Standard Model High Mass Higgs Searches at CDF

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The Higgs, THE Particle

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

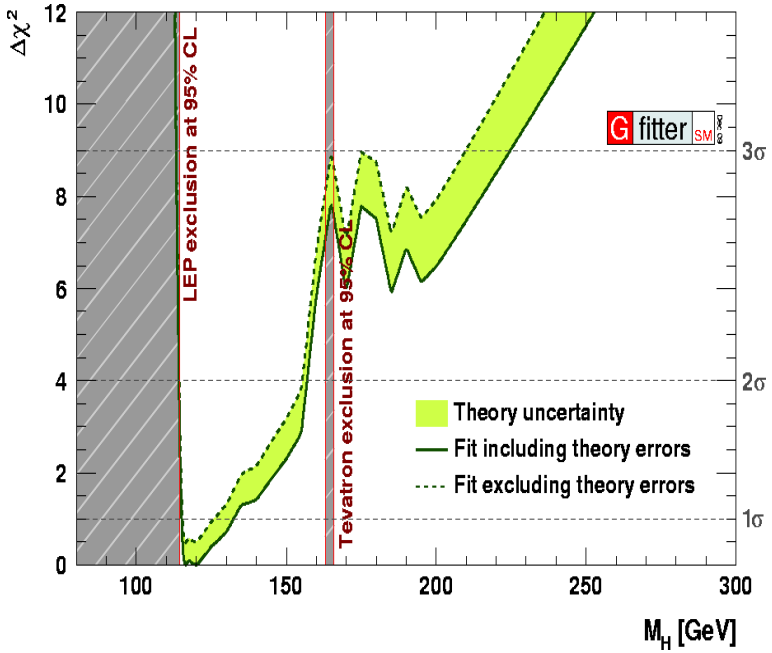
The Higgs is THE particle of the Standard Model

A. Masiero

The Standard Model Higgs

Electroweak fit including all data and the results of direct searches indicates a "light" Higgs

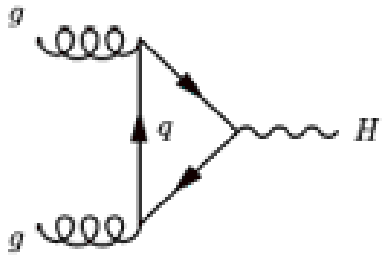
- M_H from fit with Higgs searches:
  - central value $\pm 1\sigma$: $M_H = 119.4^{+13.4}_{-4.0}$ GeV
  - 2σ interval: $[114, 157]$ GeV



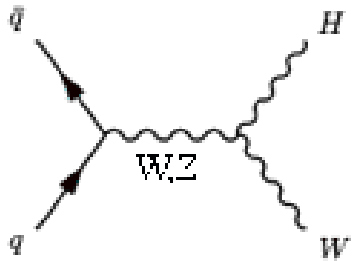
These Higgs mass ranges are within reach of the Tevatron

Higgs Production at Tevatron

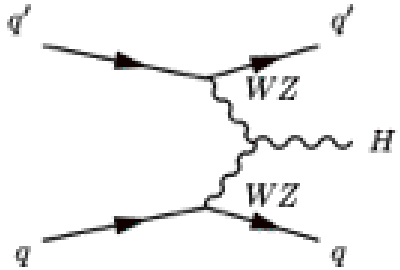
$\sigma^{SM(M_H=160\ GeV)} \sim 0.6$ pb



Gluon Fusion:~78%
$gg \rightarrow H$

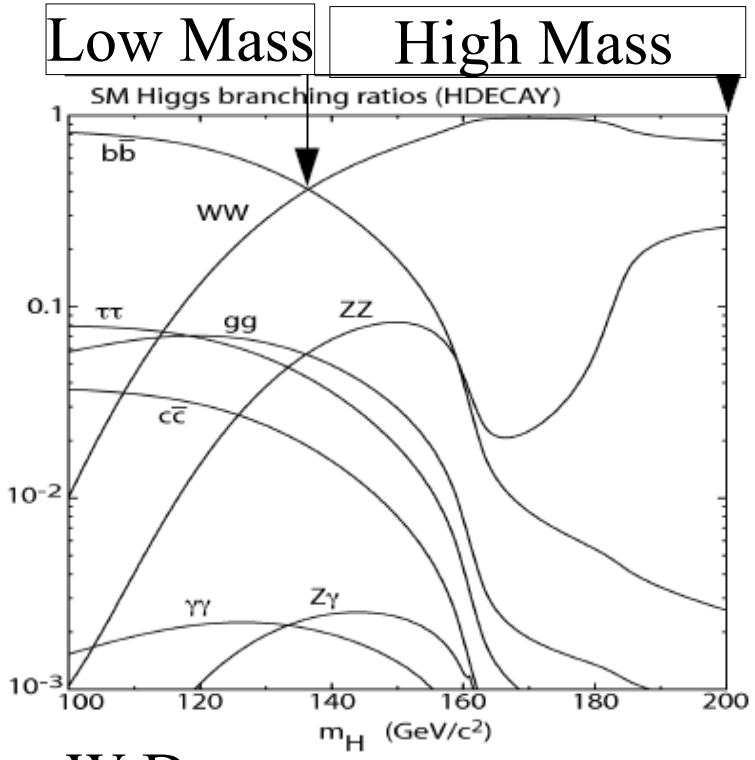


Associate Production:~15%
WH/ZH



Vector Boson Fusion:~7%
VBF

H→WW* Final State



H→WW* dominant for M_H>135 GeV

This is Tevatron definition of "High Mass"

H→ZZ can contribute above 180 GeV

W Decays:

- W→lν, where l= *e*, μ or *τ*
- Hadronic modes have large background, not included yet

Ws are required to decay:

✗W→lν, where l= *e*, μ trigger the event

✗W→lν, where l= *e*, μ or *τ*

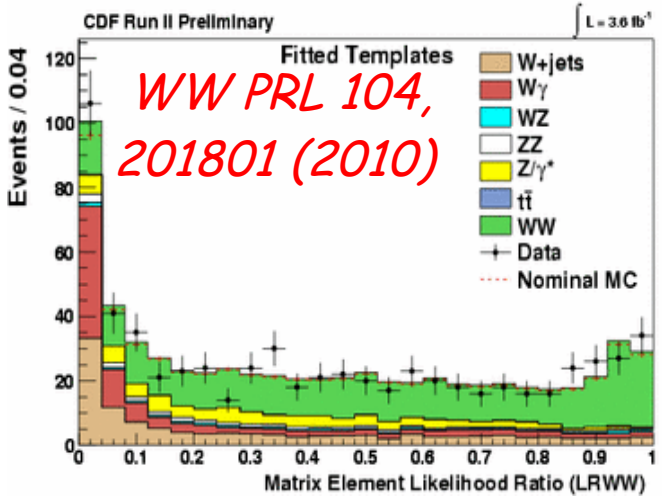
Expected Background

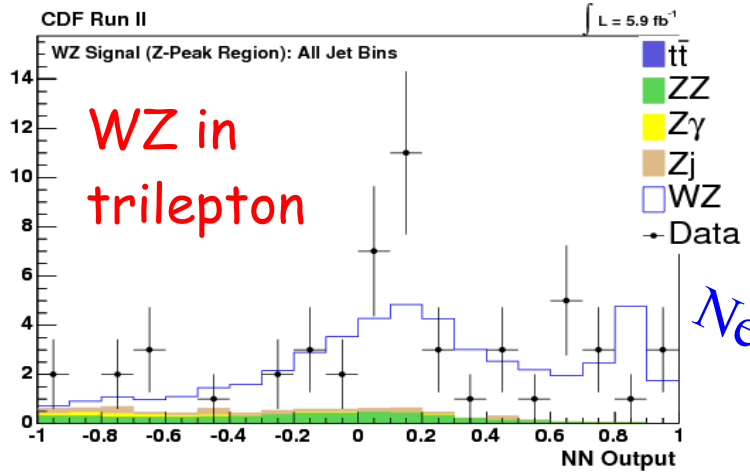
- Z/γ→ll (DY) dominates, it tends to have low missing energy (ME_T)

