Higgs Boson searches at the Tevatron

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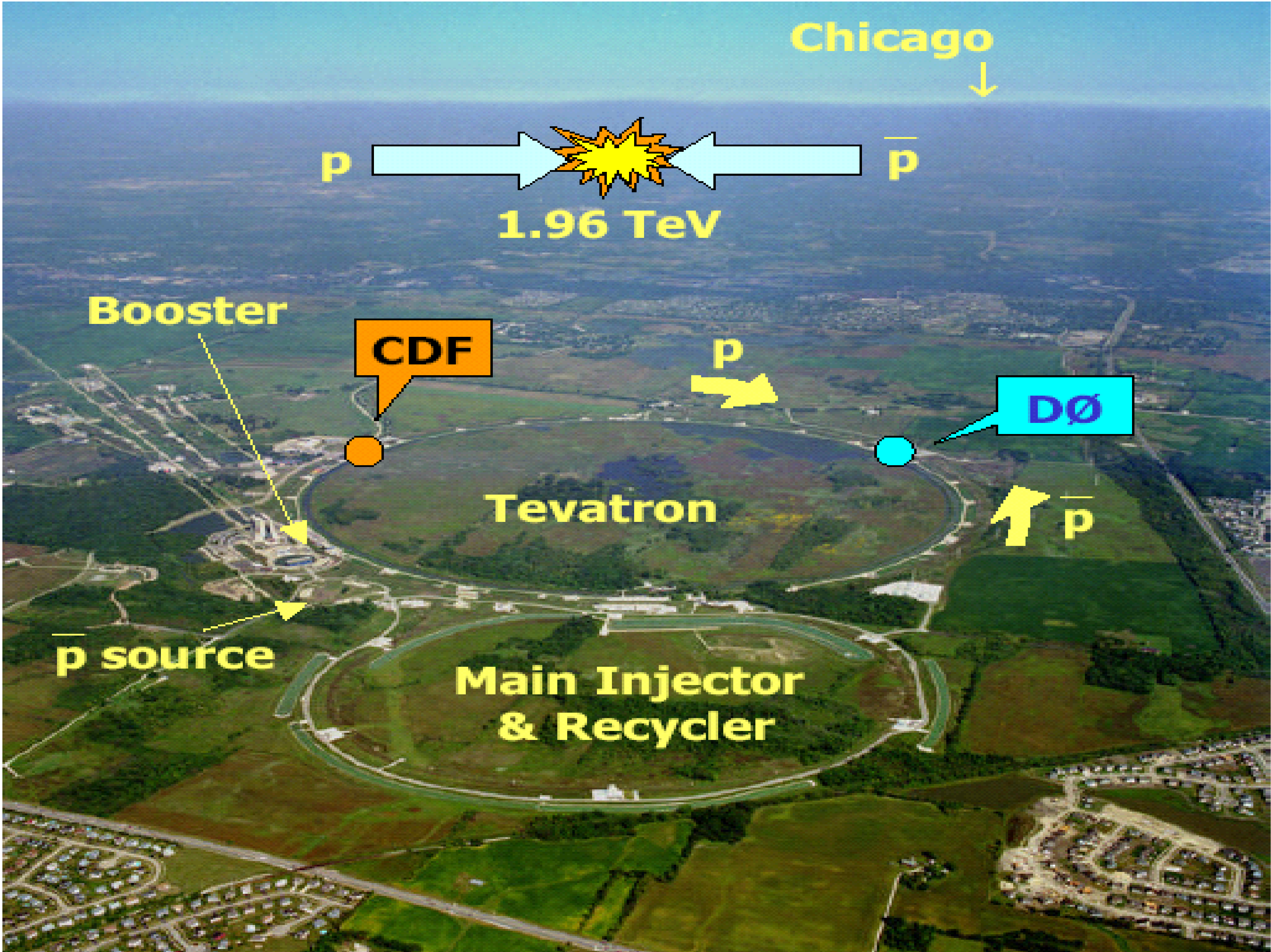
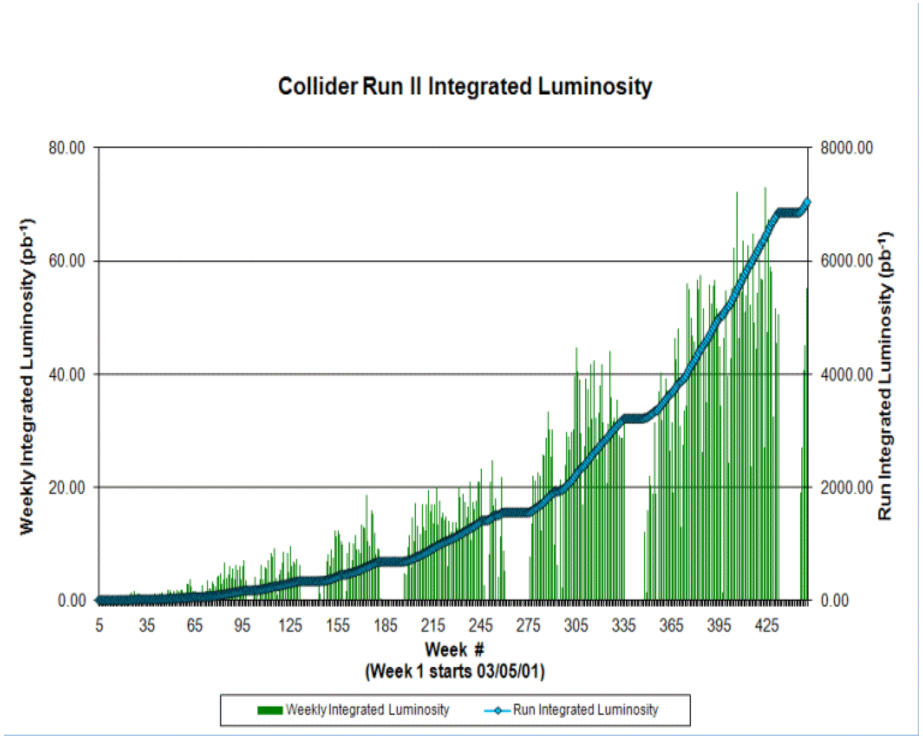
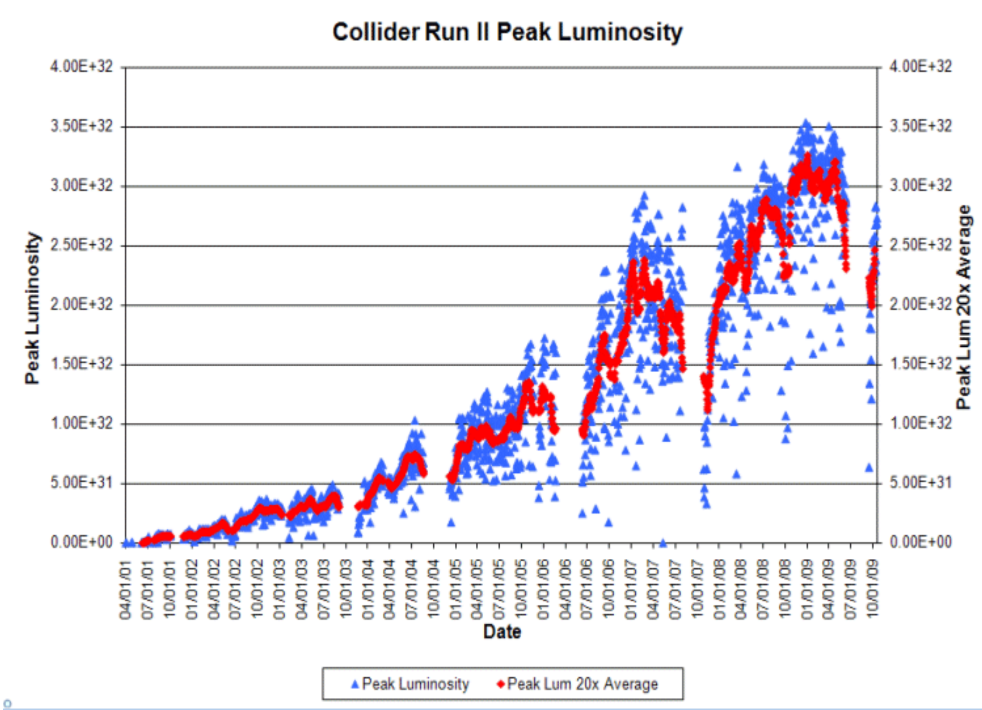


Chicago
p
$\bar{p}$
1.96 TeV
Booster
CDF
p
DØ
Tevatron
$\bar{p}$
$\bar{p}$ source
Main Injector
& Recycler

Tevatron Status





- Improved stacking rate
- Faster transfer to recycler
- Improved reliability:

  store-hours/week:110 now

  100 2004

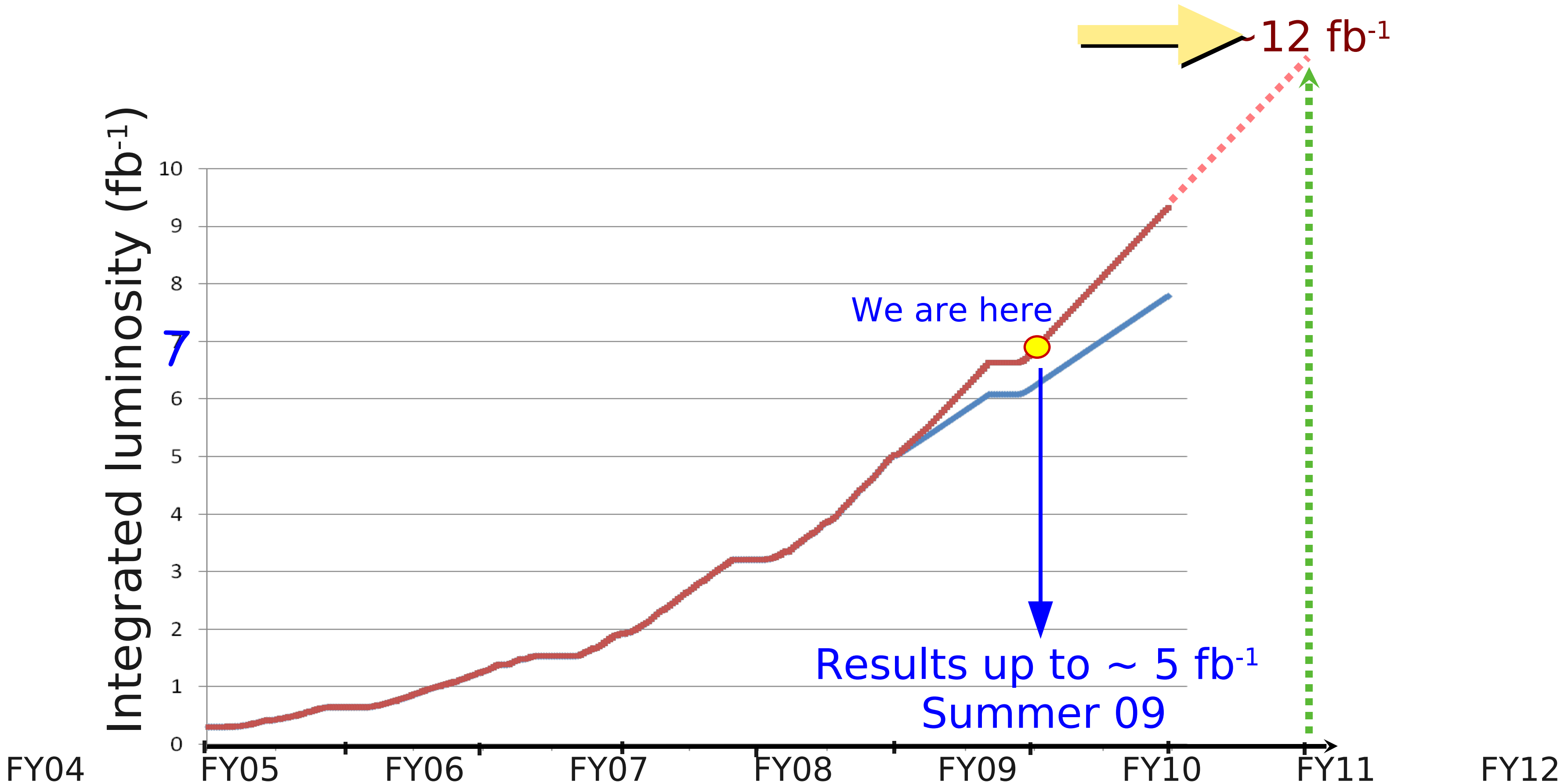
Exceptionally performing machine in terms of luminosity:

