Physics 222 UCSD/225b UCSB

Lecture 13

Higgs Hunting --- The experimental Perspective

The higgs vertices

- hWW $\propto m_W^2/v$
- hZZ $\propto m_Z^2/v$
- $hf\bar{f} \propto m_f/v$
- hhWW $\propto m_W^2/v^2$
- hhZZ $\propto m_Z^2/v^2$

v = vev of higgs ~ 246GeV

All of these vertex factors can in principle be probed experimentally.

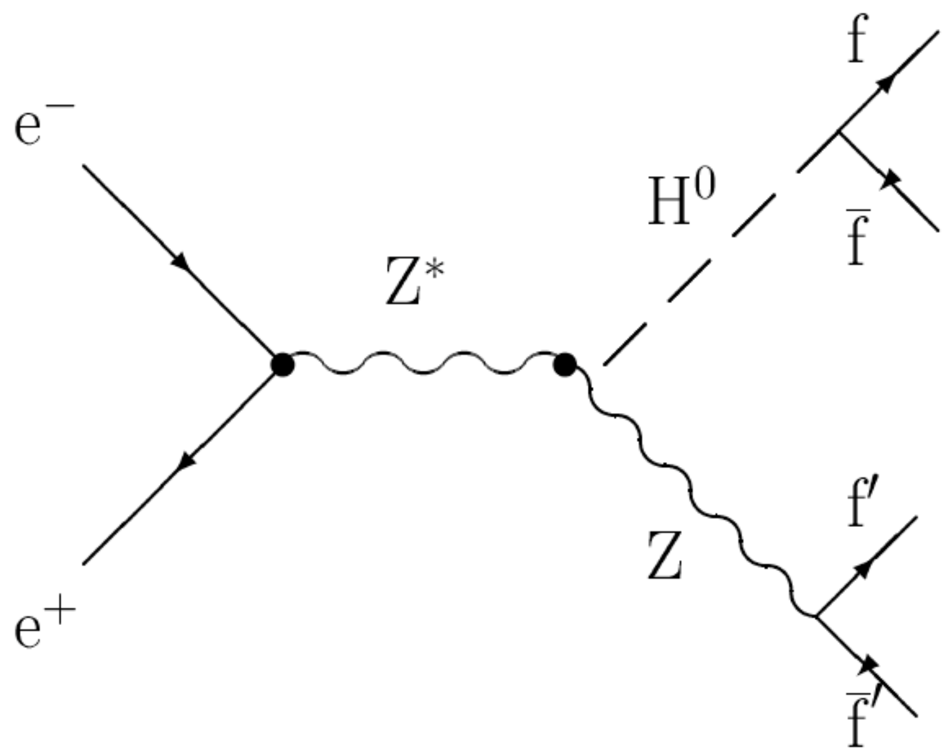
In practice, higgs physics is difficult because e,u,d have small mass, and thus couple weakly to higgs.

Particles we can easily build colliders with couple very weakly to higgs !!!

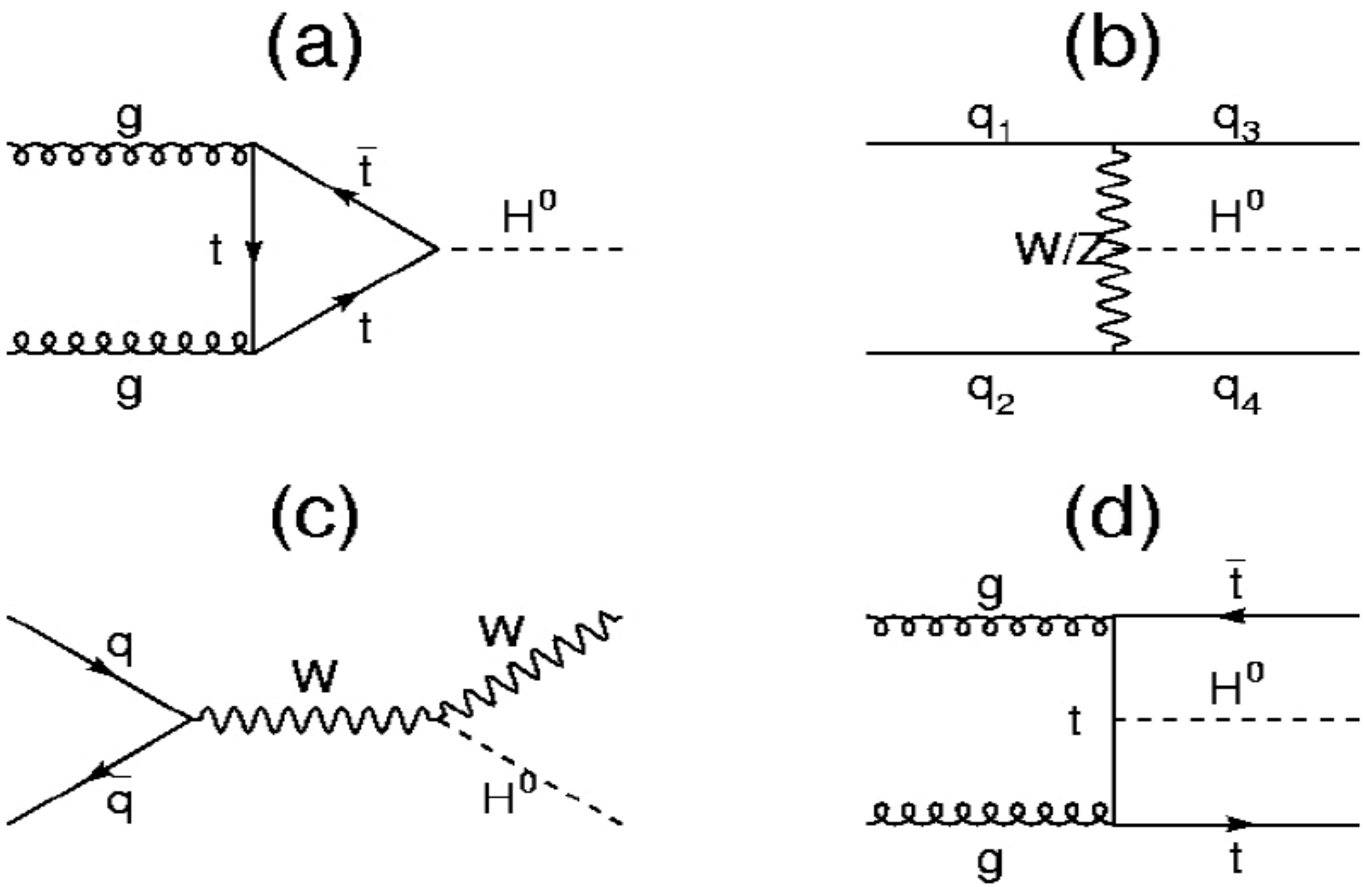
Depend on "higgsstrahlung" off W,Z and loops for higgs production !!!

Production Mechanisms (e+e-)