  Pythia Monte Carlo + Z/γ P_T spectrum matched to data

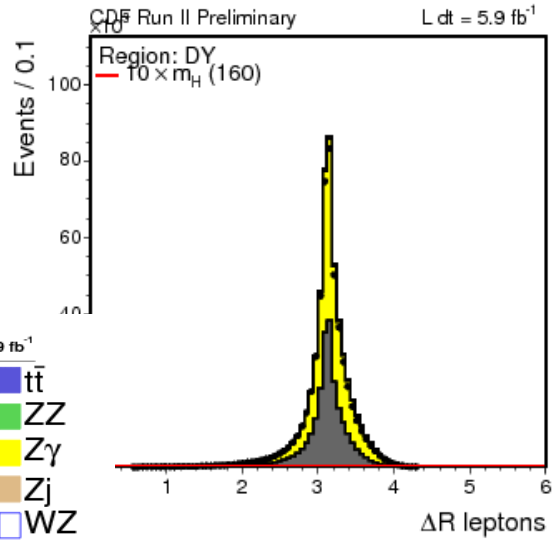
- WW, WZ and ZZ Production

  MC@NLO and Pythia Monte Carlo verified on data





New result!



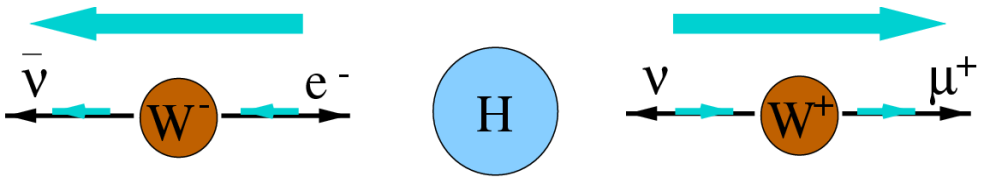
- tt̄ and single top: *Pythia Monte Carlo & data*
- Wγ, W+jet where γ or jet is misidentified as lepton

  Data driven + Bauer (Wγ) and Alpgen(W+jet)

Cross Sections normalized to (N)NLO calculations

Event Selection

- P_T>20 GeV for trigger e or μ
- Additional lepton(s) e /μ P_T>10 GeV and wider acceptance
- Recently added $e\tau$ $\mu\tau$ W decay channels with tau->hadrons
- Require significant Missing E_T → Reduce DY
- Mll >16 GeV
- Analyze separately events with M_{ll}<16 GeV
  - Dominant background Wγ where γ fakes lepton
- Exploit spin 1 Particles (WW) versus spin 0 particle (Higgs):



Leptons tend to go in the same direction

Signal Extraction

L(fb^{-1})	Signal MH=165GeV	Background	S/√B	Data
5.9	42	3067	0.76	3050

- Simple cuts not enough to isolate signal ⇒ need to improve selections
- Separate analysis into channels by signal and background contributions
  - WW+n jets (n=0,1,2+)
  - W→Tau decays
  - Final states with Same Sign leptons and Tri-leptons
- Use advanced analysis techniques:
  - Matrix Element (ME)
  - Neural Network (NN)
  - Boosted Decision Tree (BDT)
- Optimize selections for each channel and for each Higgs mass hypothesis

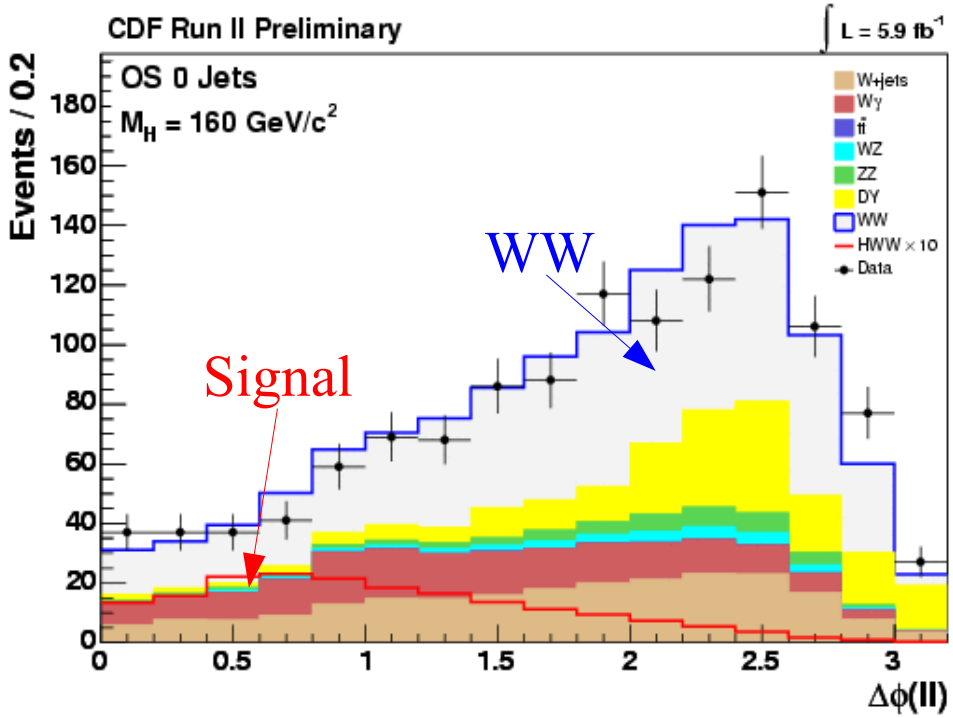
Opposite Sign Lepton + 0 jets

CDF Run II Preliminary	$\int \mathcal{L} = 5.9$ fb^{-1}		
$M_H = 165$ GeV/c^2			
$t\bar{t}$	2.23	$\pm$	0.66
DY	227	$\pm$	62
WW	563	$\pm$	56
WZ	25.5	$\pm$	3.8
ZZ	38.3	$\pm$	5.4
W+jets	215	$\pm$	51
$W\gamma$	155	$\pm$	22
Total Background	1226	$\pm$	120
$gg \rightarrow H$	16.9	$\pm$	3.0
WH	0.410	$\pm$	0.070
ZH	0.416	$\pm$	0.059
VBF	0.140	$\pm$	0.028
Total Signal	17.8	$\pm$	3.1
Data	1230		