$>60pb^{-1}$/week, $>2fb^{-1}$/year

$>350E30cm^{-2}s^{-1}$ instantaneous

7 fb^{-1} delivered so far

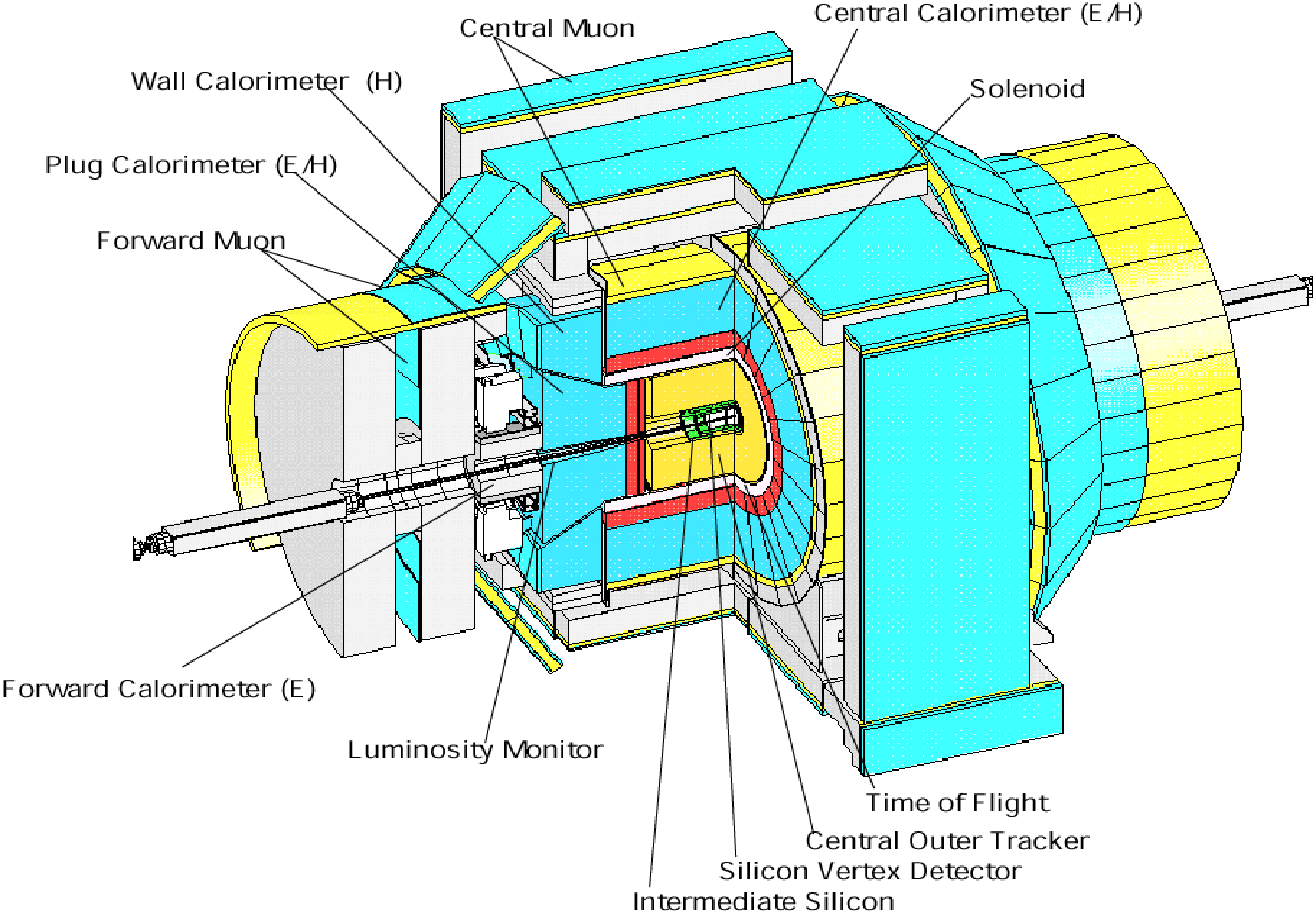
Tevatron Projections



- At the end of 2010, 12 months: >9fb^{-1}
- If running FY11: 12fb^{-1} => 10fb^{-1} for analysis

