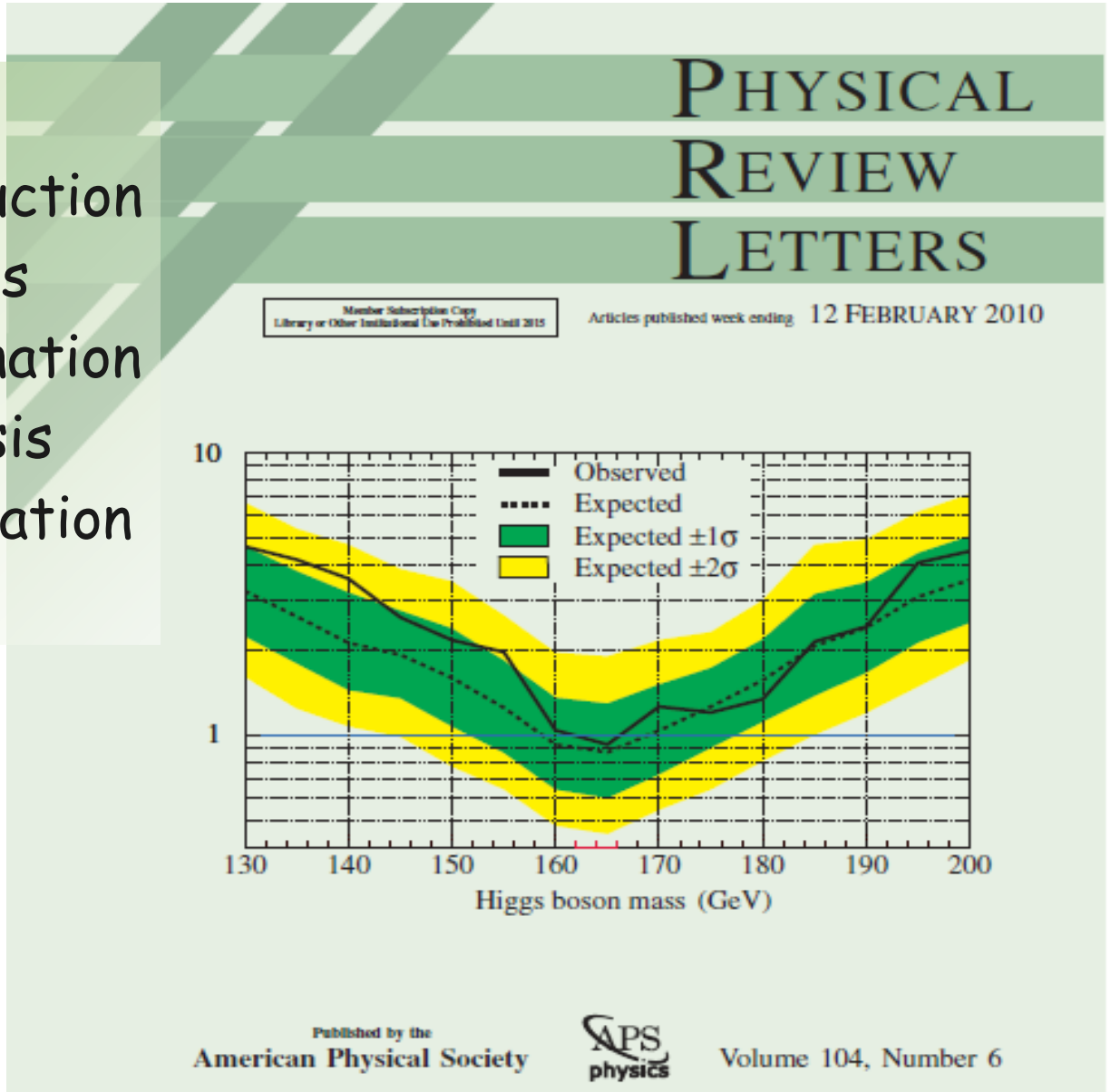
Higgs boson searches at Tevatron

- Introduction
  - Higgs searches introduction
  - Low mass Higgs analysis
  - Low mass Higgs combination
  - High mass Higgs analysis
  - Higgs searches combination
  - Future

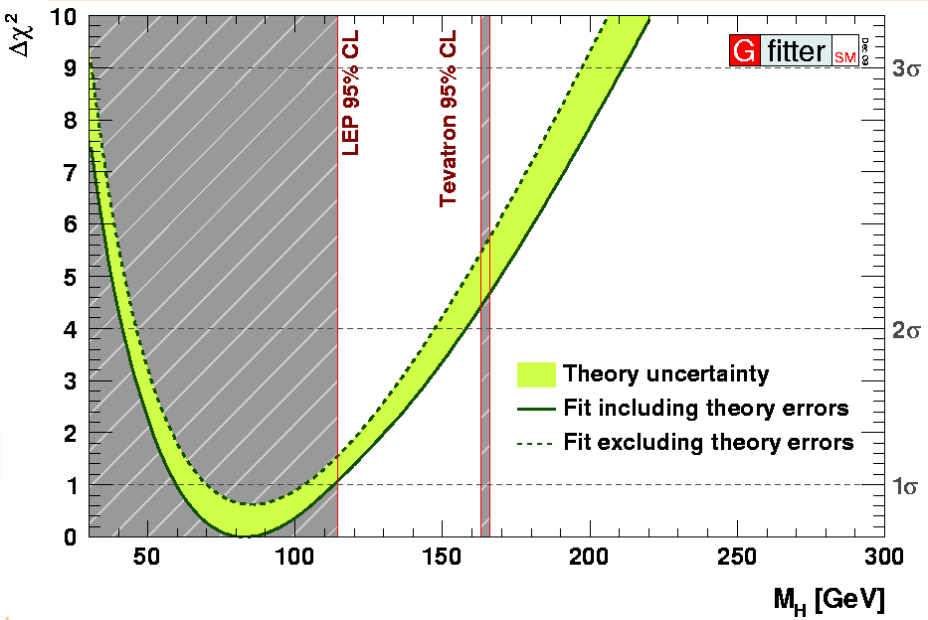


What do we know on "mass"

Quoting A. Masiero (IFAE-2010)

- Electroweak physics determined by local symmetry (gauge).
- This symmetry is spontaneously broken, ie. we do know that the Higgs mechanism does exist.
- The masses of the gauge bosons of the broken symmetry come from the Higgs mechanism.
- The SM fermions masses come from Higgs mechanism.
- The evidence (in particular from LEP) of an Higgs mechanism does not imply the existence of the Higgs particle.
- If an Higgs boson exists, elementary particle, its mass (in SM) does not derive by any symmetry breaking.

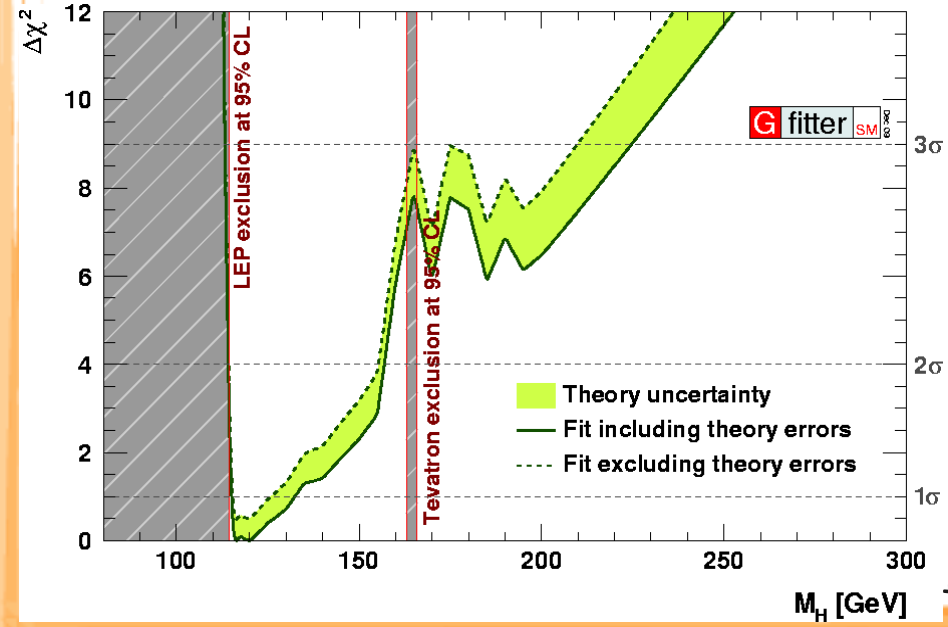
Cornering the Higgs



Standard fit: all data but results from direct Higgs searches.

Higgs mass

- central value ±1σ: $M_H = 83^{+30}_{-23}$ GeV
- 2σ interval: [42, 158] GeV
- 3σ interval: [28, 211] GeV



Complete fit: all data including LEP and Tevatron results.

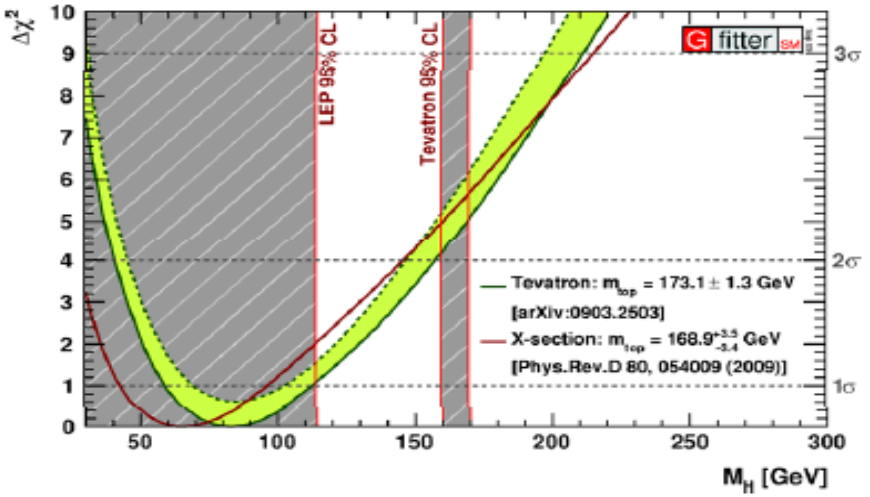
Higgs mass:

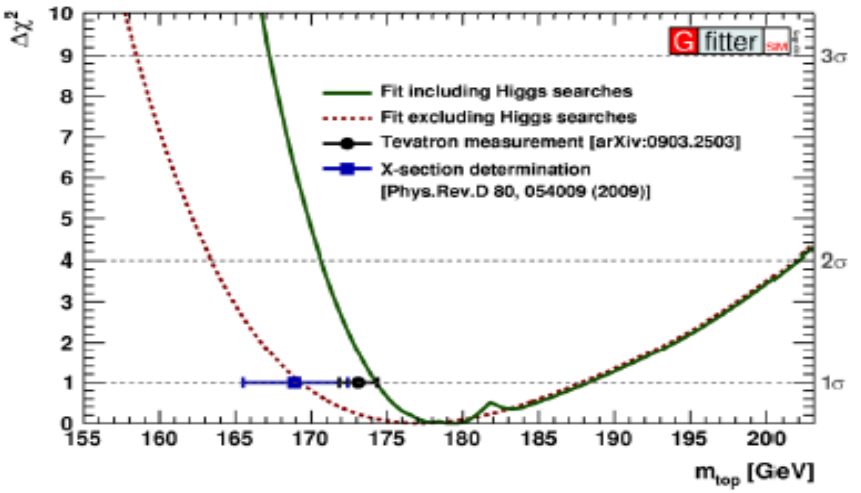
- central value ±1σ: $M_H = 116.3^{+15.6}_{-1.3}$ GeV
- 2σ interval: [114, 145] GeV

Cornering the Higgs: top mass

Top Mass Determination

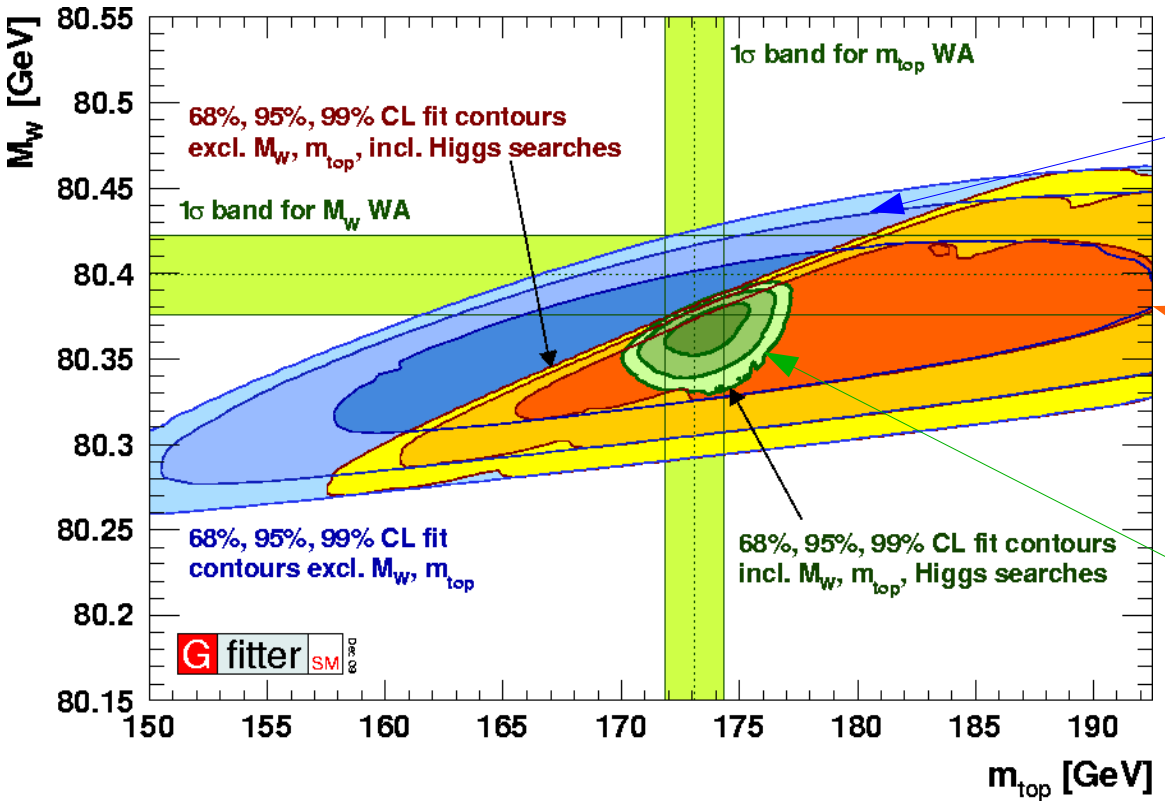
- top mass crucial input for Fit (correlation factor with M_H 0.31)
- SM calculations assume top pole mass
- which top mass at Tevatron: "MC" or pole mass
  [Hoang &Steward., Nucl.Phys.Proc.Suppl.185:220-226,2008]
- additional uncertainty?