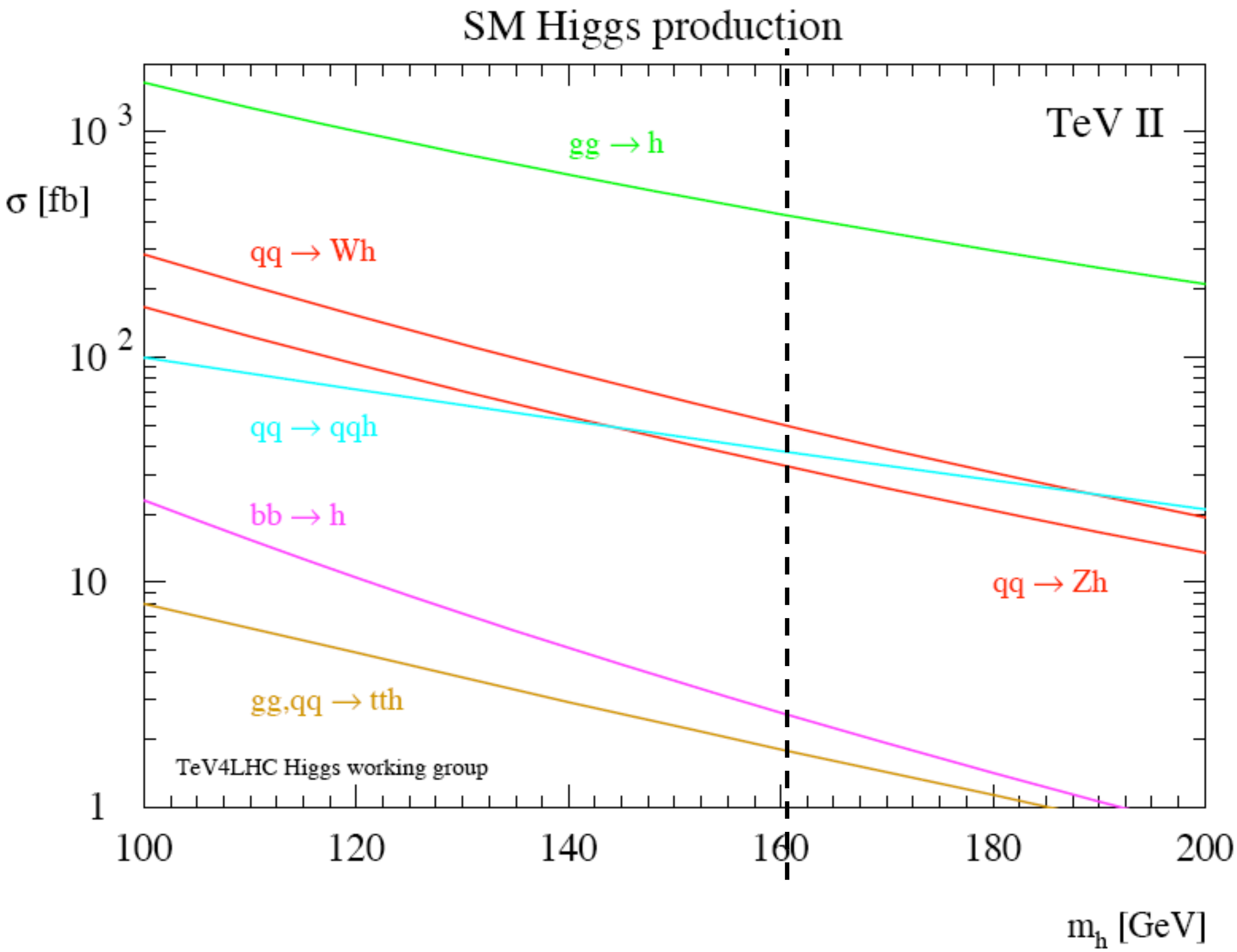
- Associative production with Z.
  - Depends on ZZh coupling:



Production Mechanisms (p+p-)

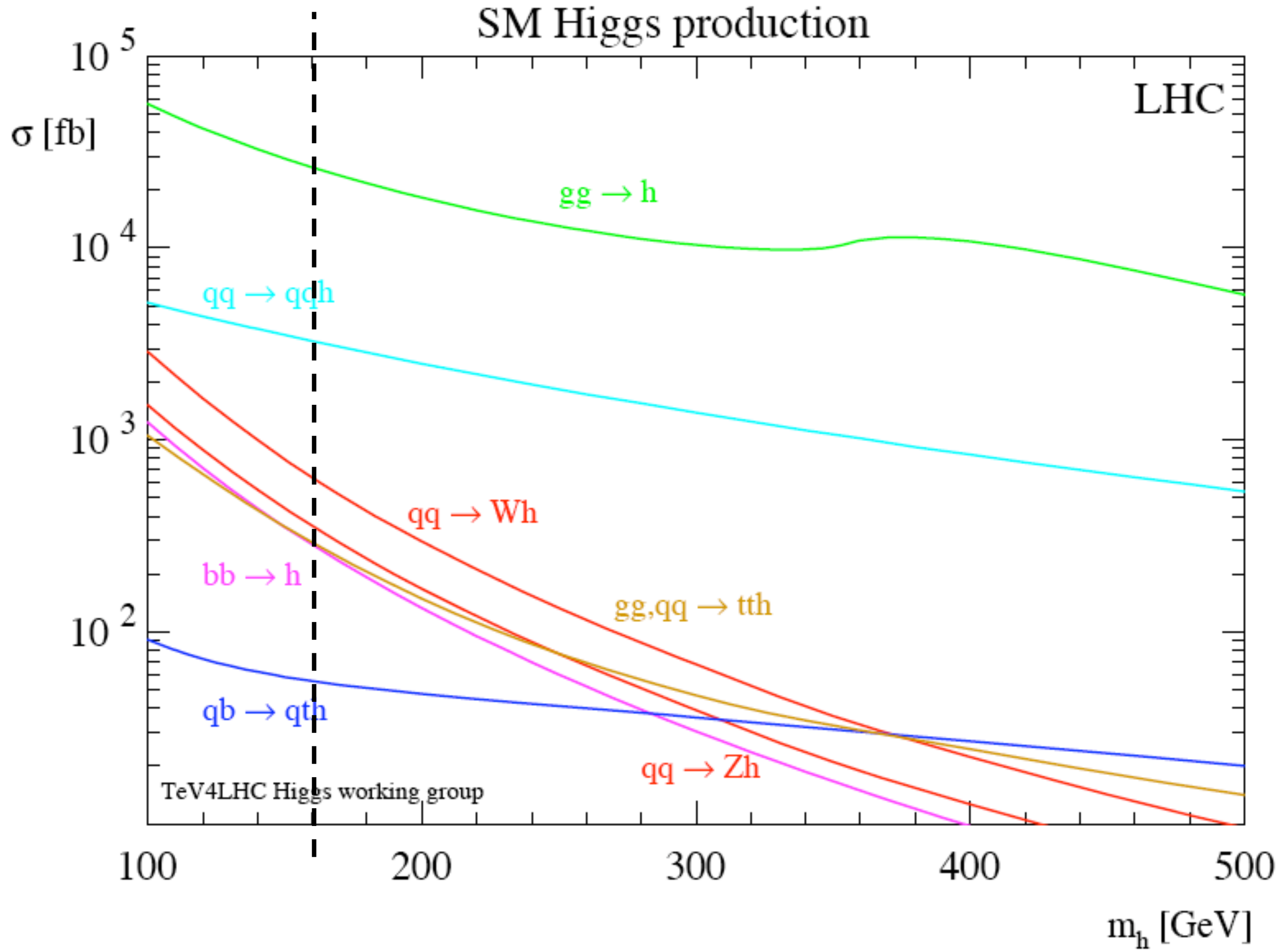


Production at Tevatron



E.g.: For h160 we expect ~430 higgs to be produced in 1fb-1.

Production at LHC



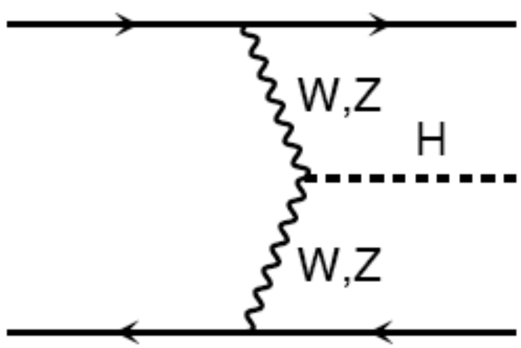
E.g.: For h160 we expect ~26,000 higgs to be produced in 1fb-1.

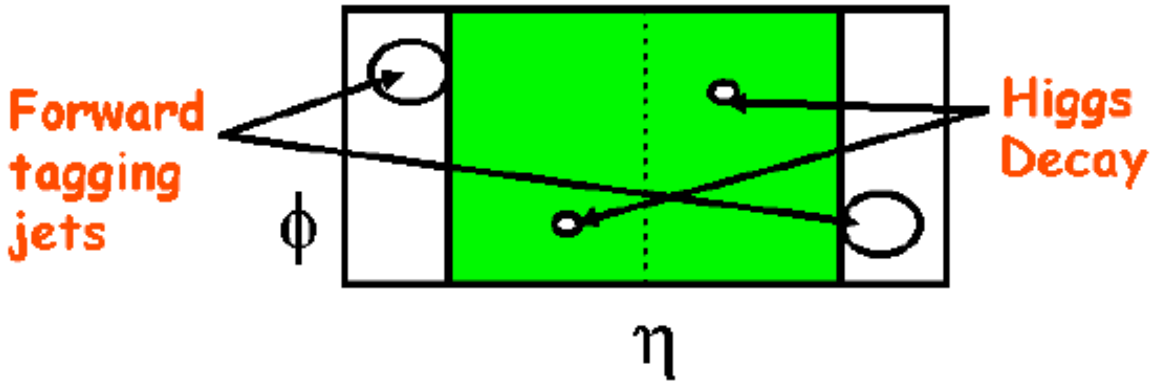
Noteworthy Details

- gg production of higgs dominates.
  - And scales by factor ~60 from Tevatron to LHC.
- Subdominant processes differ between Tevatron and LHC.
  - Associative production does not scale up as much as gg because it requires q qbar in the initial state.
    - Our understanding of PDF from last quarter applies here !!!
  - tth is close to competitive to Zh and Wh at LHC.
    - More on this later.