OS 0 Jets

Dominant backgrounds

Main signal contribution



Use likelihood ratios based on Matrix Element calculation as additional NN input variables

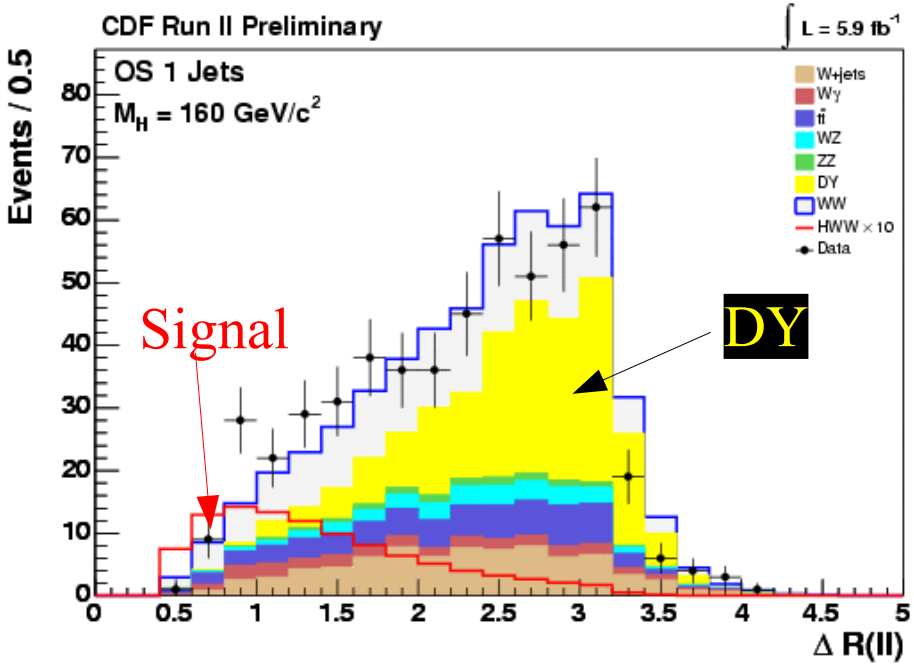
Opposite Sign Lepton + 1 jet

CDF Run II Preliminary	$\int \mathcal{L} = 5.9$ fb^{-1}		
$M_H = 165$ GeV/c^2			
$t\bar{t}$	56	$\pm$	11
DY	218	$\pm$	49
WW	151	$\pm$	18
WZ	25.4	$\pm$	3.5
ZZ	10.3	$\pm$	1.5
W+jets	77	$\pm$	20
$W\gamma$	25.1	$\pm$	4.3
Total Background	563	$\pm$	69
$gg \rightarrow H$	8.0	$\pm$	2.4
WH	1.13	$\pm$	0.18
ZH	0.439	$\pm$	0.066
VBF	0.74	$\pm$	0.13
Total Signal	10.3	$\pm$	2.5
Data		533	

OS 1 Jet

Dominant backgrounds

About 20% of the signal from VH & VBF



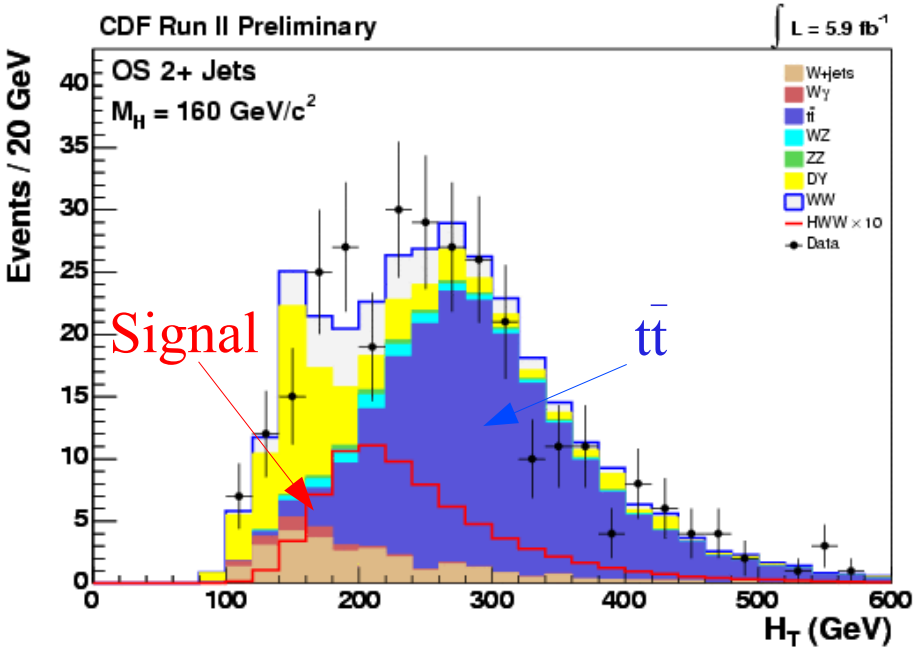
Opposite Sign Lepton +2 or more jets

CDF Run II Preliminary $\int \mathcal{L} = 5.9$ fb^{-1}			
$M_H = 165$ GeV/c^2			
$t\bar{t}$	169	±	24
DY	80	±	31
WW	33.6	±	6.1
WZ	6.8	±	1.3
ZZ	3.10	±	0.57
W+jets	26.7	±	7.5
$W\gamma$	4.4	±	1.2
Total Background	324	±	50
$gg \rightarrow H$	2.6	±	1.8
WH	2.50	±	0.35
ZH	1.28	±	0.17
VBF	1.37	±	0.23
Total Signal	7.8	±	2.0
Data	307		

