Higgs boson searches at Tevatron

- On the way of the Higgs:
  - Di-bosons
  - Standard Model expectations
- Higgs searches introduction
- Low mass Higgs analysis
- Low mass Higgs combination
- High mass Higgs analysis
- Final Higgs searches combination
- Next step

On the way to the Higgs: Di-bosons

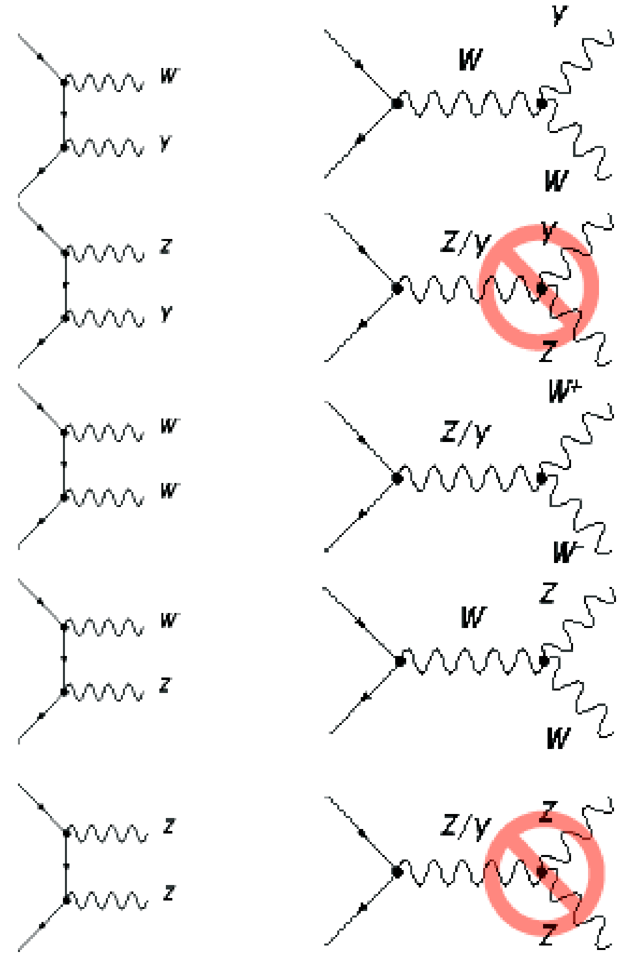
Diboson final states:

- Test Standard Model production predictions
- Look for anomalous coupling
- Cross sections similar to Higgs

CDF & D0 published results on:

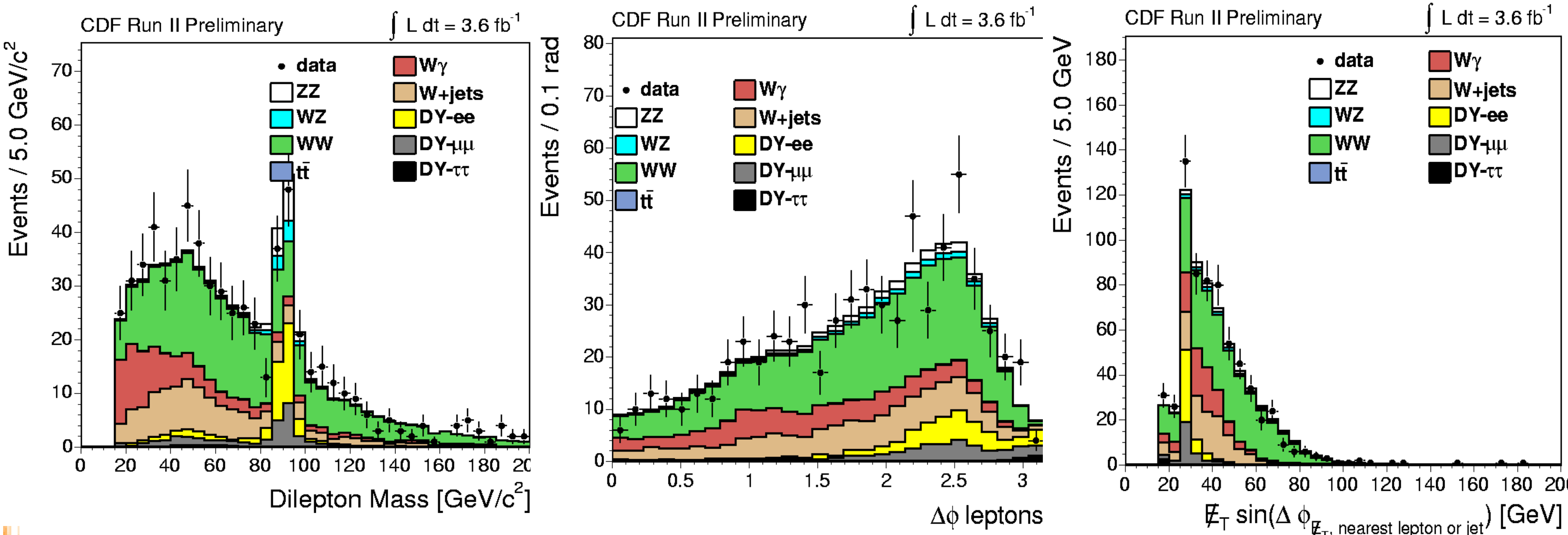
- $W\gamma$
- $Z\gamma$
- WW
- WZ
- ZZ

New D0 measurement using $1fb^{-1}$



On the way to the Higgs: WW

Final states: ee, μμ, eμ



Example of variables used as input for the Matrix Element

$$P(\vec{x}_{obs}) = \frac{1}{\langle\sigma\rangle} \int \frac{d\sigma(\vec{y})}{d\vec{y}} \epsilon(\vec{y})\, G(\vec{x}_{obs}, \vec{y})\, d\vec{y}$$

True leptons momenta

LO cross section

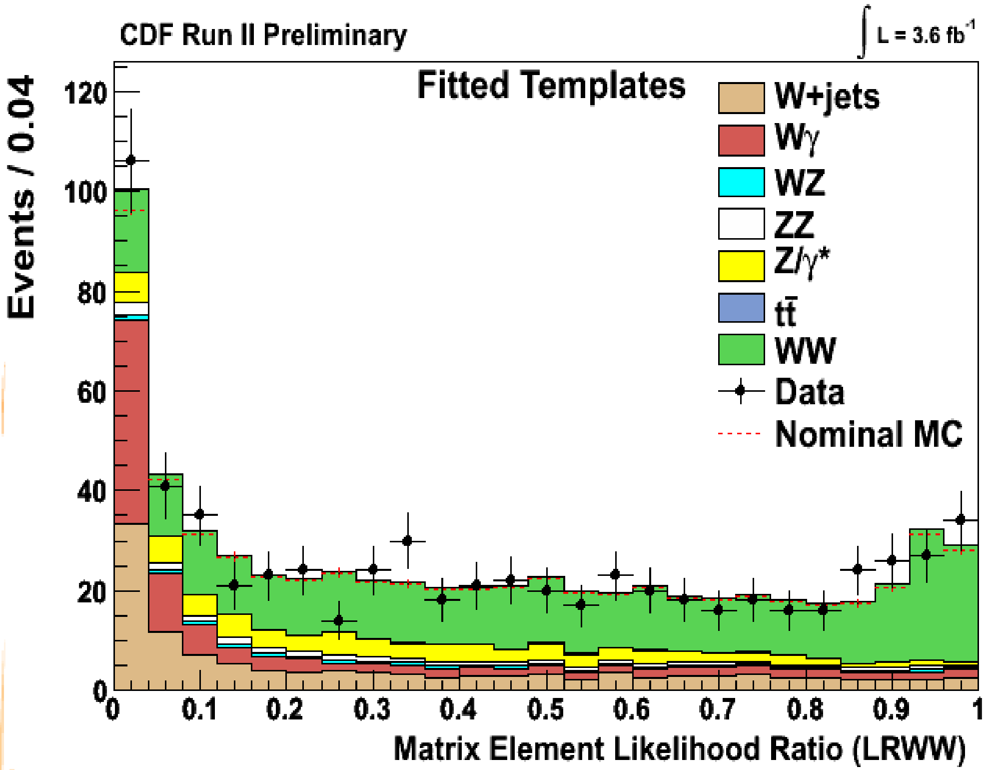
Efficiency and acceptance

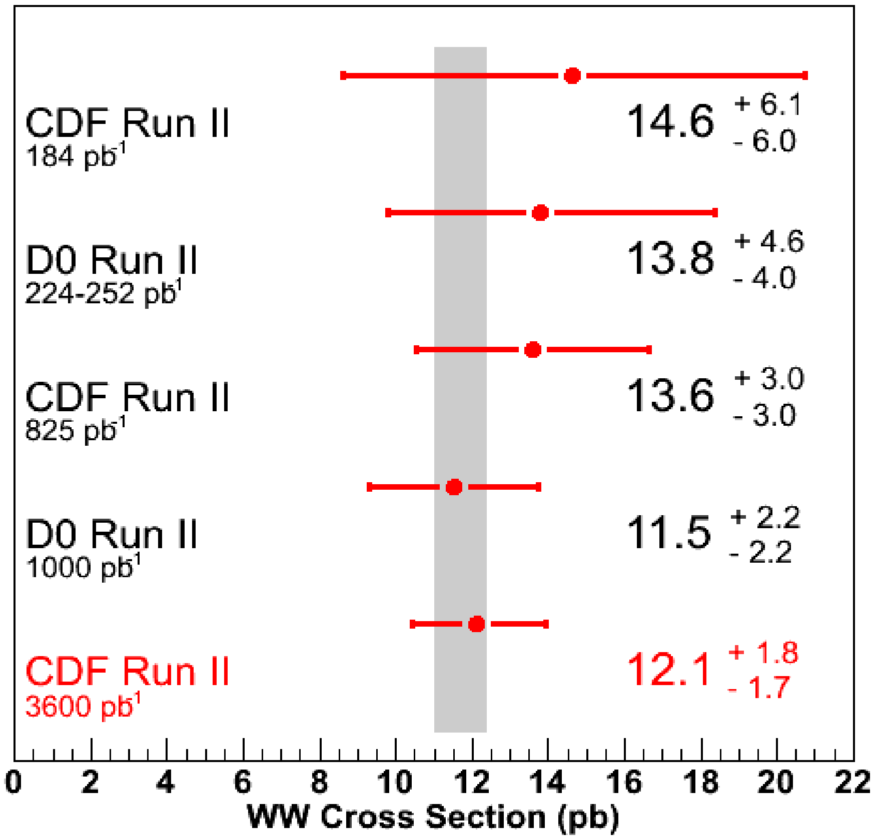
Physics observables

Likelihood ratio:

$$LR_{WW} = \frac{P_{WW}}{P_{WW} + \sum_i k_i P_i}$$

On the way to the Higgs: WW





Cross section

$$\sigma(p\bar{p} \rightarrow WW) = 12.1 \pm 0.9(\text{stat})\ ^{+1.6}_{-1.4}(\text{syst})\ \ [\text{pb}]$$

On the way to the Higgs: ZZ

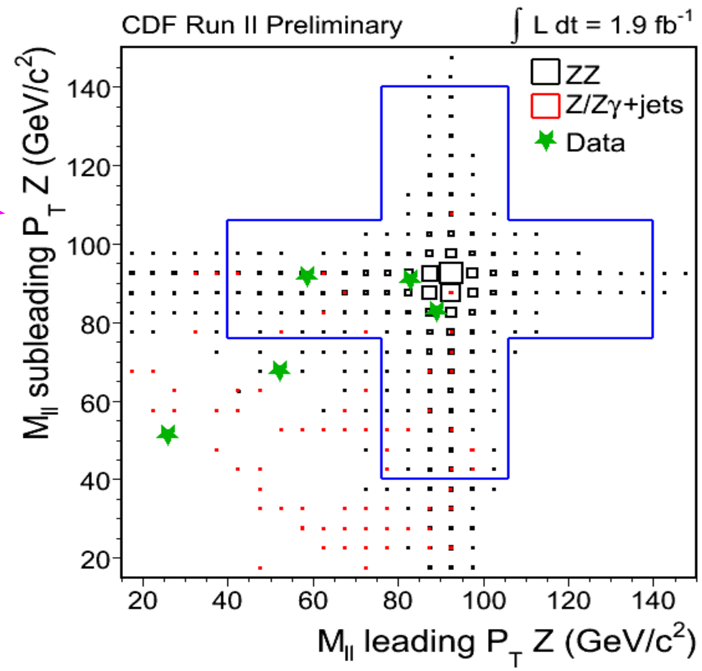
Results using final states with:

4 leptons

2 leptons and 2 ν

ZZ Fit Region

Category	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jets	Total	Data
$e\ e$	43.7	4.8	5.4	2.7	8.7	24.8	19.3	109 $\pm$10	118
$e\ \mu$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 $\pm$ 0	0
$\mu\ \mu$	33.7	3.7	4.4	2.4	7.0	0.0	2.7	54 $\pm$ 5	45
e trk	35.3	2.3	2.2	2.4	3.8	5.9	9.9	62 $\pm$ 5	69
μ trk	19.2	1.5	1.5	1.4	1.5	1.1	5.2	31 $\pm$ 3	44
Total	131.8	12.3	13.5	9.0	21.1	31.7	37.1	256 $\pm$21	276



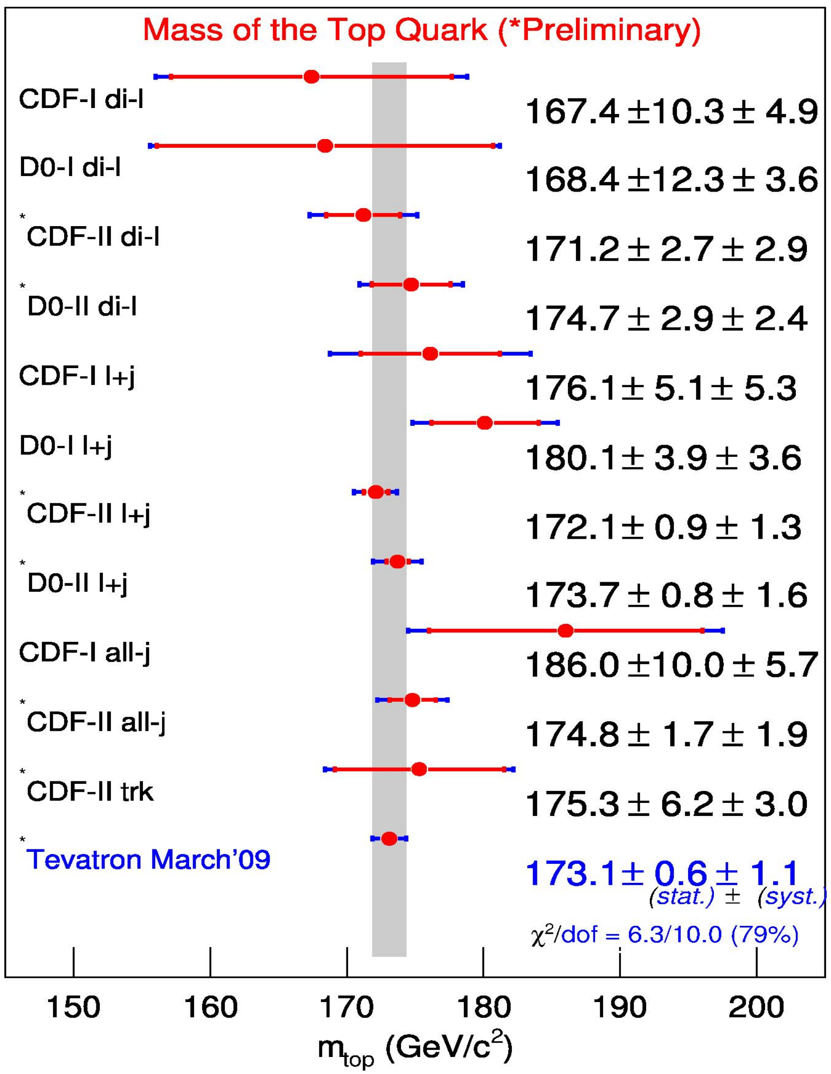
Combining the two channels D0 (2.7 fb^{-1}) signal has 5.7σ significance