Expect at least doubled delivered luminosity by the end of FY11

CDF Detector

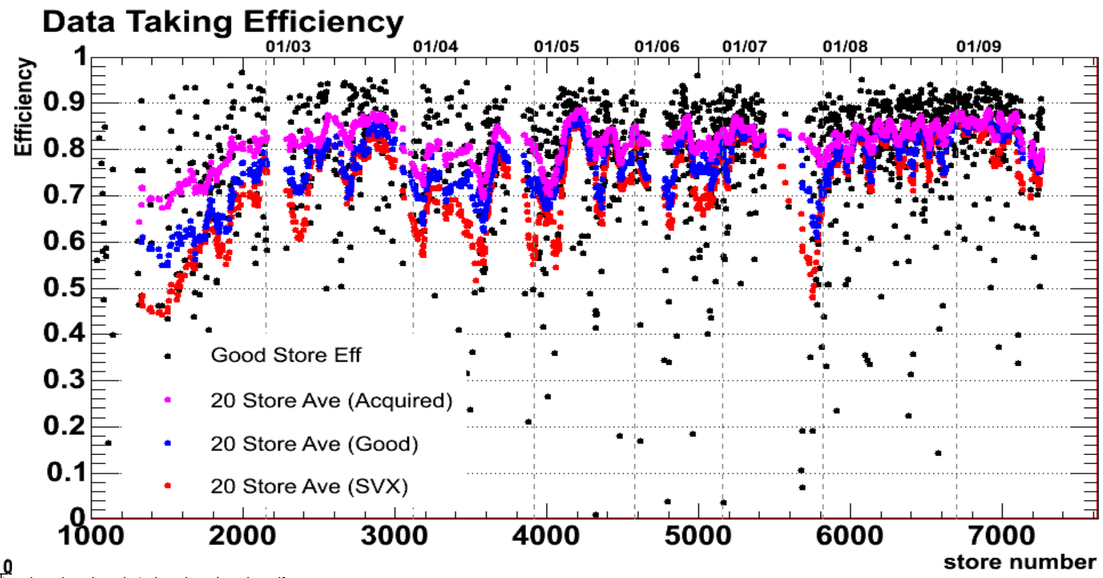


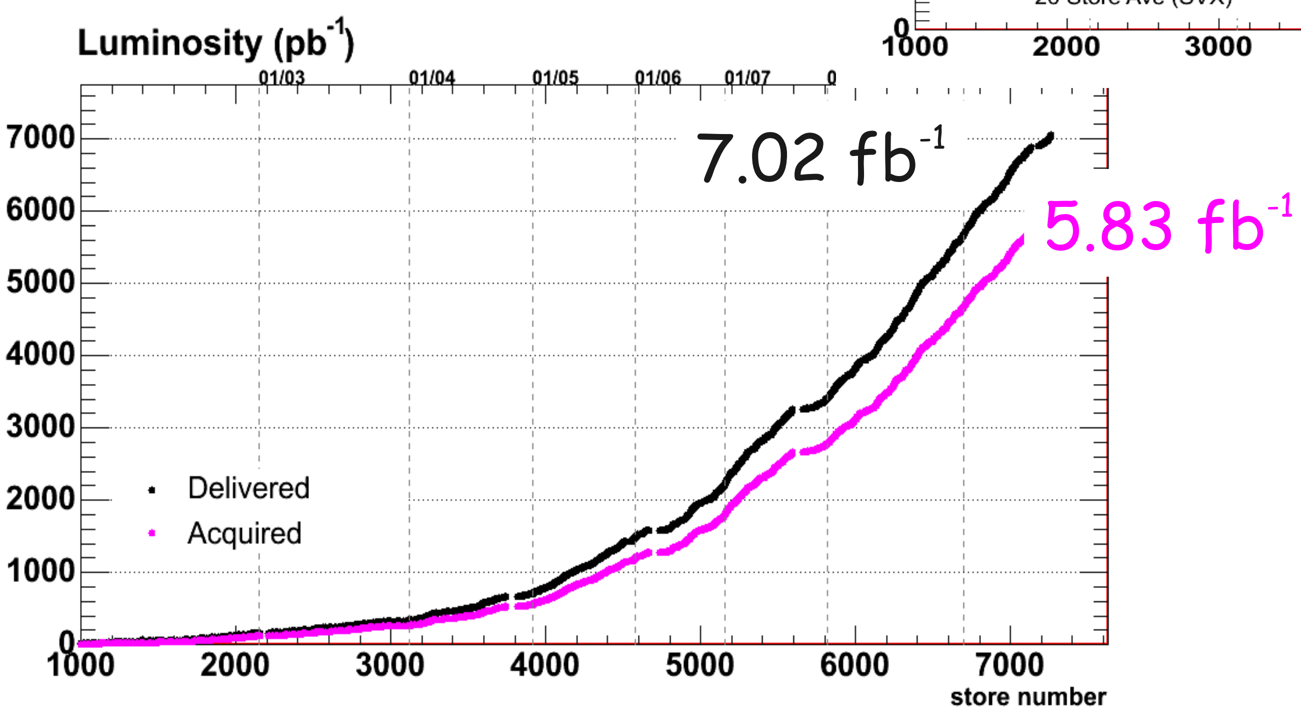
Detector Status: CDF

Stable operations

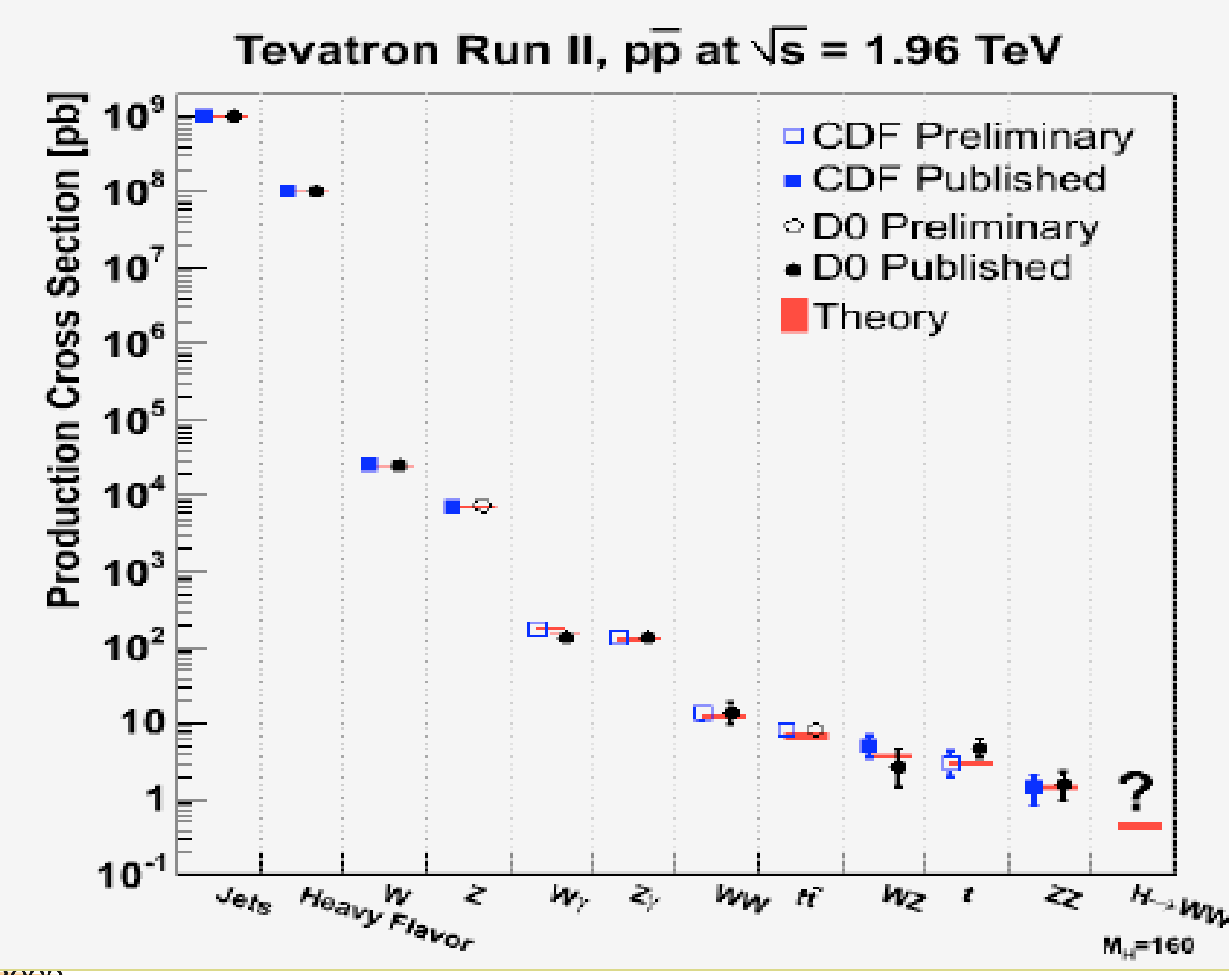
~85% efficiency

Up to now on tape $5.83 fb^{-1}$

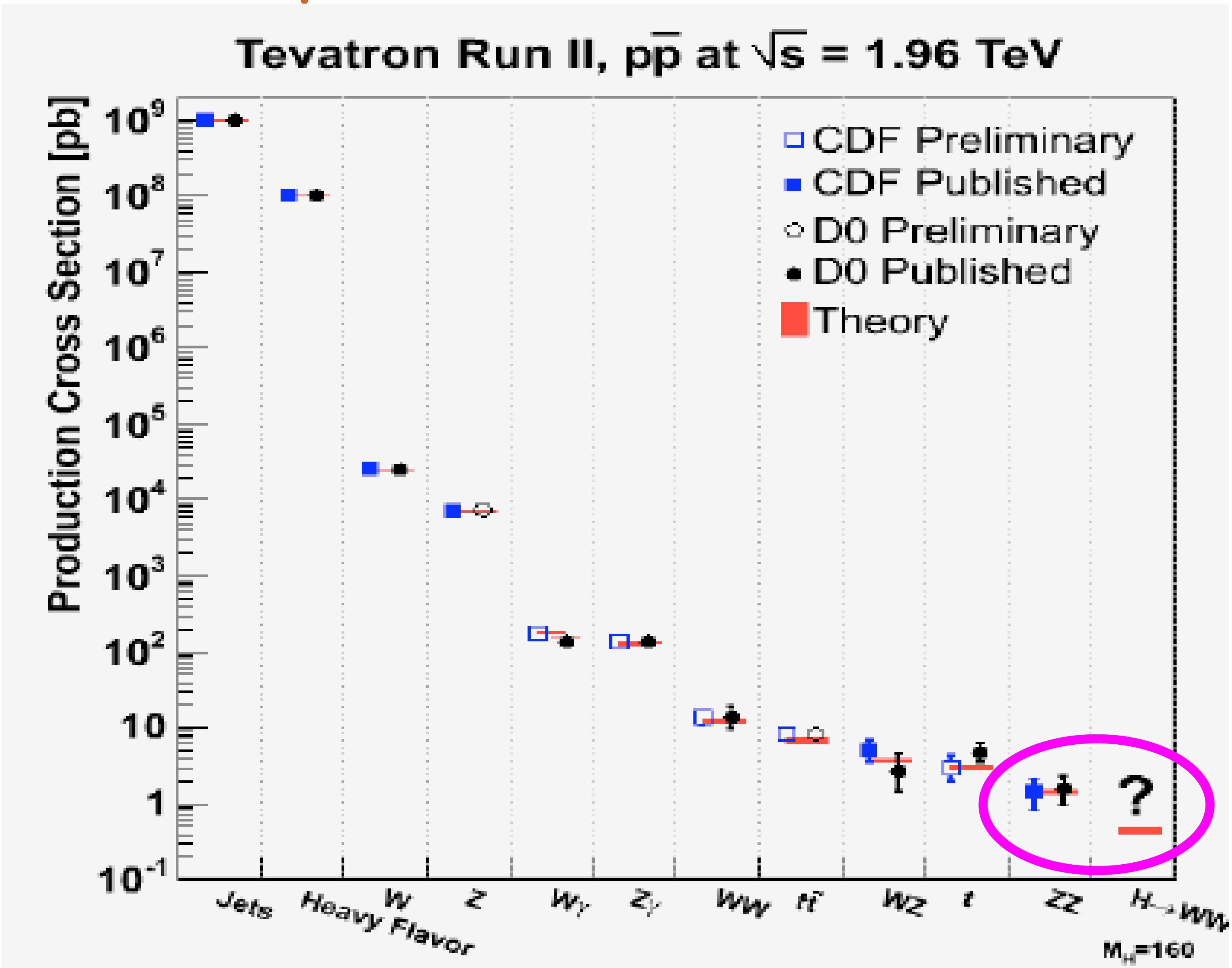




The Physics at the Tevatron



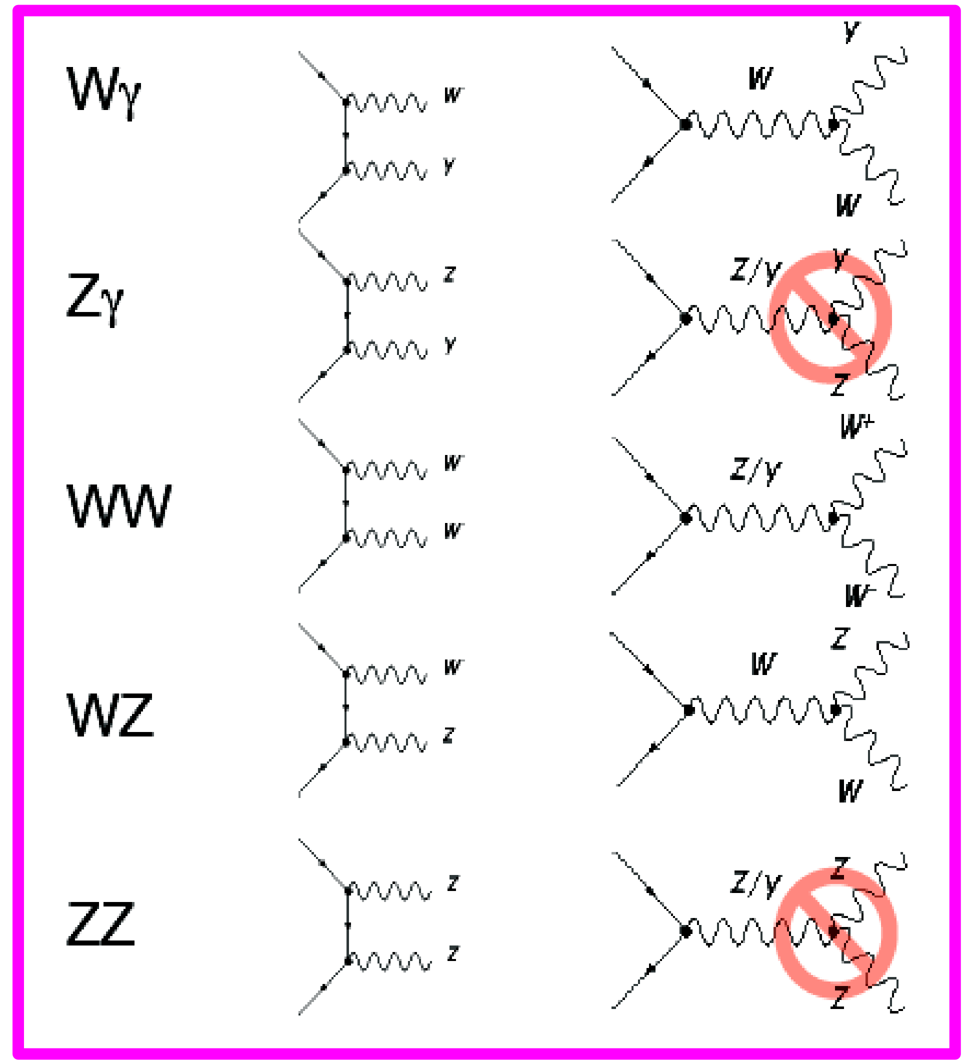
The Physics at the Tevatron



On the way to the Higgs: Di-bosons

Diboson final states:

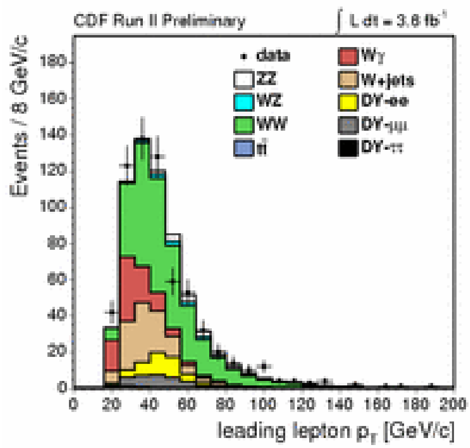
- Test Standard Model production predictions
- Look for anomalous coupling
- Cross sections similar to Higgs
- Important background for Higgs

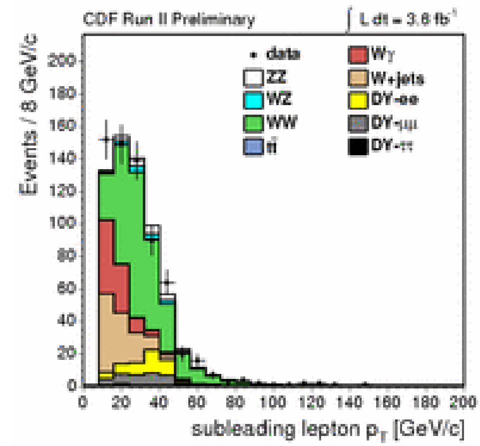


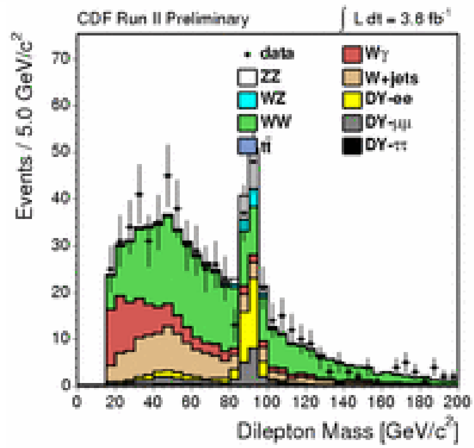
On the way to the Higgs: WW

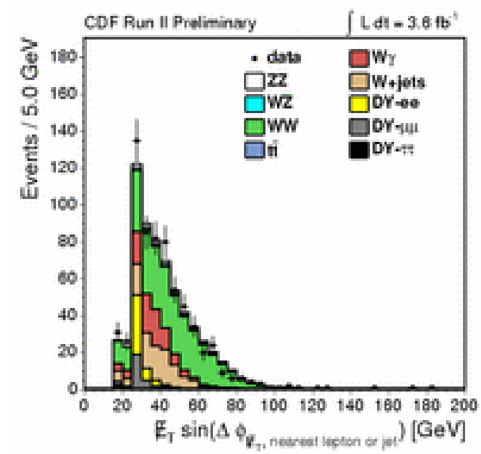
pp->WW->llνν, ll=ee, μμ, eμ +MEt

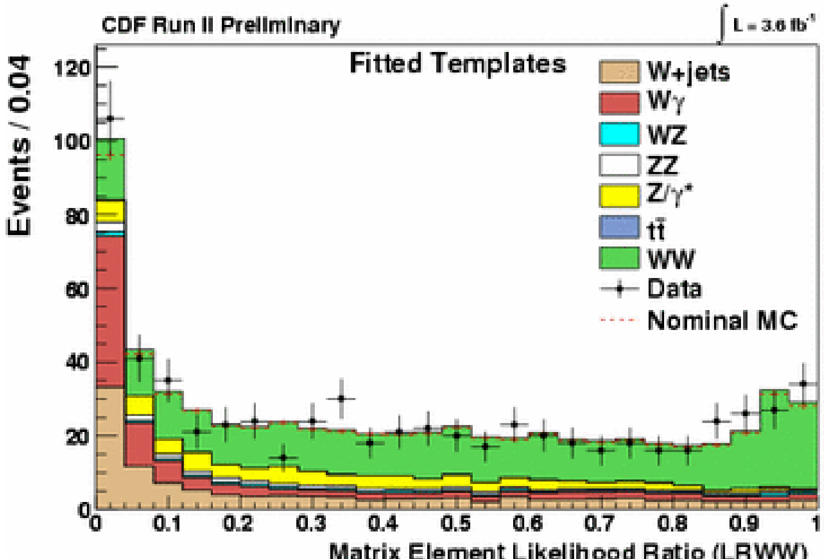
The analysis is performed as for H->WW search: a per-event probability is assigned according to a matrix element given the measured event kinematics







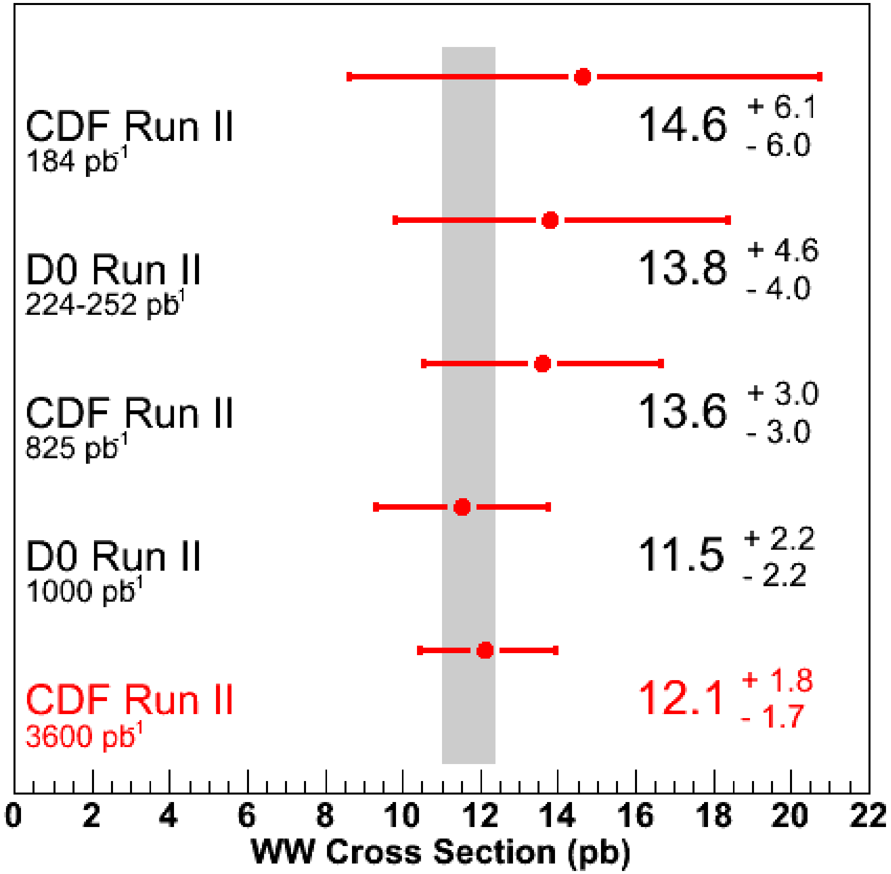




On the way to the Higgs: WW Results

Cross section in 3.6 fb^{-1}

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



Theoretical expectation:

$$\sigma(p\bar{p} \rightarrow WW) = 11.66 \pm 0.70 \text{ pb},$$

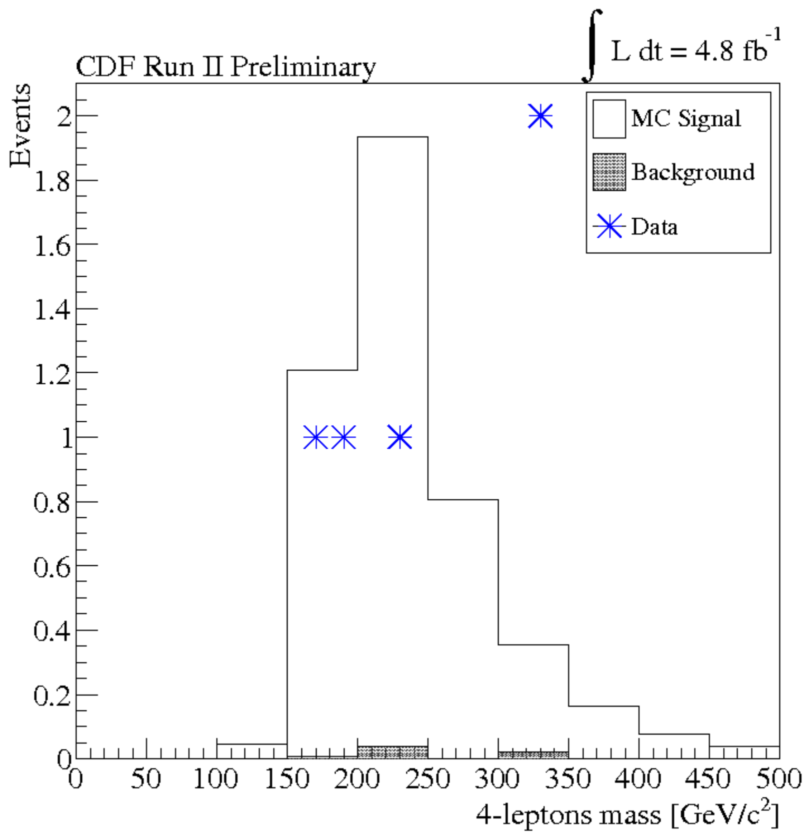
One dimensional 95% C.L. improved limits on anomalous trilinear gauge couplings