A1lSB-2JOS

$t\bar{t}$ dominant background.
Reject events with b-jets to reduce it

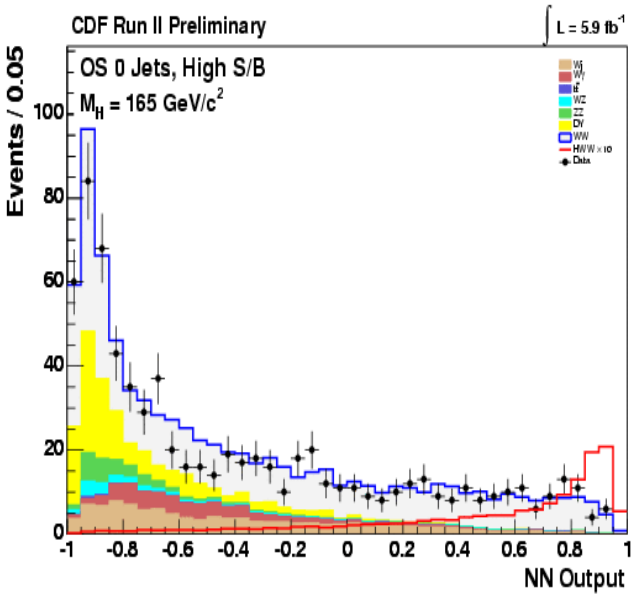
About 60% of the signal from VH & VBF

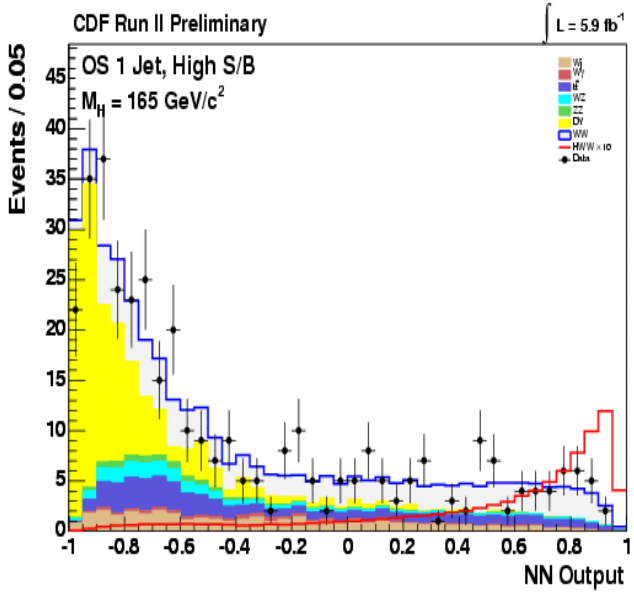


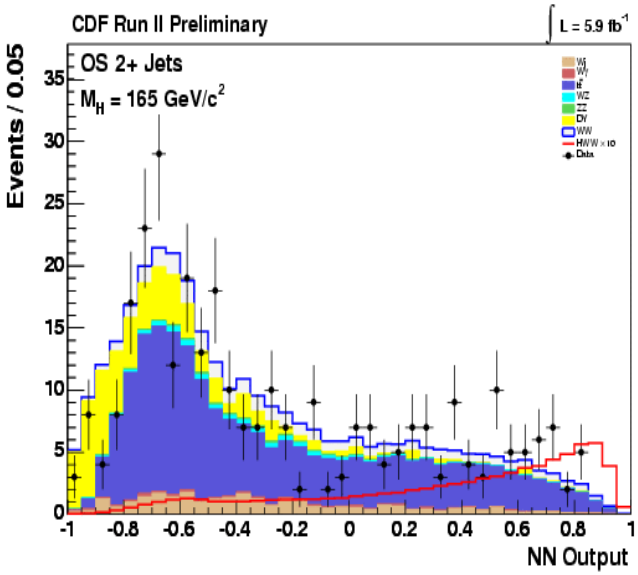
The discriminant

Separate Neural Networks are trained for each channel:
- using different kinematic variables
- for 19 different Higgs mass hypotheses

Signal and background templates used as final discriminants







Add New decay channel: H→WW →e/μτ+x

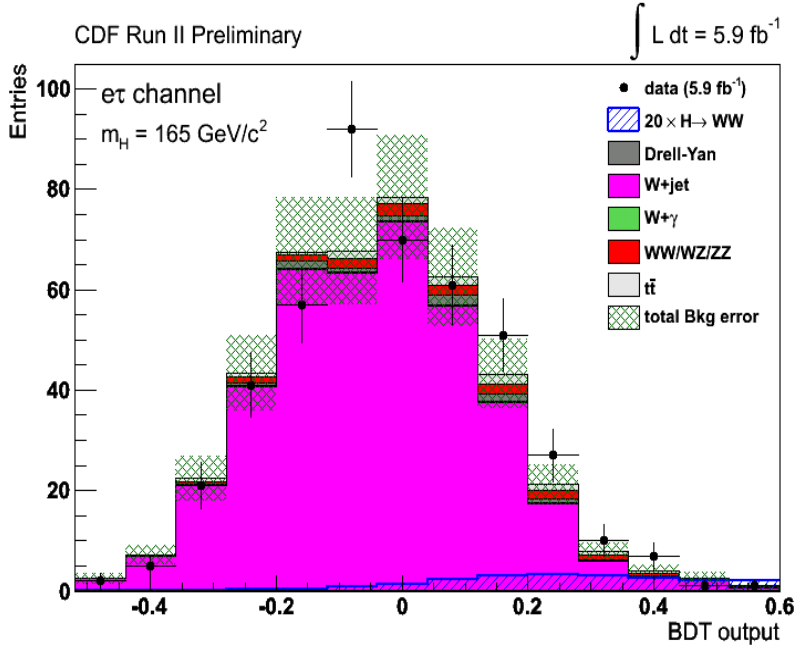
CDF Run II Preliminary $\int \mathcal{L} = 5.9$ fb^{-1}			
$m_H = 160$ GeV/c^2			
dijet, γ+ jet	9	±	27
$Z \to \tau\tau$	0.8	±	0.4
$Z \to \ell\ell$	48.8	±	6.4
W+jets	624	±	77
Wγ	3.3	±	0.4
Diboson (WW, WZ, ZZ)	25.3	±	2.7
$t\bar{t}$	15.5	±	2.8
Total Background	726	±	82
$gg \to H$	1.08	±	0.10
WH	0.261	±	0.026
ZH	0.167	±	0.017
VBF	0.095	±	0.011
Total Signal	1.60	±	0.11
Data	741		

$e\tau$-$\mu\tau$ channels

Require one lepton to be a τ→hadrons

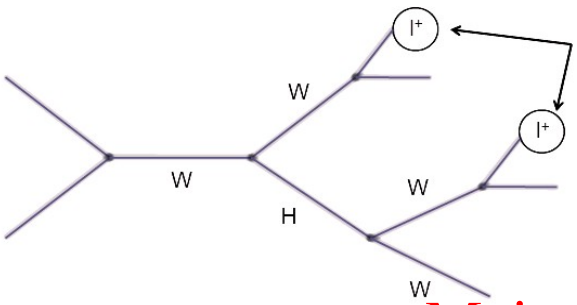
Jets fake τ

Signal efficiency dominated by τ reconstruction efficiency

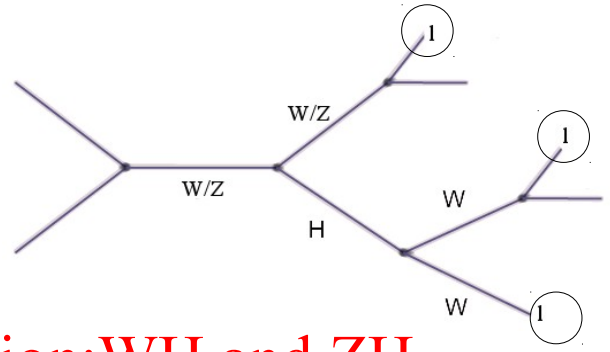


- Discriminant: Boosted Decision Tree
- Input Variables:
  - Tau identification observables
  - Global event variables

