LPNHE-Paris

Conclusions

- We’re getting into the crucial moments for the SM Higgs if Tevatron continue running beyond end of 2011… else there is a serious danger to have to wait until >2014 to discover a light SM Higgs.
- We need to validate the b-bbar observation mode at the Tevatron, with WZ/ZZ CDF-D0 combined observation
- We need to keep searching for Susy Higgses to make sure we don’t let them slip away (another talk ;))
- Tevatron could very well be the best place to measure HWW and HZZ couplings if Higgs is at low mass.