The cross section $\sigma(ZZ)=1.60\pm0.63(stat)^{+016}_{-0.17}(syst)$

Combining the two channels CDF signal has 4.4σ significance

The cross section $1.4^{+0.7}_{-0.6}(stat.+syst.)$ pb

Top Mass



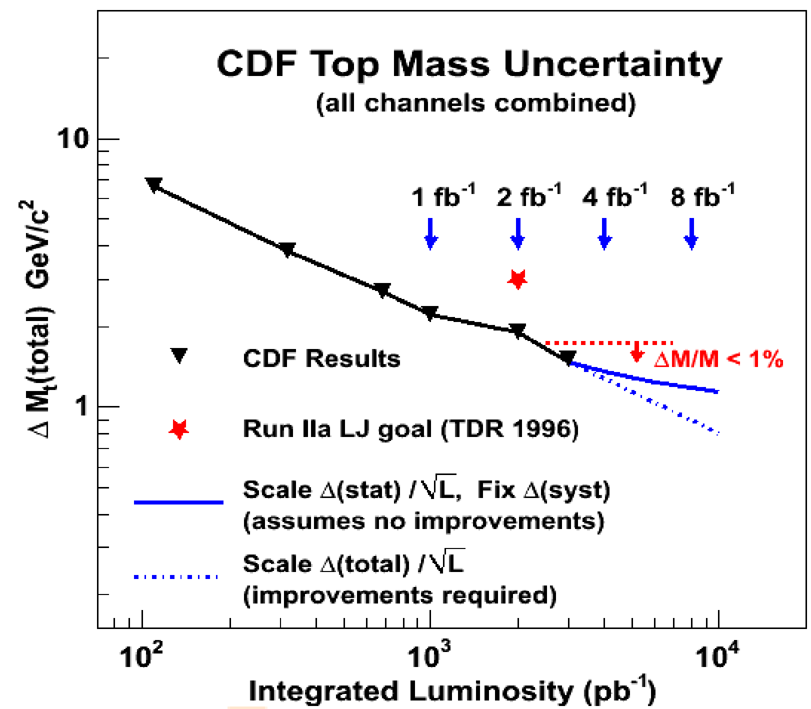
Use up to 3.6 fb^{-1} of data

CDF and D0 combined:

M_t=173.1±0.6(stat)±1.1(syst)GeV/c^2

Total uncertainty 1.3 GeV/c^2 -->

relative precision of 0.75%

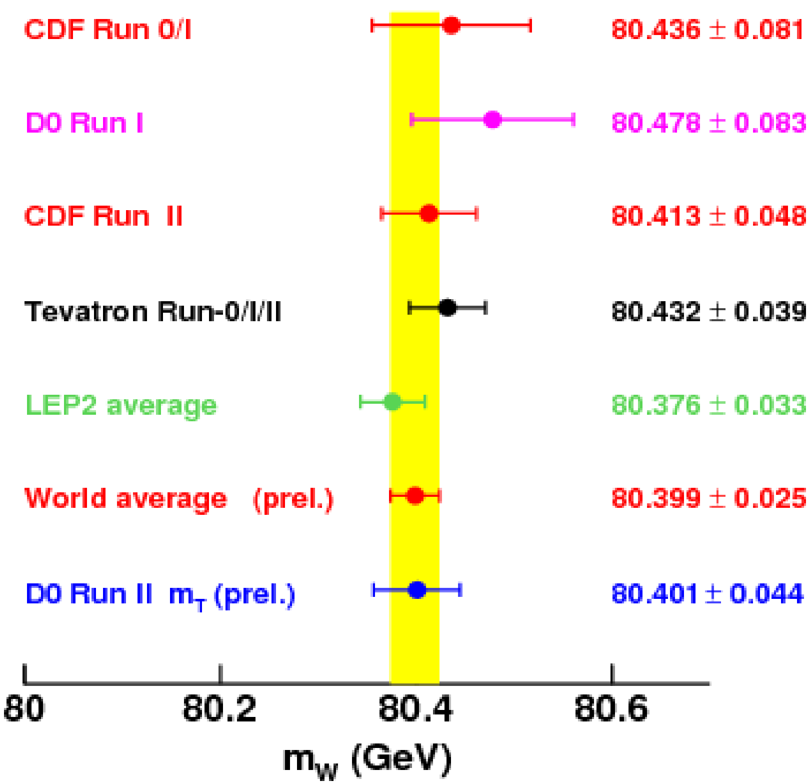


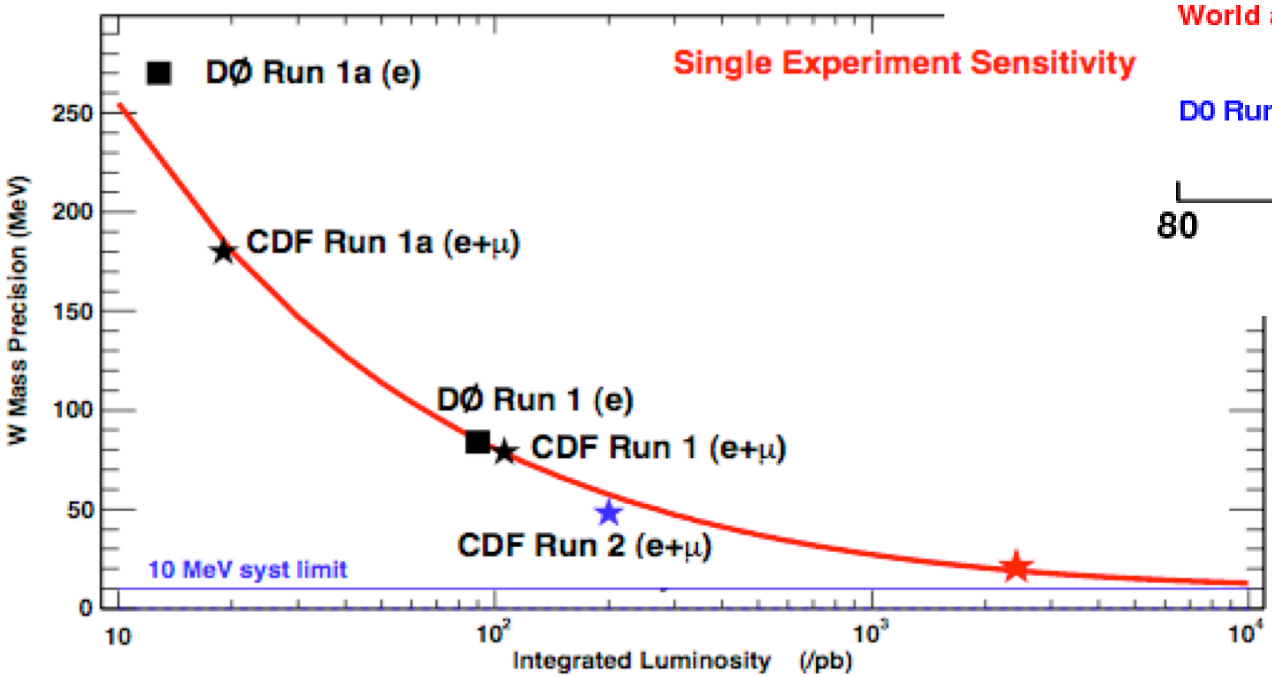
W Boson Mass

Latest results D0:

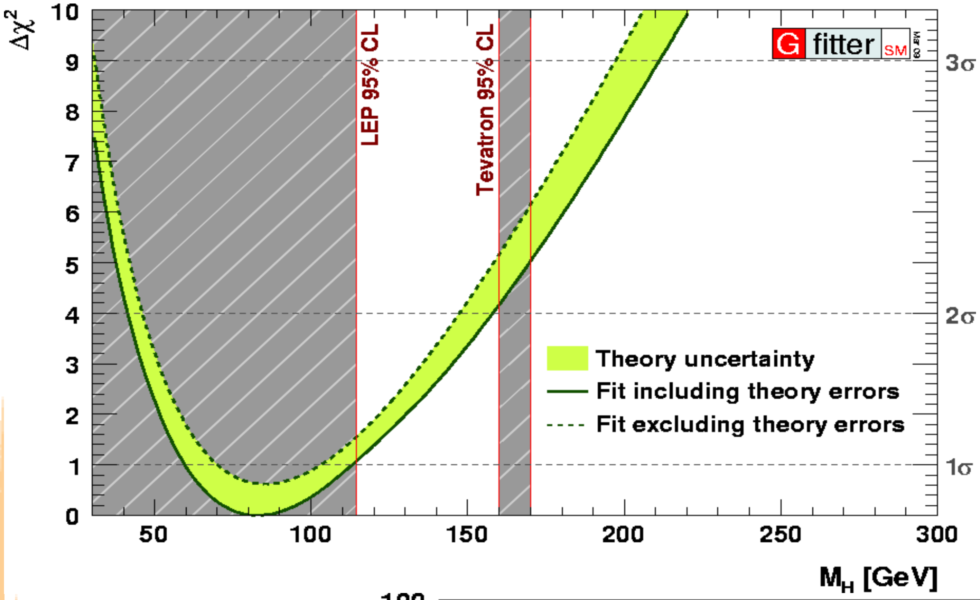
M_W 80.401±0.044 GeV

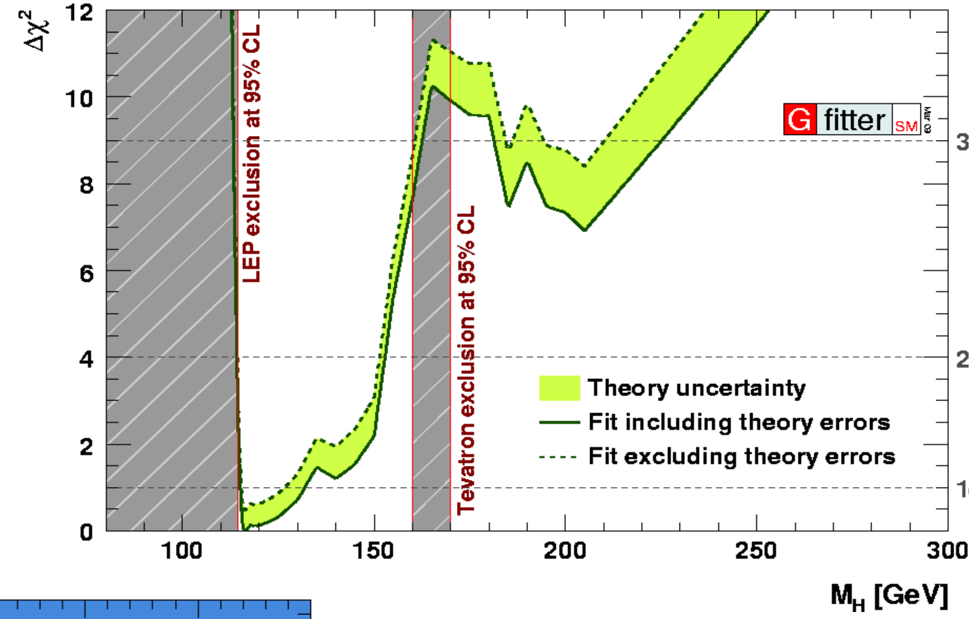
CDF has in progress the analysis on $2.4fb^{-1}$ the expected statistical error is ~15 MeV