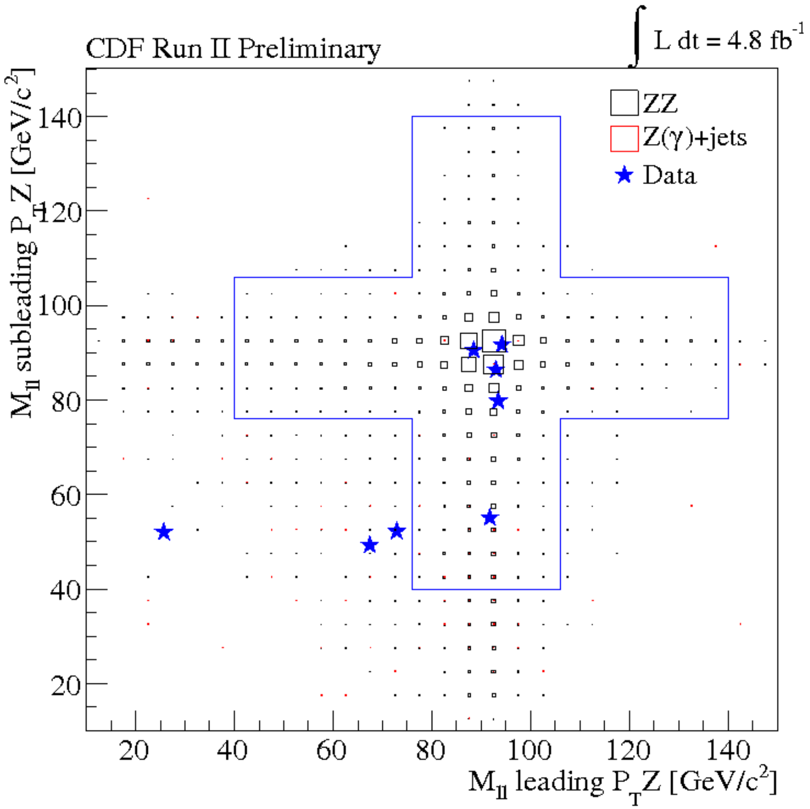
On the way to the Higgs: ZZ

ZZ-> 2 leptons+2 ν (1.9 fb^{-1})

ZZ-> 4 leptons:

5σ signal with 5 events in 4.8 fb^{-1}





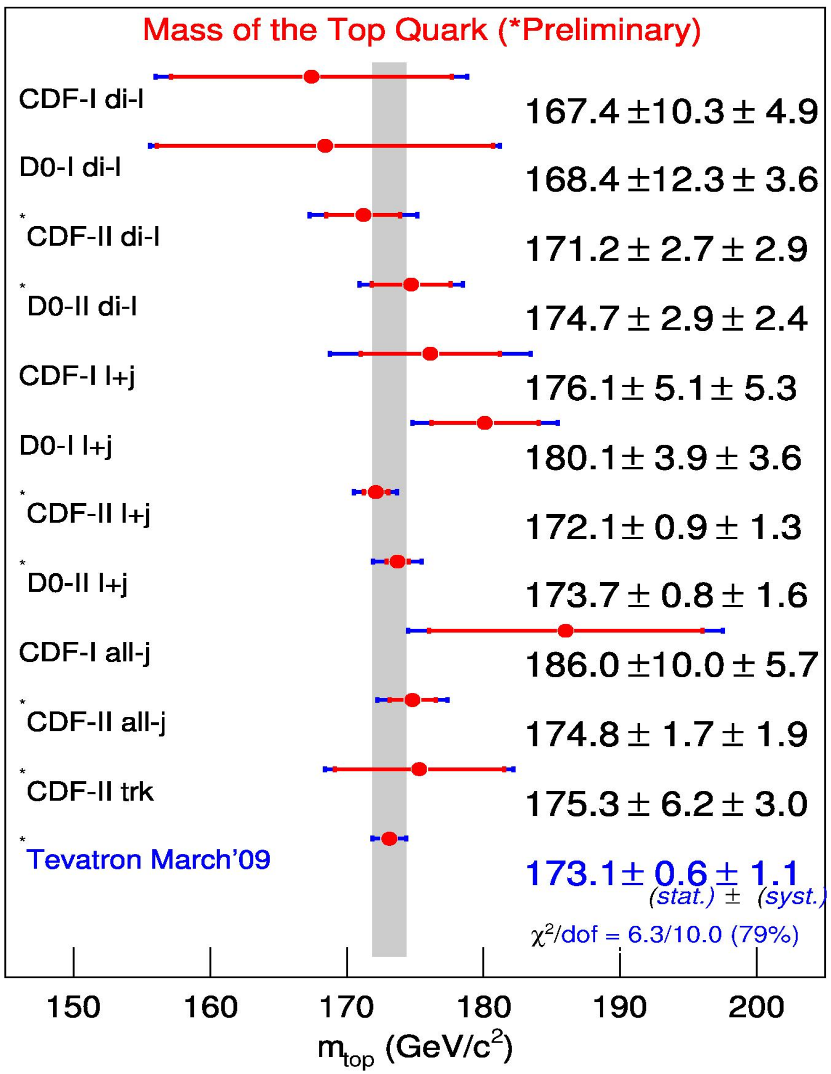
The cross section

$$\sigma_{p\bar{p}\rightarrow ZZ} = 1.56^{+0.80}_{-0.63}(stat.) \pm 0.25(syst.) \quad \text{pb}$$

Theoretical expectation:

1.4 ±0.1 pb

Top Mass

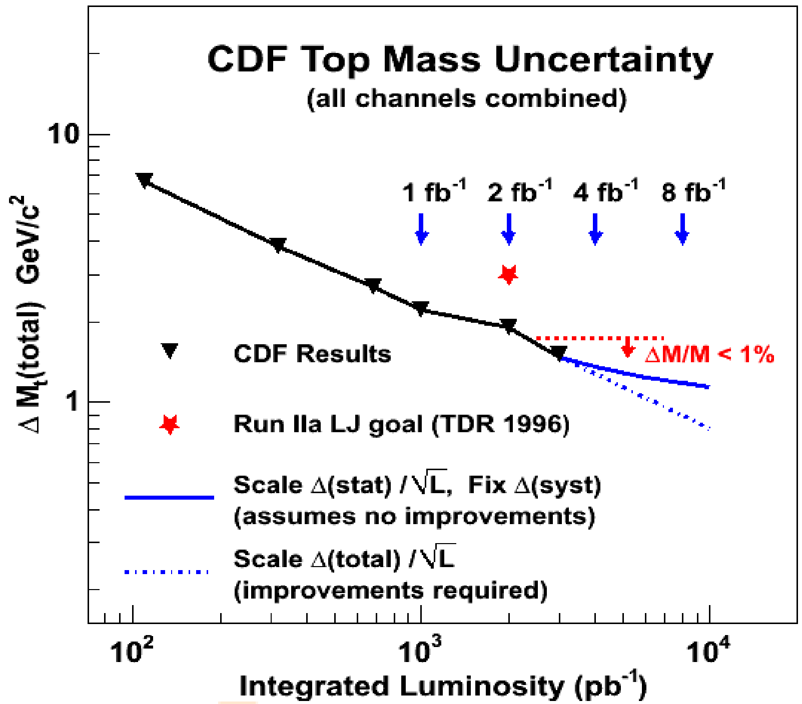


Use up to 3.6 fb^{-1} of data

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%

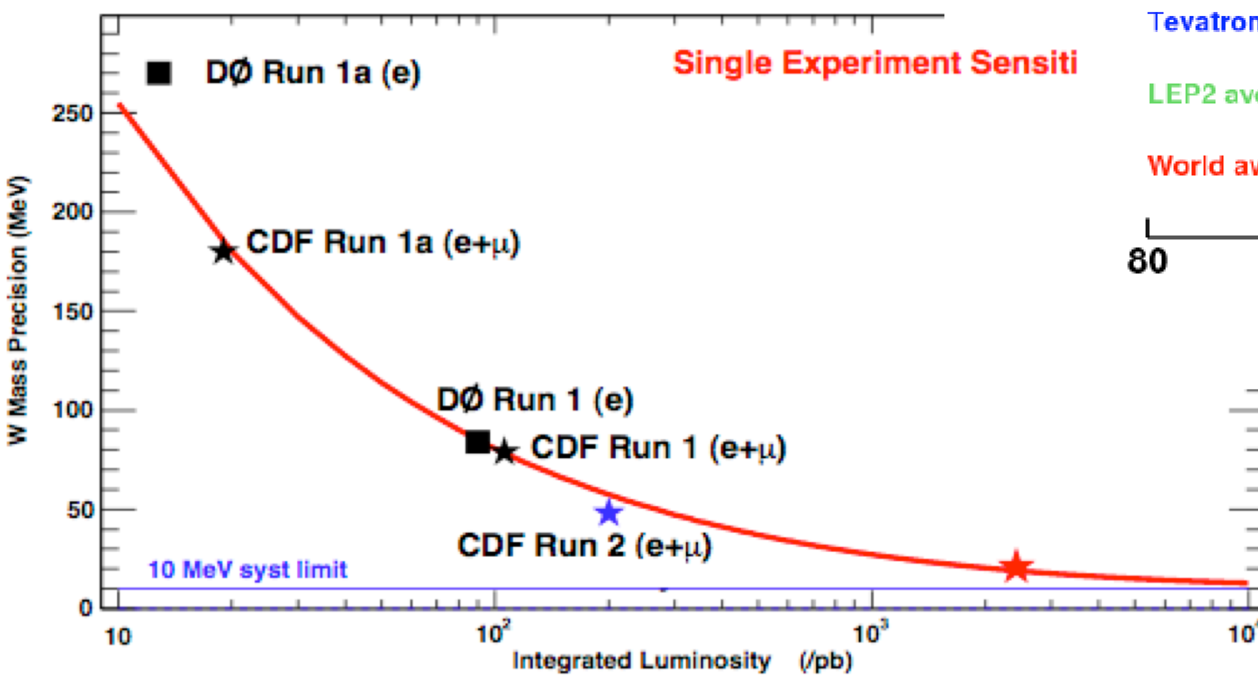


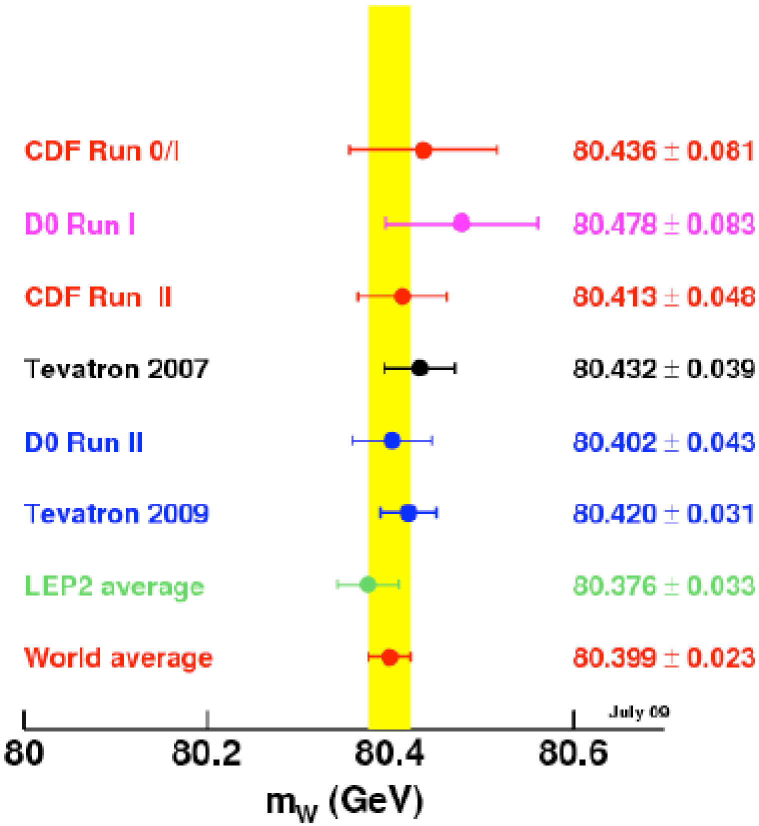
W Boson Mass

Latest results D0:

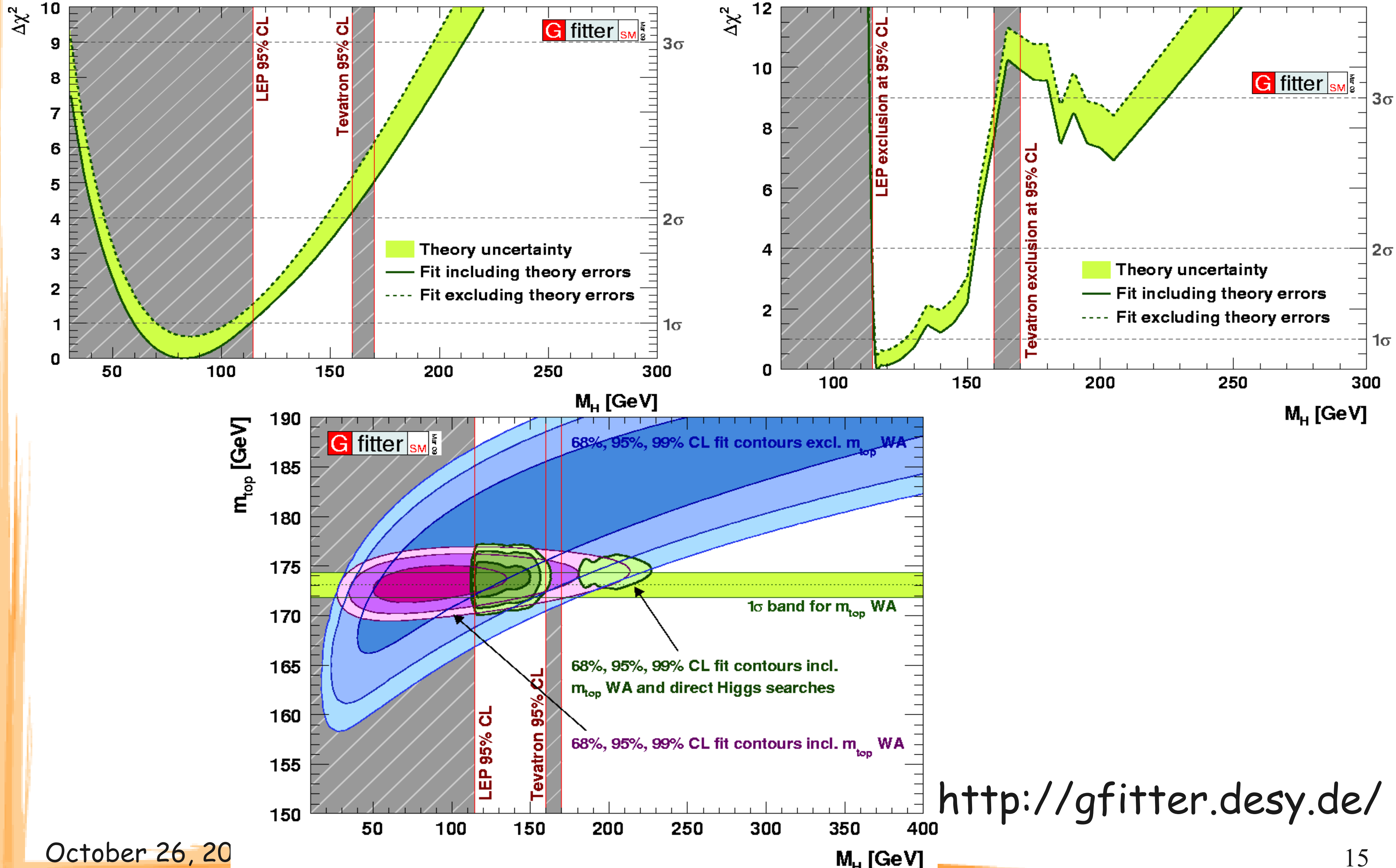
M_W 80.402±0.045 GeV

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



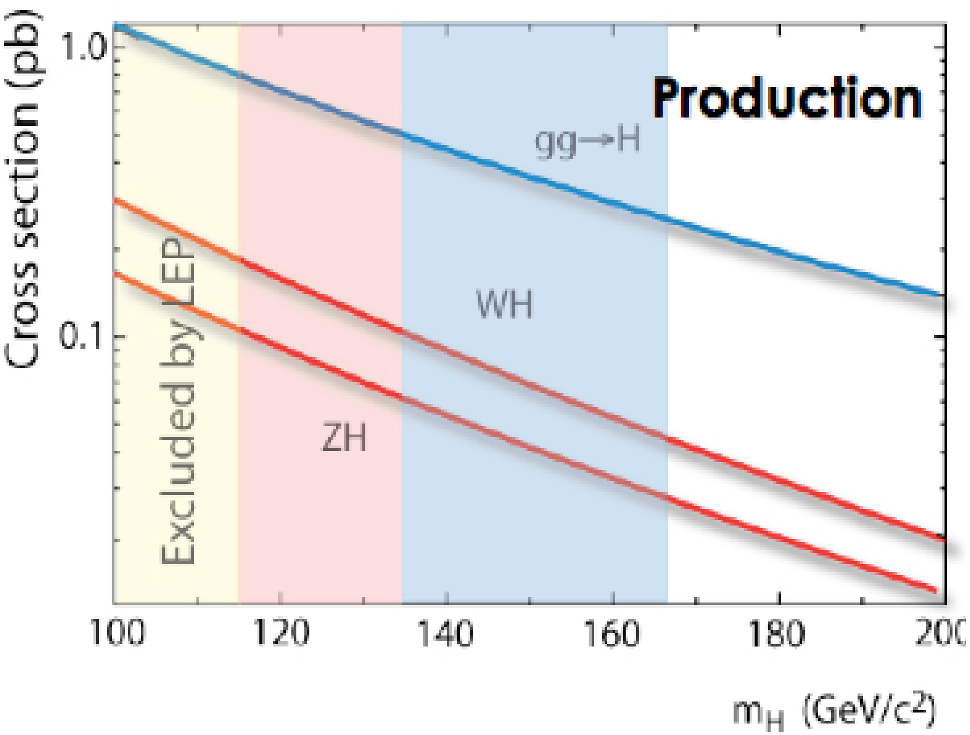


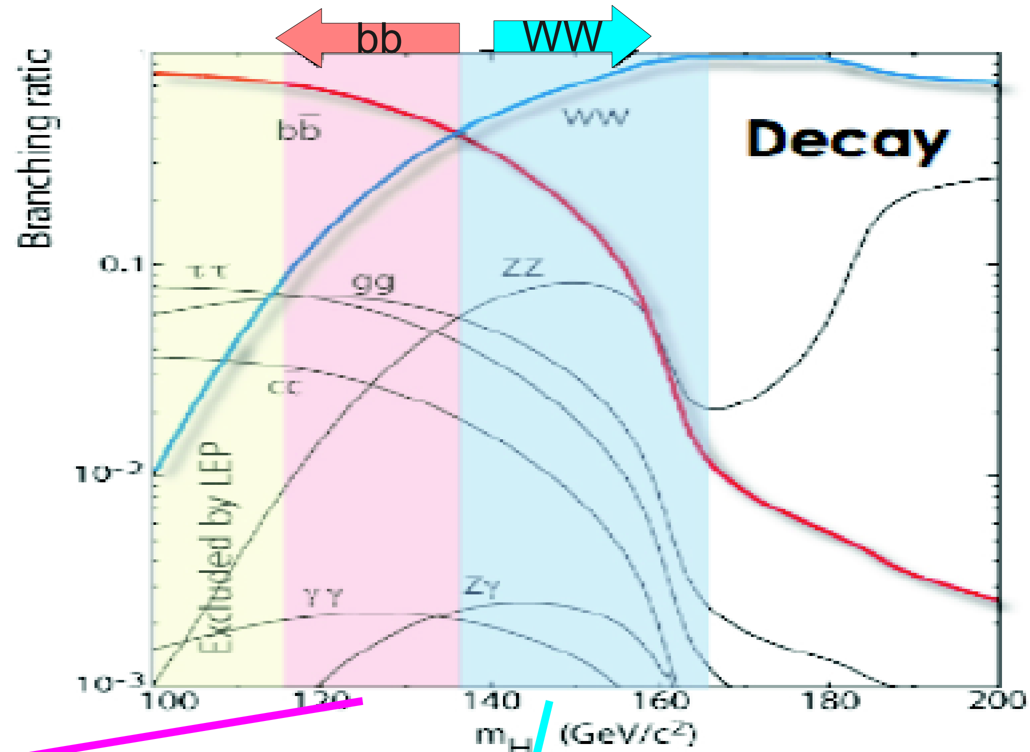
Cornering the Higgs



http://gfitter.desy.de/

Direct Higgs searches @Tevatron

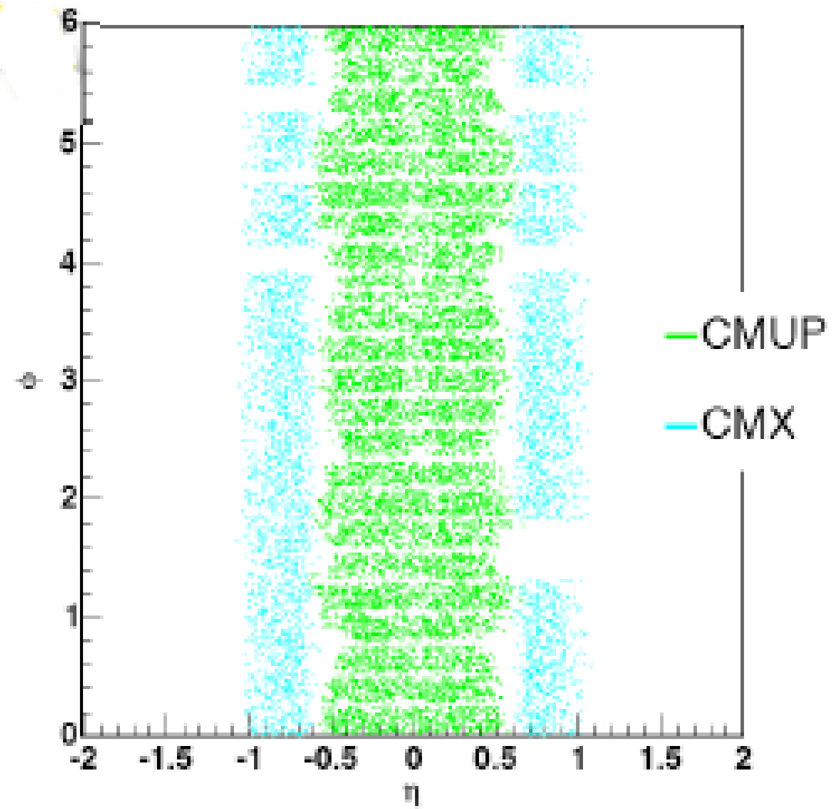




Low Mass: M_H<135 GeV/c^2 High Mass: M_H>135 GeV/c^2

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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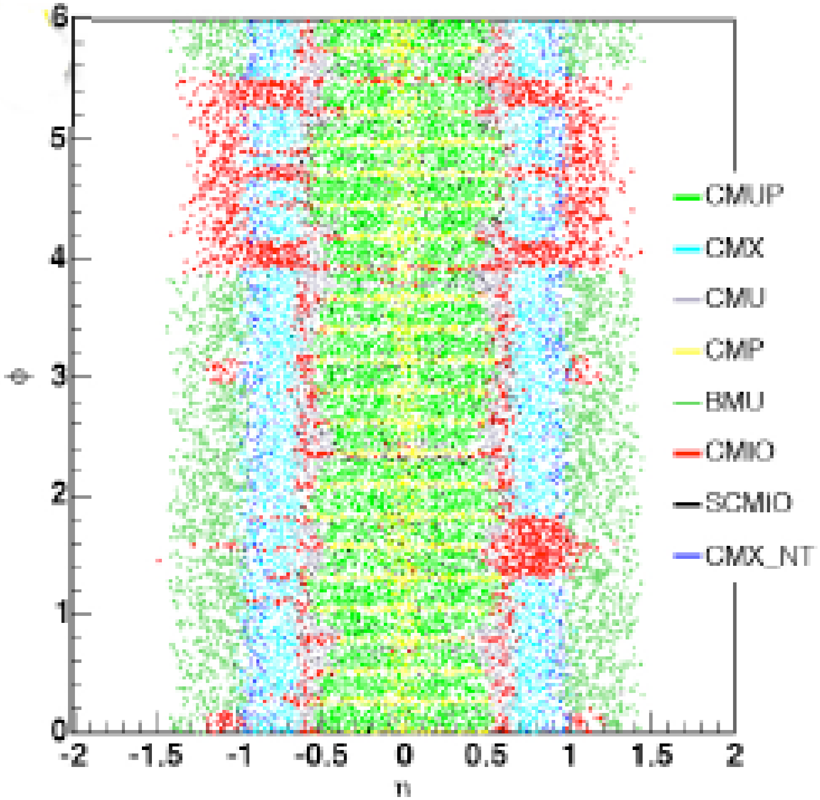