Aside on weak boson fusion

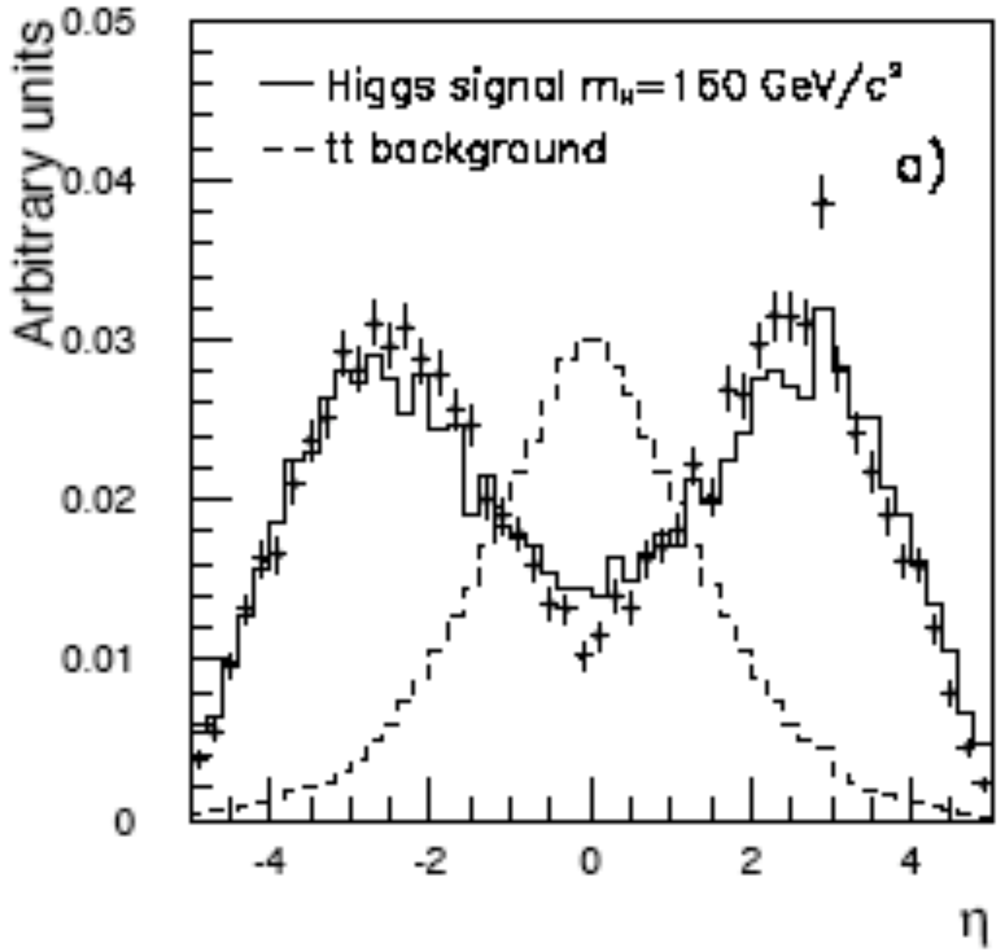
- Interesting signature:





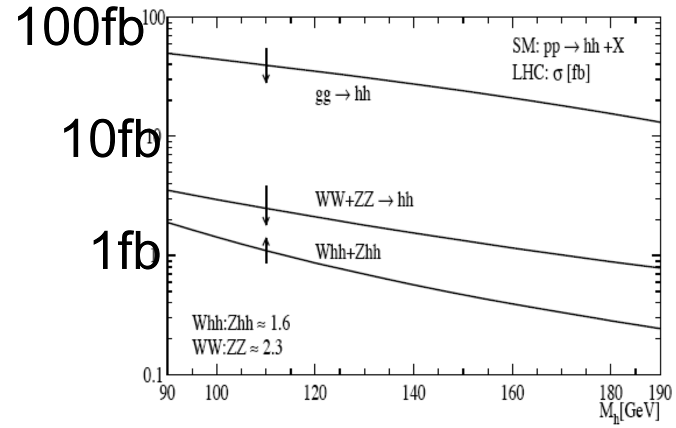
This process may play a role at the LHC if the rapidity gap signature can be made to work well.

WBF ATLAS study.
Both distributions normalized to unity.
Solid = parton level. Data = after reconstruction.

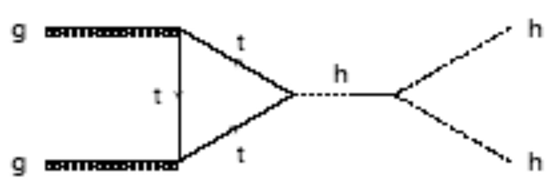


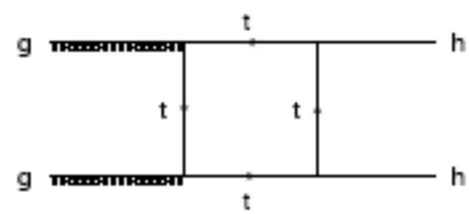
The higgs self coupling vertices

- hhh $\propto m_h^2/v$
- hhhh $\propto m_h^2/v^2$



While these vertices are very interesting theoretically, as they define the higgs potential, they are even more difficult experimentally.





In Standard Model these 2 diagrams interfere destructively, making the rate for hh production at LHC O(10-100)fb.

hh production x10^{-4} smaller than h production at LHC !!!

Higgs Decay

b dominates

Linear growth with m_h

$$\Gamma_{f\bar{f}} = \frac{N_c G_F m_f^2 M_H}{4\sqrt{2}\pi}\beta^3 \qquad \text{where } \beta = \sqrt{1 - \frac{4m_f^2}{M_H^2}}$$

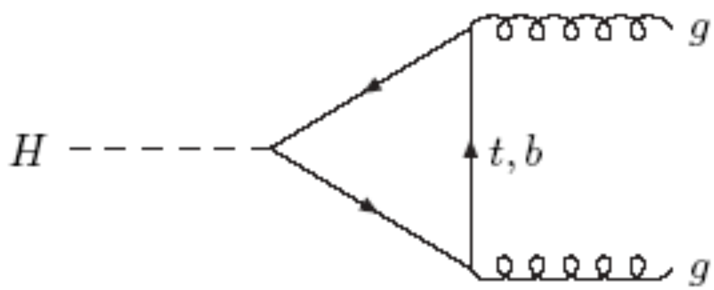
Above threshold for VV production:

$$\Gamma_{VV} = \frac{G_F M_H^3}{16\sqrt{2}\pi}\delta_V \beta\left(1 - x_V + \frac{3}{4}x_V^2\right) \text{ where } \begin{cases} \delta_{W,Z} = 2, 1 \\ \beta = \sqrt{1 - x_V} \\ x_V = \frac{4M_V^2}{M_H^2} \end{cases}$$

WW and ZZ are 2:1

W,Z dominate over fermions above threshold.