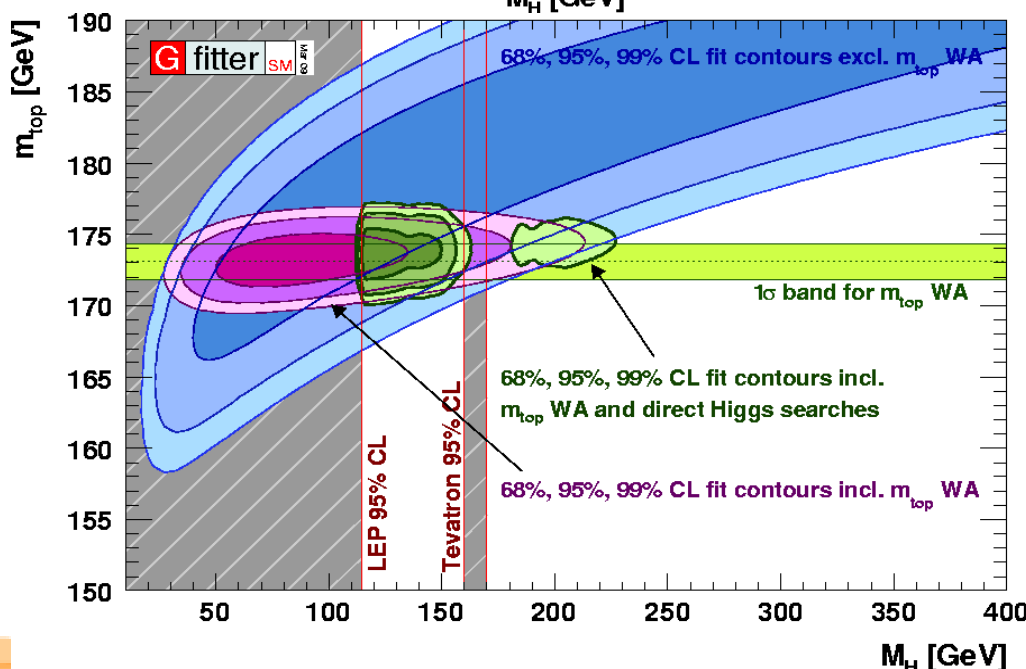




Cornering the Higgs

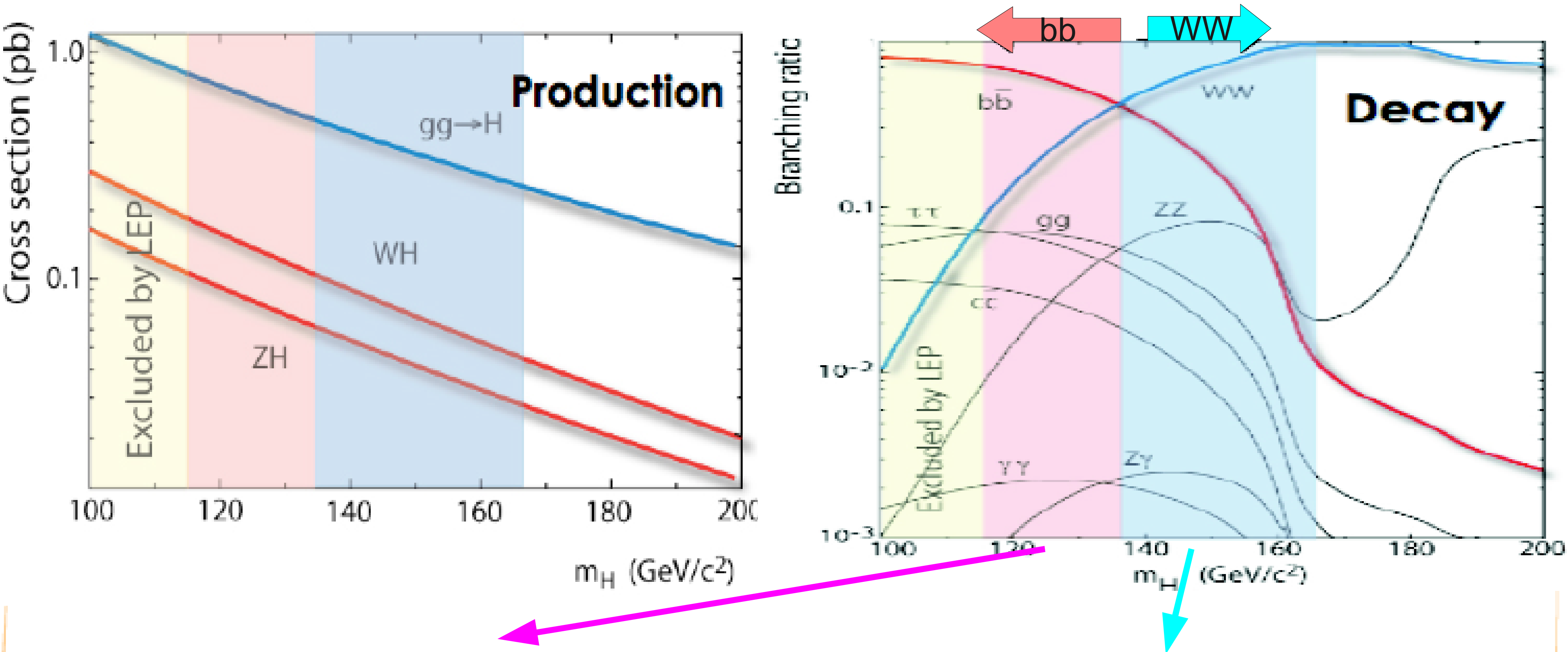






http://gfitter.desy.de/

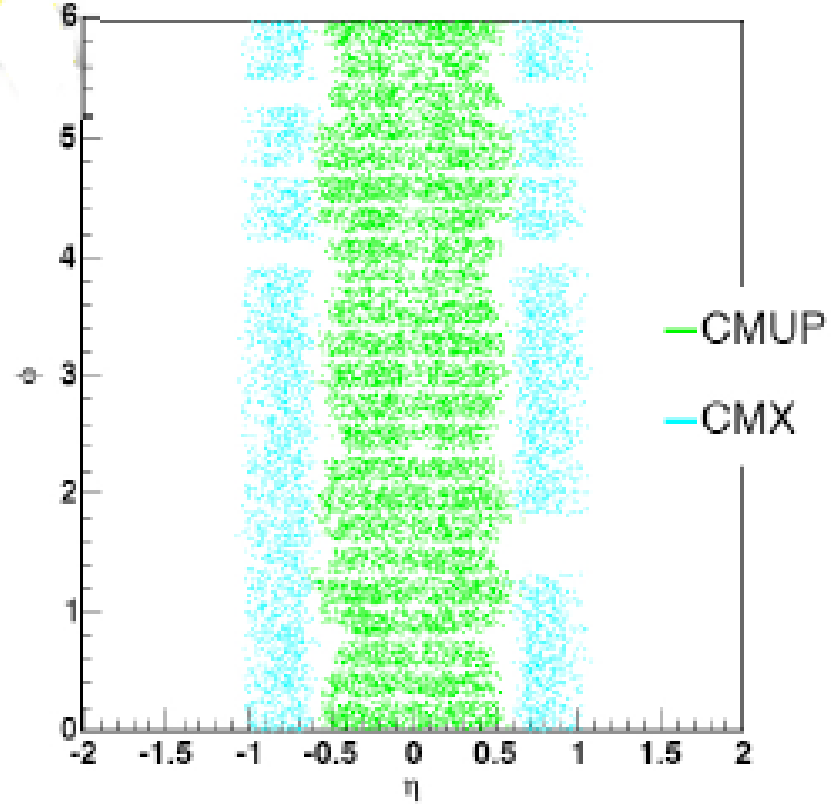
Direct Higgs searches @Tevatron



Low Mass: M_H<135 GeV/c^2 High Mass: M_H>135 GeV/c^2

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



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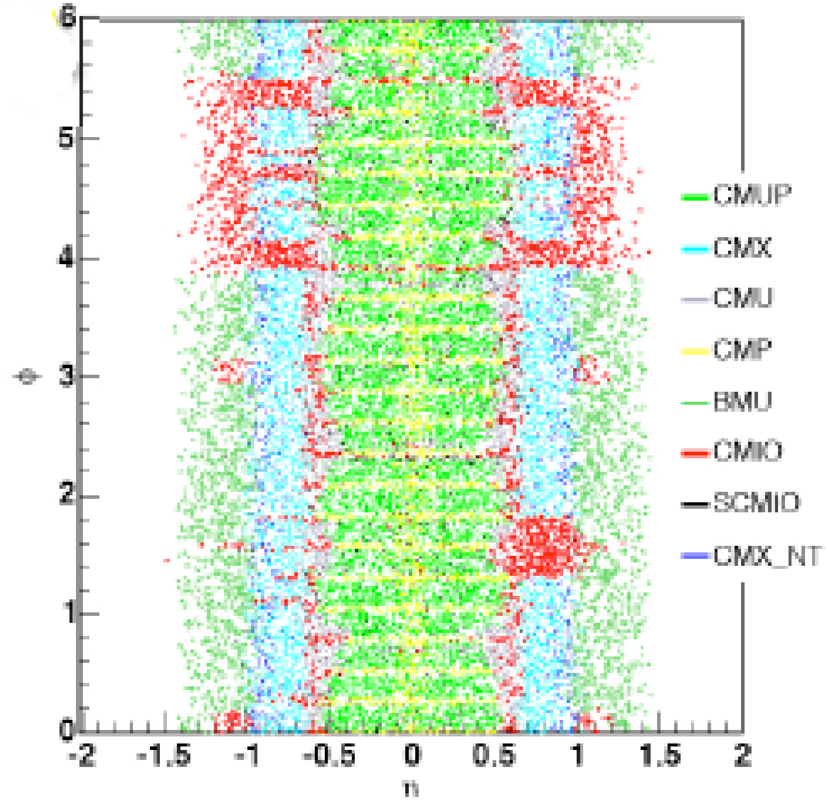

Analysis Tools: Lepton Identification

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  - electrons: tracks matched to ECAL
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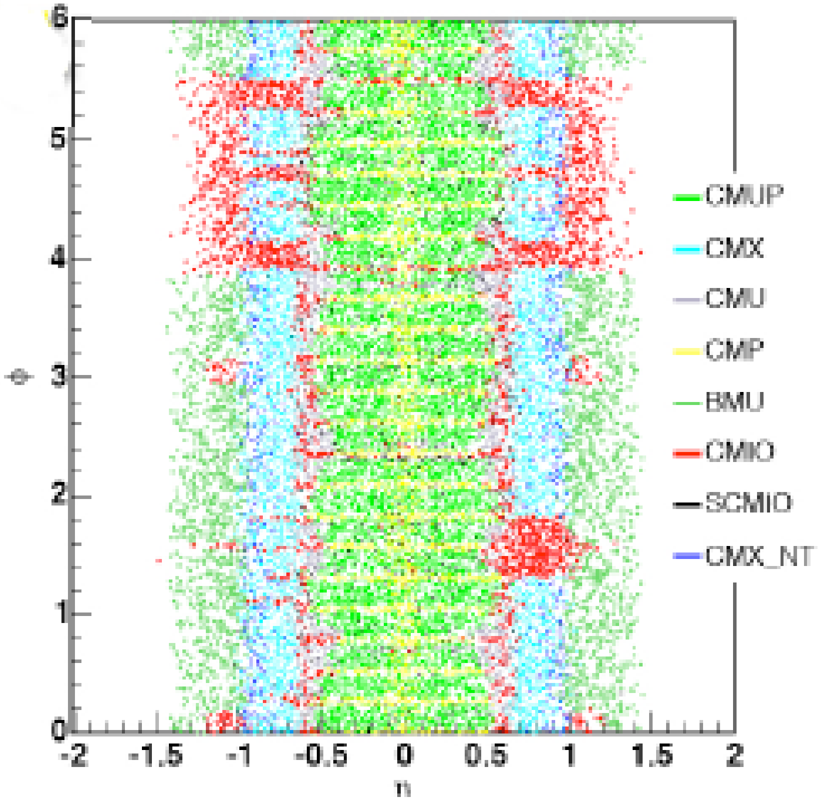
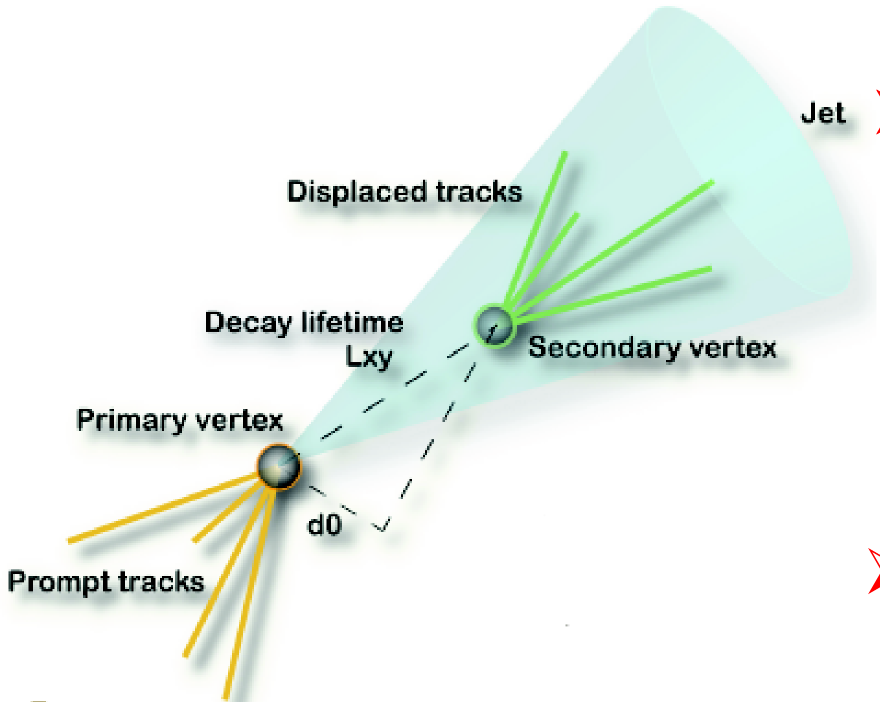
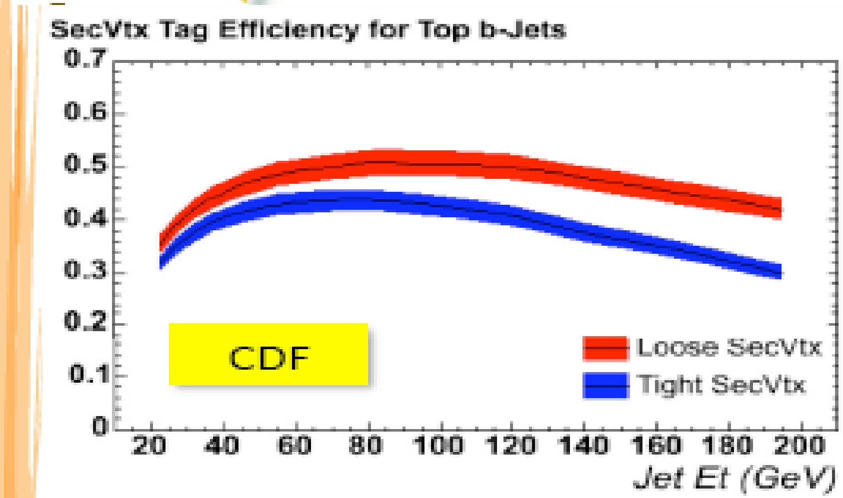
  - taus: tracks matched to calorimeter cluster
- Expand lepton coverage:
  - interplay between sub-detectors to cover holes
  - include forward detectors
- Good Missing E_T (MET) trigger :
  - select events with neutrinos and charged lepton that fail ID
  - remove events with fake MET