- extraction of MS top mass from total X-section
  [Langenfeld ,Moch,Uwer, Phys.Rev.D80:054009,2009]
- smaller mean value, but larger error than direct measurement

Cornering the Higgs: top vs. W mass



M_W vs. M_T excluding direct H searches

M_W vs. M_T including direct H searches

M_W vs. M_T constrained to measured values

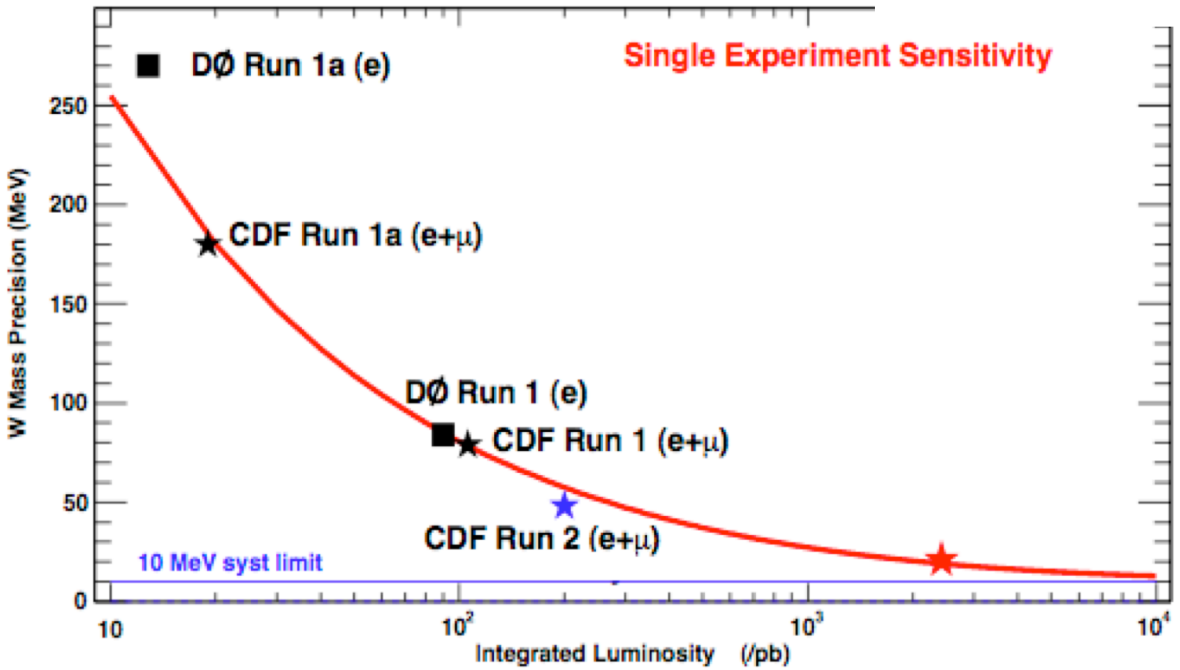
http://gfitter.desy.de/

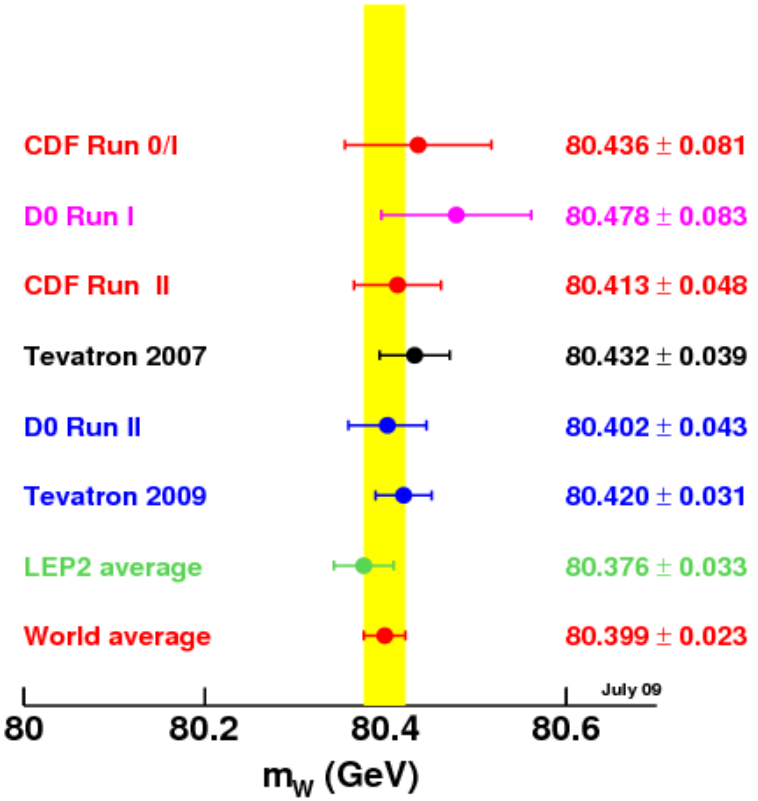
W Mass Results

Latest results D0:

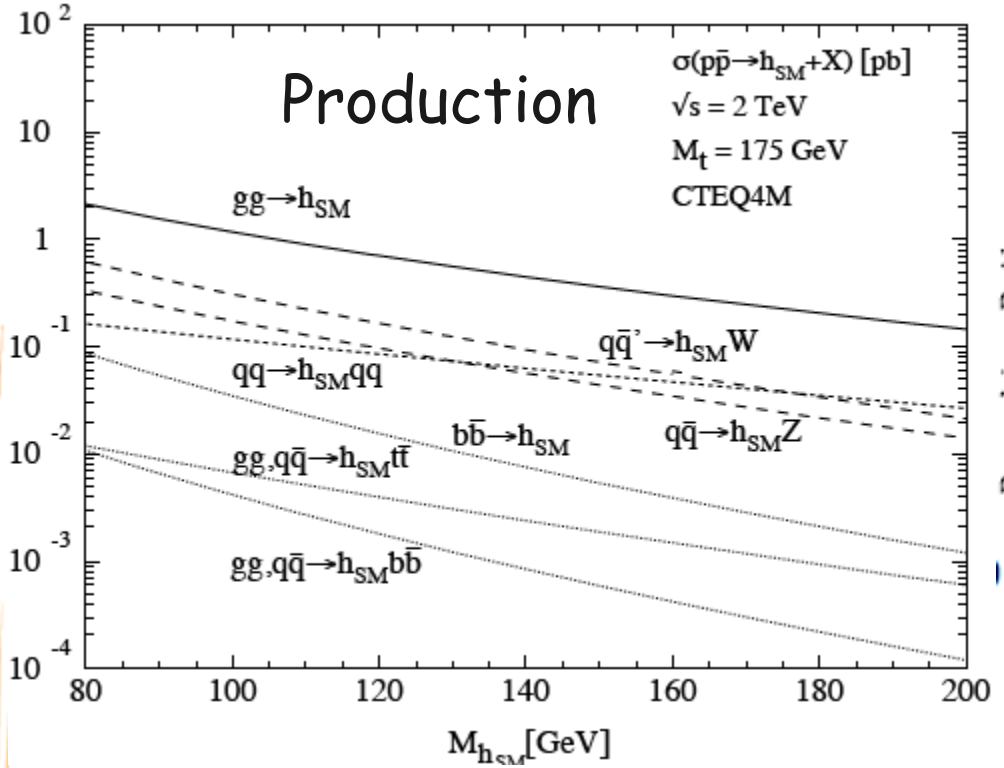
M_W 80.401±0.044 GeV

CDF has in progress the analysis on 2.4fb^{-1} the expected statistical error is ~15 MeV

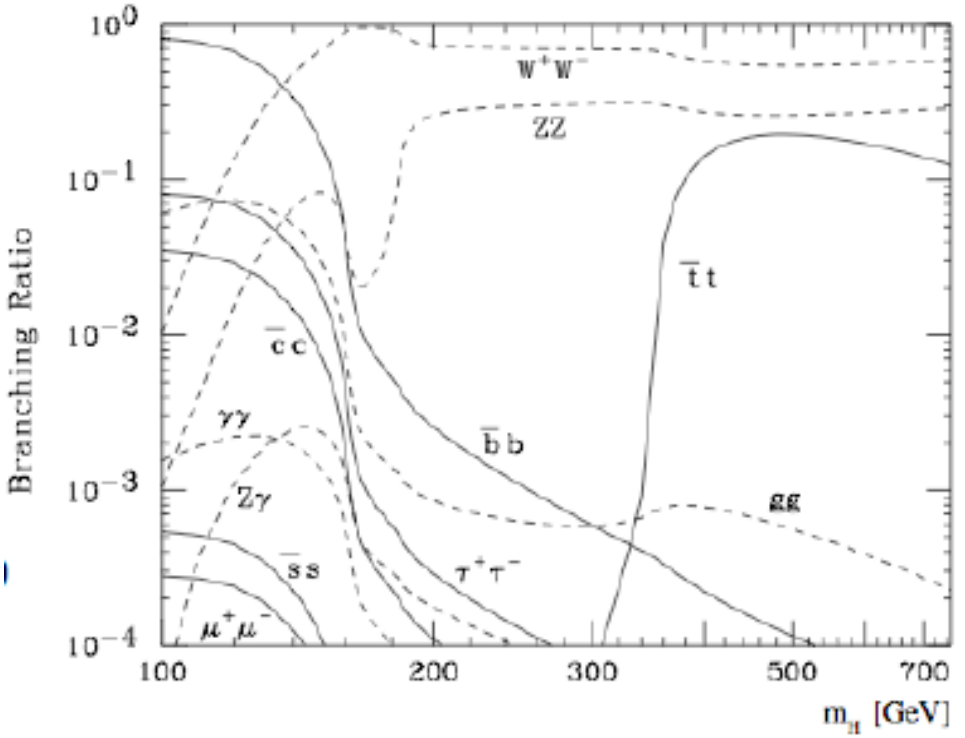




Direct Higgs searches @Tevatron

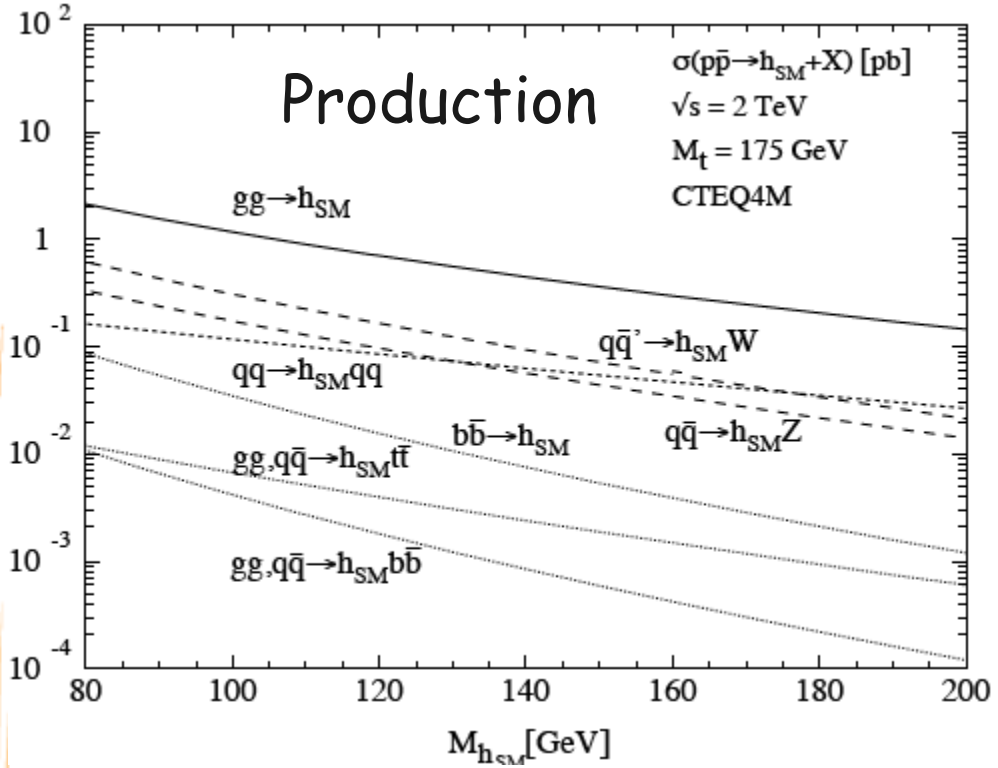


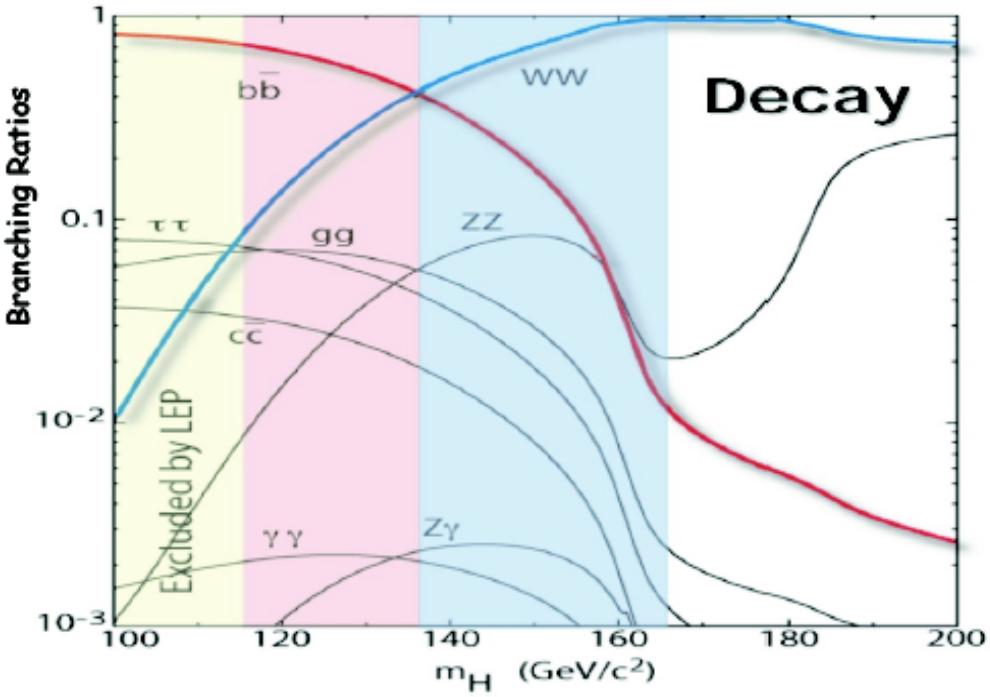
Low cross section



There is no an "easy" dominant decay if m_H<200 GeV

Direct Higgs searches @Tevatron



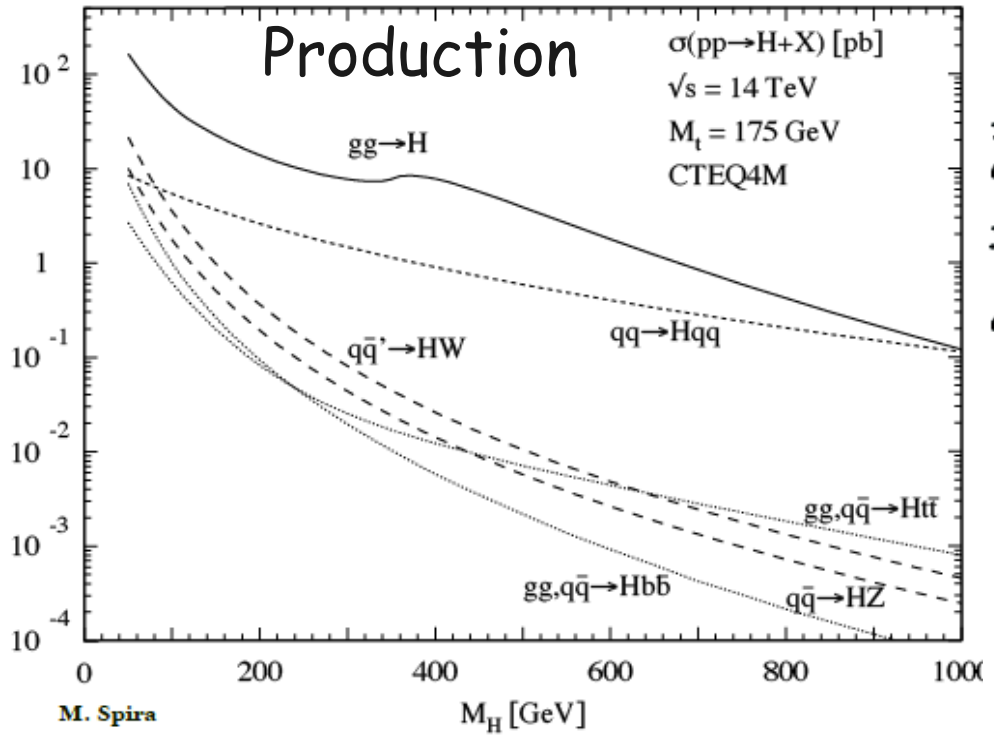


Low Mass: $M_H < 135$ GeV/c^2

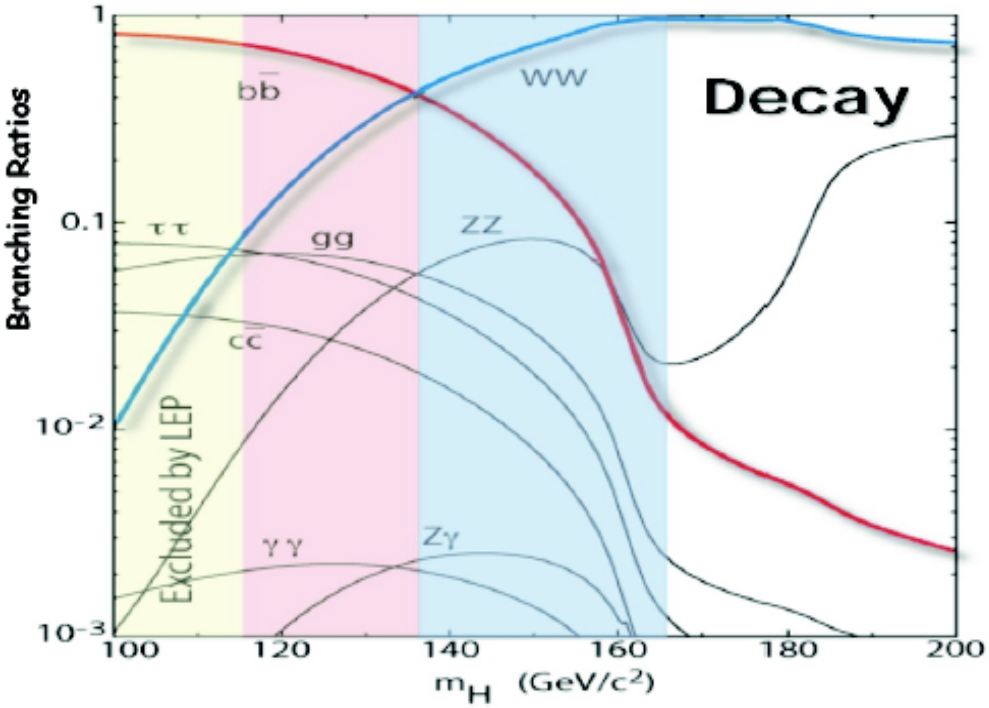
High Mass: $M_H > 135$ GeV/c^2

See later for details

Direct Higgs searches @LHC (14 TeV)