Same Sign Lepton and Tri-lepton



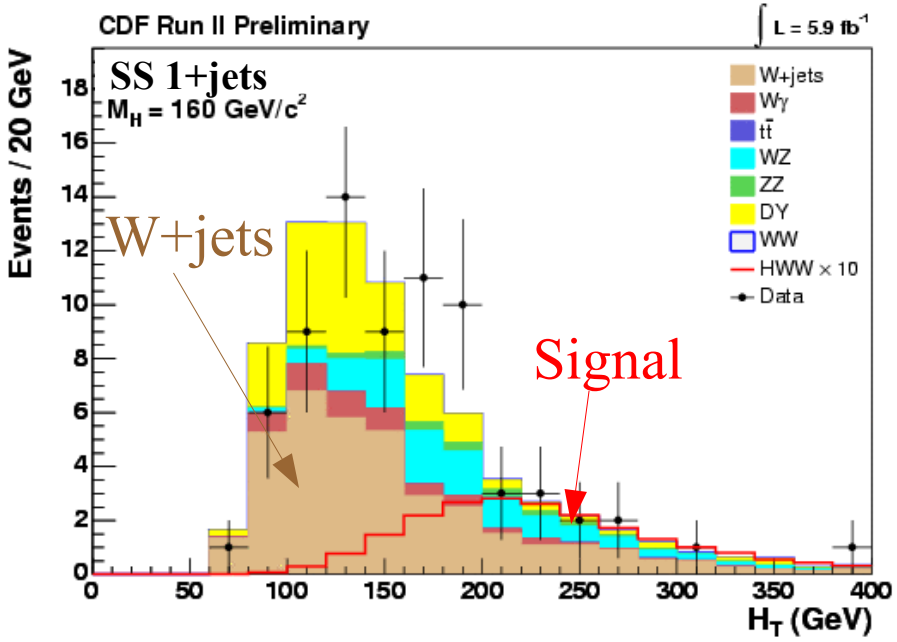
Same sign lepton



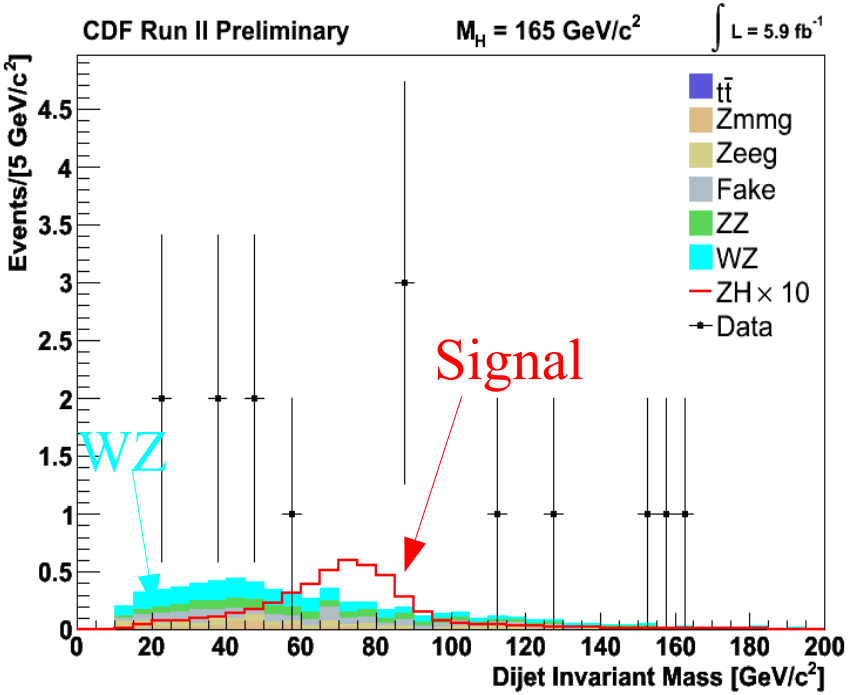
Trilepton

Main signal contribution:WH and ZH

Dominant background from W+jet with jet faking l



Dominant background from WZ

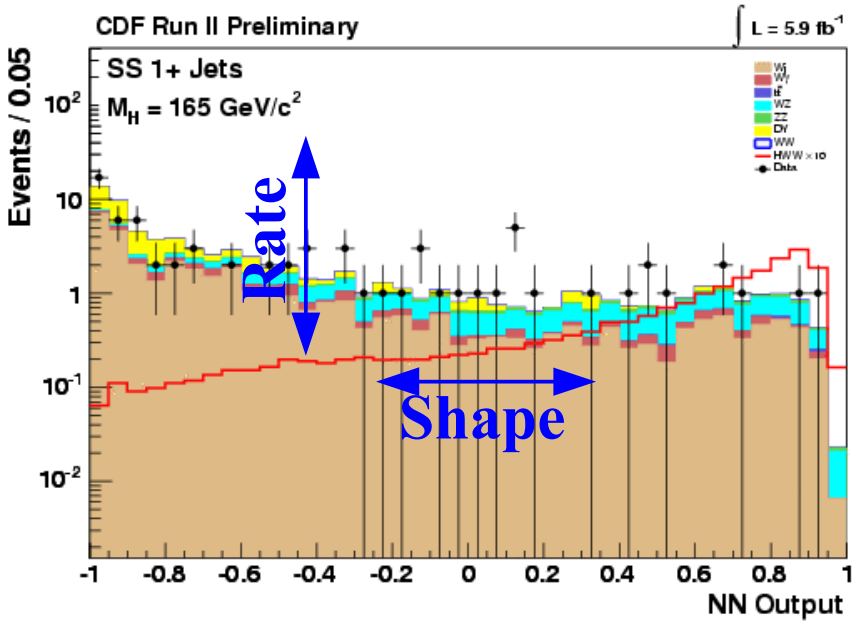


NN discriminant used as for OS analysis

Systematic uncertainties

Systematics on signal and background

- Affect template normalization
- Modify the shape of NN output

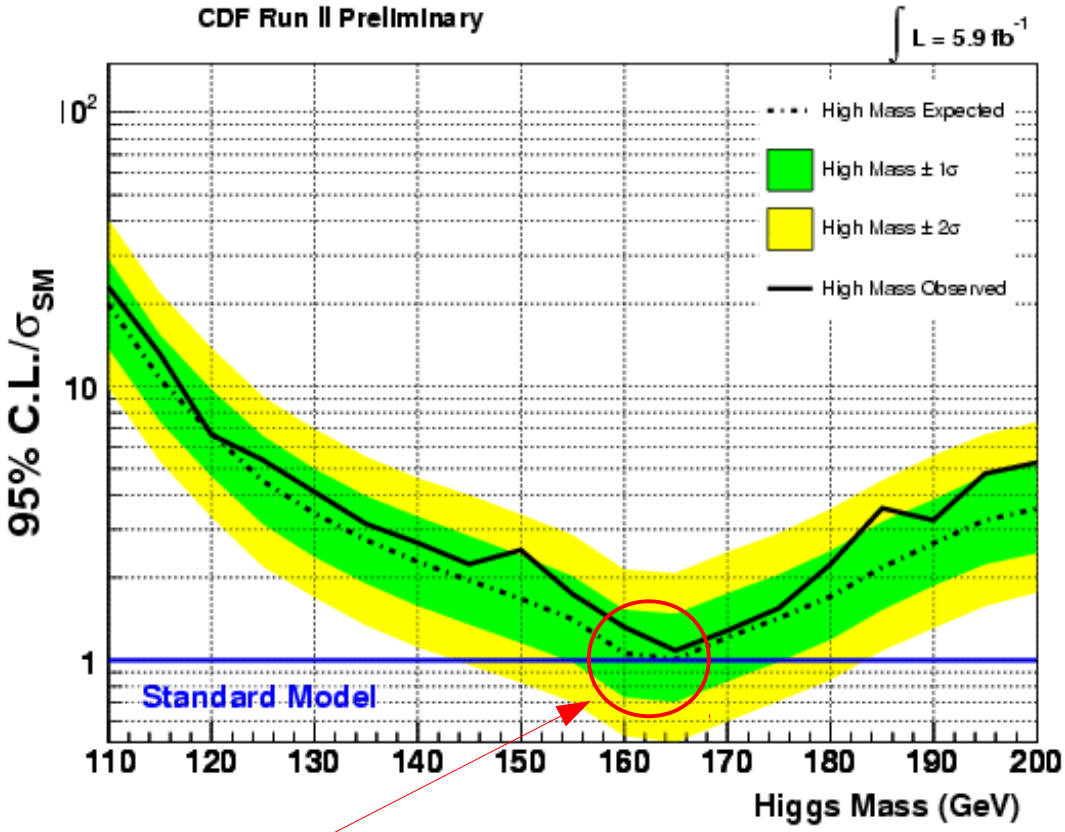


- Signal and background
  - Cross section [5%-67%]
  - Higher order diagrams [5%-11%]
  - Jet E_T [3%-29%]
  - Luminosity 7.3%
- Background:
  - DY ME_T modeling 26%
  - W+Jet data driven modeling 28%
  - Wγ data driven modeling 11%

Combine everything together