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

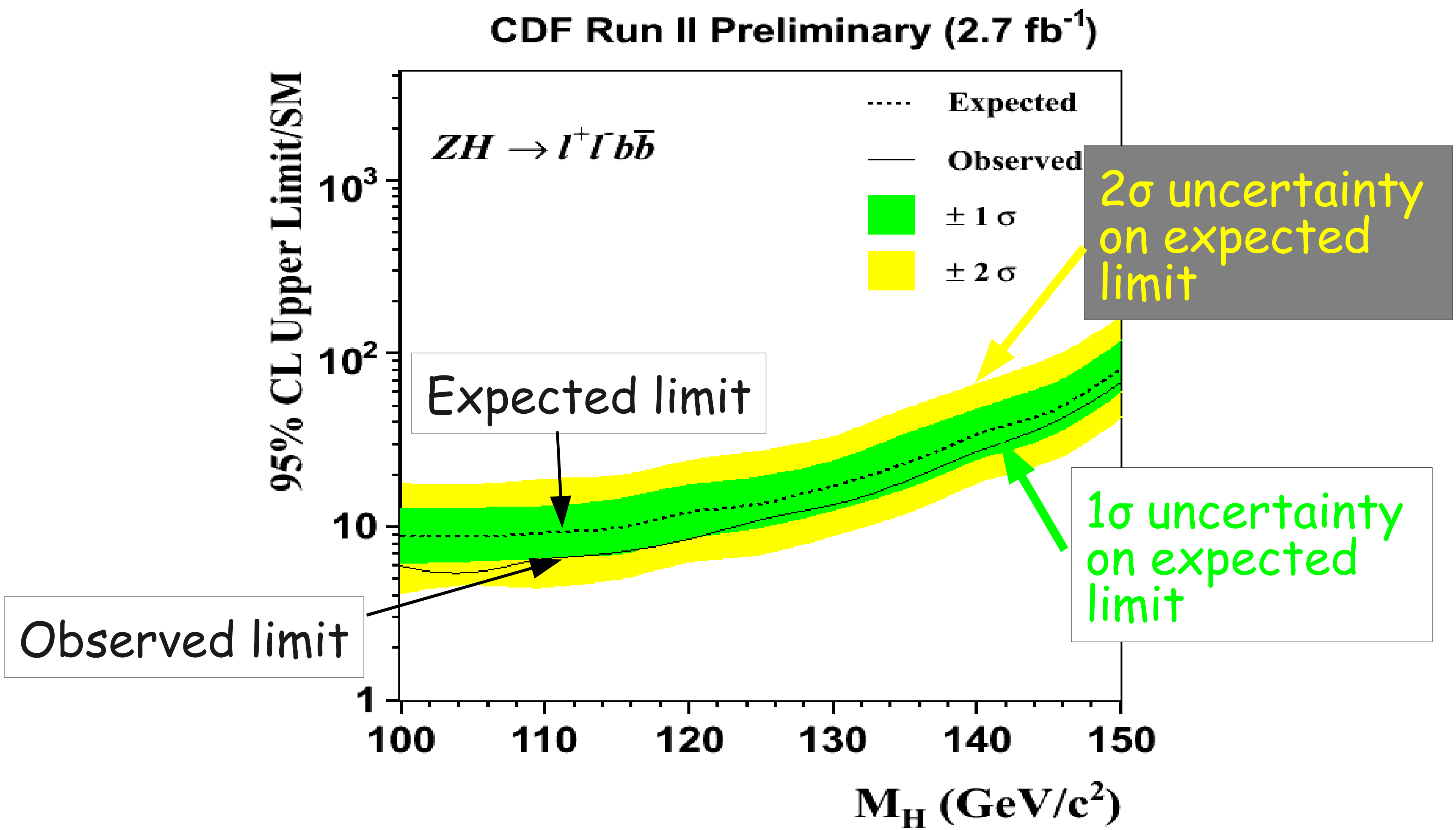
Analysis Tools: Multivariate techniques

- 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

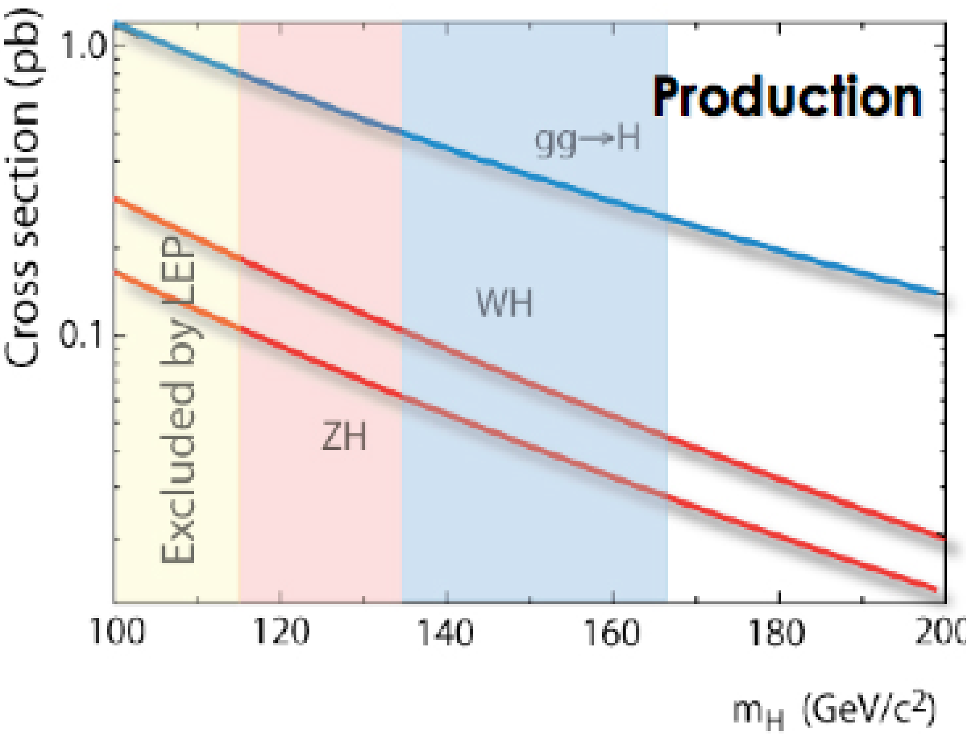
- Used already in many many analysis

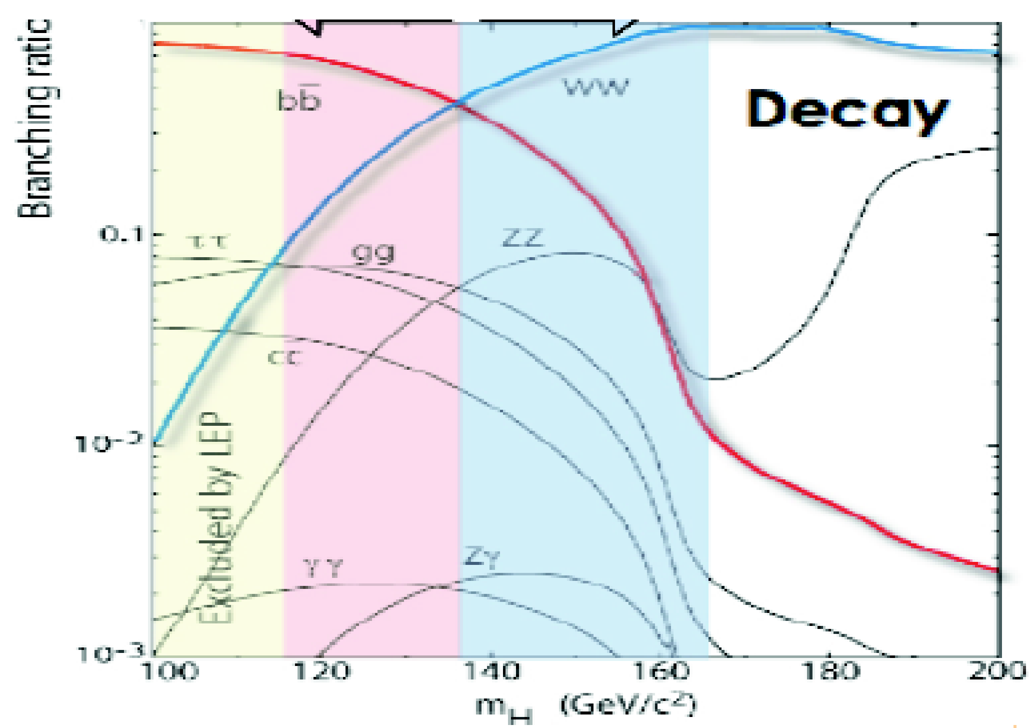
Reminder: Limit Plots



Low Mass Higgs searches

Low Mass: M_H<135 GeV/c^2





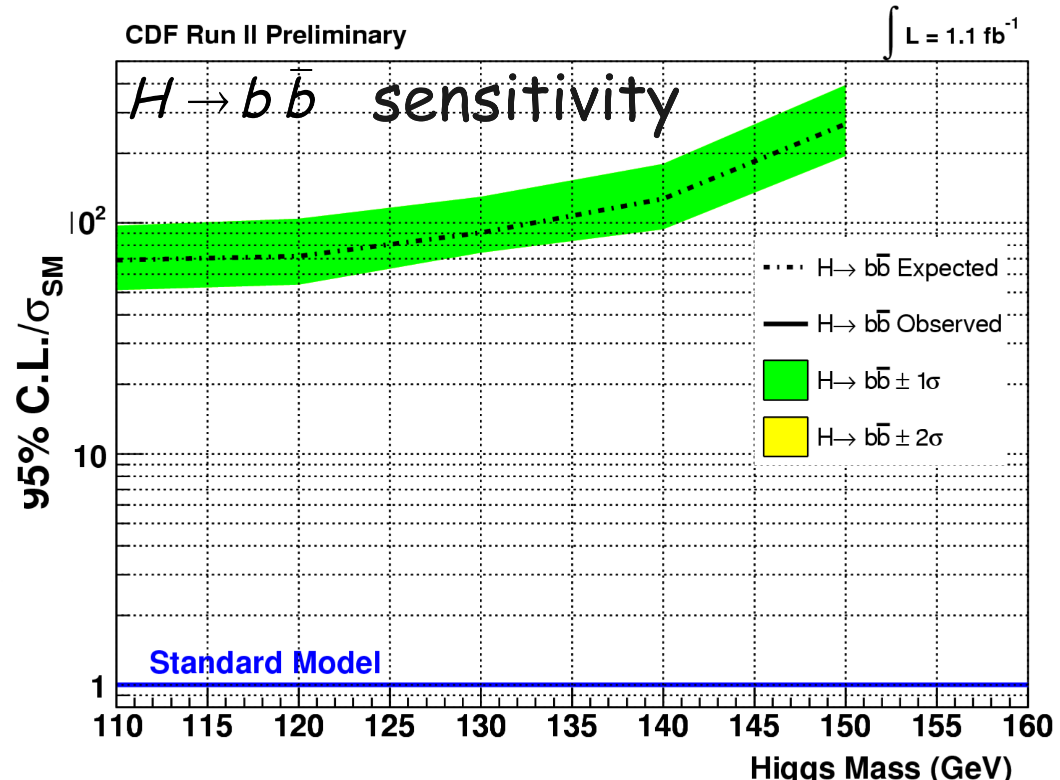
Dominant production mechanism: gg->H

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 designed and implemented by "us"

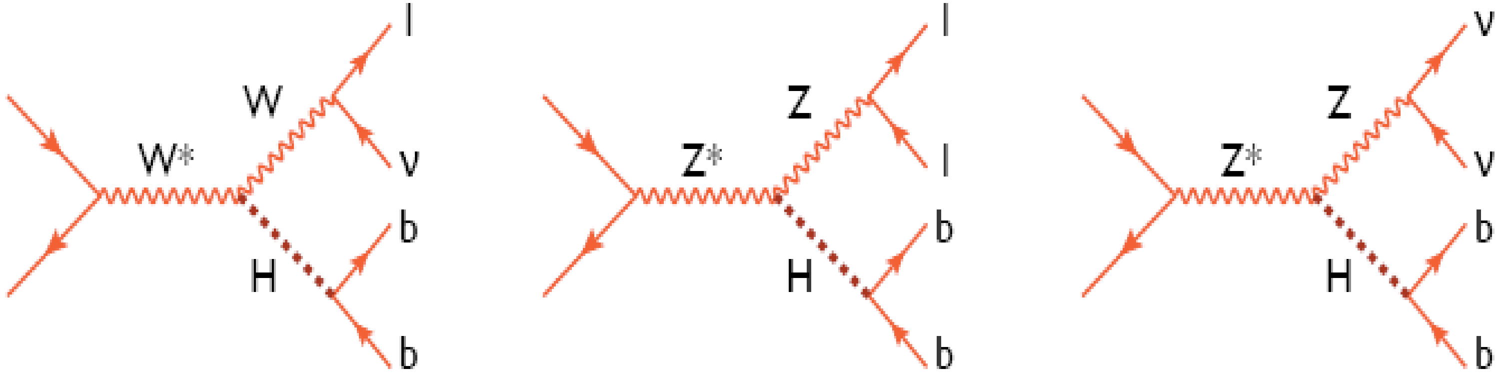
Trigger algorithms	$\epsilon(H \to bb)$	$\epsilon(\phi \to bb)$	$\epsilon(Z \to bb)$
Vertex b-tag	13%	11%	4%
Muon b-tag	5%	6%	2%

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->γγ and H->ττ 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 ττ 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: $ZH \to \ell^+\ell^- b\bar{b}, \ell = e, \mu$

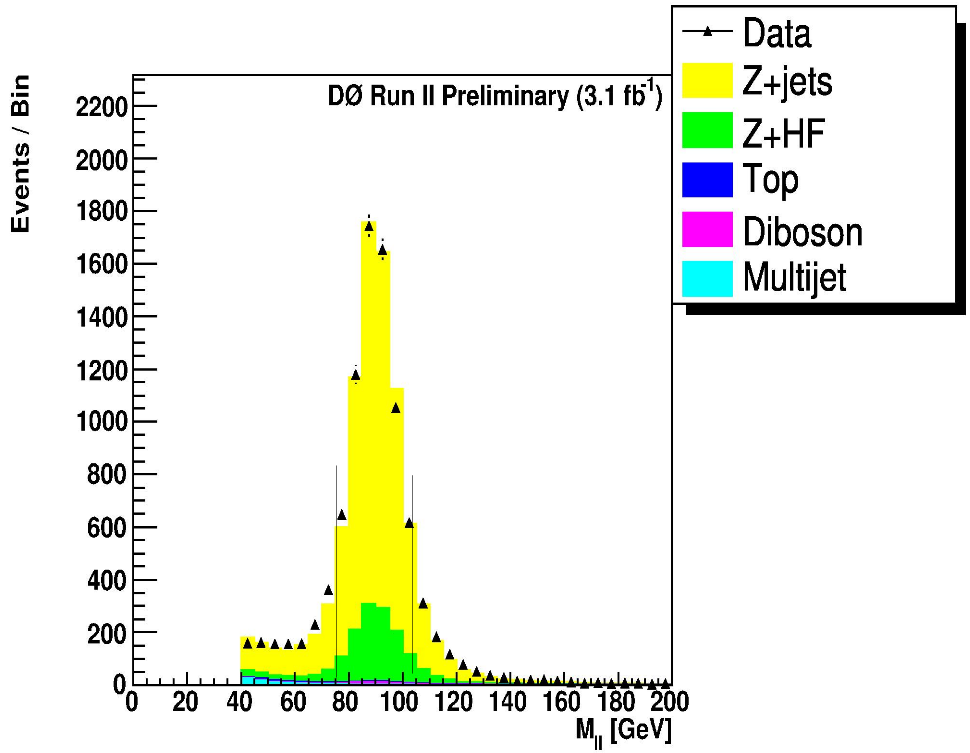
Signature: 2 high Pt leptons and 2+ b-jets

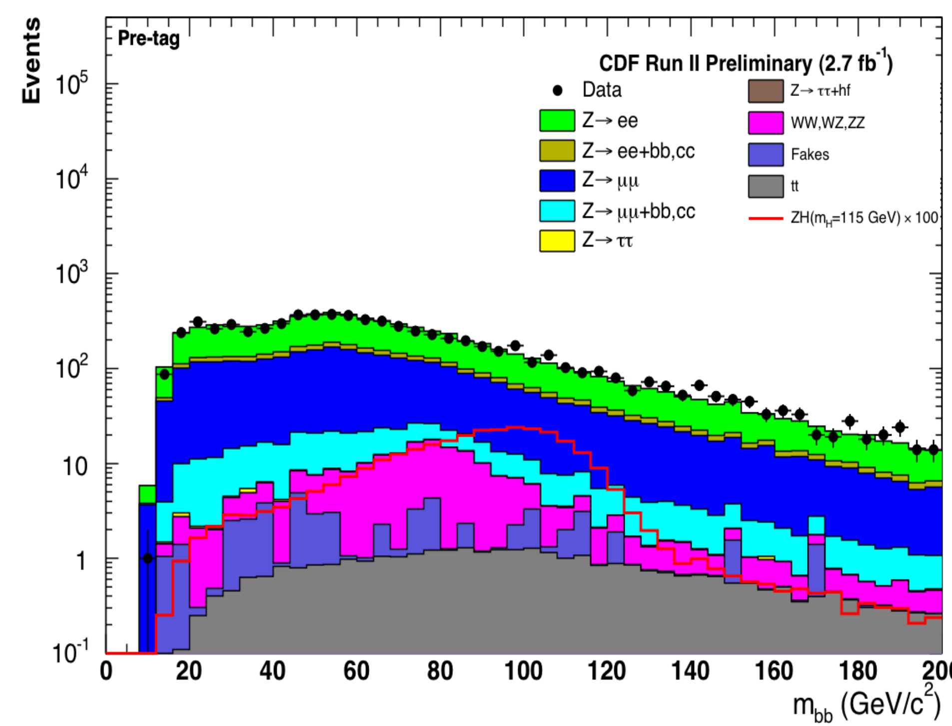
Trigger Path: single lepton

CDF: 2.7 fb^{-1} D0: 3.1 – 4.2 fb^{-1}

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

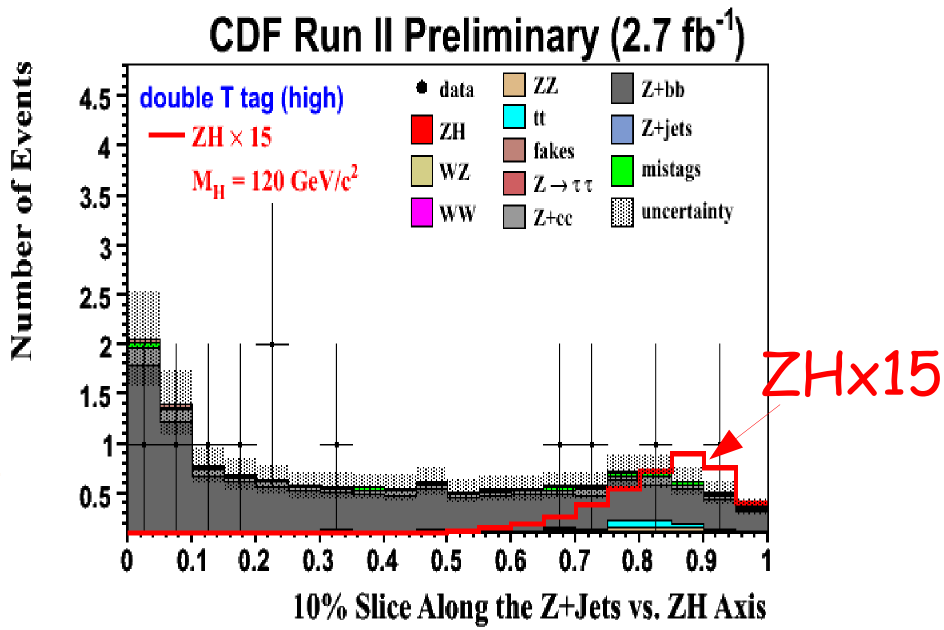
Small σxBR ~ 1 event/fb^{-1} Important to increase acceptance

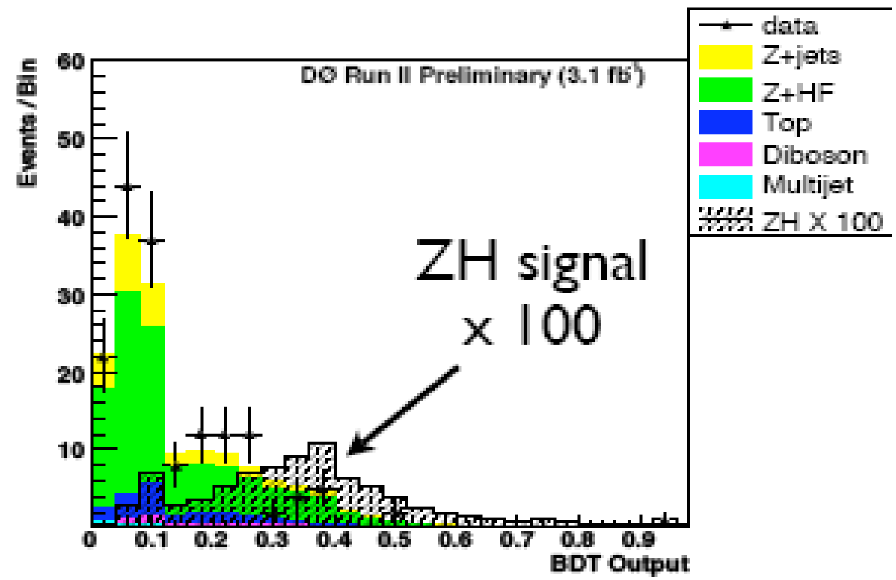




Low Mass Higgs: $ZH \to \ell^+\ell^- b\bar{b},\ \ell = e, \mu$

Use multivariate techniques to improve S/B





Analysis 115	Lumi fb^{-1}	Expected limit	Observed limit
CDF ME	2.7	12.3	7.8
CDF NN	2.7	9.9	7.1
D0 BDT	3.1	8	9.1