Low mass dominated by gg



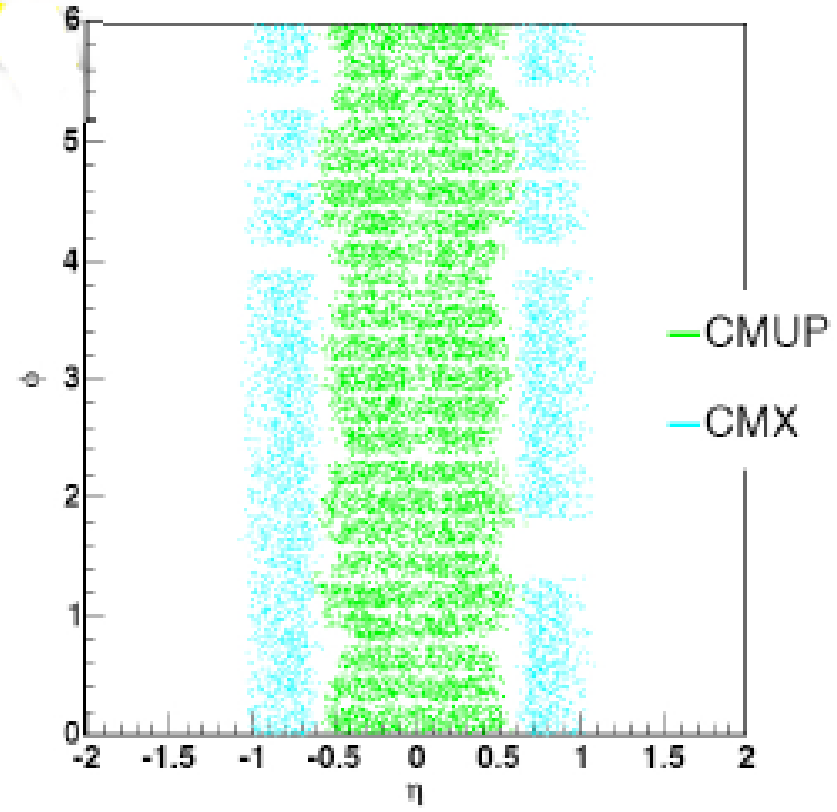
High mass H->WW, H->ZZ

Low mass H->γγ, H–>ττ, VH

Experimental Tools

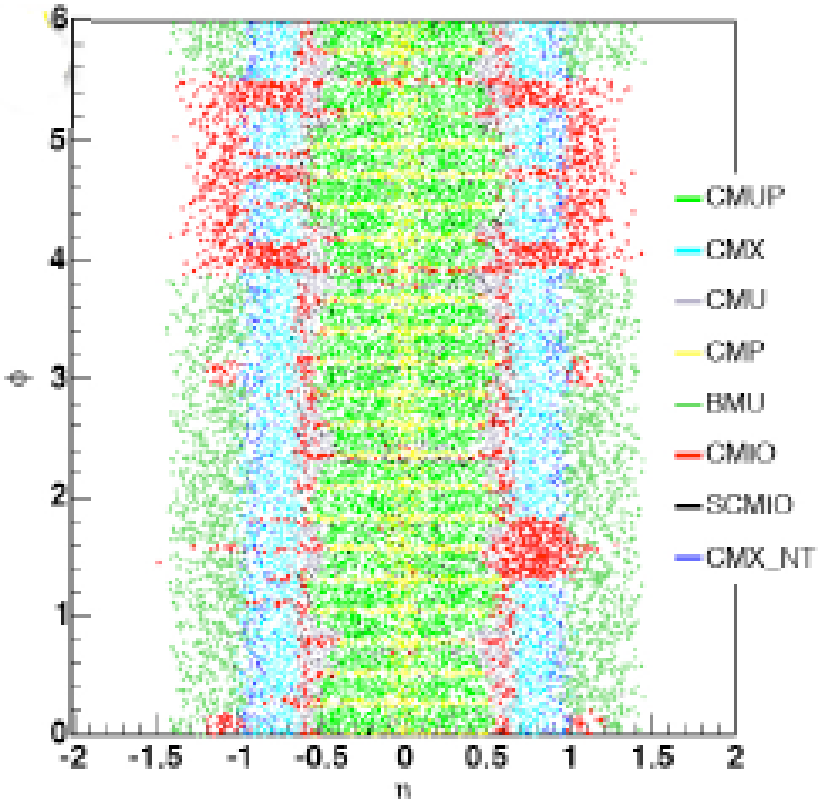
Analysis Tools: Lepton Identification

- Identify the decay of W/Z
  - ✔ electrons: tracks matched to ECAL
  - ✔ muons: tracks matched to muon chambers
  - ✔ taus: tracks matched to calorimeter cluster
- Expand lepton coverage:
  - ✔ interplay between sub-detectors to cover holes
  - ✔ include forward detectors



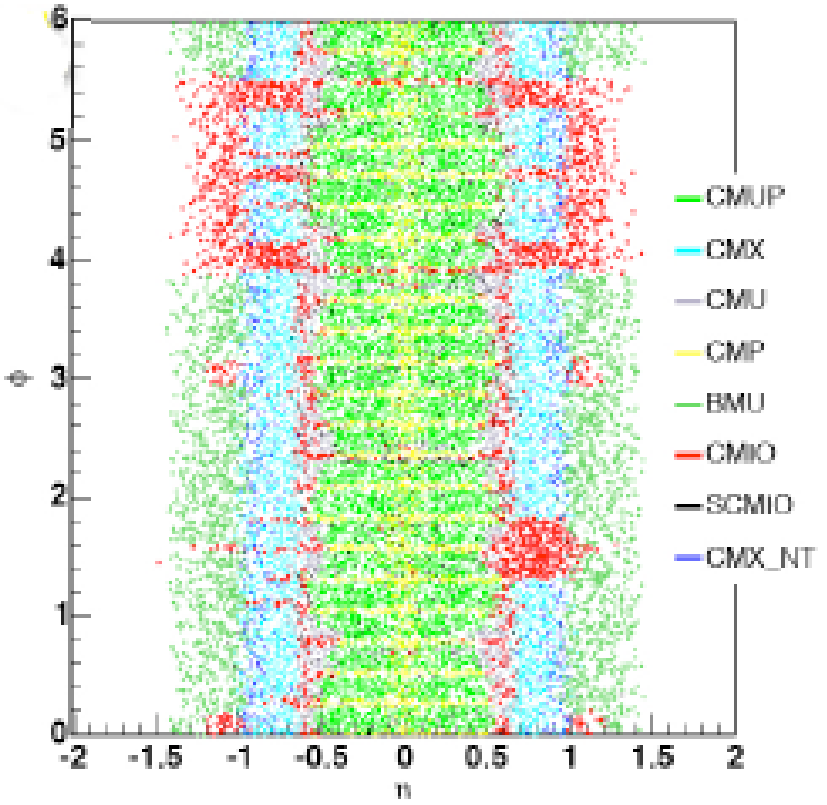
Analysis Tools: Lepton Identification

- Identify the decay of W/Z
  - ✔ electrons: tracks matched to ECAL
  - ✔ muons: tracks matched to muon chambers
  - ✔ taus: tracks matched to calorimeter cluster
- Expand lepton coverage:
  - ✔ interplay between sub-detectors to cover holes
  - ✔ include forward detectors

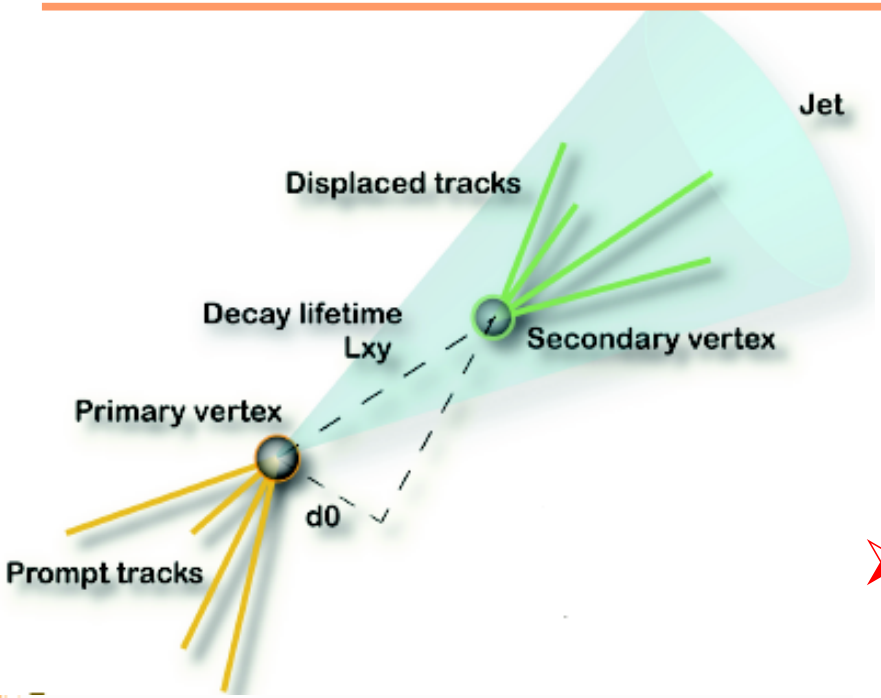


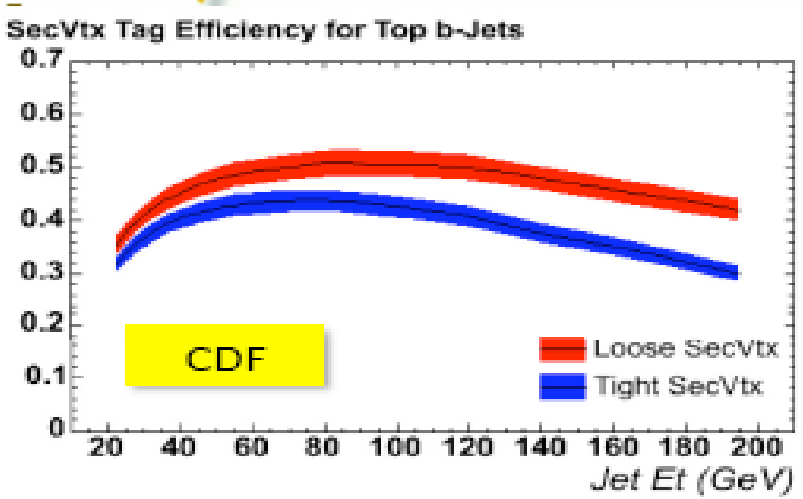
Analysis Tools: Lepton Identification

- Identify the decay of W/Z
  - ✔ electrons: tracks matched to ECAL
  - ✔ muons: tracks matched to muon chambers
  - ✔ taus: tracks matched to calorimeter cluster
- Expand lepton coverage:
  - ✔ interplay between sub-detectors to cover holes
  - ✔ include forward detectors
- Good Missing E_T (MET) trigger :
  - ✔ select events with neutrinos and charged lepton that fail ID
  - ✔ remove events with fake MET



Analysis Tools: b-jet Identification



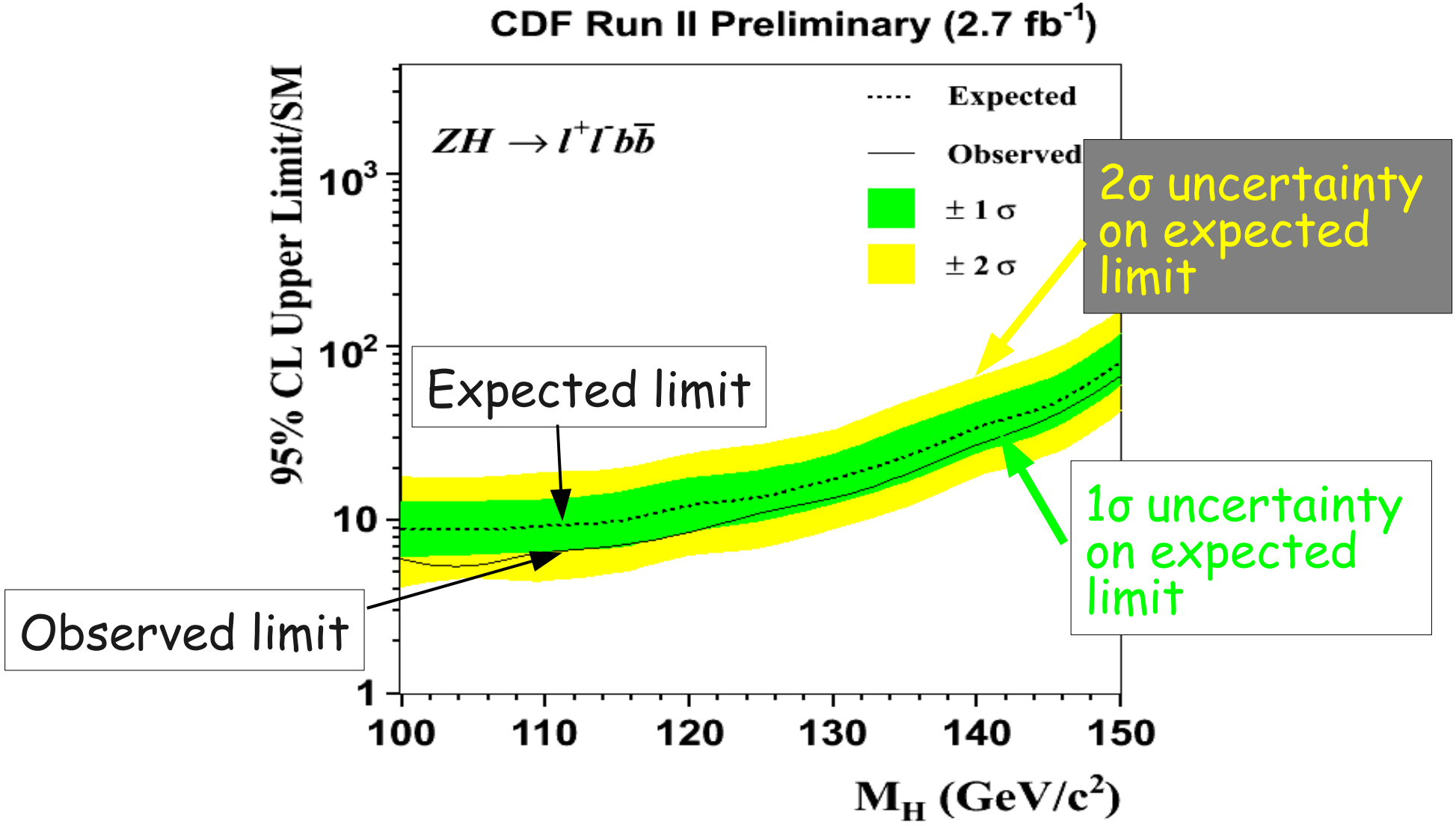


- B-tagging:
  - ✔ exploit long lifetime of b-hadrons
  - ✔ Suppress light flavor background
  - ✔ Improves S/B
- Various algorithms used by CDF/D0
  - ✔ Identify displaced vertex
  - ✔ Exploit multiple feature of b-jets
  - ✔ Probability that tracks come from primary vertex
  - ✔ b-tagging efficiency: 40-70%
- D-jet invariant mass