Higgs Decays via Loops



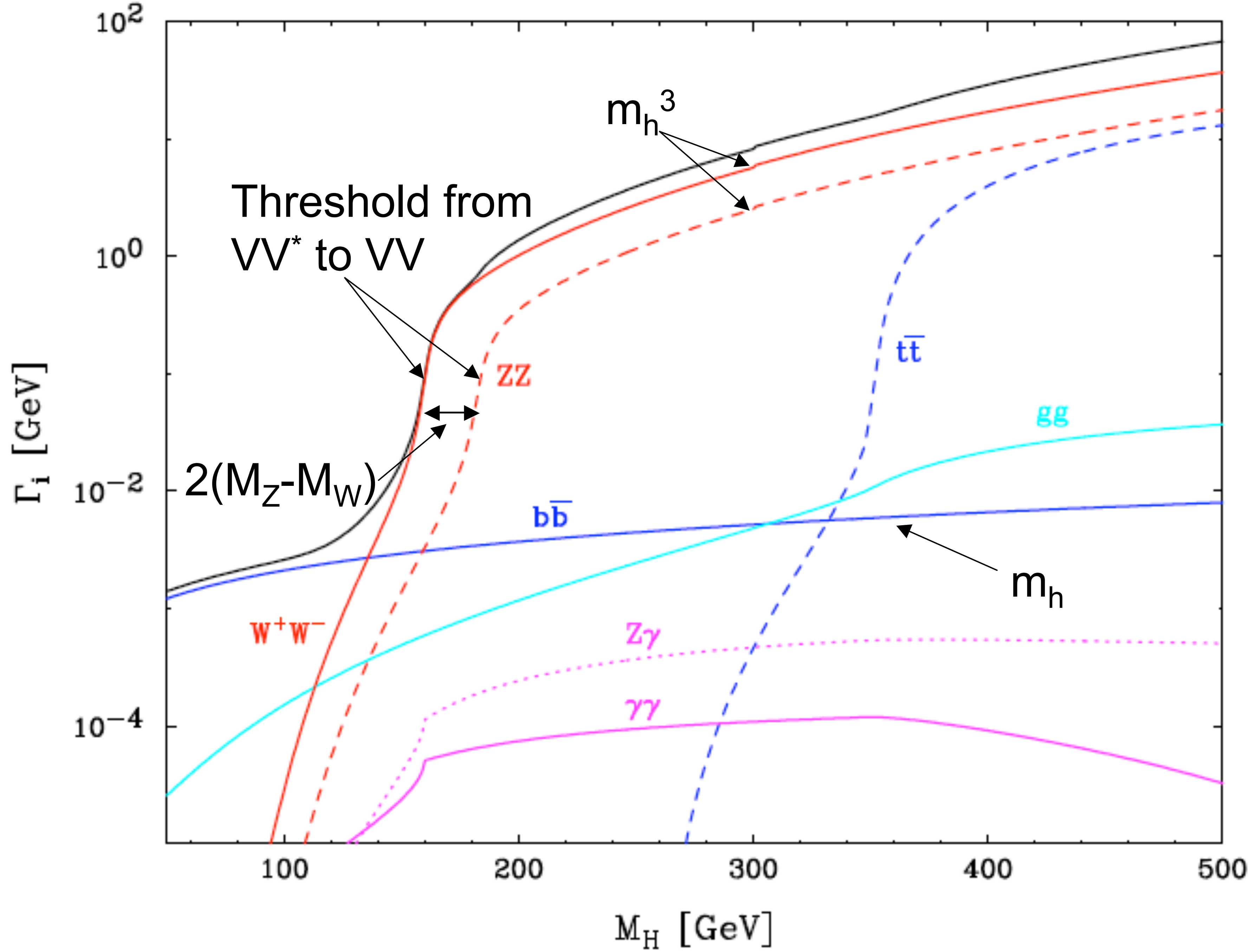
h -> $\gamma\gamma$

h -> $Z\gamma$

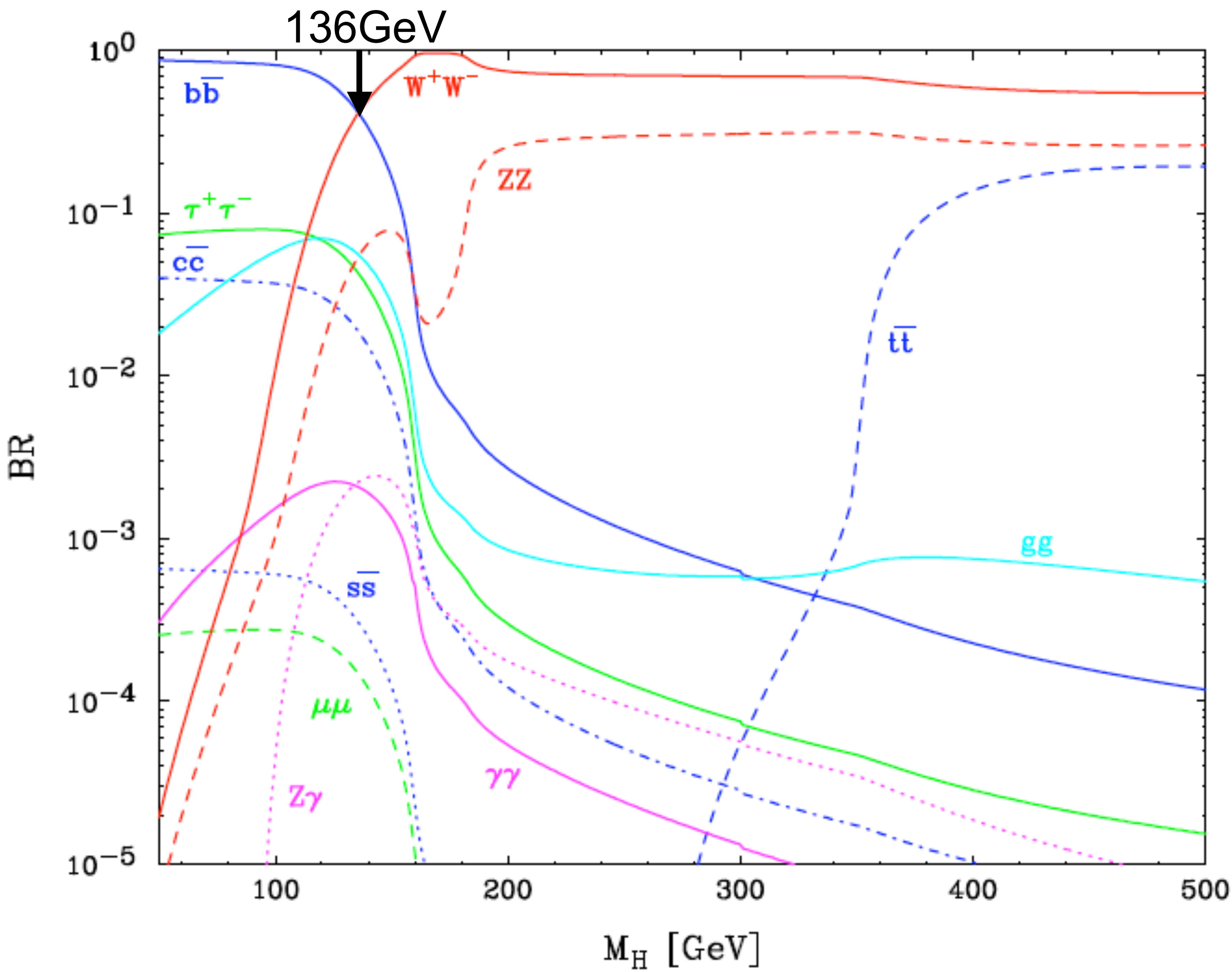
h -> gg

$$\Gamma \propto m_h^3 \times F((m_f/m_h)^2)$$

Here f=fermion in the loop. For photon and Z, there can also be a W in the loop. F modifies the dependence on higgs mass significantly, and differently for each case.



m_h^3
Threshold from
VV^* to VV
ZZ
$t\bar{t}$
gg
$2(M_Z-M_W)$
$b\bar{b}$
m_h
W^+W^-
$Z\gamma$
$\gamma\gamma$
10^2
10^0
10^{-2}
10^{-4}
Γ_i [GeV]
100
200
300
400
500
M_H [GeV]



136GeV
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
BR
$b\bar{b}$
W^+W^-
ZZ
$\tau^+\tau^-$
$c\bar{c}$
$t\bar{t}$
gg
$s\bar{s}$
$\mu\mu$
$\gamma\gamma$
$Z\gamma$
100
200
300
400
500
M_H [GeV]

Aside on Branching Ratio

- $BR_i = \Gamma_i / \Gamma_{total}$
- If Γ_i varies little near threshold of WW but Γ_{WW} increases dramatically, then Br_i for all final states except WW will decrease dramatically.
- This significally changes the higgs phenomenology near WW threshold.

Detection Issues

- Triggering
  - For the purpose of higgs physics, ATLAS and CMS trigger only on leptons and photons.