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

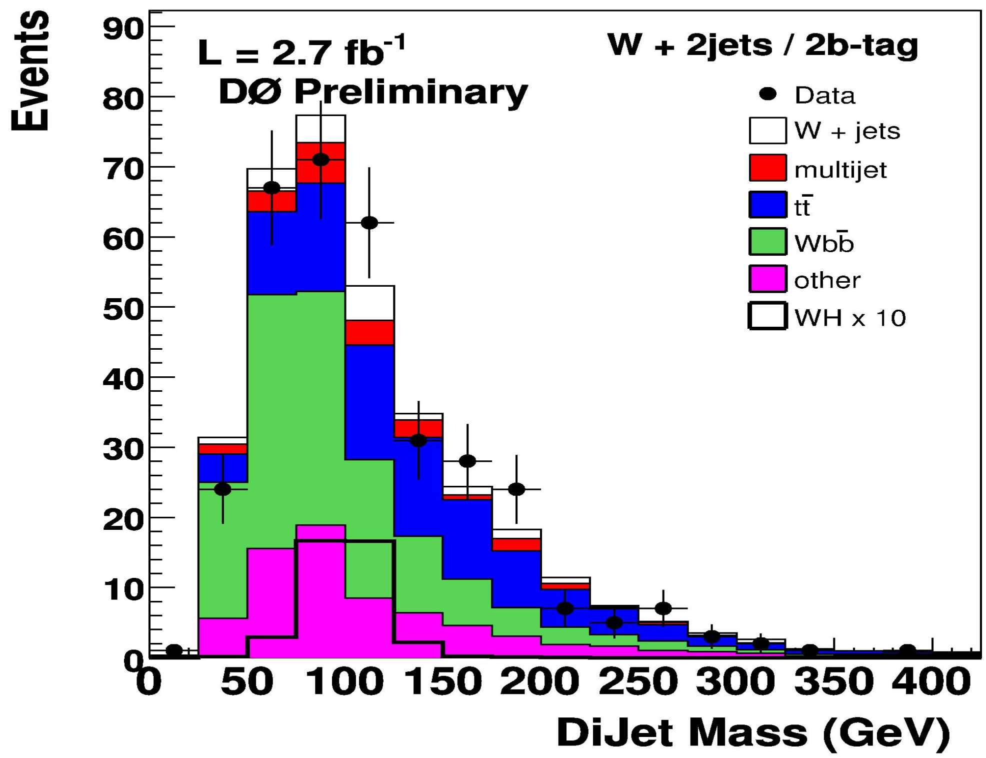
Signature: 1 high Pt lepton large MET and 2+ b-jets

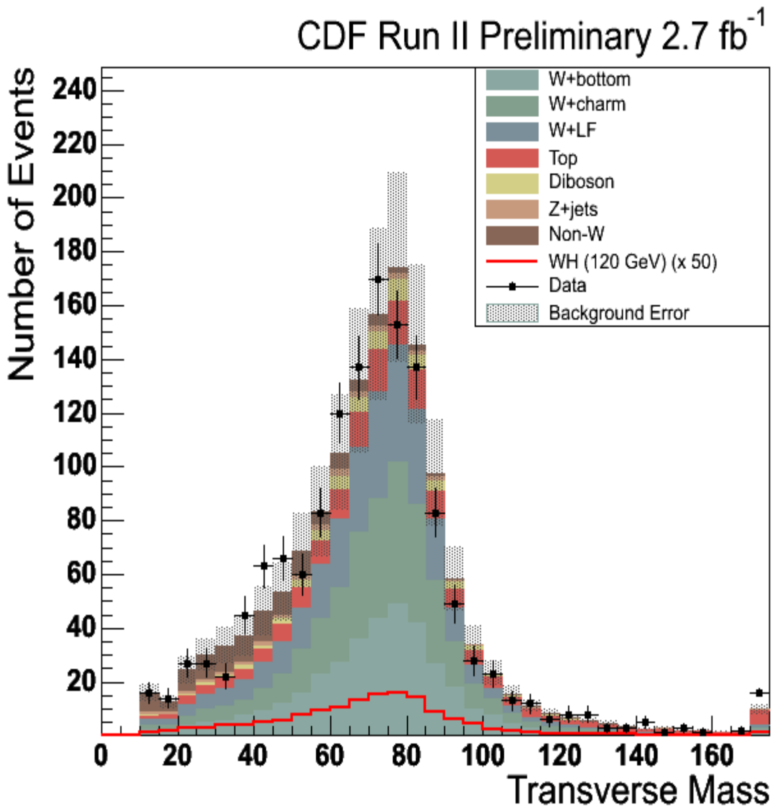
Trigger path: single lepton

CDF and D0 : 2.7 fb^{-1}

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

"Large" σxBR ~ 3-4 event/fb^{-1}



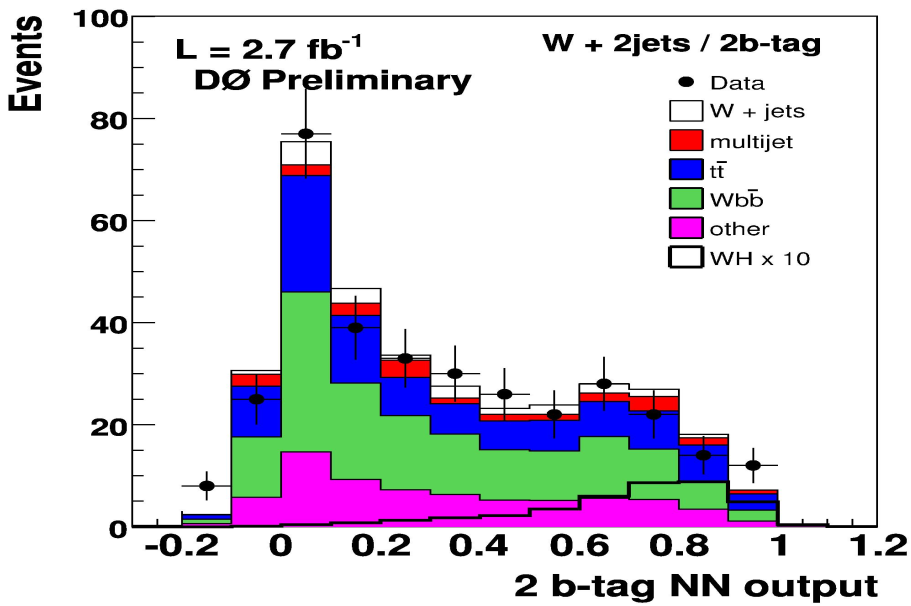


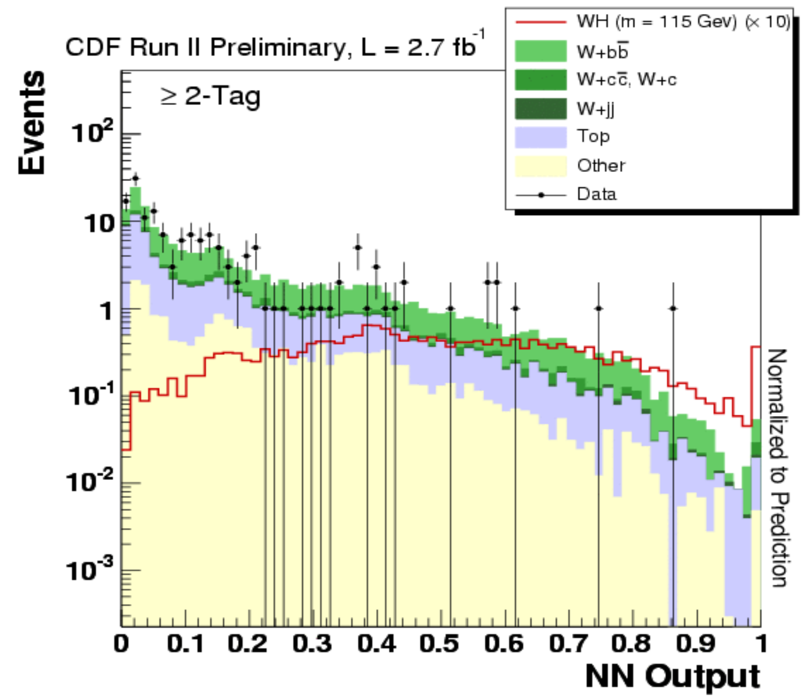
Low Mass Higgs: $WH \to \ell \nu b\bar{b},\ \ell = e,\mu$

Multivariate techniques to improve S/B:

D0: NN

CDF: NEAT=BDT+NN+ME





Analysis M_H=115	Lumi fb^{-1}	Expected limit	Observed limit
CDF NEAT	2.7	4.8	5.6
D0 NN+ME	2.7	6.4	6.7

Low Mass Higgs: $VH \to \not{E}_T b\bar{b}$

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

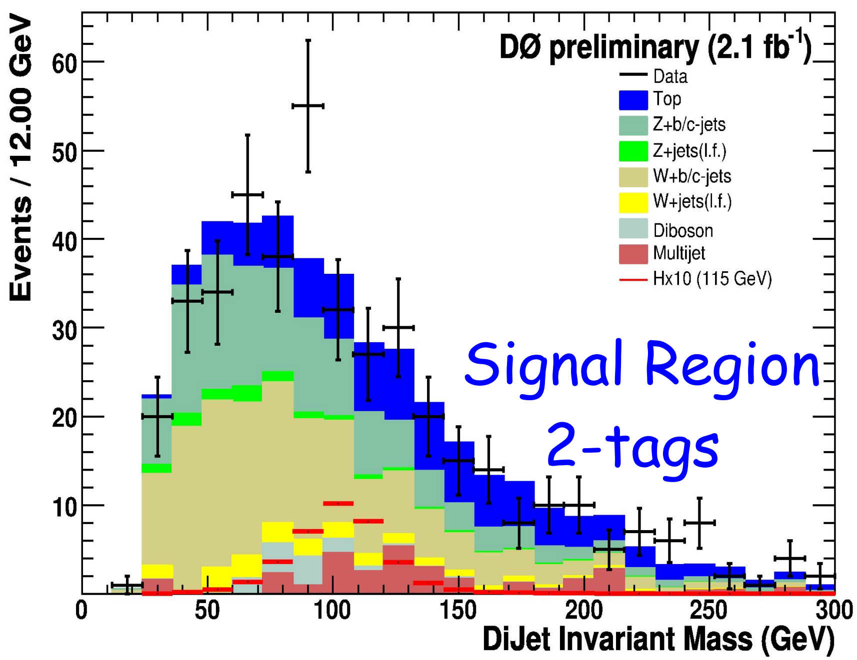
Signature: large MET and 2+ b-jets

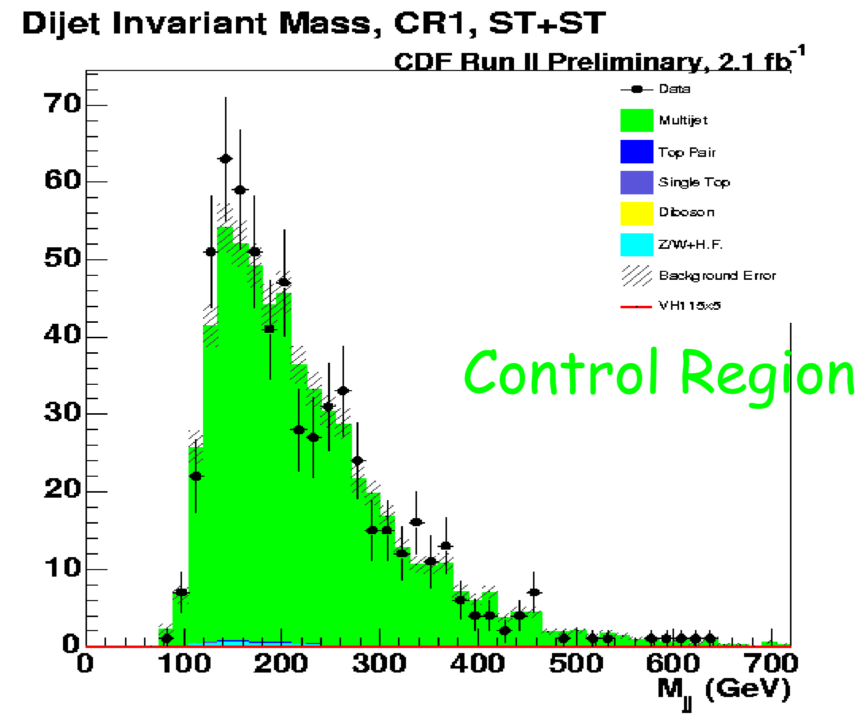
Trigger Path: MET

CDF and D0 : 2.1 fb^{-1}

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

Background modeled using data



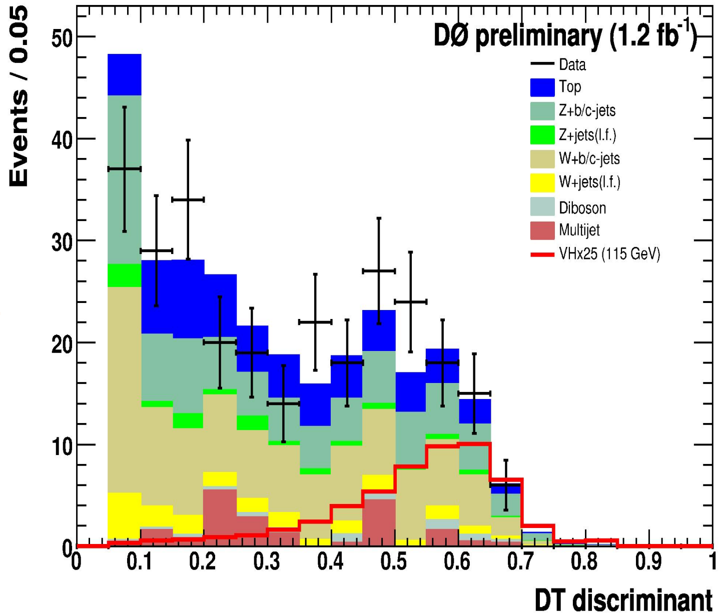


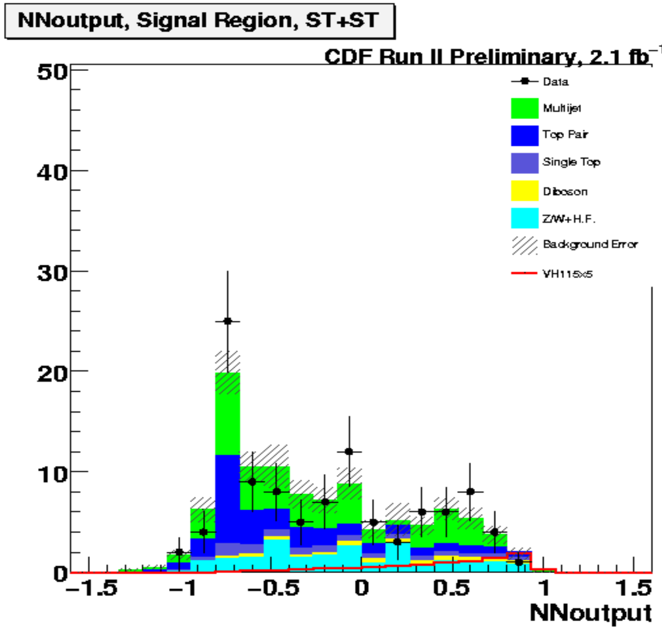
Low Mass Higgs: $VH \rightarrow \not{E}_T b\bar{b}$