Analysis Tools: Multivariate techniques

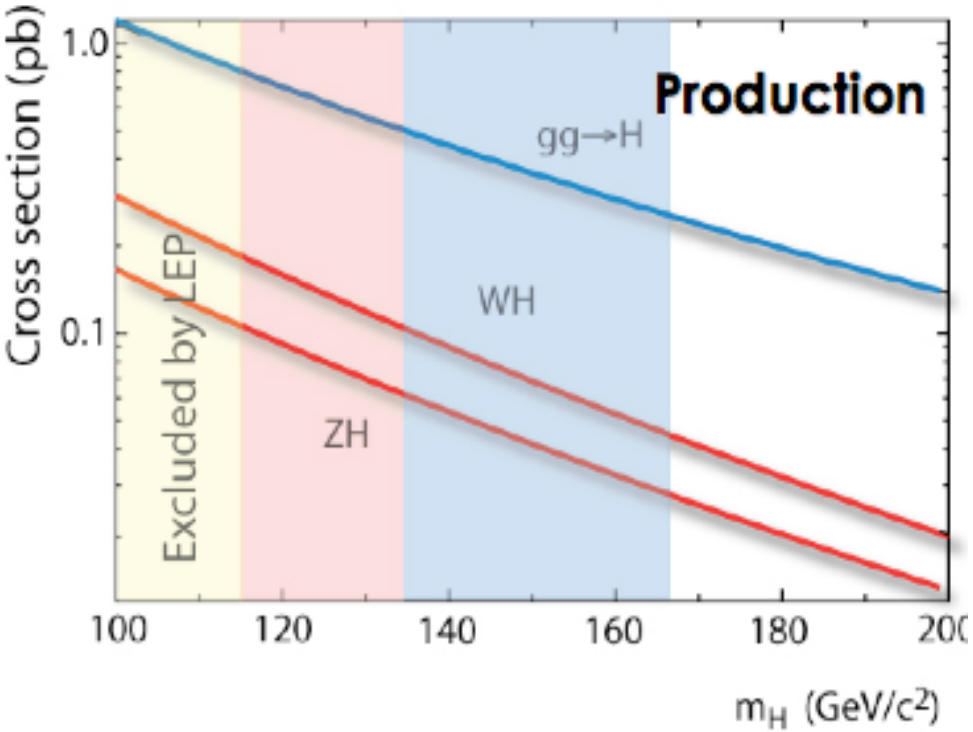
- Maximize discriminating power using global kinematics of signal and background
  - ✔ Machine learning techniques: Neural Network and Boost Decision Tree (BDT)
  - ✔ For each event calculate the probability to come from signal from LO Matrix Element
- Multivariate techniques help to improve sensitivity
- Used already in many many analysis

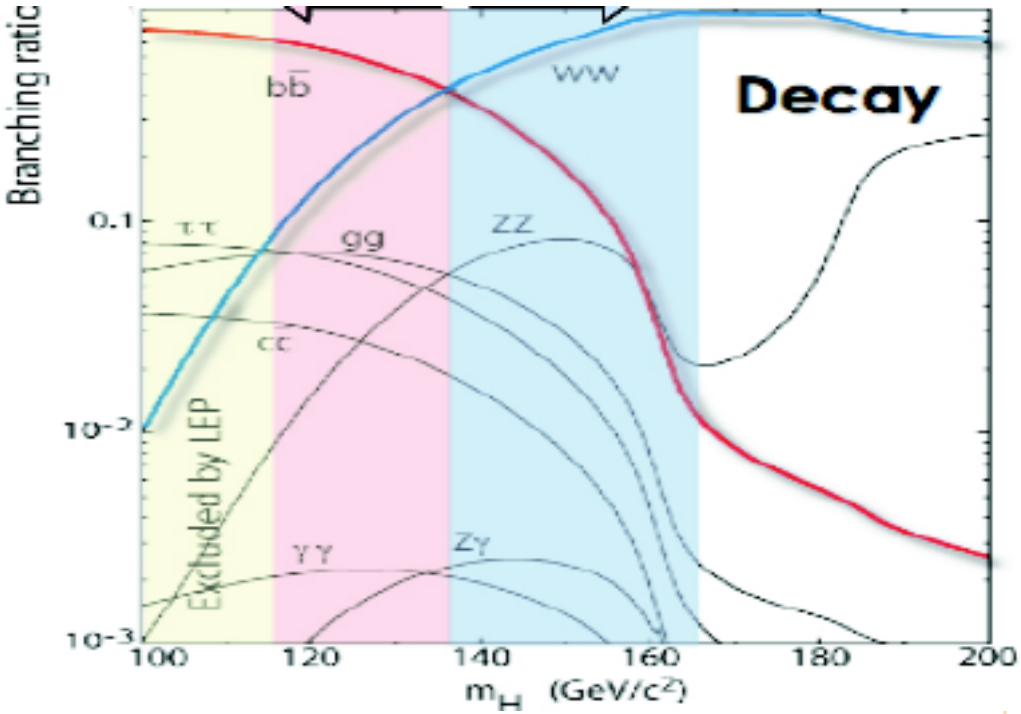
Reminder: Limit Plots



Low Mass Higgs searches

Low Mass: $M_H < 135\ GeV/c^2$





Dominant production mechanism: gg->H

Dominant decay mode: H->bb-bar

Low Mass Higgs searches

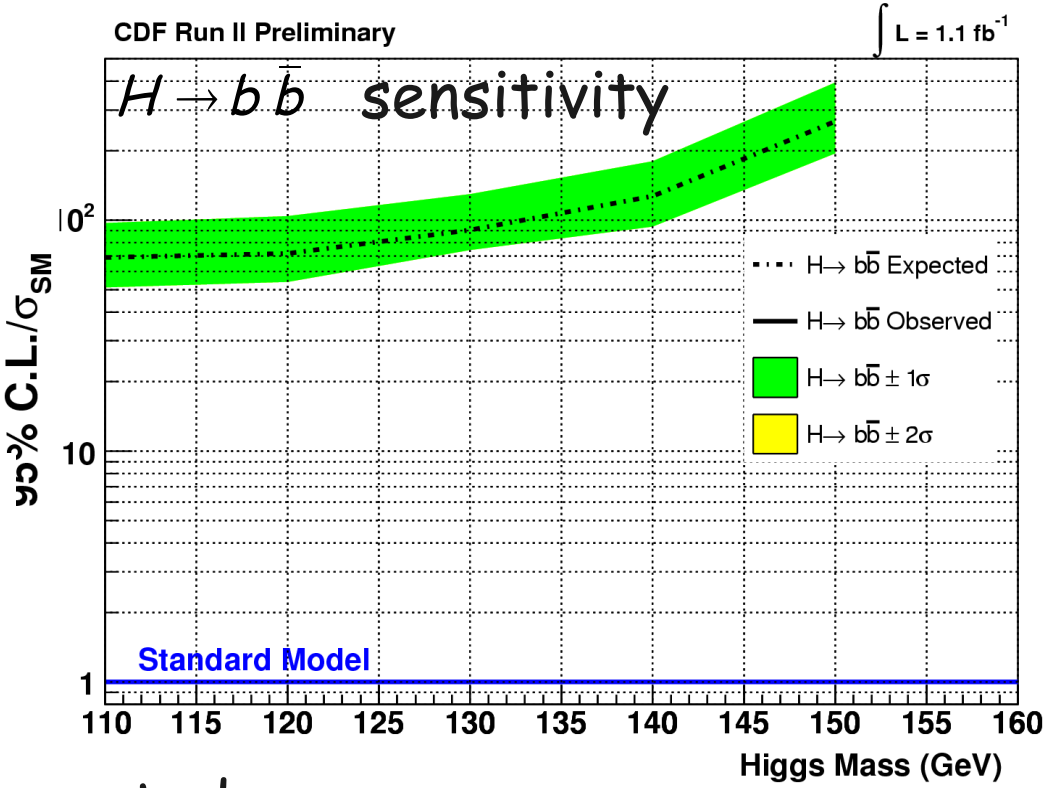
Decay channels

- Look for as many final states as possible with $H \to b\bar{b}$, highest BR
- gg-> $H \to b\bar{b}$ dominant production mode not available right now due to background.

These data are collected with b-tag trigger

Trigger algorithms	$\epsilon(H \to b\bar{b})$	$\epsilon(\phi \to b\bar{b})$	$\epsilon(Z \to b\bar{b})$
Vertex b-tag	13%	11%	4%
Muon b-tag	5%	6%	2%

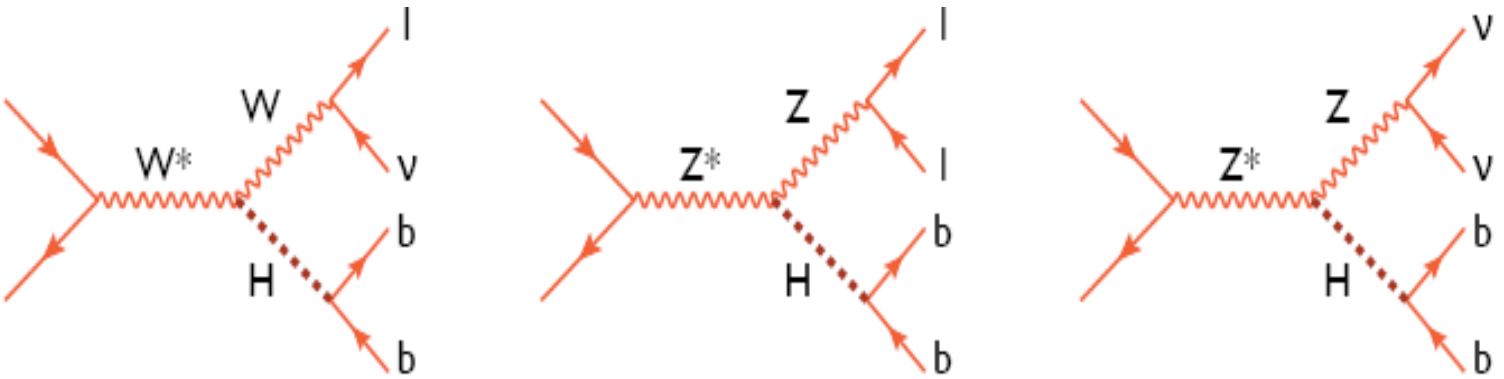
Table 1: Trigger efficiencies for H, ϕ and Z decays



Useful for Z->bb, b-jet energy study

Low Mass Higgs searches cont'd

- Look for VH and ZH associated production:
  - Higgs decays in two high pT b-jets
  - Leptonic decays of W/Z reduce QCD background and allow easy trigger strategy



- Reconstruct also H-> $\gamma\ \gamma$ and H-> $\tau\ \tau$ with gluon-gluon fusion, associated production and Vector Boson Fusion

Low Mass Higgs: Strategy

- Efficient trigger to keep most of potential Higgs candidates
  - high pt charged leptons: e μ to select W/Z
  - missing Et+jets to select HZ, Z->νν or HW W->lν (l not identified)
  - lepton+track for $\tau\ \tau$ modes

- Increase signal yields
  - increase lepton acceptance improving e/μ ID
  - more efficient b-tag algorithms
  - better understanding of calorimeter response

- Look for a resonance in dijets mass
  - large backgrounds with large uncertainties
  - use multivariate techniques to separate signal from background

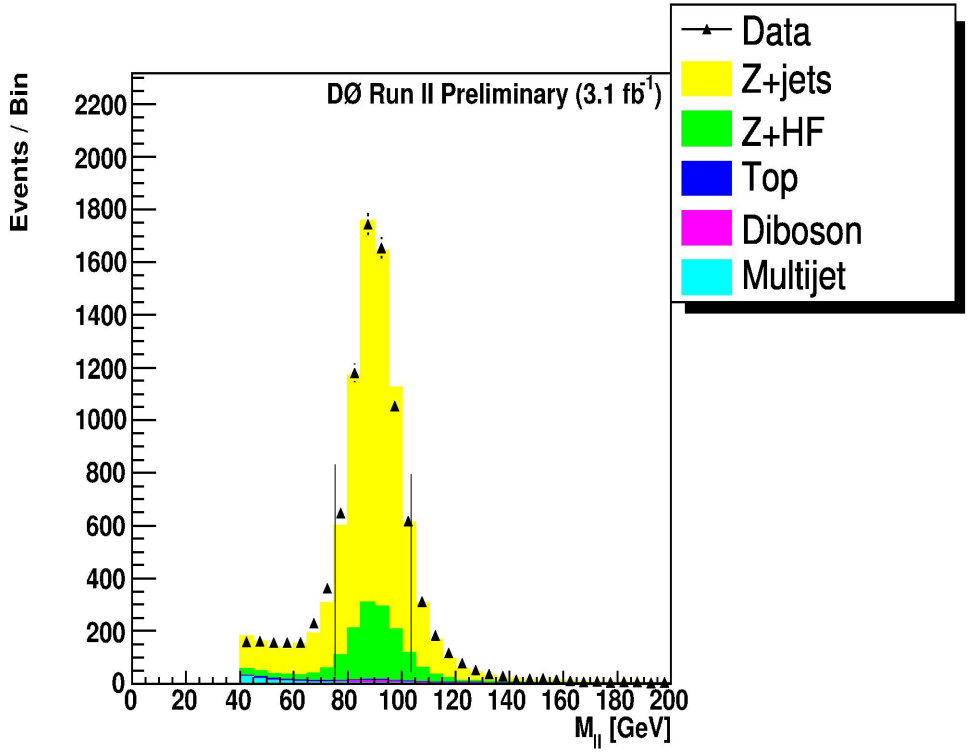
Low Mass Higgs: $ZH \to \ell^+\ell^- b\bar{b},\ \ell = e,\mu$

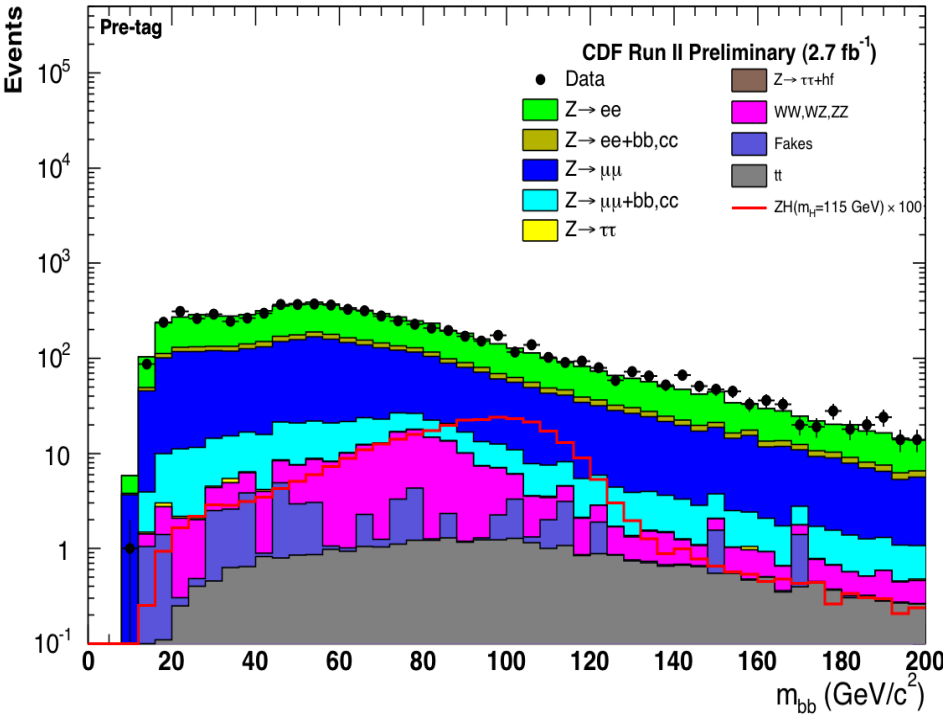
Signature: 2 high Pt leptons and 2+ b-jets