- A binned likelihood for each Higgs mass and for each channel is constructed including systematics and correlations
- Expected limit: background only experiments

M_H=165	Expected limit	Observed limit
0 jets	1.67	2.39
1 jet	2.35	2.46
2+ jets	3.16	6.14
SS 1+jet	4.86	5.92
Tri-lep. NoZ	7.37	7.85
Tri-lep. Z1J	31.8	36.4
Tri-lep. Z2+J	9.16	10.4
Hadr. Tau	14.5	23.5
Low Mll	11.2	7.21
Combined	1.00	1.08



Standard Model sensitivity

The Future

IMPROVEMENTS

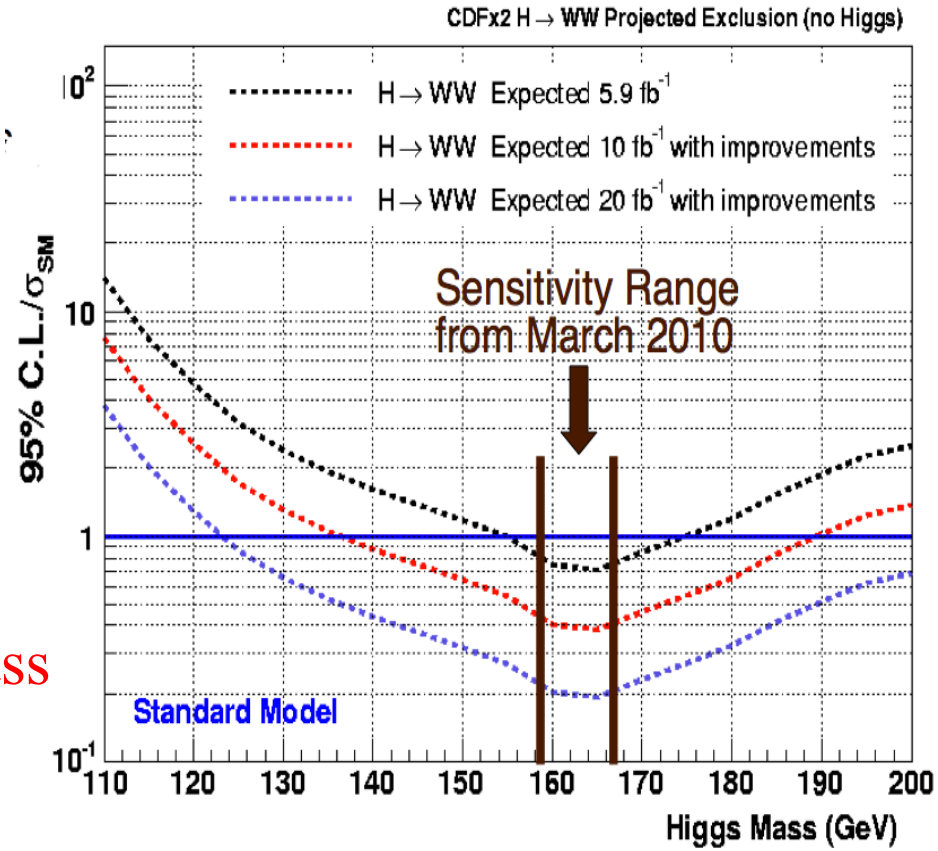
Statistics

- By the end of 2011 we expect ~10/fb per experiment
- Possible data taking extension?

...but not only

- optimize lepton isolation cut
- include additional trigger paths
- further optimize analysis techniques
- add hadronic W decay
- add ZZ Higgs decay

2xCDF but only high mass



Tevatron can do it!