Multivariate techniques to improve S/B:

D0: BDT on double tagged sample

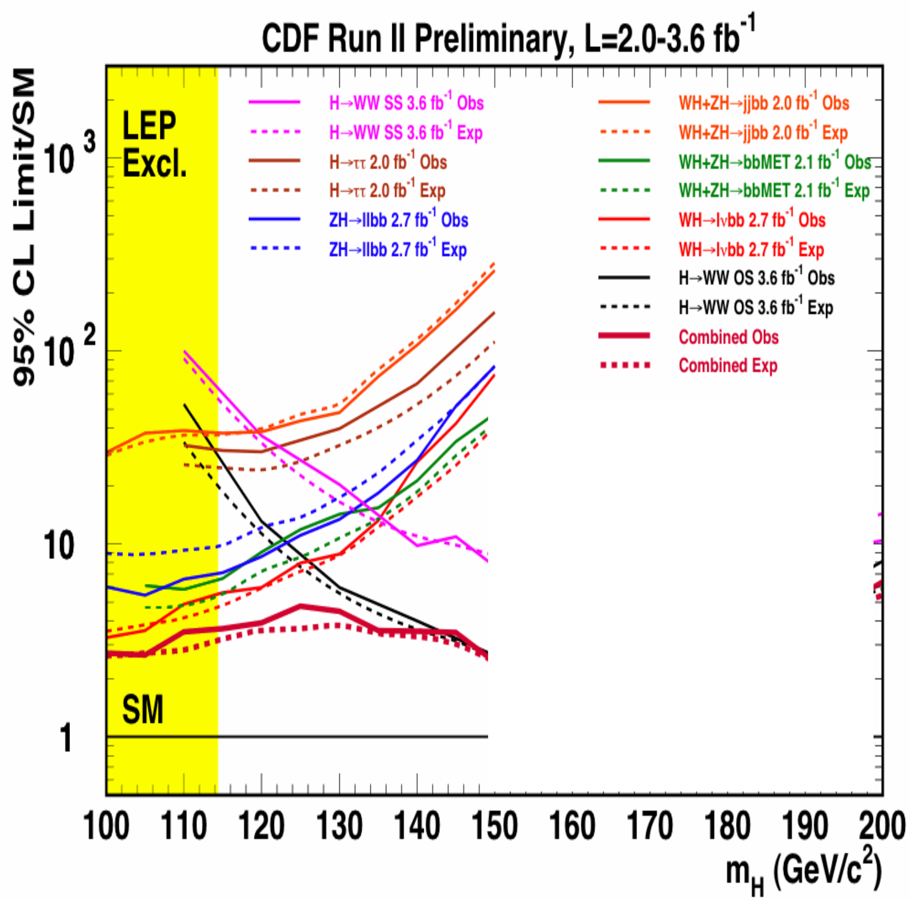
CDF: NN with separate training for 2 and 3 jets

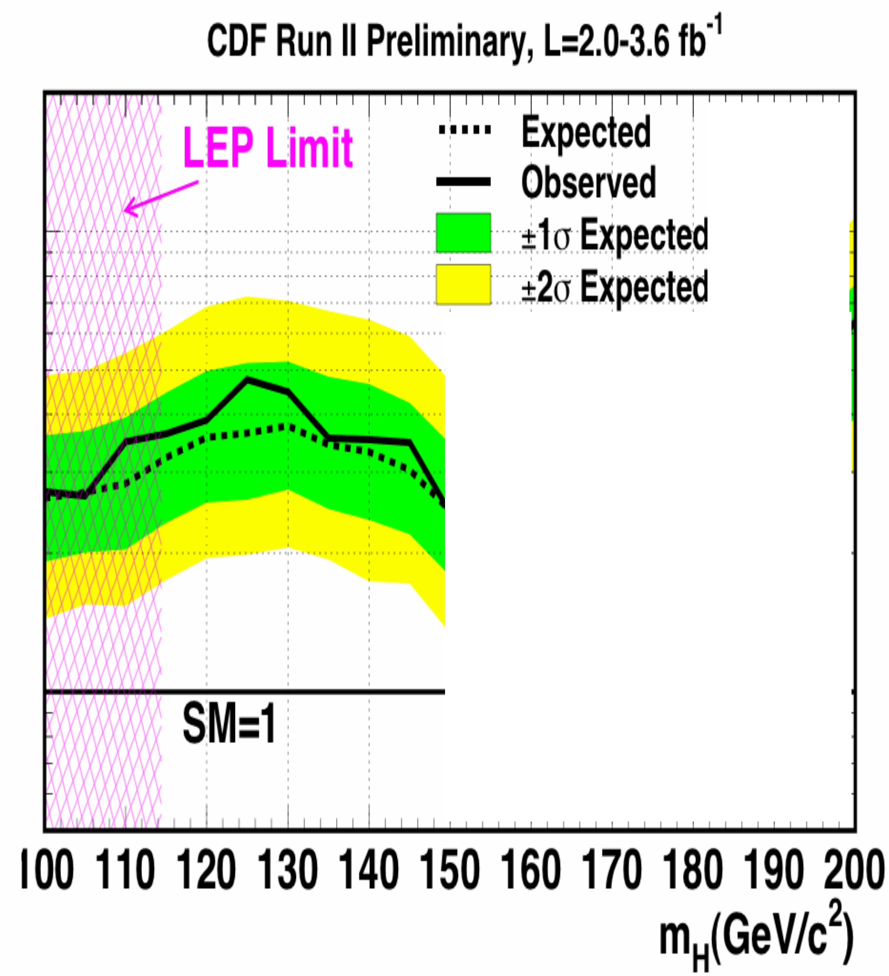




Analysis M_H=115	Lumi fb^{-1}	Expected limit	Observed limit
CDF NN	2.1	5.6	6.9
D0 BDT	2.1	8.4	7.5

Low Mass Higgs Combination

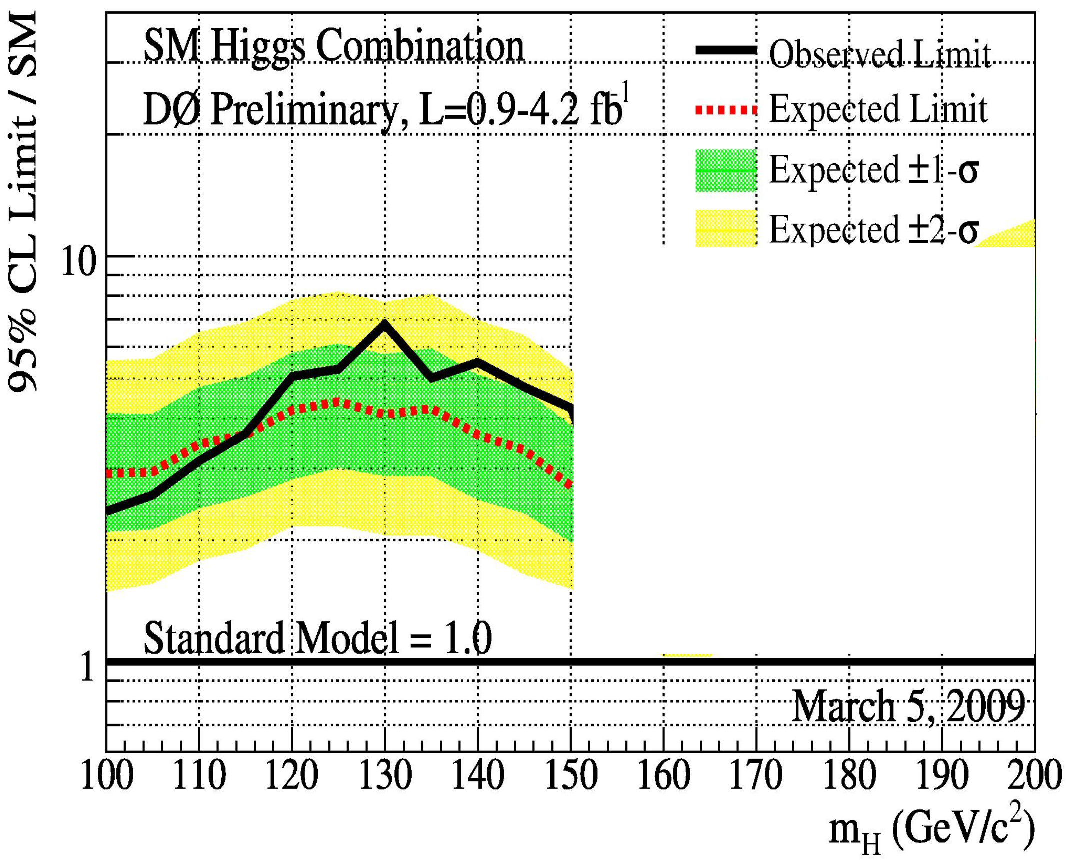




M_H=115 Expected limit 3.22

Observed limit 3.64

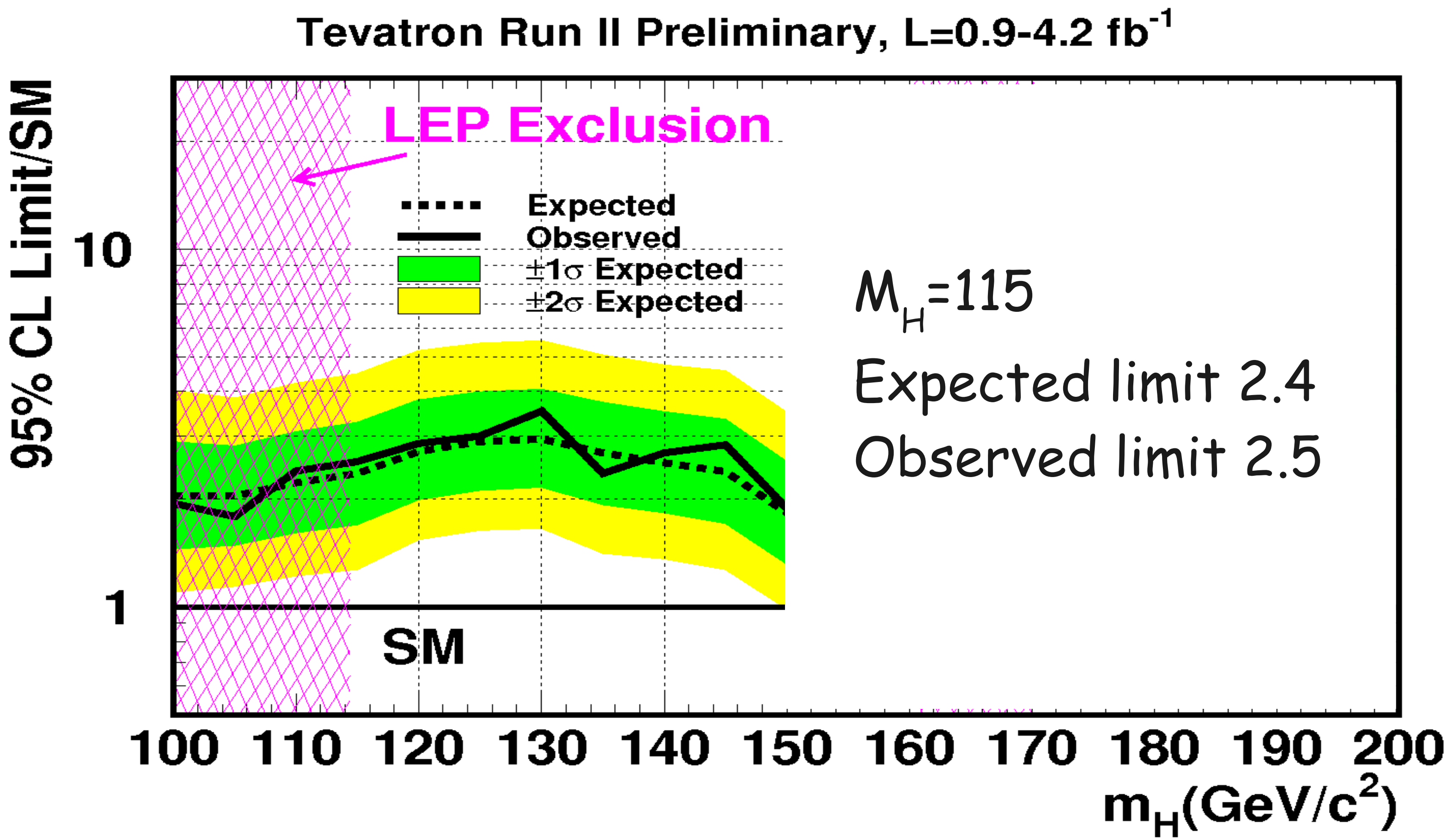
Low Mass Higgs Combination



M_H=115 Expected limit 3.80

Observed limit 3.60

Low Mass Higgs Tevatron Combination



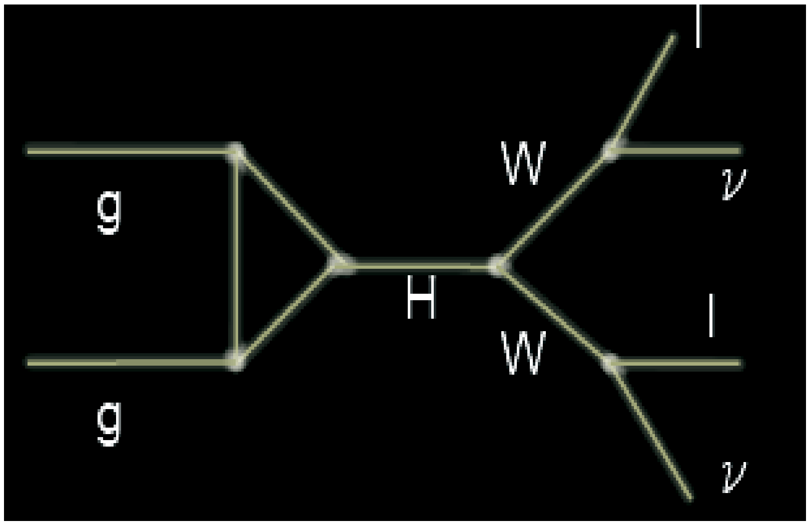
M_H=115

Expected limit 2.4

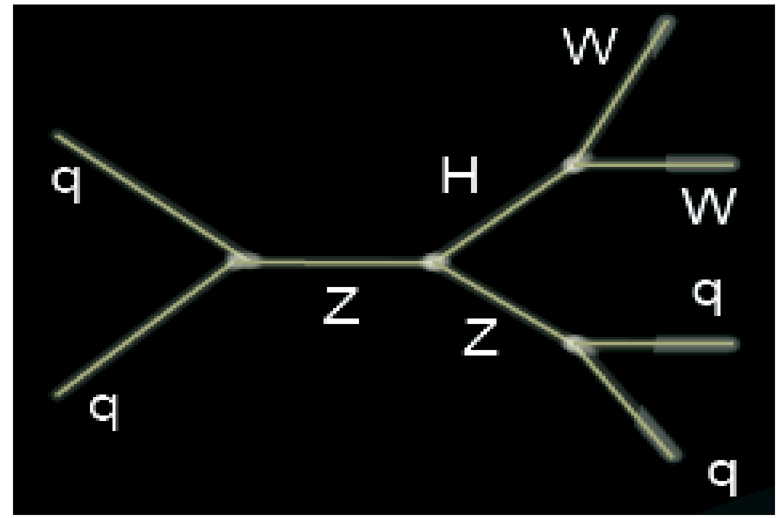
Observed limit 2.5

High Mass Higgs: $H \to WW$

Signal:



0 jets at LO (gg->H)