Trigger Path: single lepton

Major backgrounds: Z + jets/heavy flavors, top, di-bosons

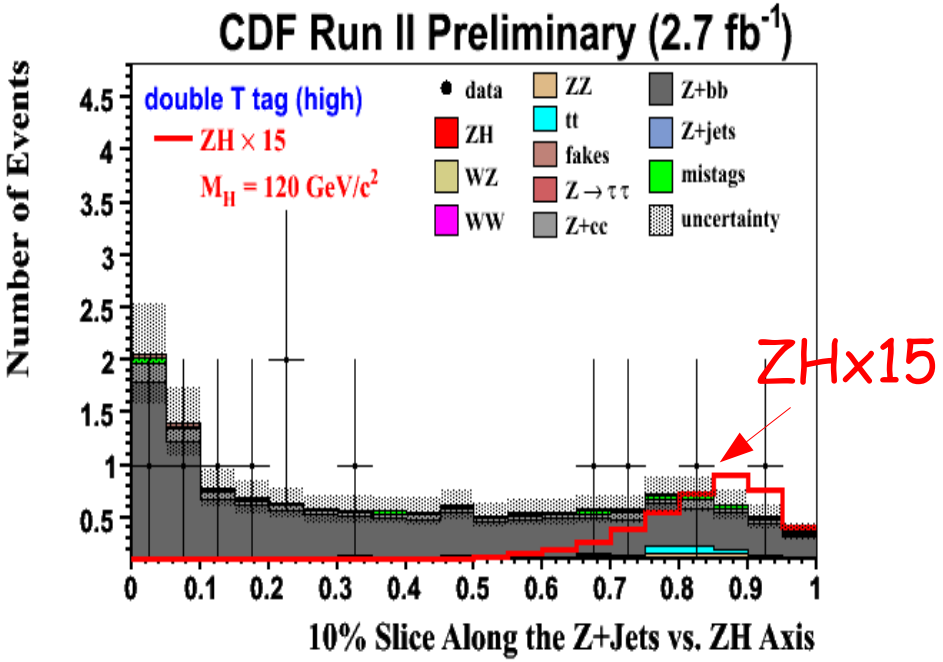
Small σxBR ~ 1 event/fb^{-1} Important to increase acceptance

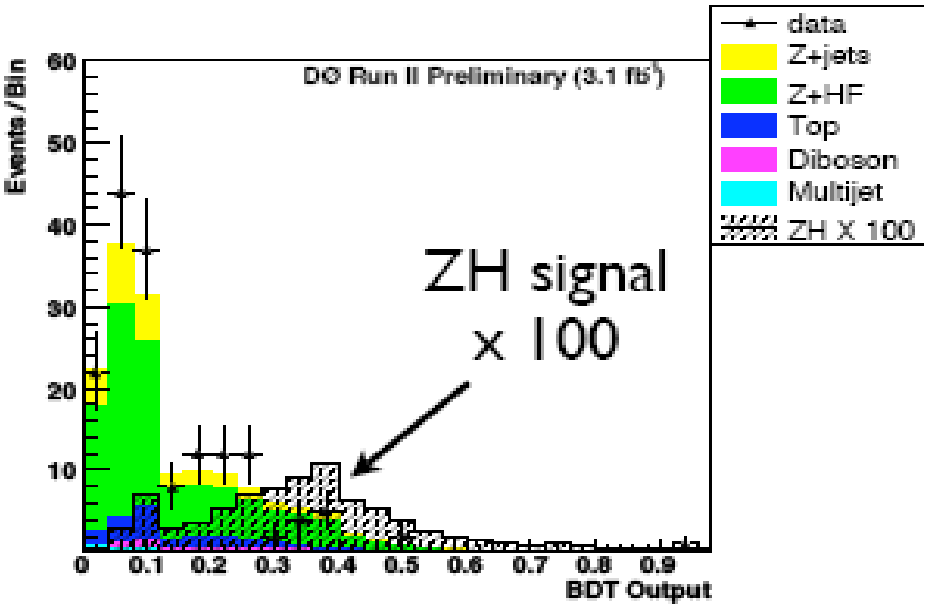




Low Mass Higgs: $ZH \to \ell^+\ell^- b\bar{b},\ \ell = e,\mu$

Use multivariate techniques to improve S/B





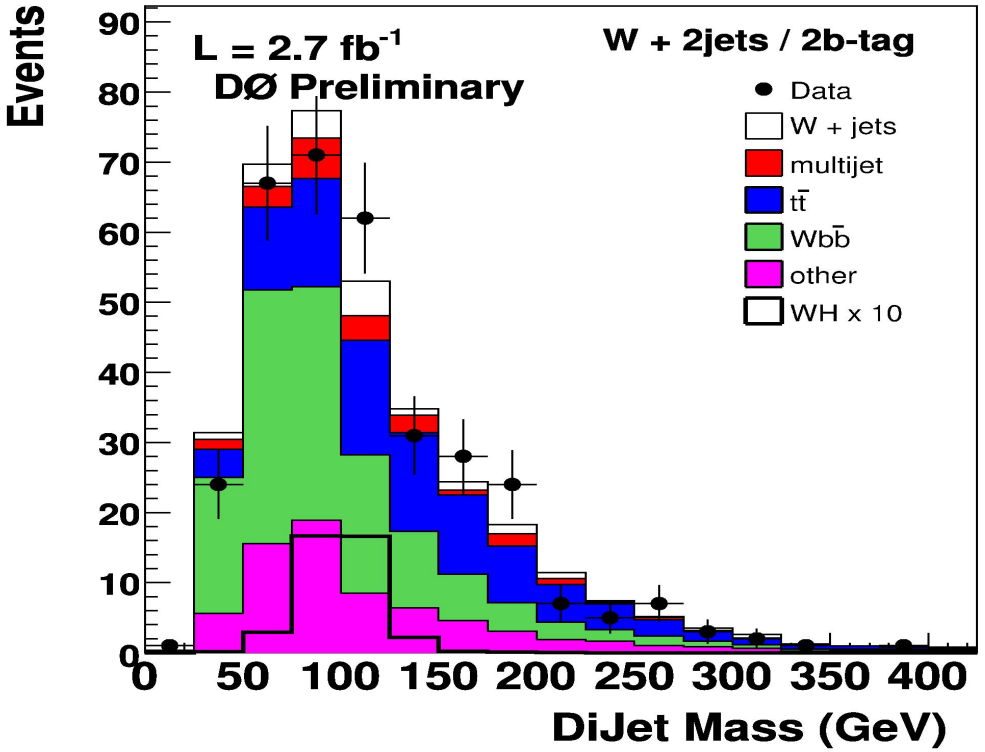
Low Mass Higgs: $WH \to \ell\nu b\bar{b},\ \ell = e, \mu$

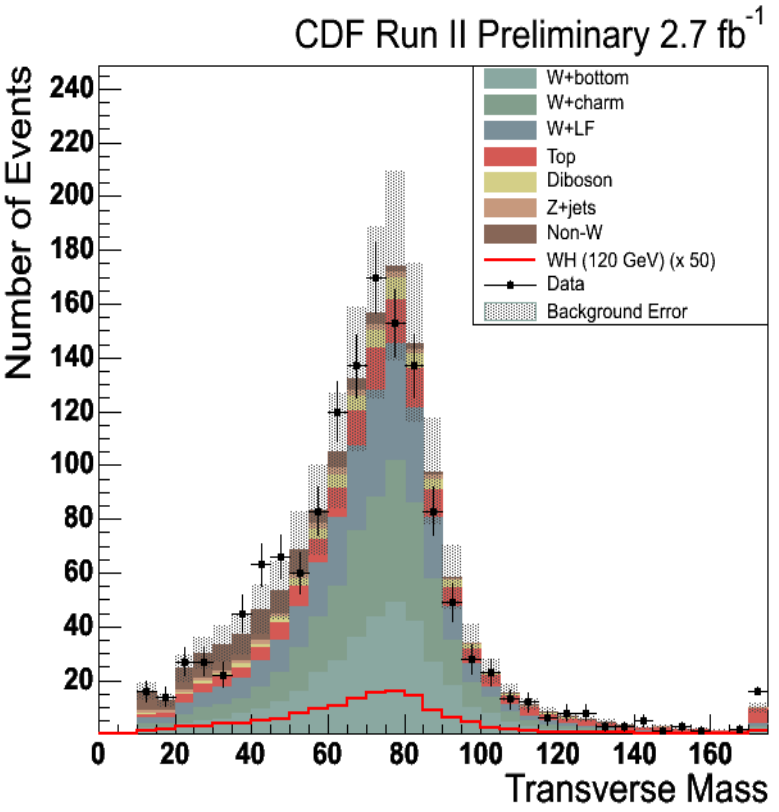
Signature: 1 high Pt lepton large MET and 2+ b-jets

Trigger path: single lepton

Major backgrounds: W+bb-jets, top, multijets

"Large" σxBR ~ 3-4 event/fb^{-1}



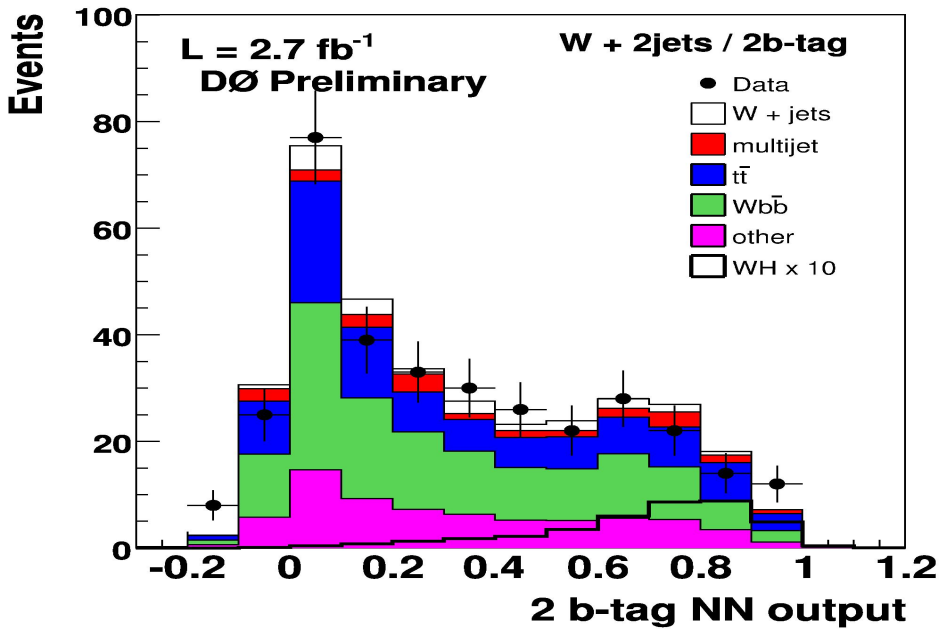


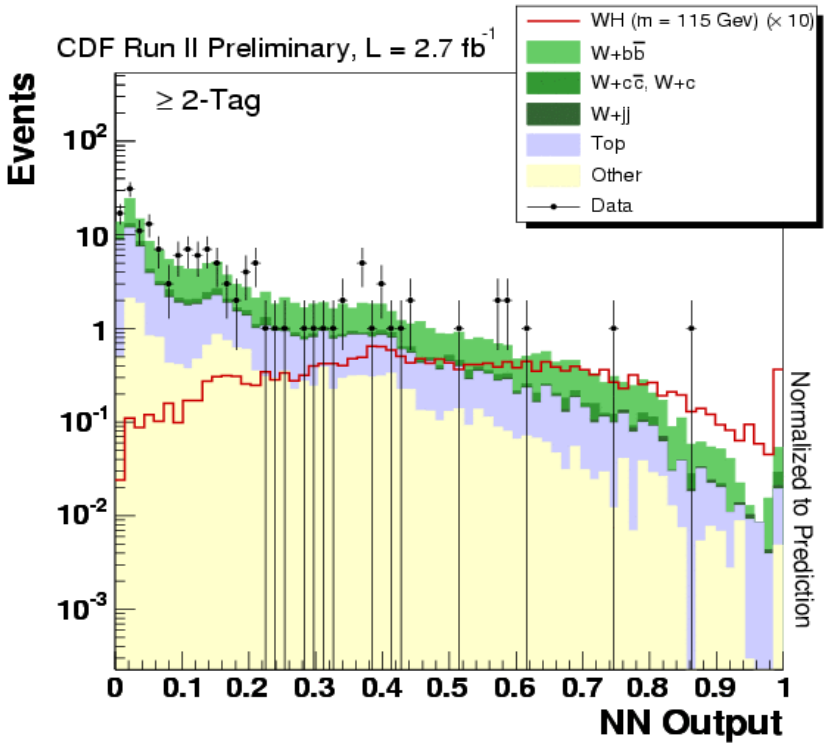
Low Mass Higgs: $WH \to \ell\nu b\bar{b},\ \ell = e,\mu$

Multivariate techniques to improve S/B:

D0: NN

CDF: NEAT=BDT+NN+ME





Low Mass Higgs: $VH \rightarrow \not\!\!E_T b\bar{b}$

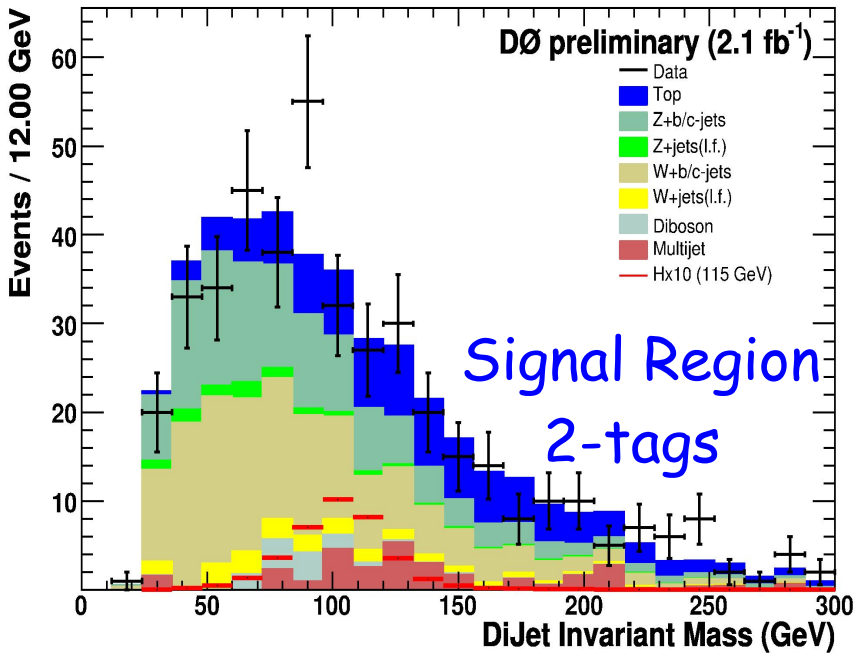
Signal acceptance ZH->vvbb and WH->lvbb (l missed)