  => Need a leptonic W or Z decay for all higgs decays except for two-photons !!!
- W -> (e || mu) nu ~23%
- Z -> (ee || mumu) ~7%
- top -> Wb -> (e || mu) nu ~23%

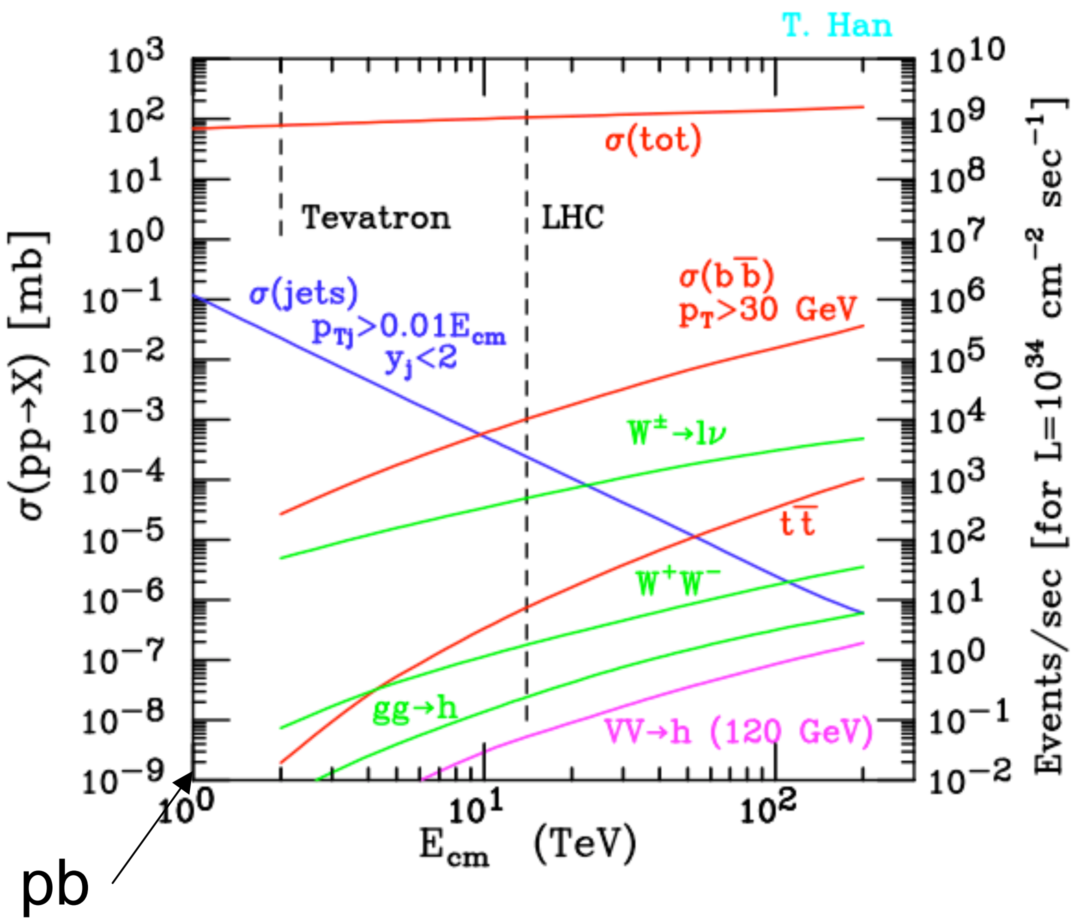
Signal vs Background @ LHC

$\sigma(bb) / \sigma(h_{120}) \sim 10^5$
$\Rightarrow$ hopeless

$\sigma(tt) / \sigma(tth_{120}) \sim 10^4$
$\Rightarrow$ very difficult but at least there are clear signatures:

ll & MET & bbbb
l & MET & bbbb

$\sigma(WW) / \sigma(h_{160}) \sim 5$



Low Mass Higgs @ LHC

- Example: 115GeV
  - h -> $\gamma\gamma$ has a BR penalty of ~ 10^{-3}
  - tth -> l & MET & bbbb has a Xsect x BR penalty of ~$3x10^{-3}$
  - h -> WW -> ll & MET has a BR penalty of ~ $6x10^{-3}$
  - h -> ZZ -> 4l has a BR penalty of ~ $5x10^{-5}$

Comparing the penalty gives you an idea of the signal yield. Estimating the bkg is harder.

Low Mass Higgs @ LHC

- Example: 136GeV
  - h -> $\gamma\gamma$ has a BR penalty of ~ 2×10^{-3}
  - tth -> l & MET & bbbb has a Xsect x BR penalty of ~3×10^{-3}
  - h -> WW -> ll & MET has a BR penalty of ~ 3%
  - h -> ZZ -> 4l has a BR penalty of ~ 5×10^{-4}

Comparing the penalty gives you an idea of the signal yield. Estimating the bkg is harder.

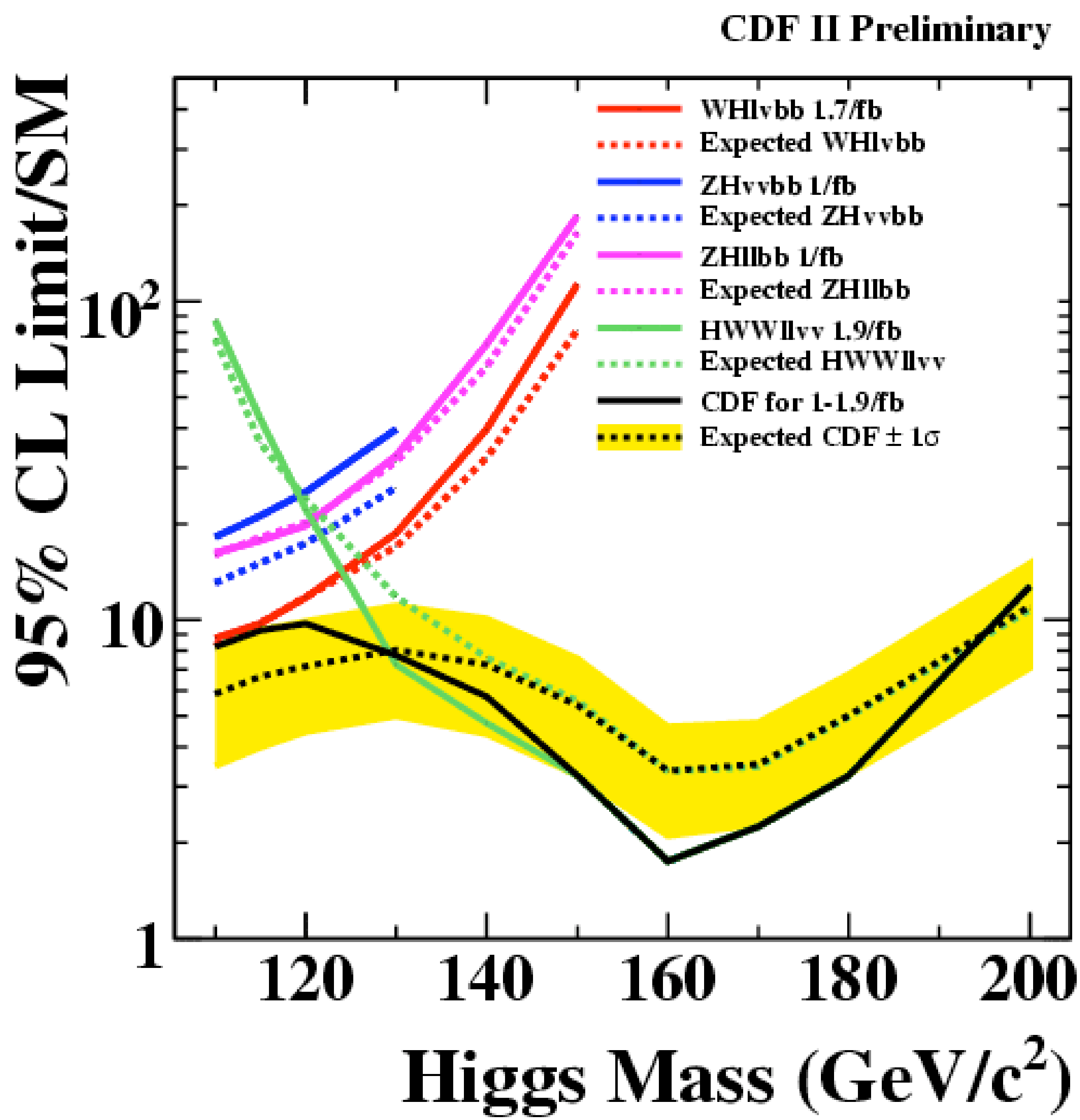
Low Mass Higgs

- Example: 160GeV
    - h -> WW -> ll & MET has a BR penalty of ~ 6%
  - At Tevatron we expect 430 higgs / fb-1.
    - 26 after BR penalty
    - 4 after complete CDF analysis
    - With a bkg of 130 events from WW.
  - At LHC we expected 26,000 higgs / fb-1
    - 1600 after BR penalty
    - ?? After complete CMS analysis.

Ratio of h160/WW changes from 1/30 to 1/5 when going from Tevatron to LHC !!!

Let’s take a close look at Tevatron

- Tevatron searches divide up in two types:
  - m_h < ~140GeV they use h -> bb with associate production of W or Z.
    - Leptonic decay of W or Z provides the necessary trigger.
      - Wh -> l & MET & bb
      - Zh -> ll & bb and MET & bb
  - m_h > ~130GeV they use h -> WW -> ll & MET
  - Small overlap region where both sets of analyses have some sensitivity.
- They plot two sets of curves:
  - Expected sensitivity, i.e. 95% CL limit for higgs Xsect.
  - Actual 95% CL limit.
- Both sets of curves are expressed as ratios to the Standard Model Xsect at NNLO.