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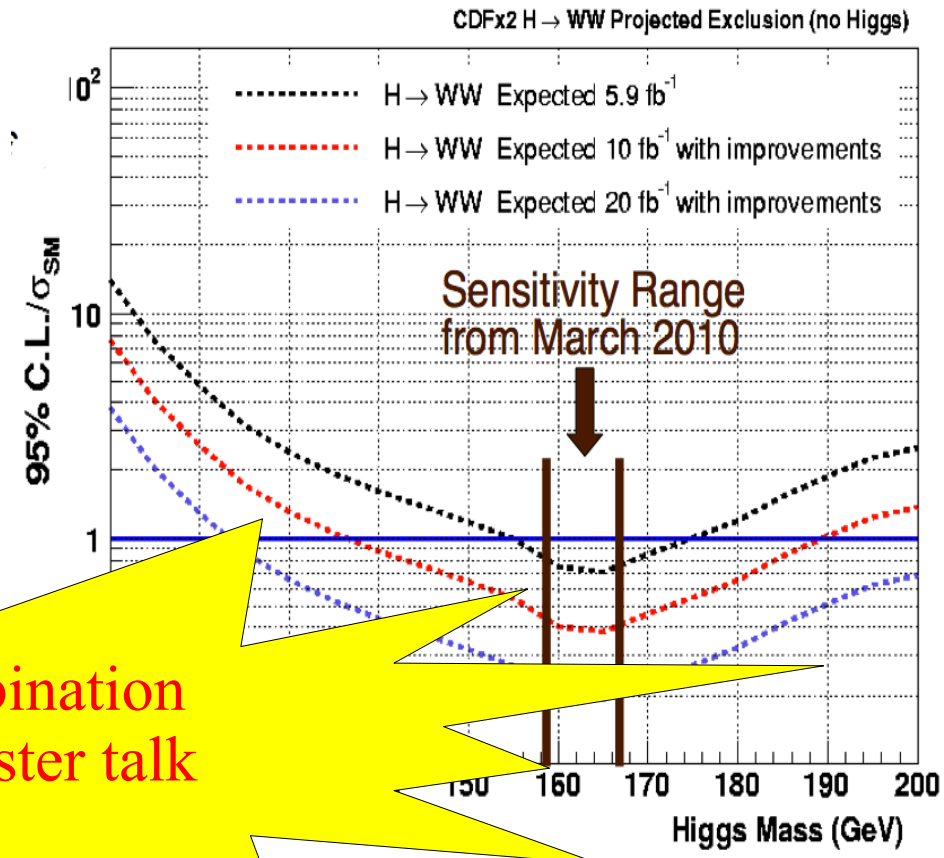
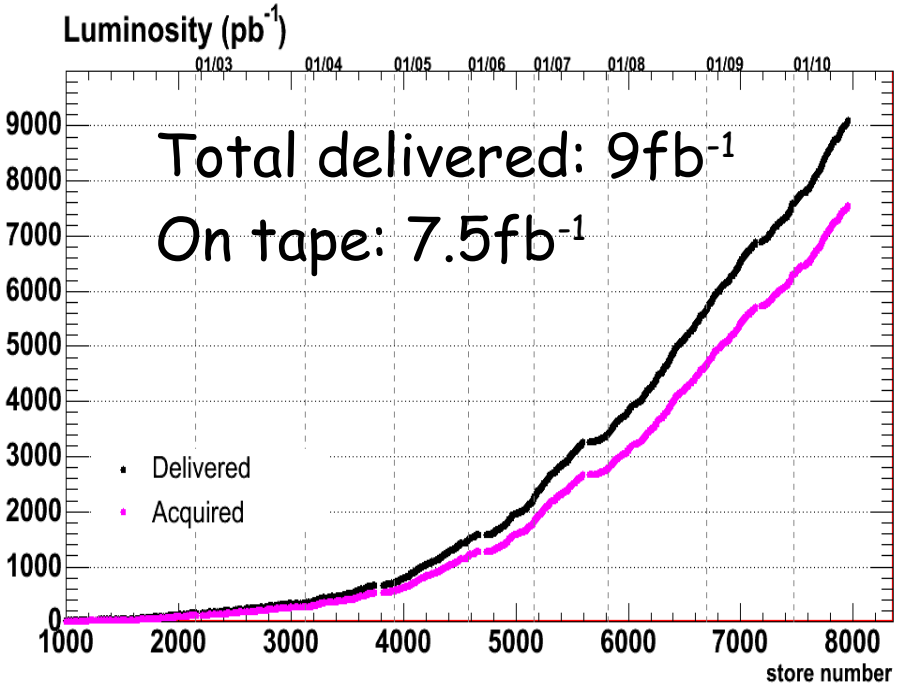
2xC