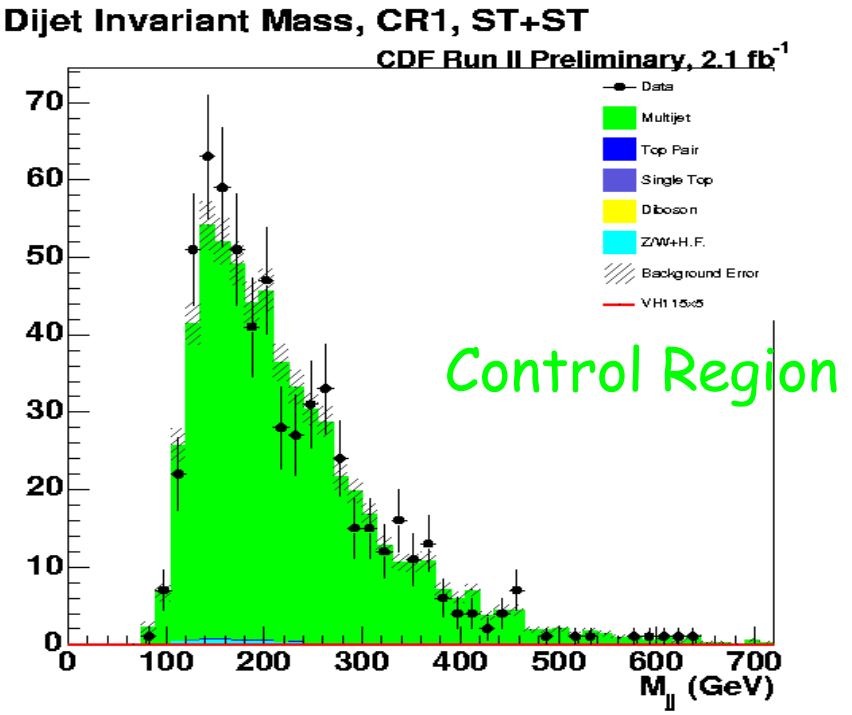
Signature: large MET and 2+ b-jets

Trigger Path: MET

Major backgrounds: QCD with fake MET,W/Z+bb-jets, top,diboson

Background modeled using data



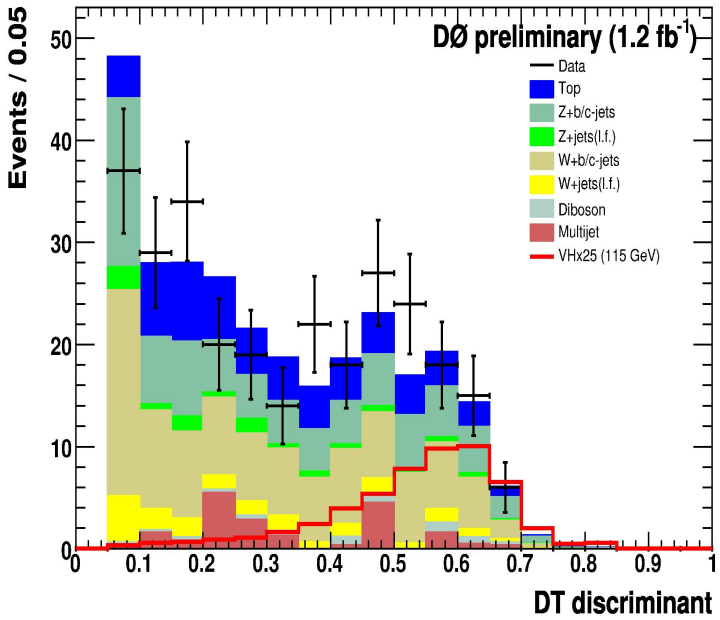


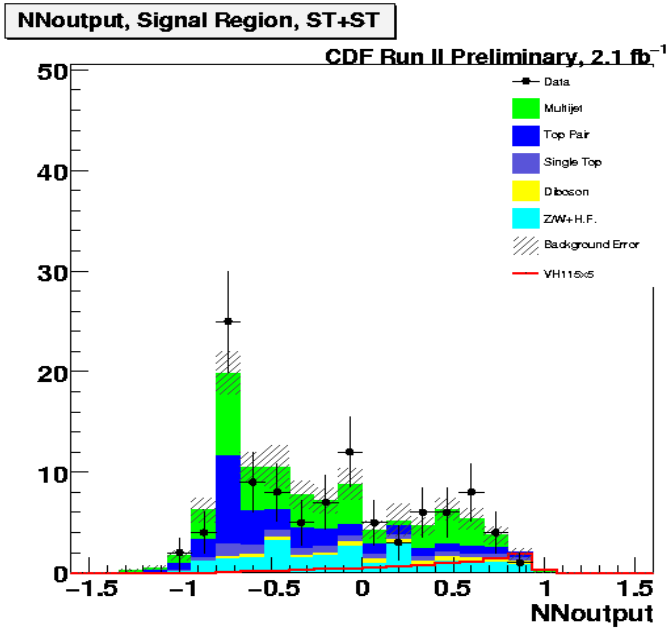
Low Mass Higgs: $VH \rightarrow \not\!\!E_T b\bar{b}$

Multivariate techniques to improve S/B:

D0: BDT on double tagged sample

CDF: NN with separate training for 2 and 3 jets





Events Summary

No signal excess and a limit is set respect to SM.

Obs. (Exp) 95% CL upper limits / SM @ M_H = 115 GeV/c^2		
Channel	CDF II	DØ
$WH \to l^{\pm}\nu\, b\bar{b}$	4.3 (3.8) in 4.3 fb^{-1}	6.9 (5.1) in 5.0 fb^{-1}
$VH \to \nu\nu\, b\bar{b}$	6.1 (4.2) in 3.6 fb^{-1}	3.7 (4.6) in 5.2 fb^{-1}
$ZH \to l^+l^-\, b\bar{b}$	5.9 (6.8) in 4.1 fb^{-1}	9.1 (8.0) in 4.2 fb^{-1}

Additional decay channels

Other decay channels are searched, but more challenging.

$H \to \gamma\gamma$ CDF and D0 detector not optimal. Narrow resonance but Br($H \to \gamma\gamma$) 300 times smaller than H->bb

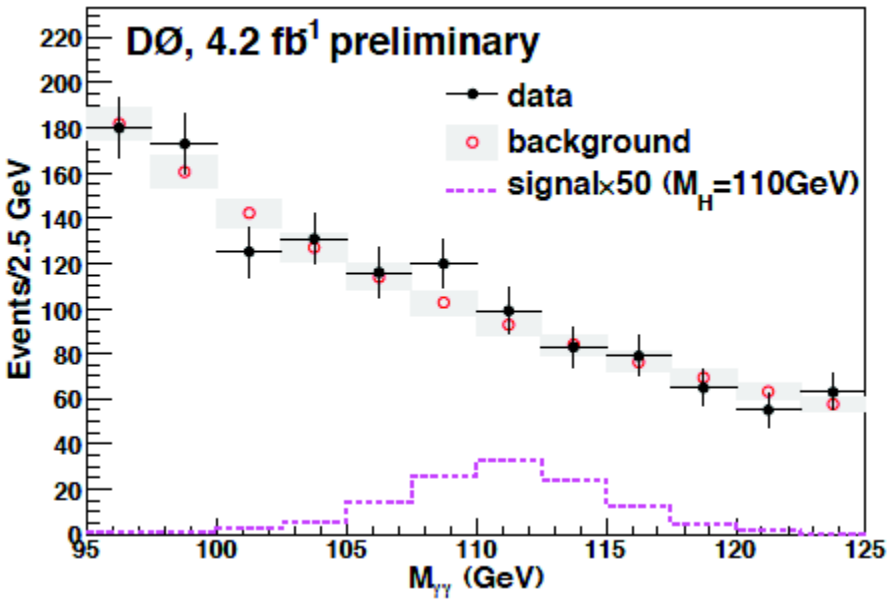
$H \to \tau\tau$ Br($H \to \tau\tau$) 10 times smaller than H->bb, but low τ reconstruction efficiency

W/Z+H H->bb and W/Z->qq a lot of signal but enormous QCD!

W+H H->bb W->$\tau\nu$ hard to select at trigger level. A lot of QCD

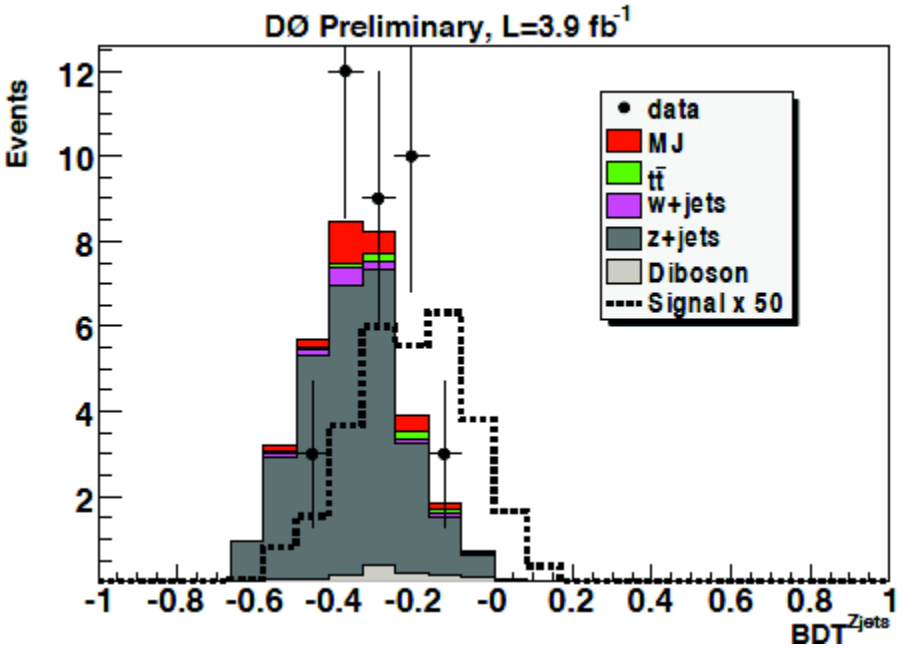
Additional decay channels

H–>γγ



16*SM (19*SM exp.)

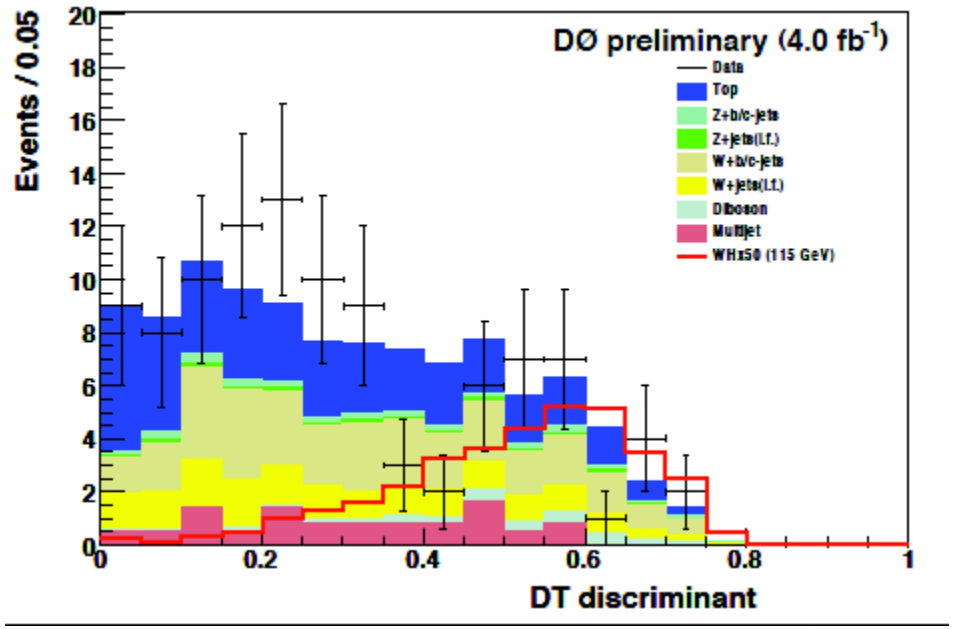
H–>ττ



27*SM (16*SM exp.)

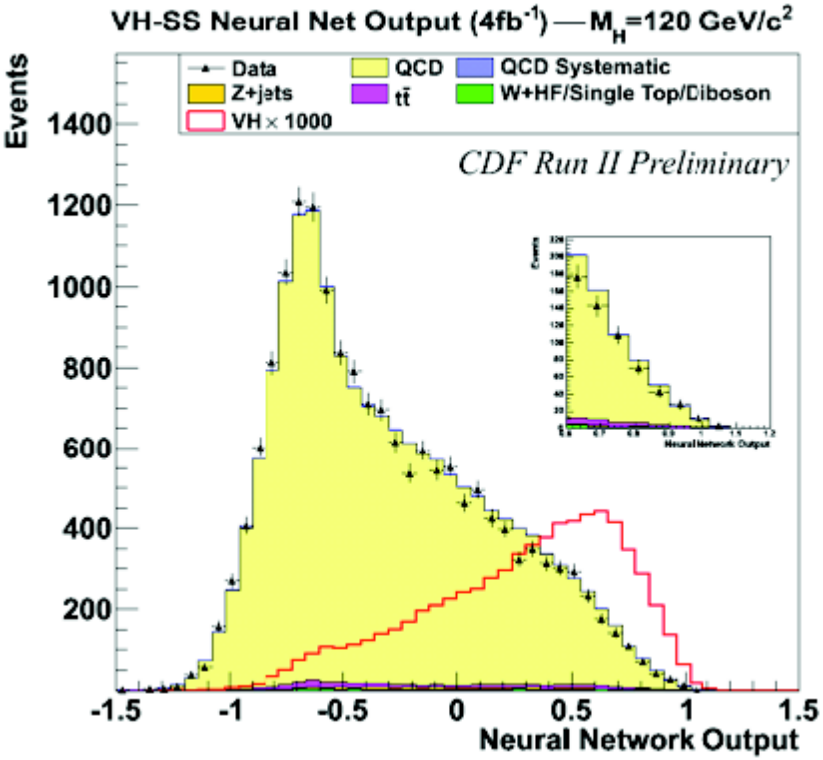
Additional decay channels

WH→τνbb



14*SM (22*SM exp.)