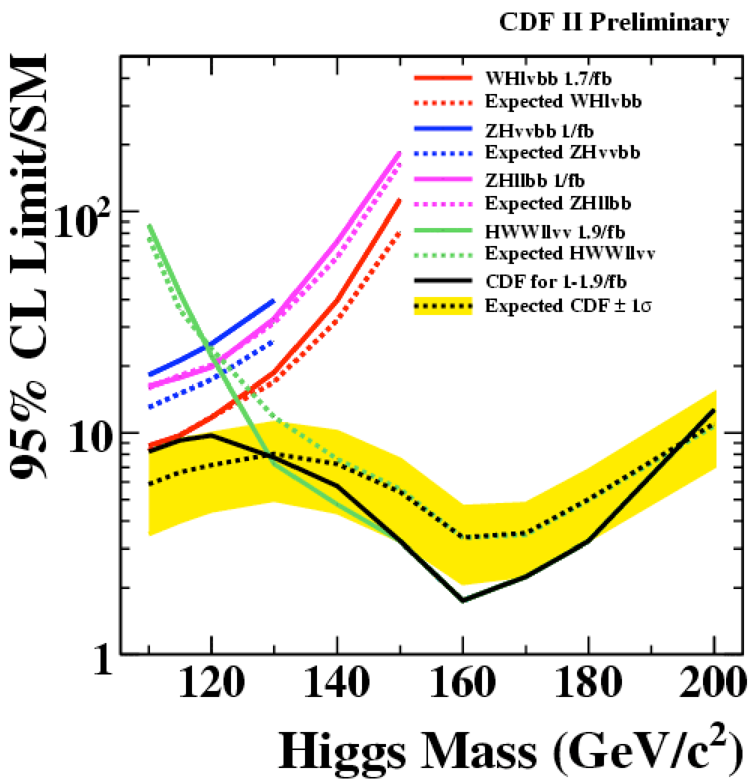
CDF II Preliminary
WHlvbb 1.7/fb
Expected WHlvbb
ZHvvbb 1/fb
Expected ZHvvbb
ZHllbb 1/fb
Expected ZHllbb
HWWllvv 1.9/fb
Expected HWWllvv
CDF for 1-1.9/fb
Expected CDF ± 1σ
95% CL Limit/SM
1
10
10^2
120
140
160
180
200
Higgs Mass (GeV/c^2)

A note of caution

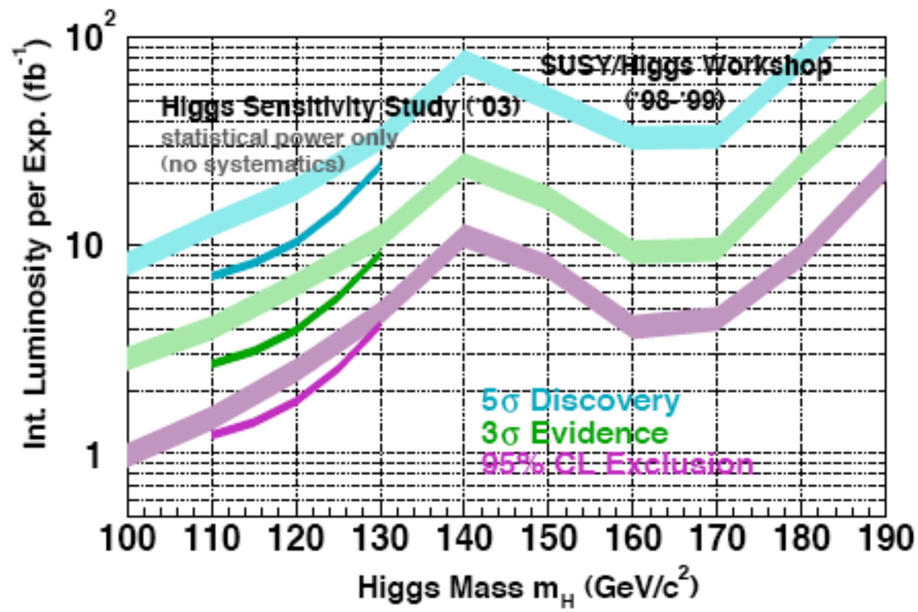
- Before we look at the expected sensitivity for the LHC experiments, let’s look at what the Tevatron experiments expected their senstivity to be before they started data taking.