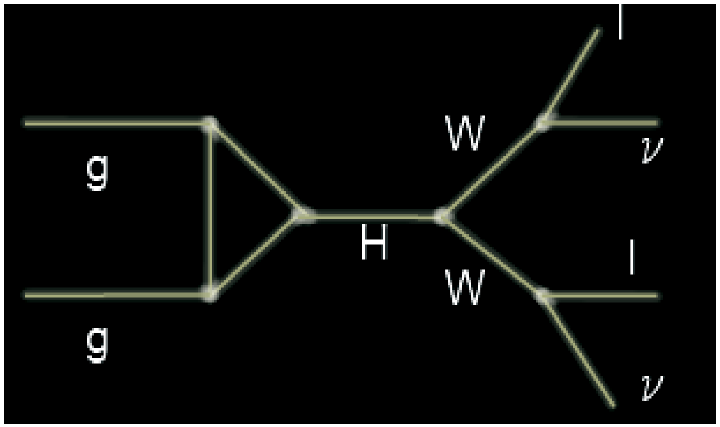


2 jets at LO (ZH/WH/VBF)

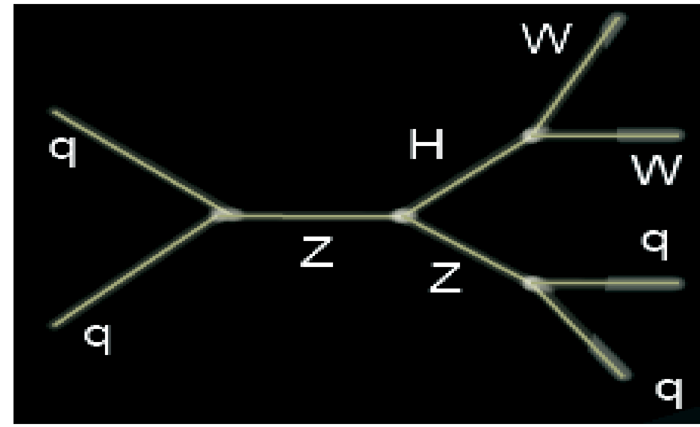
Separate in 0, 1, 2+ jets bin because of different backgrounds

High Mass Higgs: $H \to WW$

Signal:

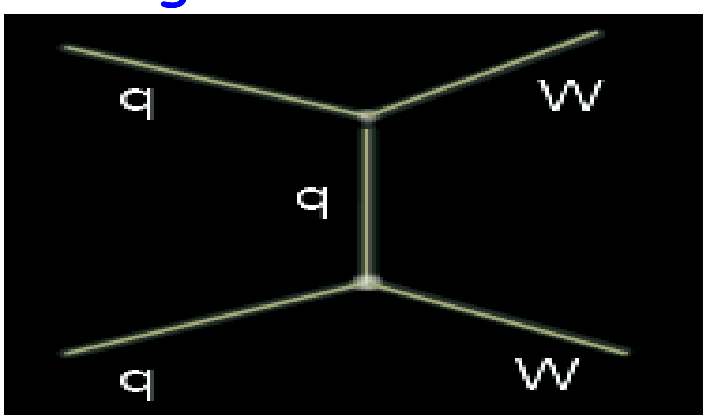


0 jets at LO (gg->H)

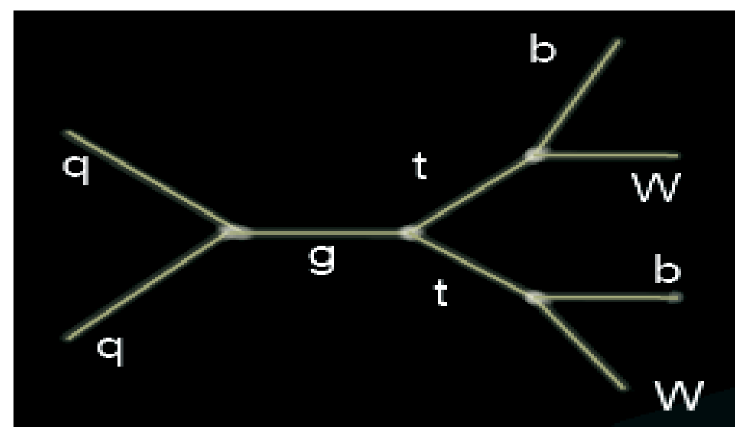


2 jets at LO (ZH/WH/VBF)

Background:



LO: WW, Drell Yan, W+γ



LO: WZ, ZZ, tt

High Mass Higgs: $H \rightarrow WW$

0 jets:
Good use of LO ME
majority of signal gg fusion
background from WW

1 jet:
ME not so powerful
extra signal: VH and VBF ~20%

2 jets:
tt main background
extra signal: VH and VBF ~60%

CDF Run II Preliminary $\int \mathcal{L} = 3.6\ \text{fb}^{-1}$

$M_H = 160\ \text{GeV}/c^2$

$t\bar{t}$	1.35	±	0.21
DY	80	±	18
WW	318	±	35
WZ	14	±	1.9
ZZ	20.7	±	2.8
W+jets	113	±	27
$W\gamma$	92	±	25
Total Background	637	±	67
$gg \rightarrow H$	9.5	±	1.4
Total Signal	9.5	±	1.4
Data	654		

OS 0 Jets

CDF Run II Preliminary $\int \mathcal{L} = 3.6\ \text{fb}^{-1}$

$M_H = 160\ \text{GeV}/c^2$

$t\bar{t}$	100	±	17
DY	33	±	11
WW	17.6	±	4.0
WZ	3.76	±	0.52
ZZ	1.62	±	0.22
W+jets	14.7	±	4.0
$W\gamma$	2.12	±	0.70
Total Background	173	±	23
$gg \rightarrow H$	1.75	±	0.30
WH	1.39	±	0.18
ZH	0.693	±	0.090
VBF	0.70	±	0.11
Total Signal	4.53	±	0.52
Data	169		

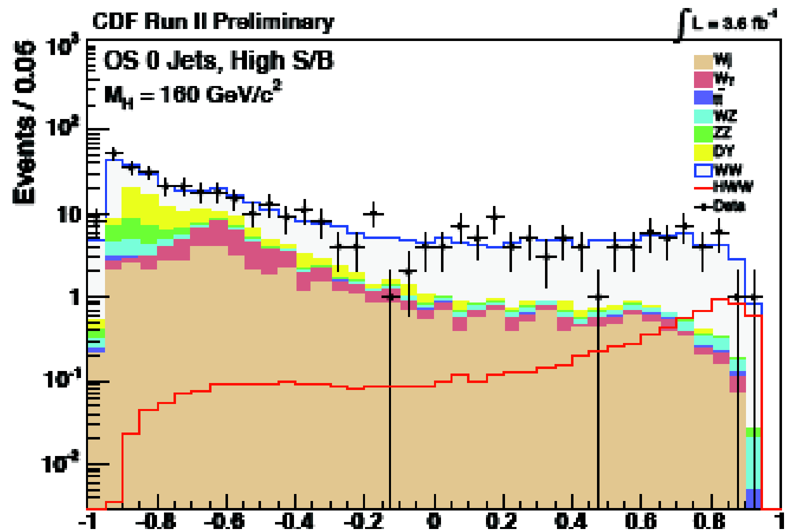
OS 2+ Jets

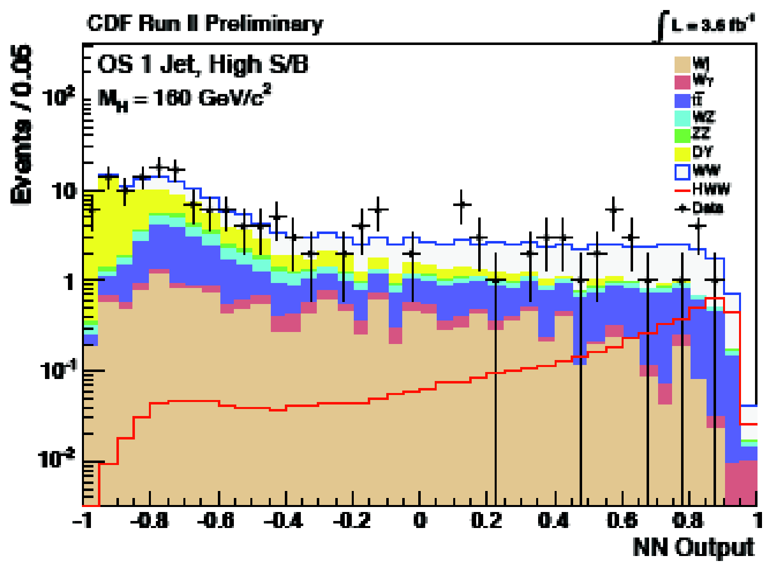
High Mass Higgs: $H \rightarrow WW$

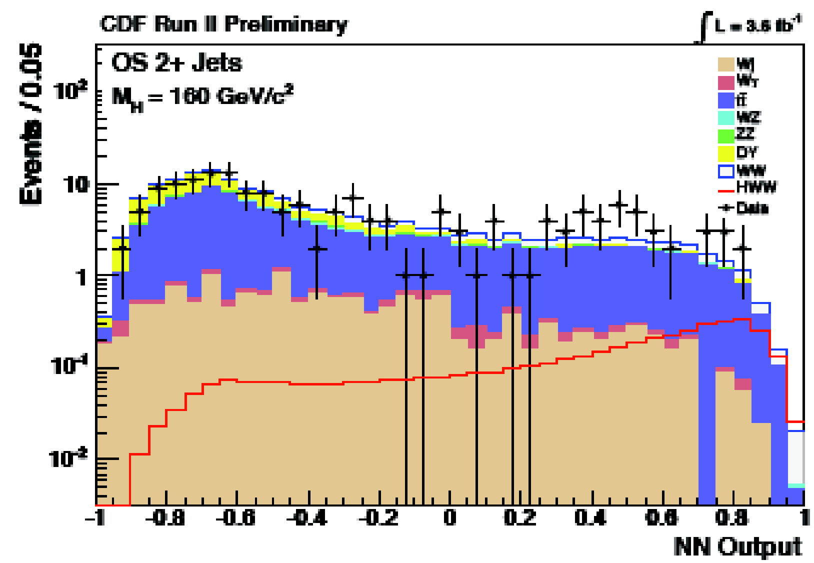
Apply selection cut:

- 2 opposite sign isolated leptons
- di-lepton opening angle
- significant MET

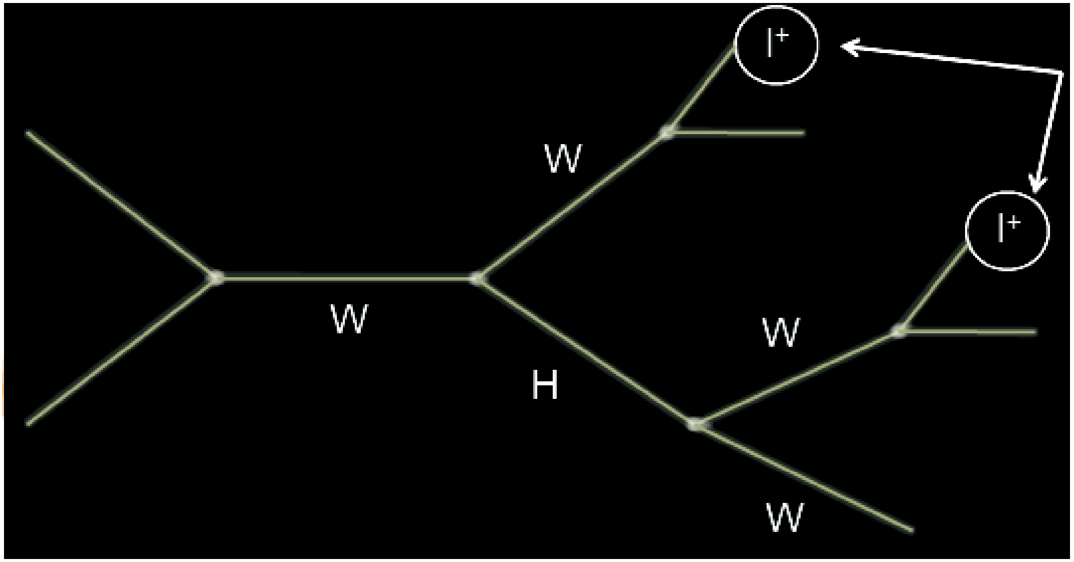
Then use combinations of ME and NN depending on jet bin







High Mass Higgs: add other final states



Same sign leptons

Two lepton Pt>20 GeV

No forward electrons

Njets≥1

No MET cut

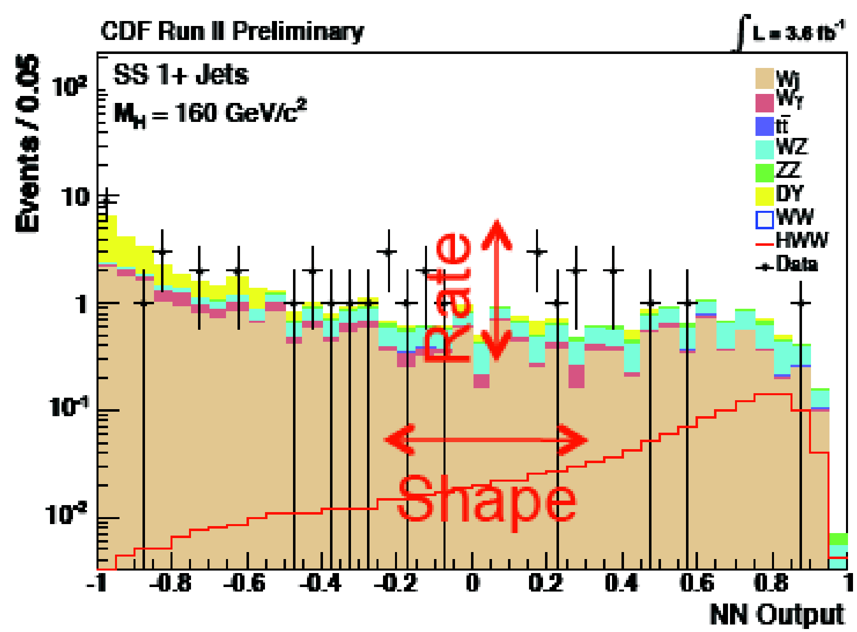
Add 5% sensitivity

CDF Run II Preliminary	$\int \mathcal{L} = 3.6\ \mathrm{fb}^{-1}$		
$M_H = 160\ \mathrm{GeV}/c^2$			
$t\bar{t}$	0.11	±	0.03
DY	11.99	±	3.65
WW	0.020	±	0.005
WZ	6.82	±	0.93
ZZ	1.44	±	0.20
W+jets	22.45	±	6.73
$W\gamma$	3.23	±	1.00
Total Background	**46.07**	±	**8.02**
WH	1.19	±	0.16
ZH	0.19	±	0.02
Total Signal	**1.38**	±	**0.18**
Data		**41**	

High Mass Higgs: Systematics

Two classes

- Rate Systematics:
  - ✔affect only templates normalization, do not affect the shapes
  - ✔dominant theoretical cross section uncertainties, 10-30%
- Shape systematics:
  - ✔ modify the shape of NN output
  - ✔ Found negligible up to now (PDF modeling, Energy scale, Pt scale)