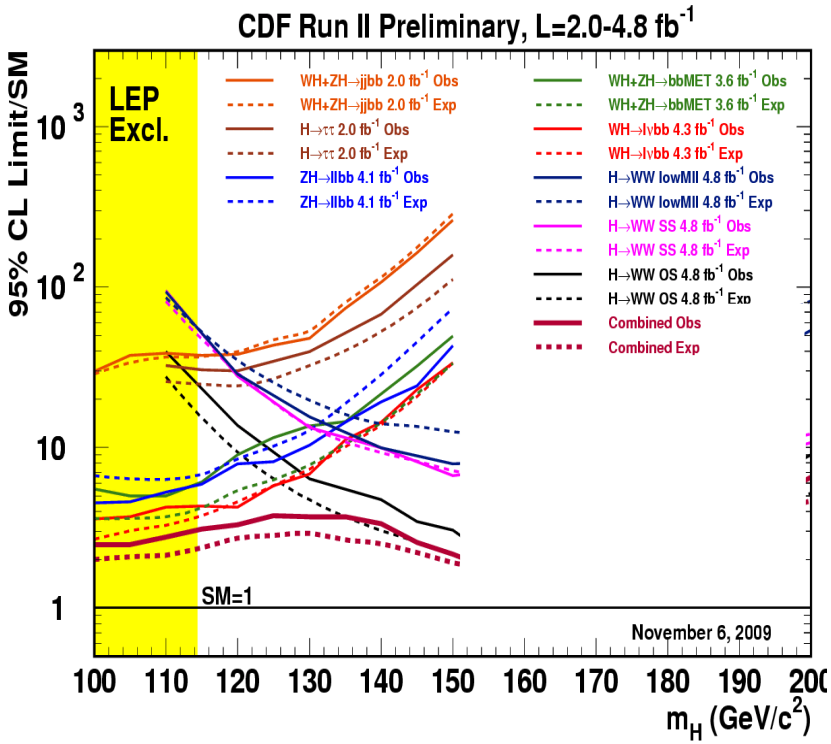
WH/ZH → qqbb



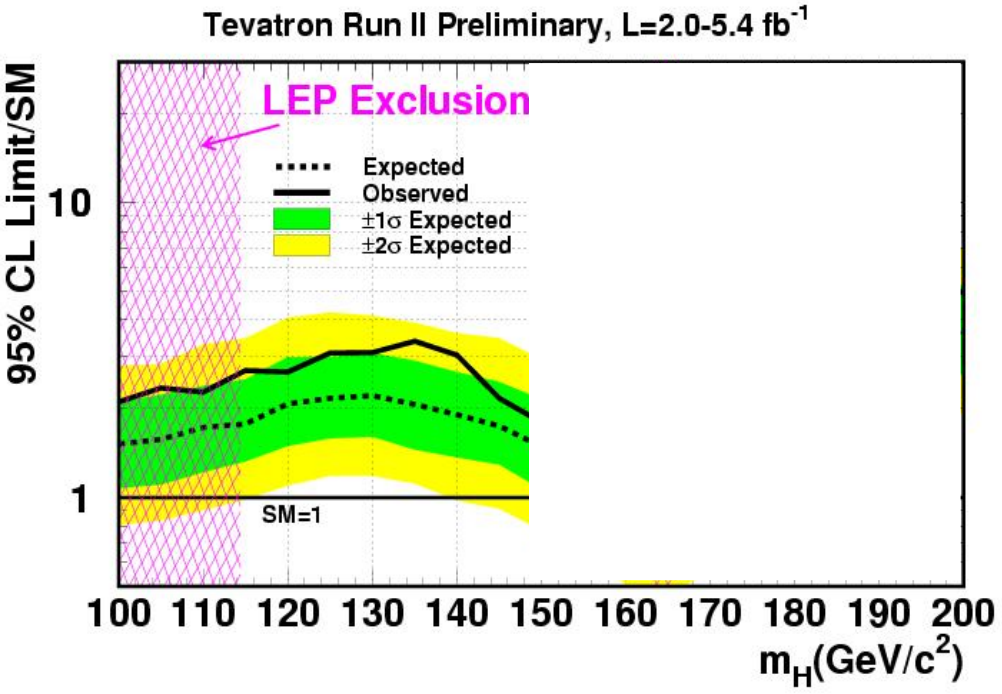
10*SM (18*SM exp.)

Low Mass Higgs Combination

CDF

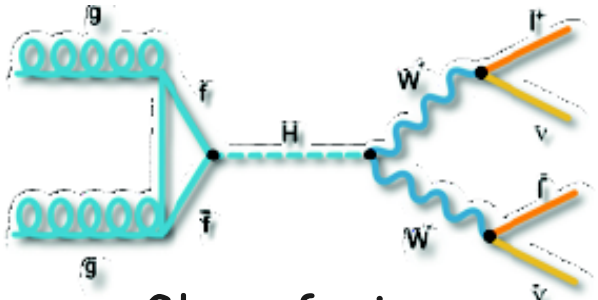


DO has similar results.
Most sensitive results are combined

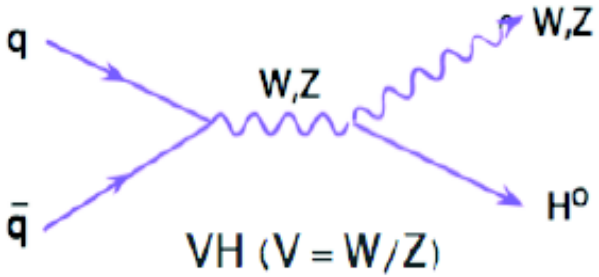


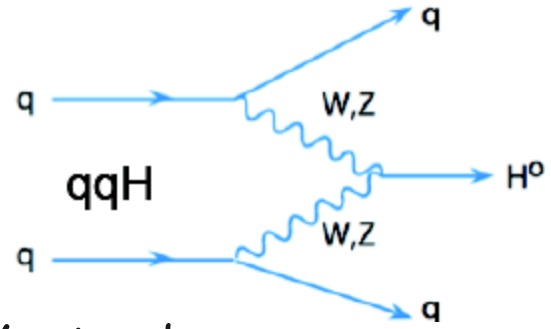
High Mass Higgs

Signal



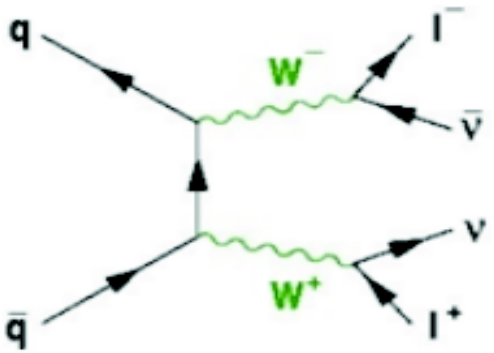
Gluon fusion

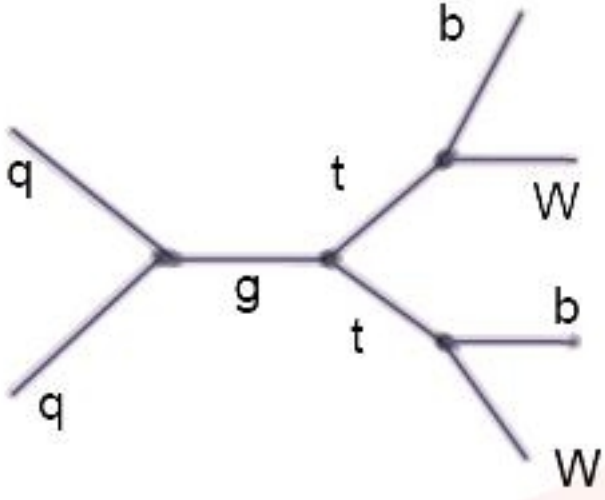




Vector boson fusion

Background

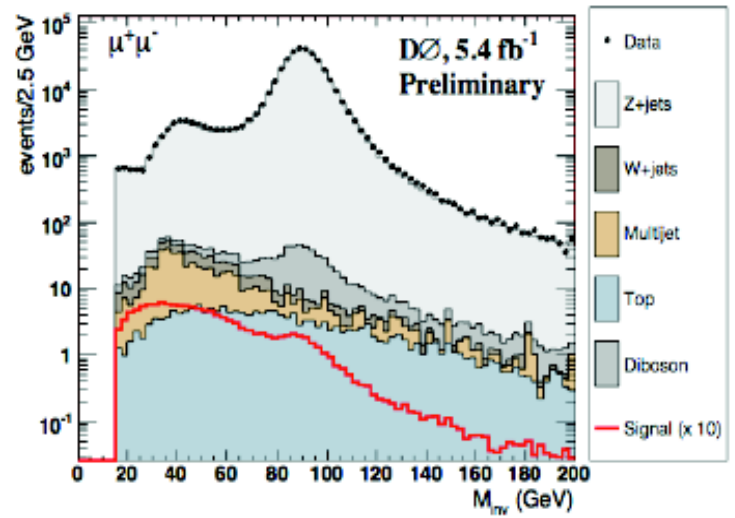


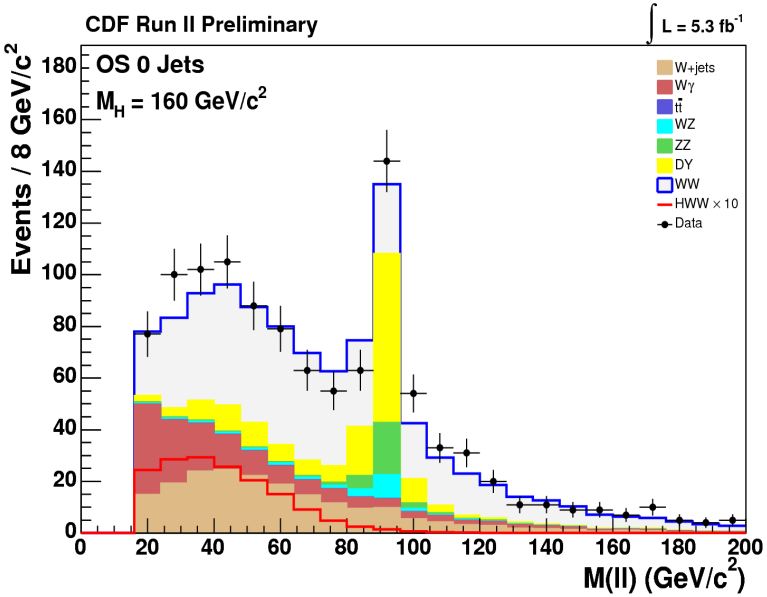


High Mass Higgs Strategies

Analysis split in different orthogonal channels:

- D0 separate reconstruction in ee/eμ/μμ final states
- CDF classify events depending on the number of jets in the final states (ie high/low signal to noise)
- Cut discriminant variables to reduce background
- Apply multivariate techniques to increase signal sensitivity

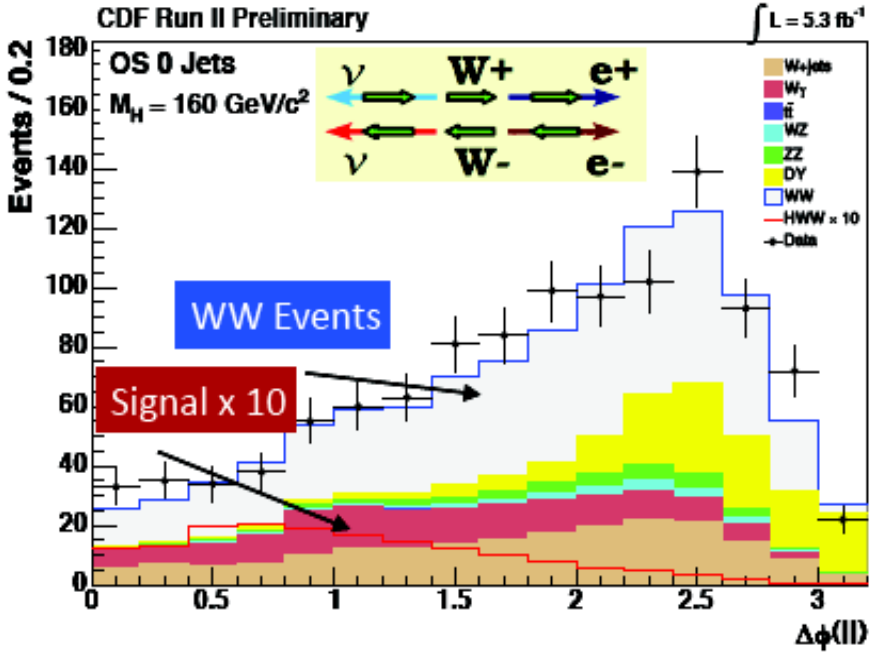


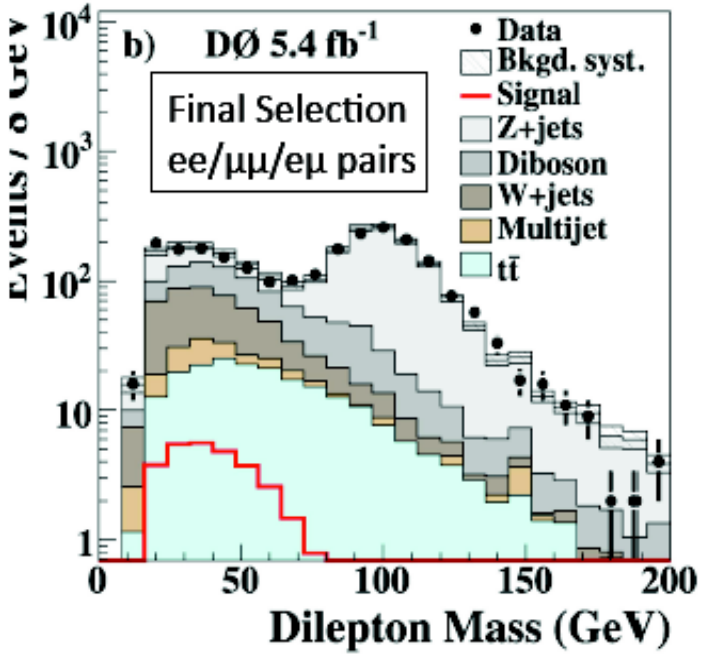


High Mass Higgs Strategies(2)

Discriminating Variables

- Leptons angular separation: small angular separation if Ws are from H due to spin correlation. Reduce WW
- Dilepton invariant mass: effective against any background

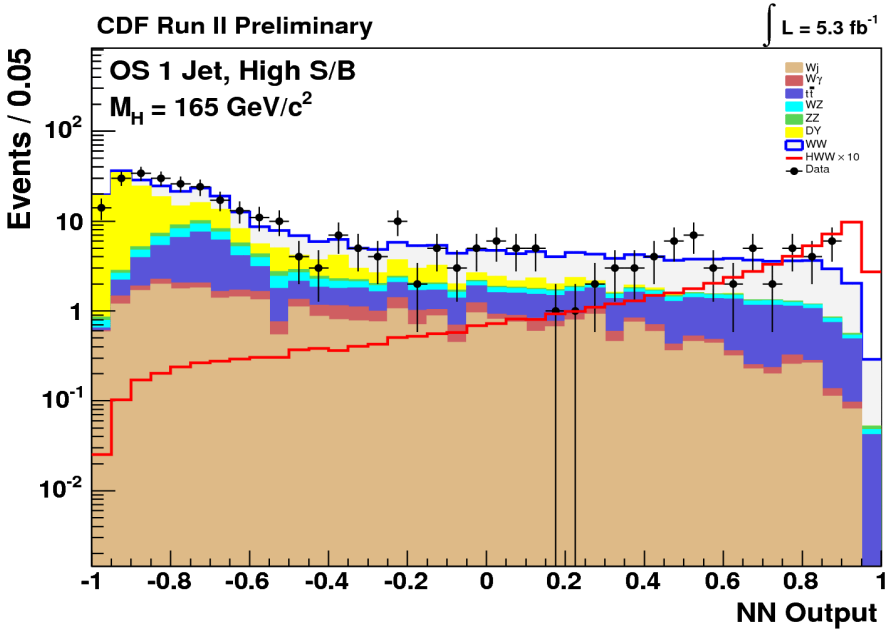


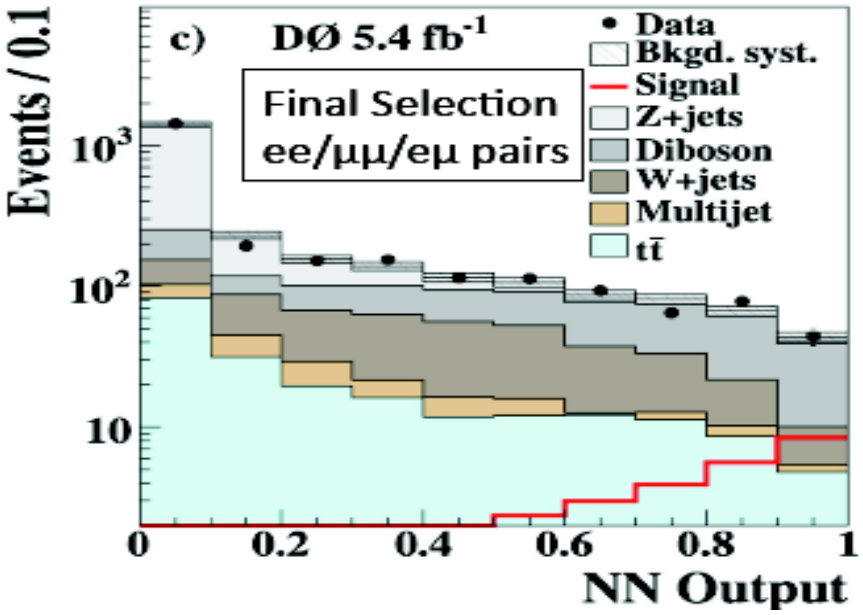


High Mass Higgs Strategies(3)