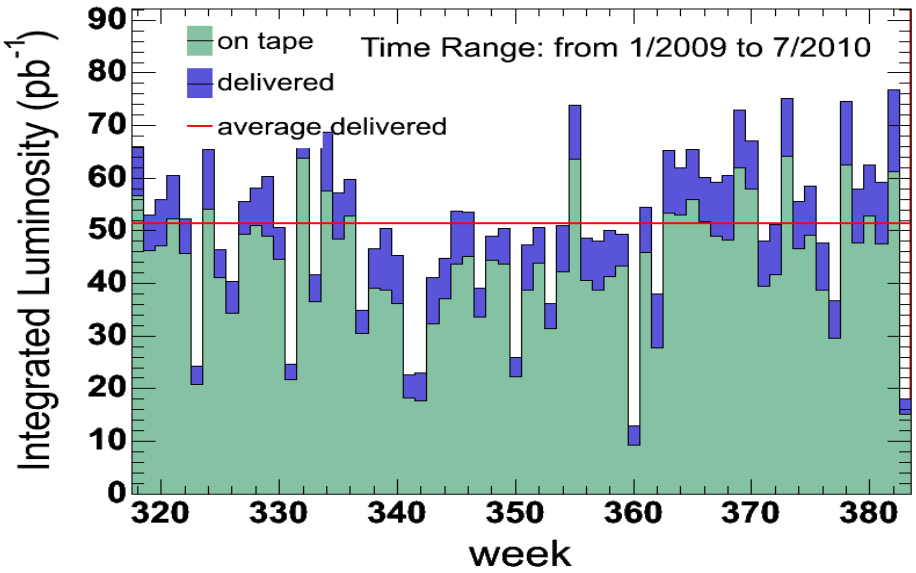


For Tevatron combination
Attend Ben Kilminster talk
July 26th

Additional Material

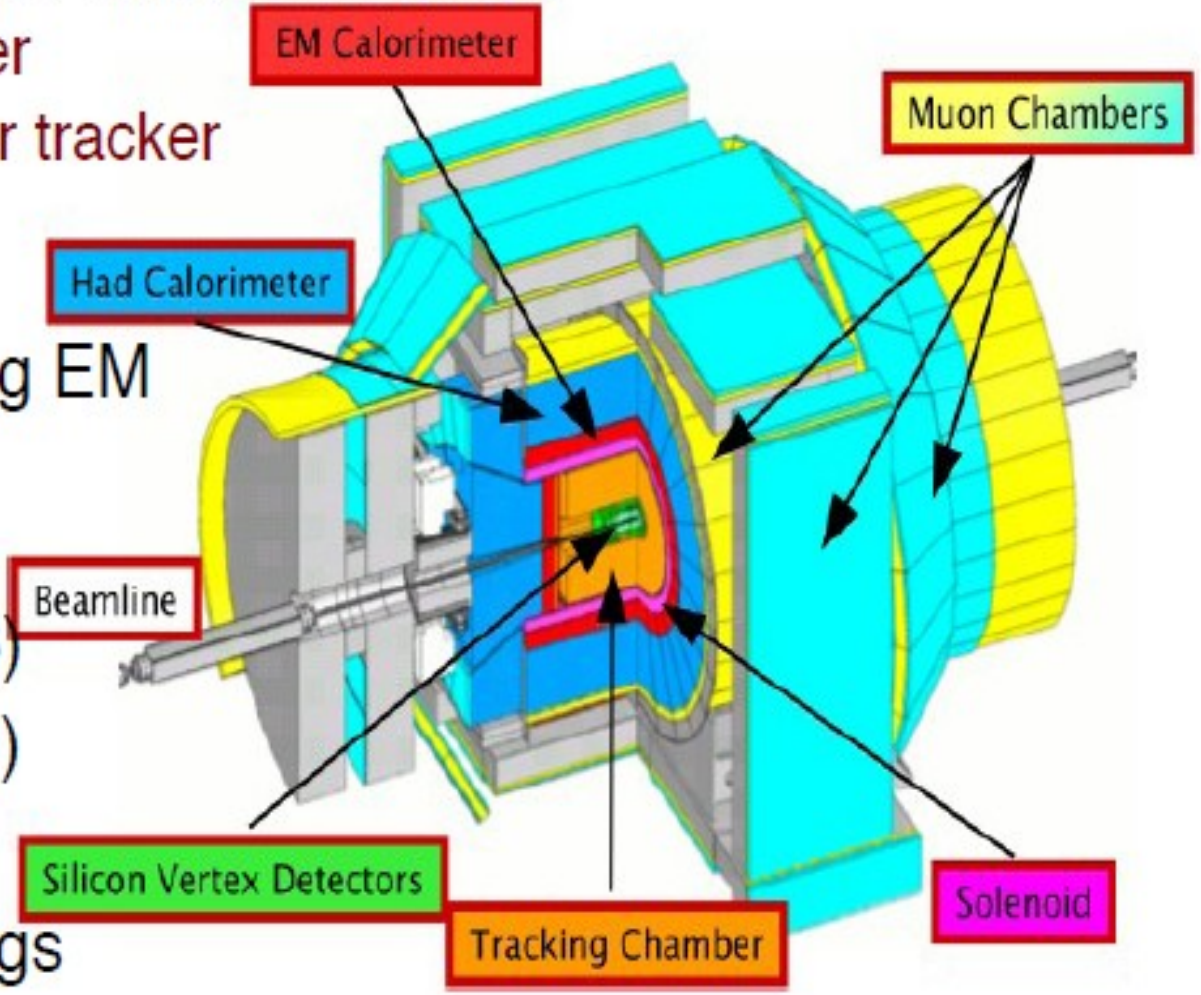
CDF Luminosity



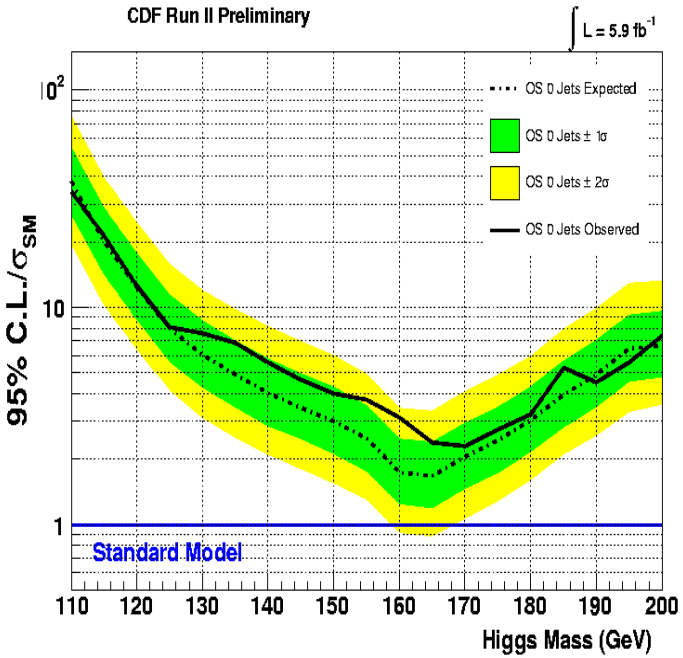


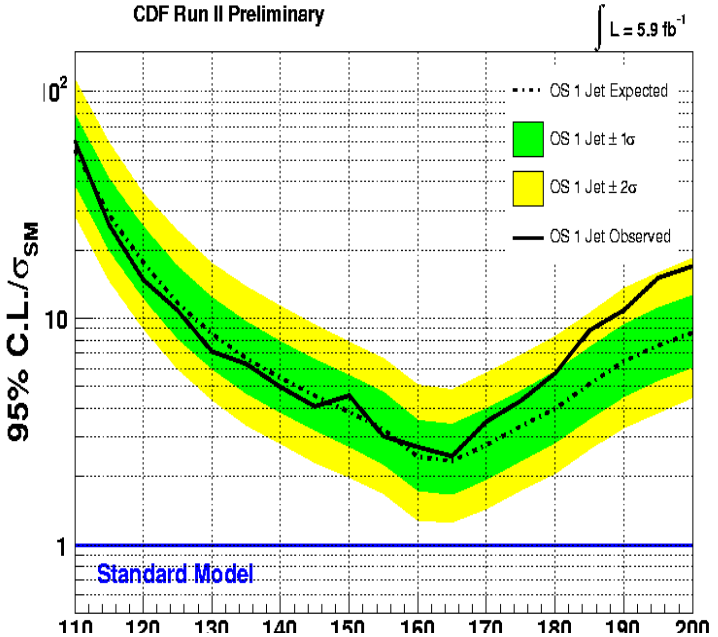
The CDF Detector

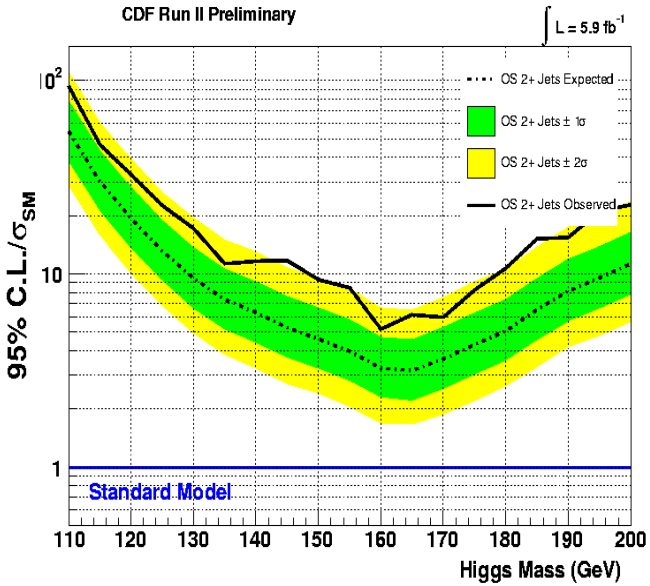
- General multipurpose detector
  - Excellent tracking and mass resolution:
    - Silicon inner tracker
    - Drift chamber outer tracker
- Calorimeters
  - Segmented sampling EM and Hadronic
- Muon chambers
  - CMU/CMP ($|\eta| < 0.6$)
  - CMX ($0.6 < |\eta| < 1.0$)
- Complex geometry
  - Try to maximize Higgs acceptance

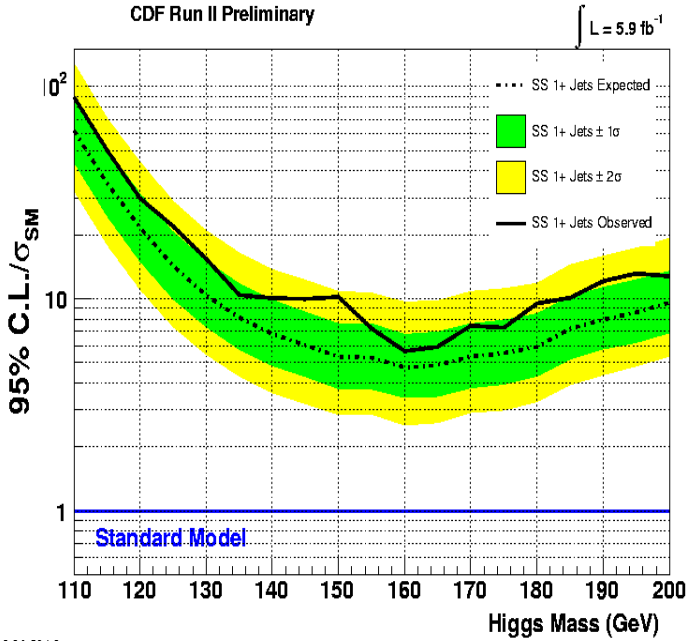


Individual Limits









Individual Limits