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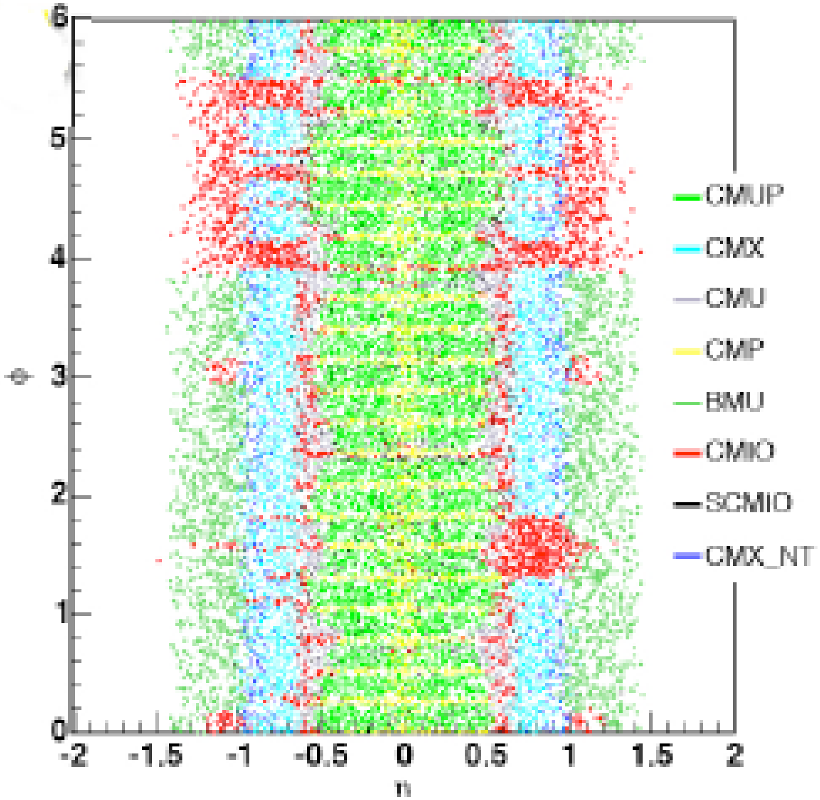
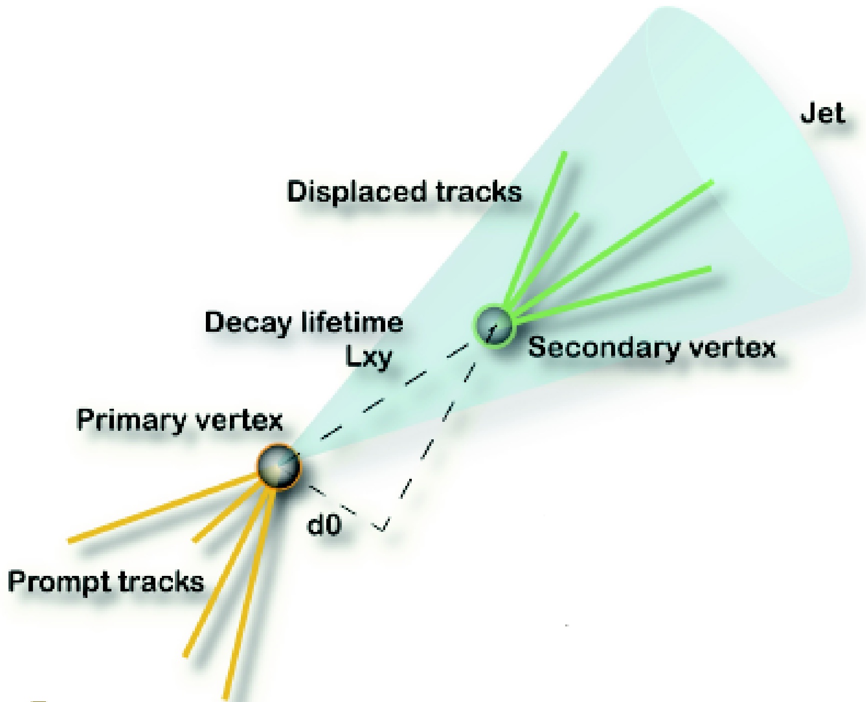
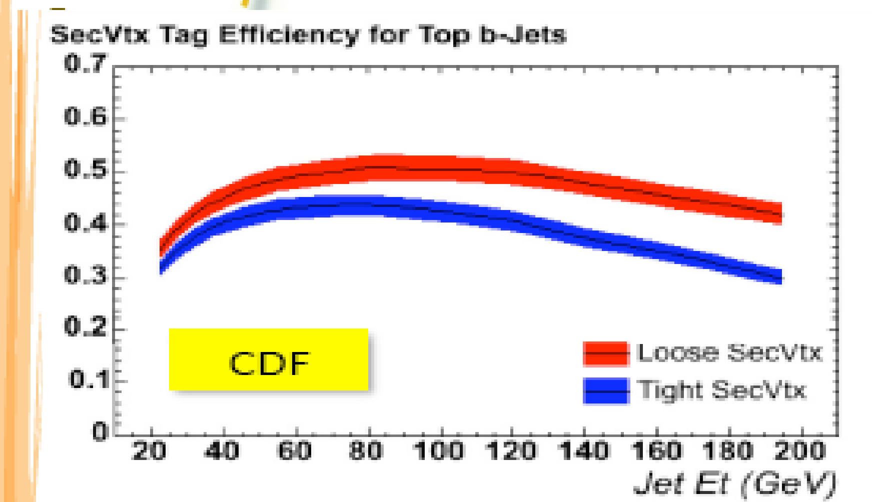
  - taus: tracks matched to calorimeter cluster
- Expand lepton coverage:
  - interplay between sub-detectors to cover holes
  - include forward detectors
- Good Missing E_T (MET) trigger :
  - select events with neutrinos and charged lepton that fail ID
  - remove events with fake MET