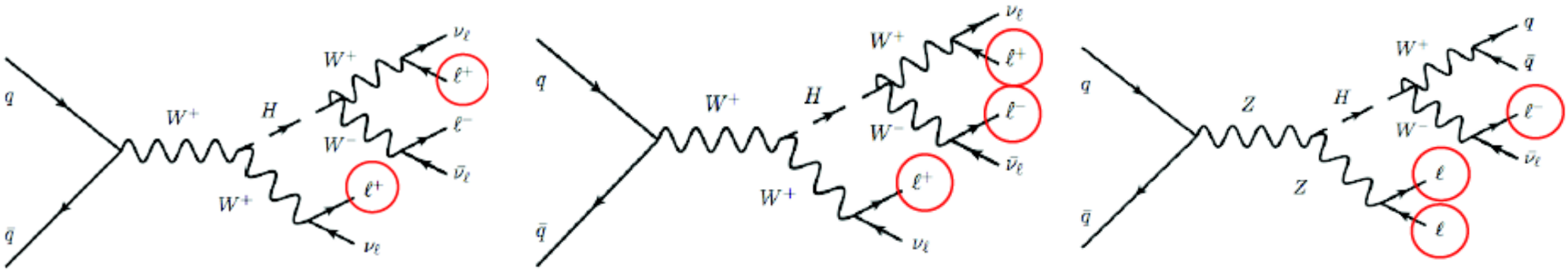
Multivariate techniques

- Use a set of quantities and Matrix Element in a Neural Network
- A NN is trained for each H mass point hypothesis and for
- Each orthogonal analysis channel

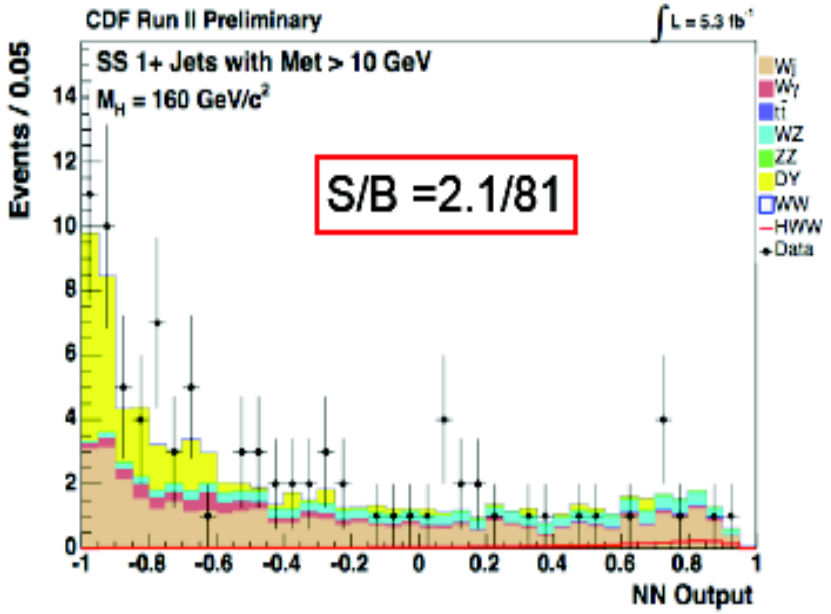


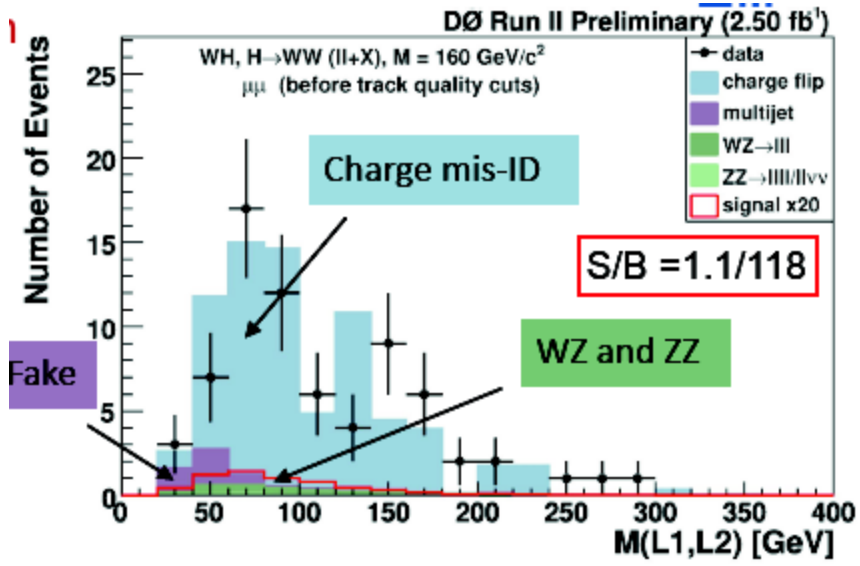


Additional Acceptance: VH

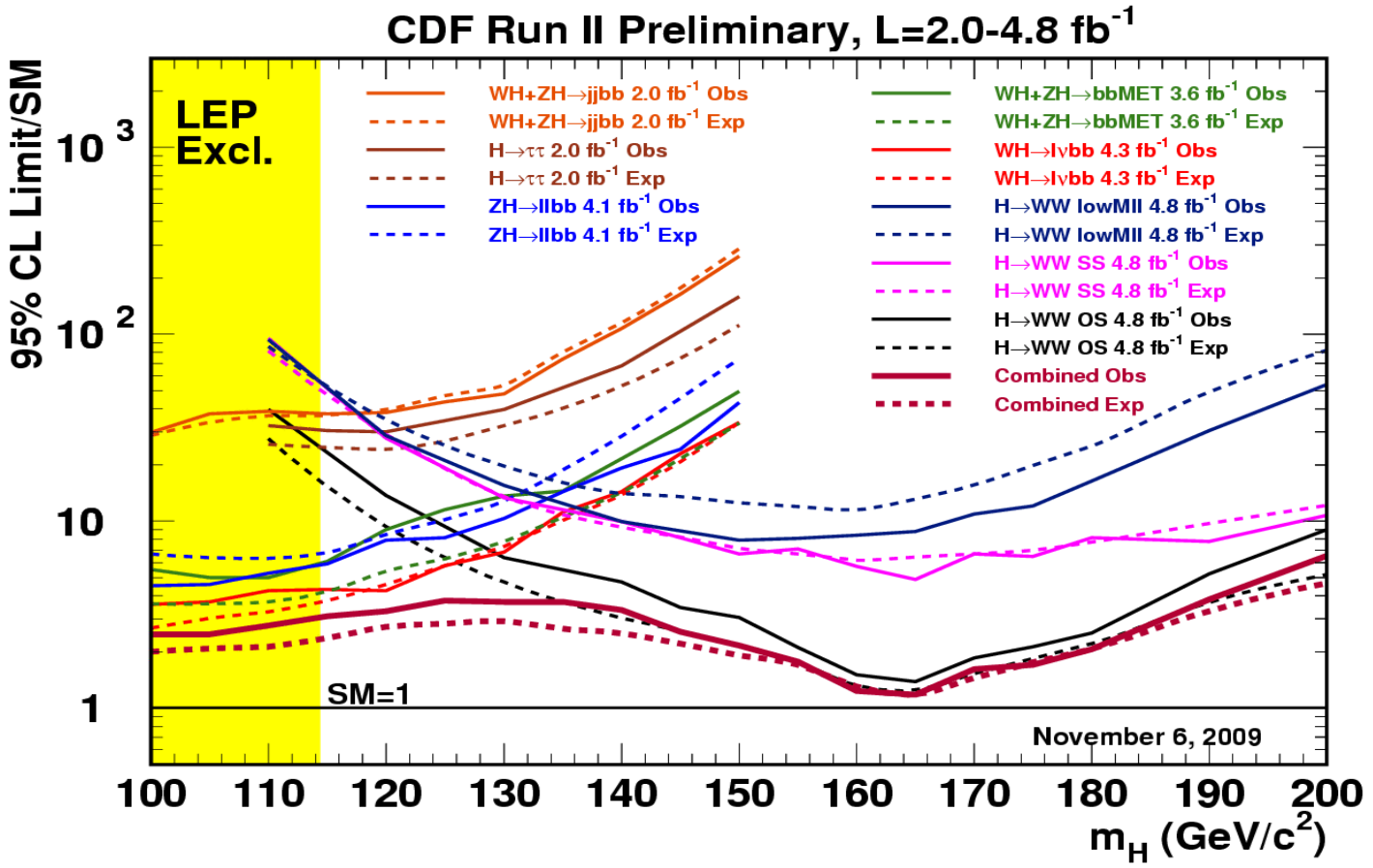


Three vector bosons in the final state. Exploit their decays



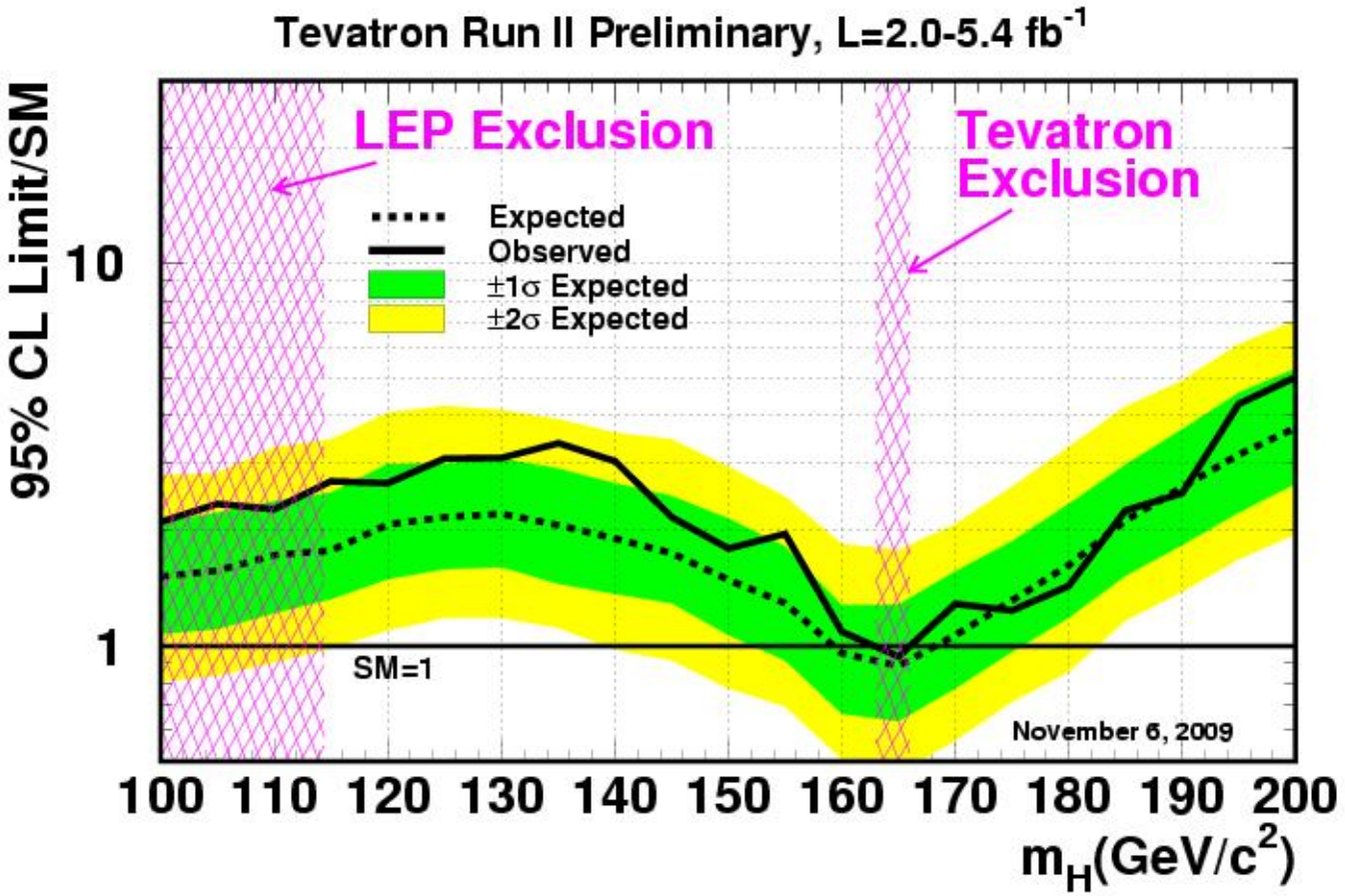


Higgs Combination: single experiment

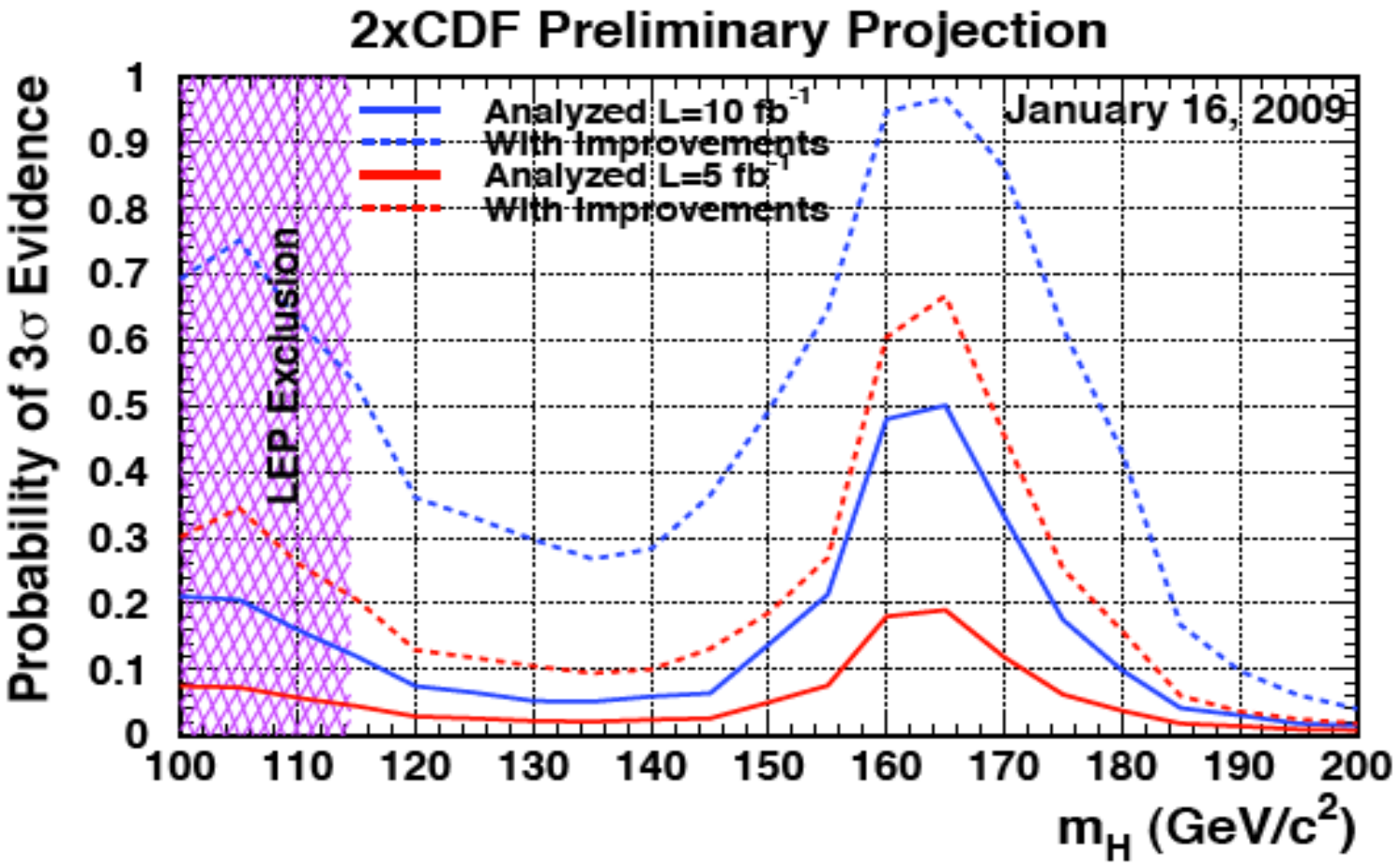


Higgs Combination: Tevatron

It's more than √2 in statistics



Future


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