High Mass Higgs Combination

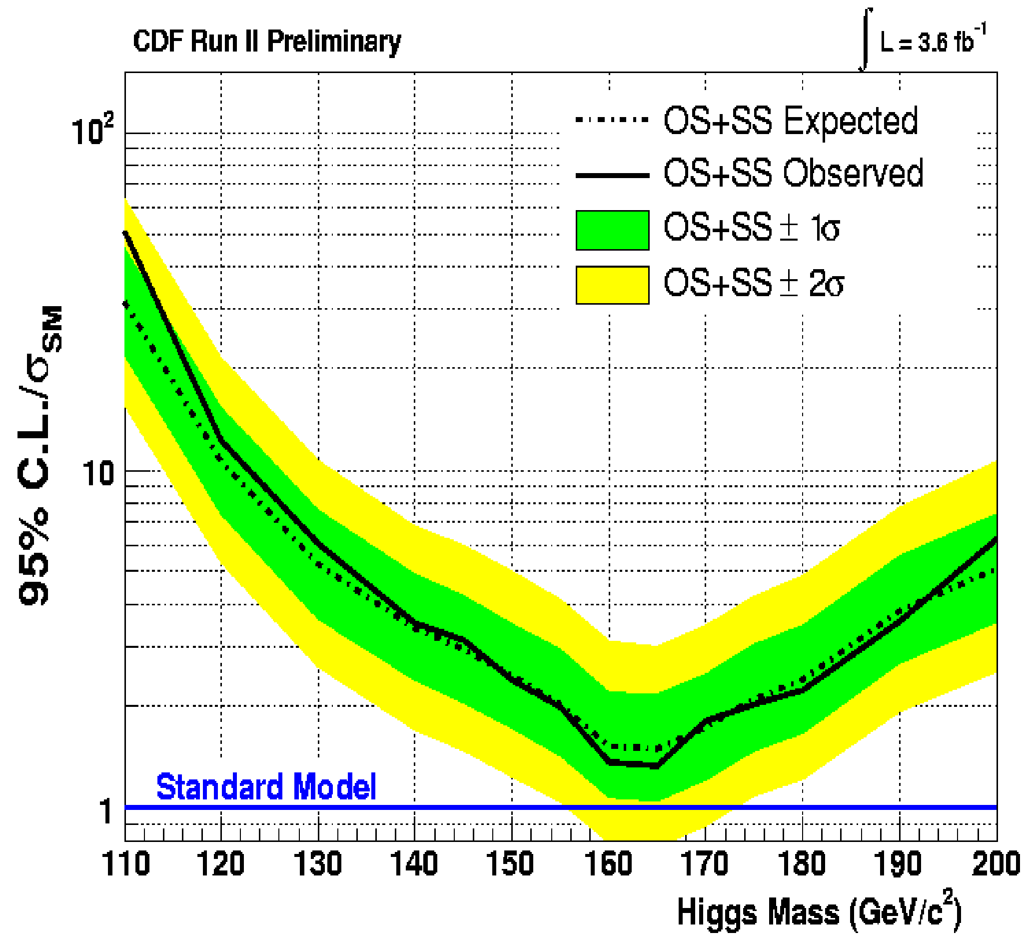
Latest gg->H cross section (Florian and Grazzini)

- ✔ Latest PDF MSTW2008
- ✔ NNLL QCD
- ✔ NLO b-quark treatment

VH from hep-ph/0406152

VBF from TEV4LHC

M_H=160	Expected limit	Observed limit
0 jets	2.39	2.35
1 jet	2.89	2
2+ jets	3.71	6.34
SS +jet	7.22	6.6
Combined	1.52	1.37



High Mass Higgs: $H + X \rightarrow ll + missing\,Et$

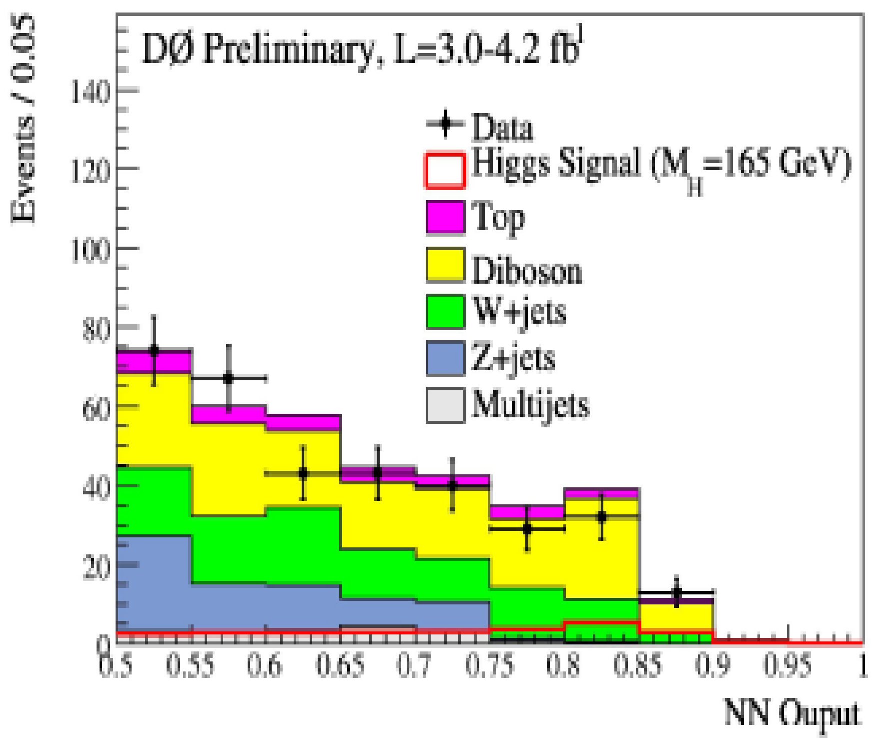
Analysis separated by lepton type: ee, μμ, eμ

Apply minimal requirements then use NN

Sample composition input to NN

Channel	ee	eμ	μμ
Luminosity (fb^{-1})	4.2	4.2	3.0
Z	108	13	3987
Diboson	84	162	127
tt	40	82	13
W+jets	98	79	134
Multijets	2	1	64
Total Background	332	337	4325
Data	336	329	4084
Signal (M_H=165 GeV)	6.1	12.2	4.9

NN output



High Mass Higgs Combination

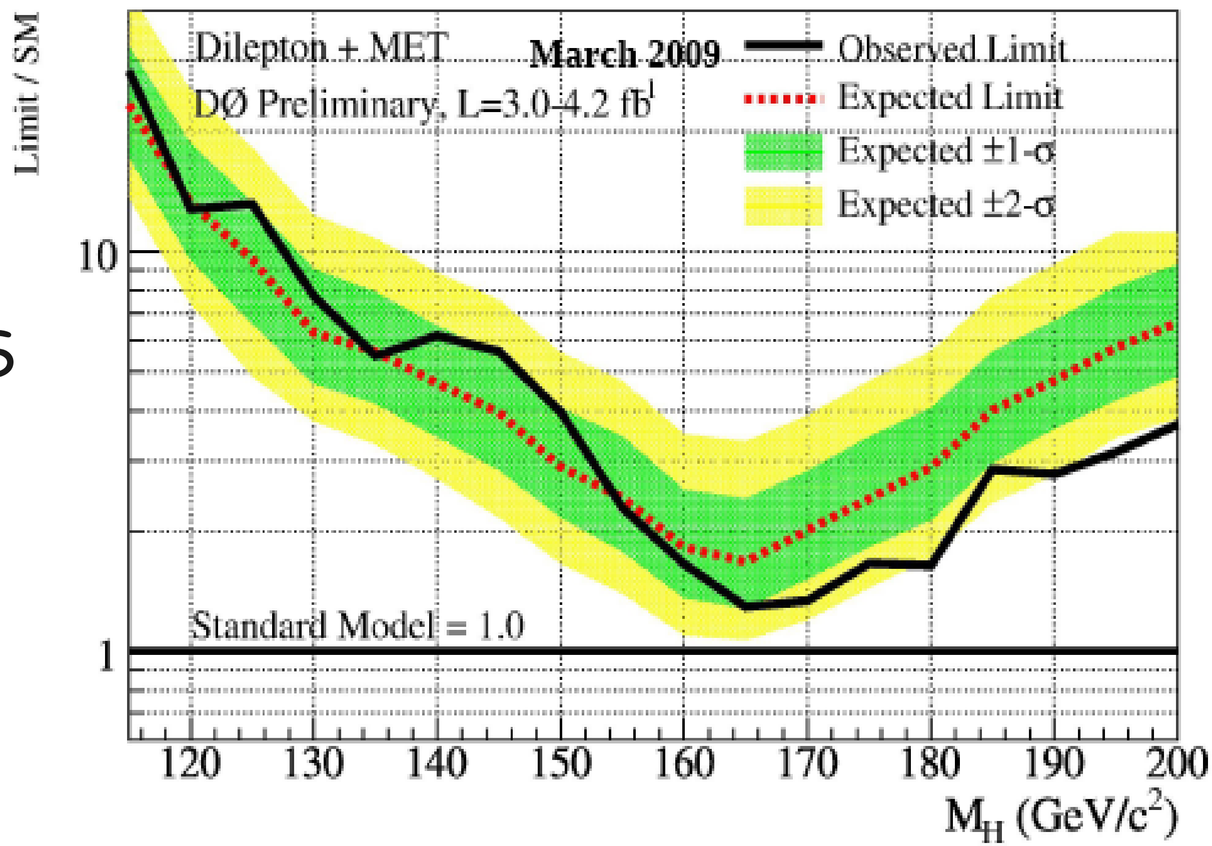
Use the same systematic of CDF, same inputs

M_H=165

expected limit 1.7

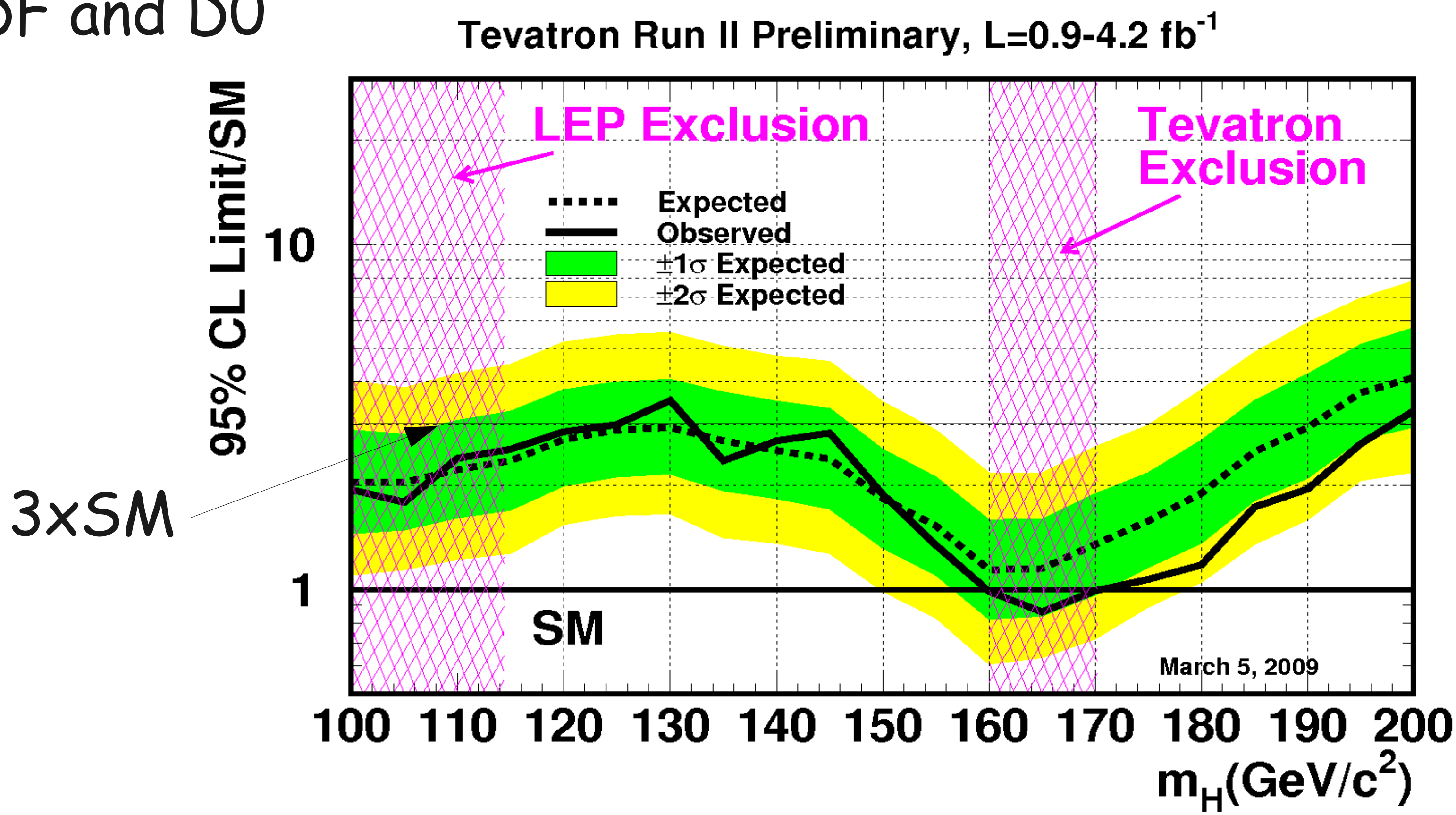
observed limit 1.3

It does not include SS



Tevatron Combination

Not just a √2 factor, many systematics are correlated between CDF and D0



We exclude SM Higgs in a mass range 160-170 GeV at 95% CL

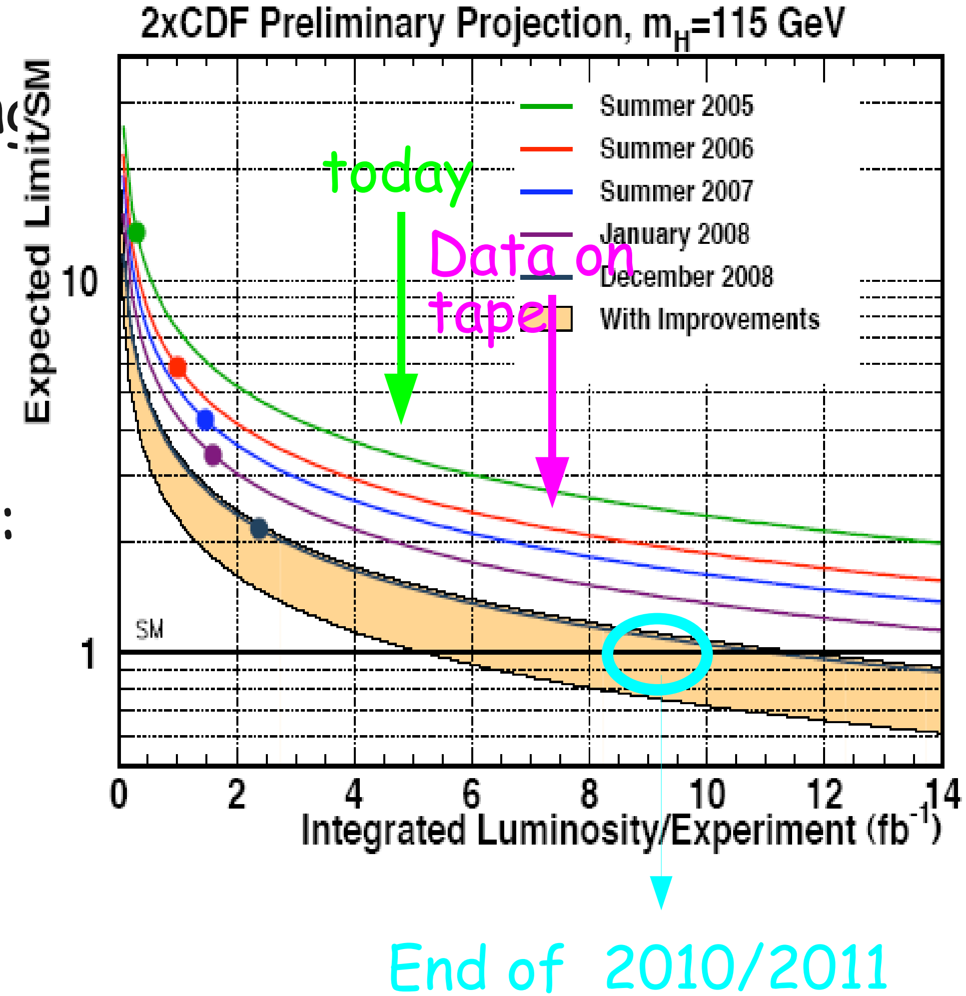
Future Prospects: Low Mass

Includes "standard analysis" improvements:

- extended b-tag "a la top"
- better background understanding
- more sophisticated analysis techniques

It does not include new triggers:

- more efficient MET
- b-tag trigger



Efficiency respect to double tag events

Future Prospects: High Mass

Plan to include:

- new lepton triggers (by the summer)
- lower cut on MET (by summer)
- tri-leptons (summer)
- lepton isolation (next year)
- low di-lepton mass