Higgs Sensitivity at the Tevatron

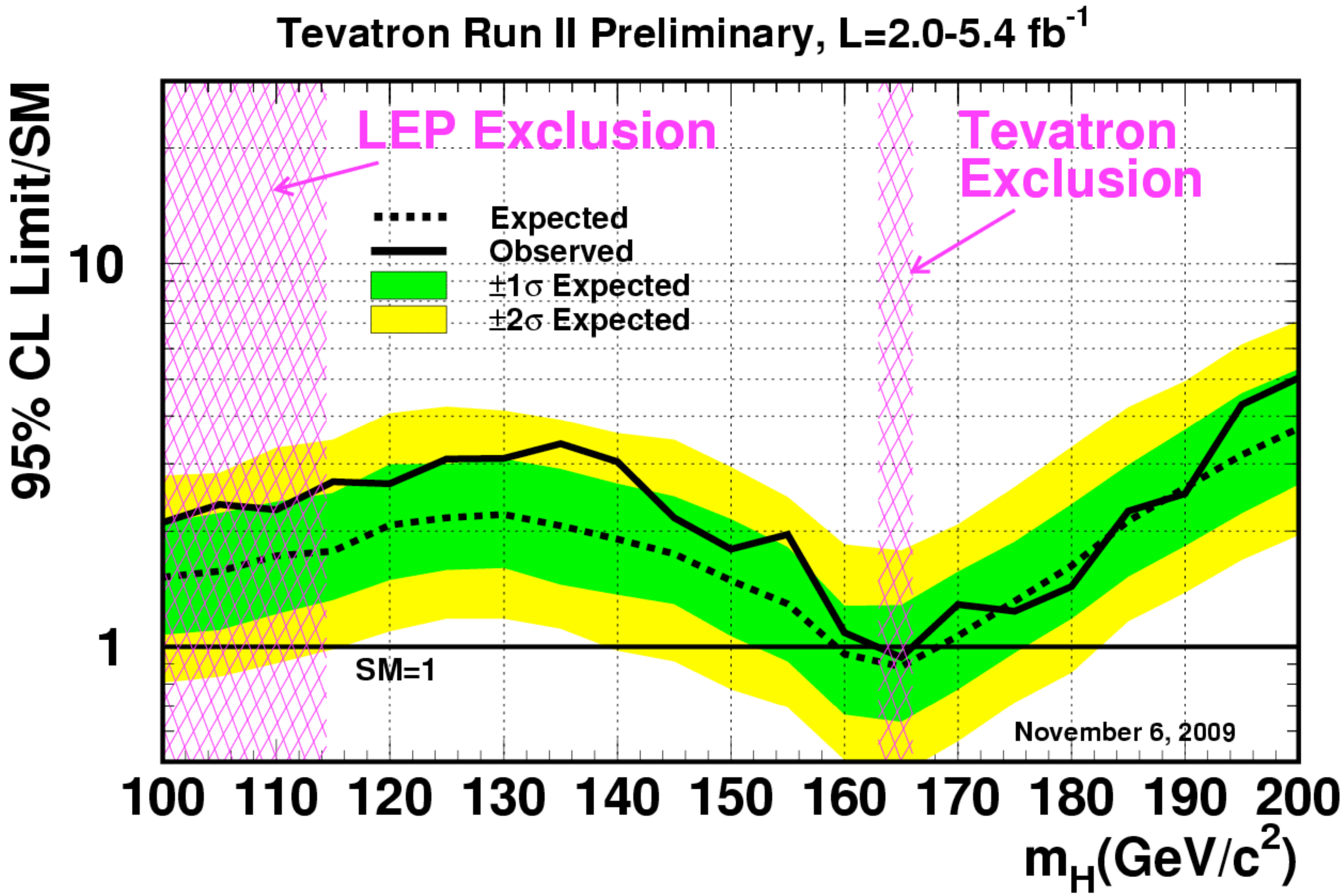
Reality after Data taking



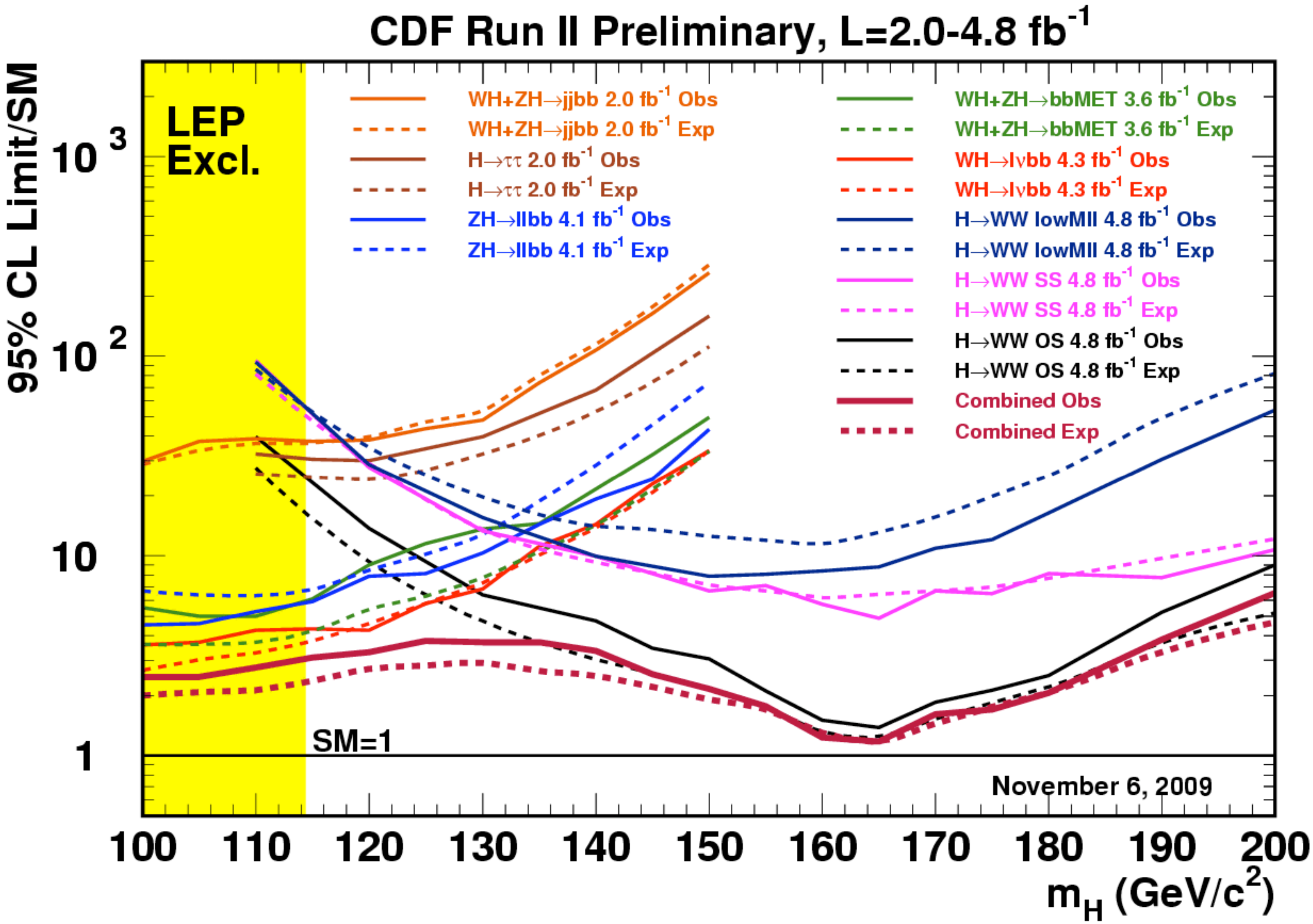
Fantasy before Data taking

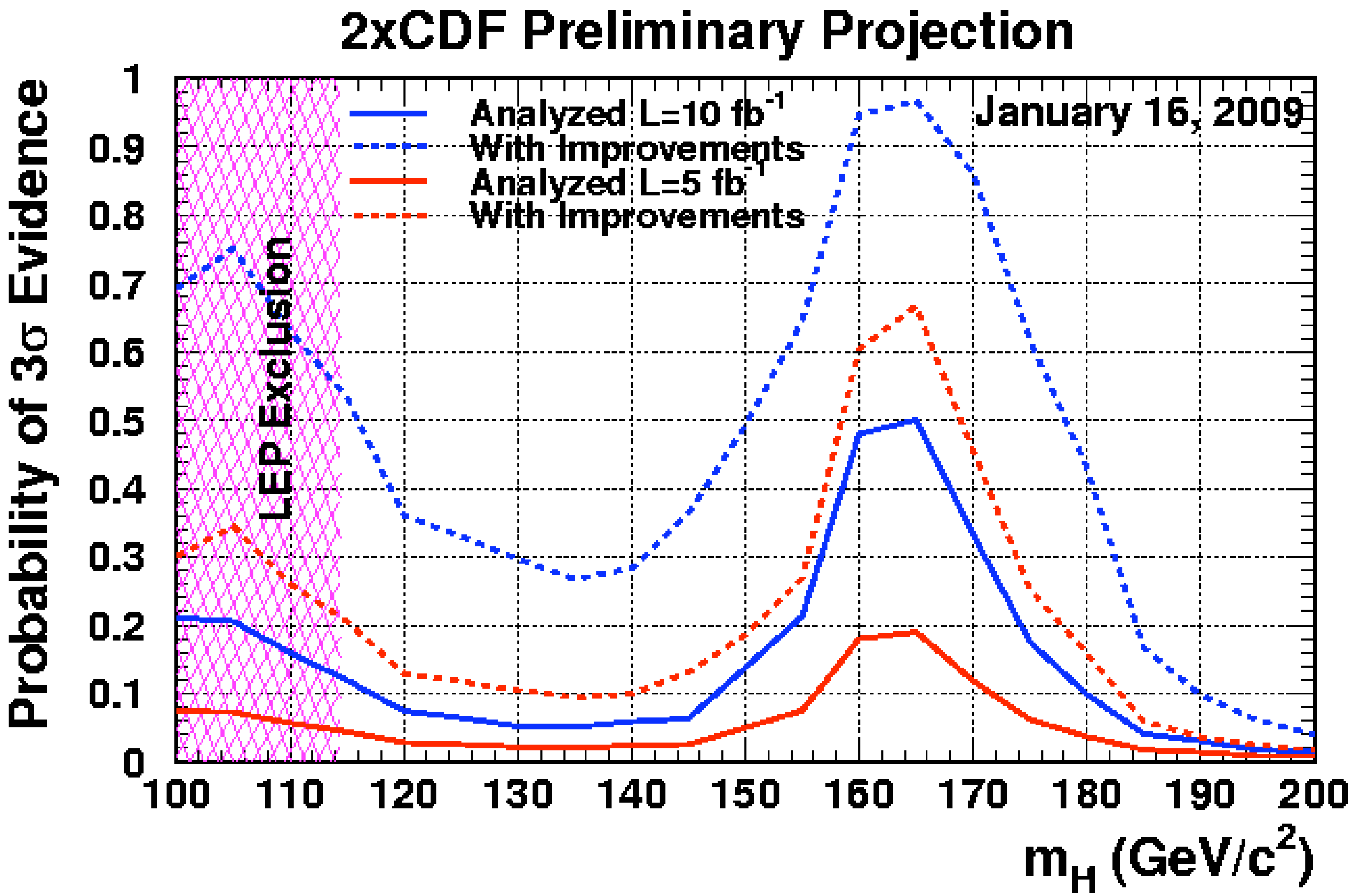


Sensitivity at ~110GeV is about x8 worse than expected.
Sensitivity at ~160GeV is about x1.4 worse than expected.

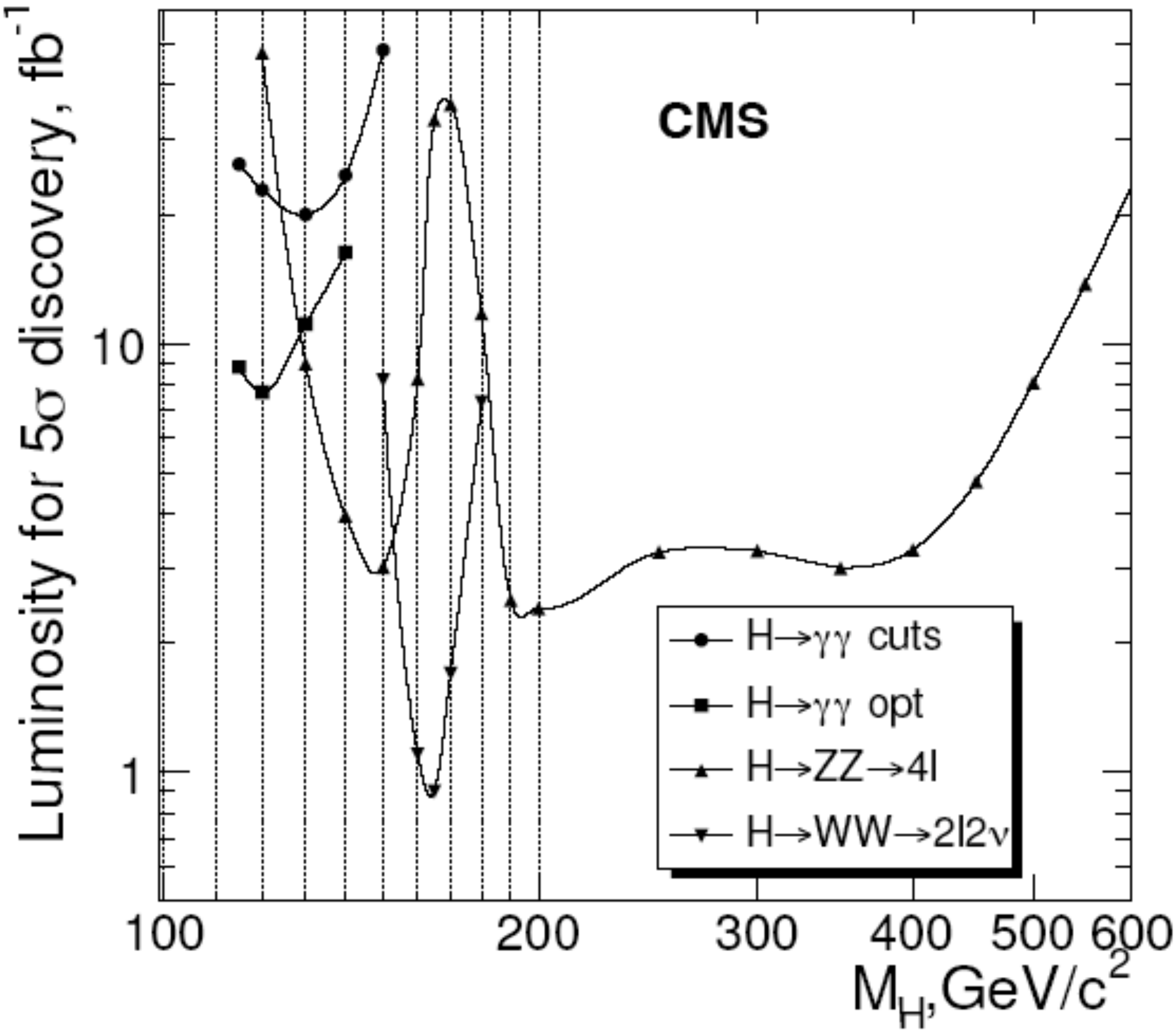


Tevatron Run II Preliminary, L=2.0-5.4 fb-1
95% CL Limit/SM
LEP Exclusion
Tevatron Exclusion
Expected
Observed
±1σ Expected
±2σ Expected
SM=1
November 6, 2009
10
1
100
110
120
130
140
150
160
170
180
190
200
mH(GeV/c2)

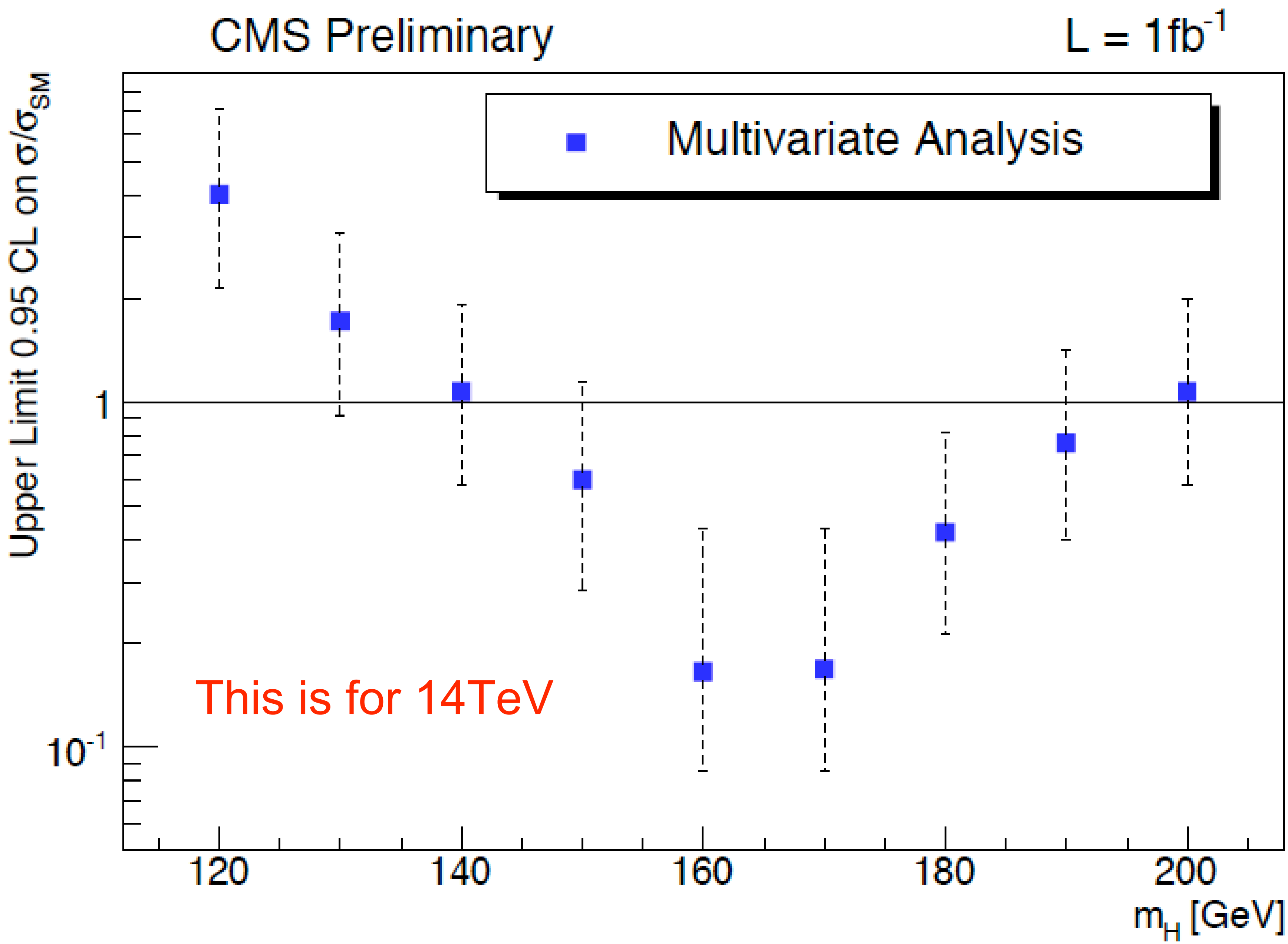

CDF Run II Preliminary, L=2.0-4.8 fb-1
95% CL Limit/SM
LEP Excl.
WH+ZH→jjbb 2.0 fb-1 Obs
WH+ZH→jjbb 2.0 fb-1 Exp
H→ττ 2.0 fb-1 Obs
H→ττ 2.0 fb-1 Exp
ZH→llbb 4.1 fb-1 Obs
ZH→llbb 4.1 fb-1 Exp
WH+ZH→bbMET 3.6 fb-1 Obs
WH+ZH→bbMET 3.6 fb-1 Exp
WH→lνbb 4.3 fb-1 Obs
WH→lνbb 4.3 fb-1 Exp
H→WW lowMll 4.8 fb-1 Obs
H→WW lowMll 4.8 fb-1 Exp
H→WW SS 4.8 fb-1 Obs
H→WW SS 4.8 fb-1 Exp
H→WW OS 4.8 fb-1 Obs
H→WW OS 4.8 fb-1 Exp
Combined Obs
Combined Exp
SM=1
November 6, 2009
mH (GeV/c2)



2xCDF Preliminary Projection
Analyzed L=10 fb-1
With Improvements
Analyzed L=5 fb-1
With Improvements
January 16, 2009
LEP Exclusion
Probability of 3σ Evidence
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
100
110
120
130
140
150
160
170
180
190
200
mH (GeV/c2)



CMS
Luminosity for 5σ discovery, fb⁻¹
10
1
100
200
300
400
500
600
M_H,GeV/c²
H→γγ cuts
H→γγ opt
H→ZZ→4l
H→WW→2l2ν



CMS Preliminary
L = 1fb-1
Multivariate Analysis
Upper Limit 0.95 CL on σ/σSM
1
10-1
120
140
160
180
200
mH [GeV]
This is for 14TeV