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

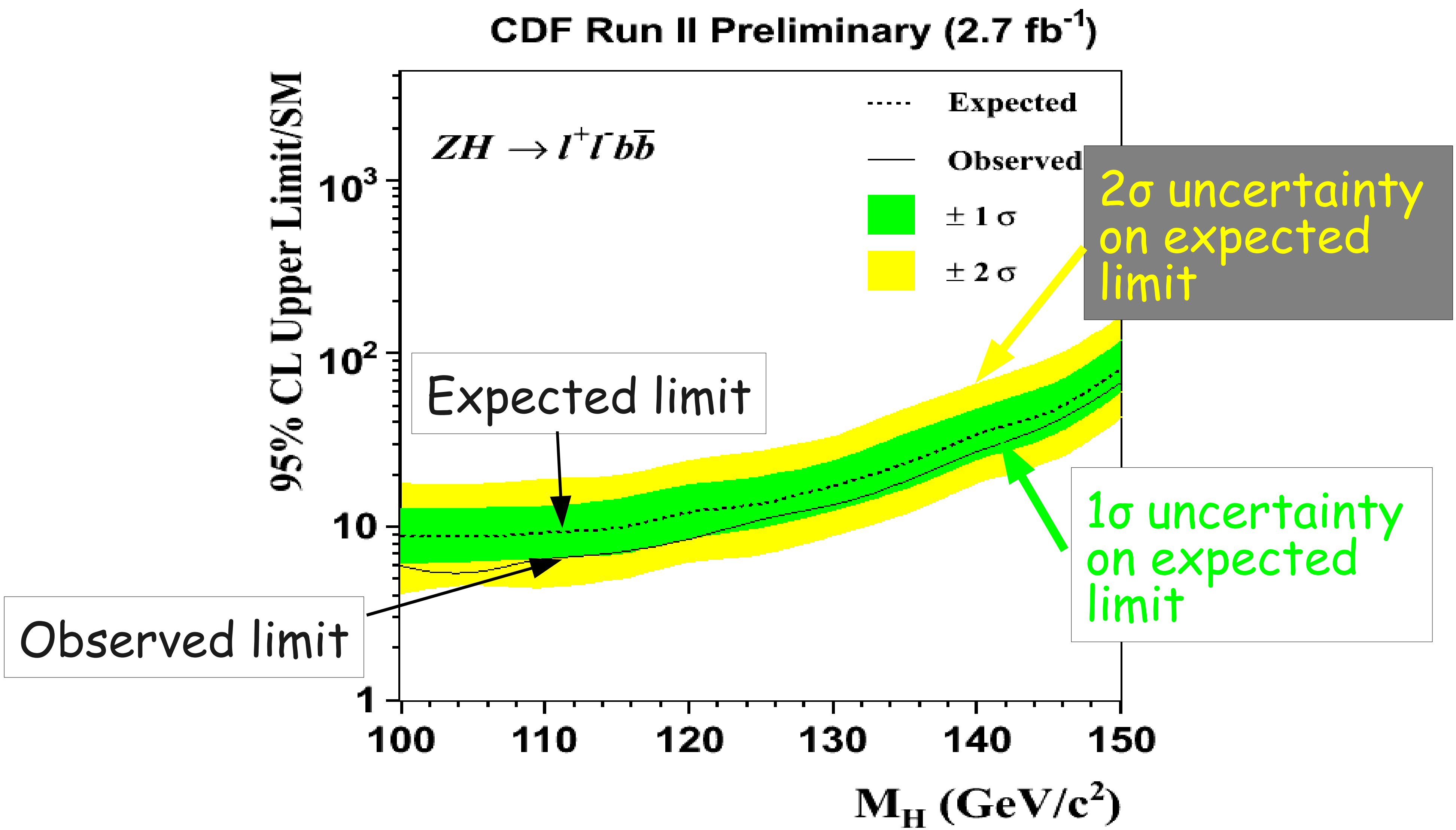
Analysis Tools: Multivariate techniques

- 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

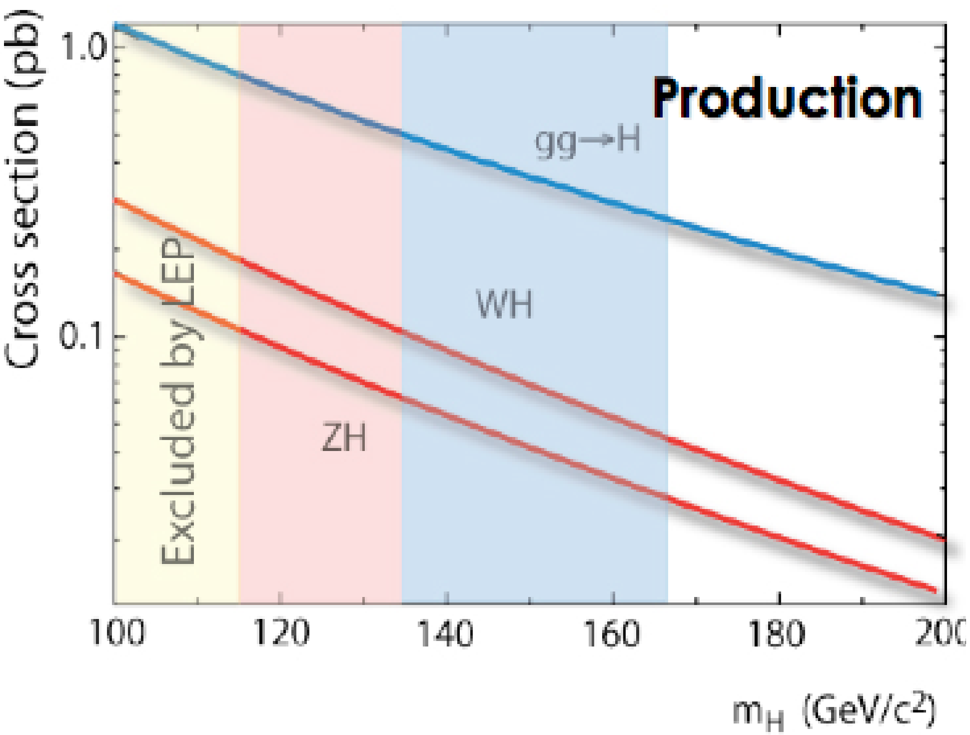
- Multivariate techniques help to improve sensitivity

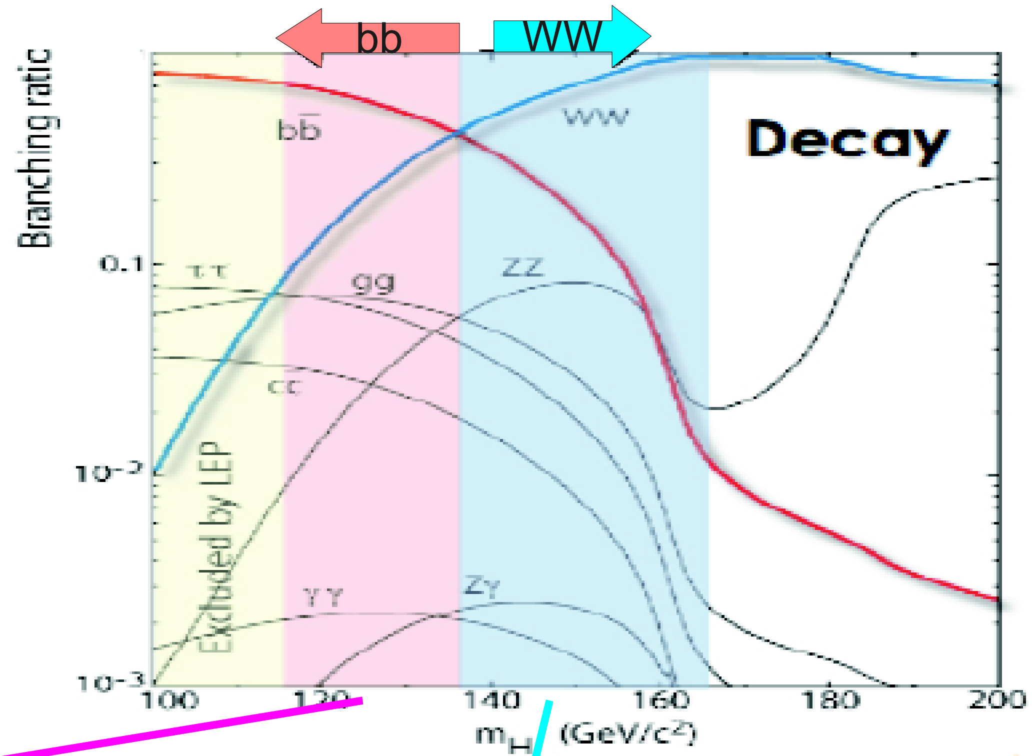
- Used already in many many analysis

Reminder: Limit Plots



Direct Higgs searches @Tevatron





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

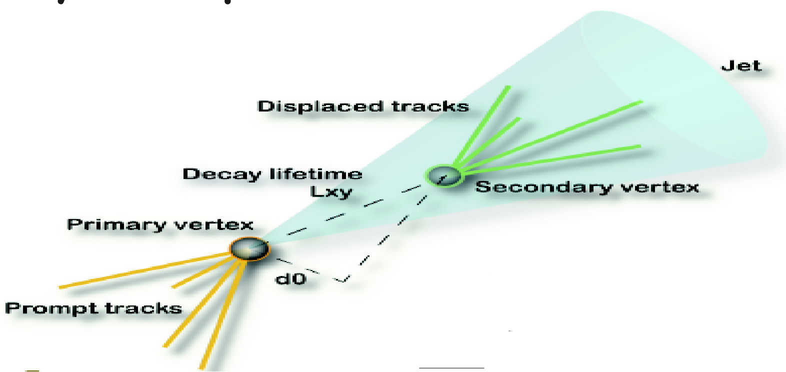
Low Mass Higgs searches

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.

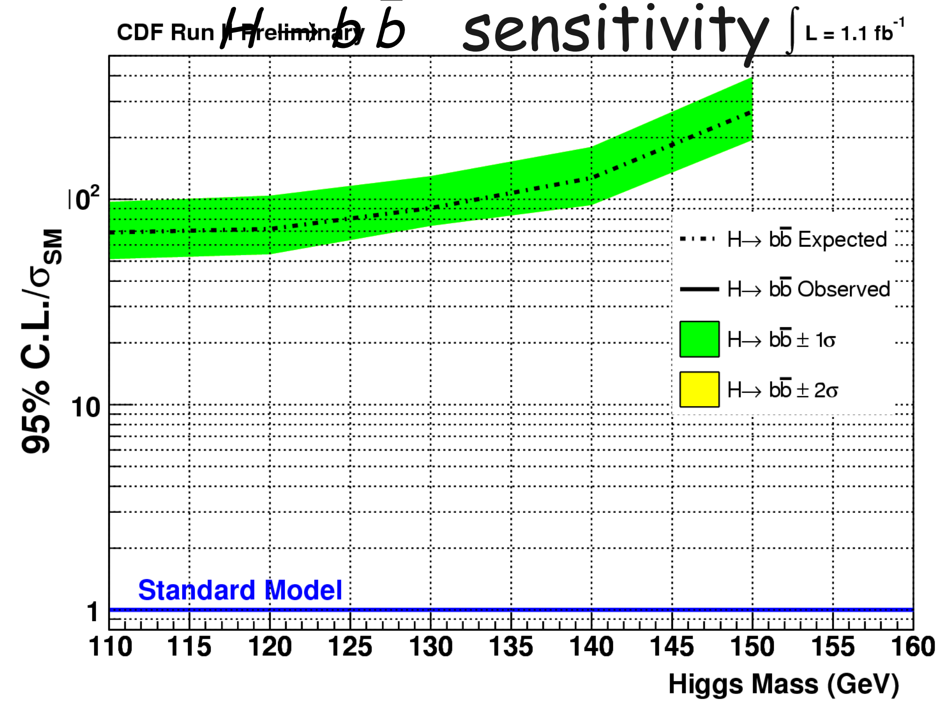
Data collected with b-tag trigger:

- at least 2 tracks displaced from primary vertex
- Lxy compatible with b-hadrons



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

$H \to b\bar{b}$ sensitivity

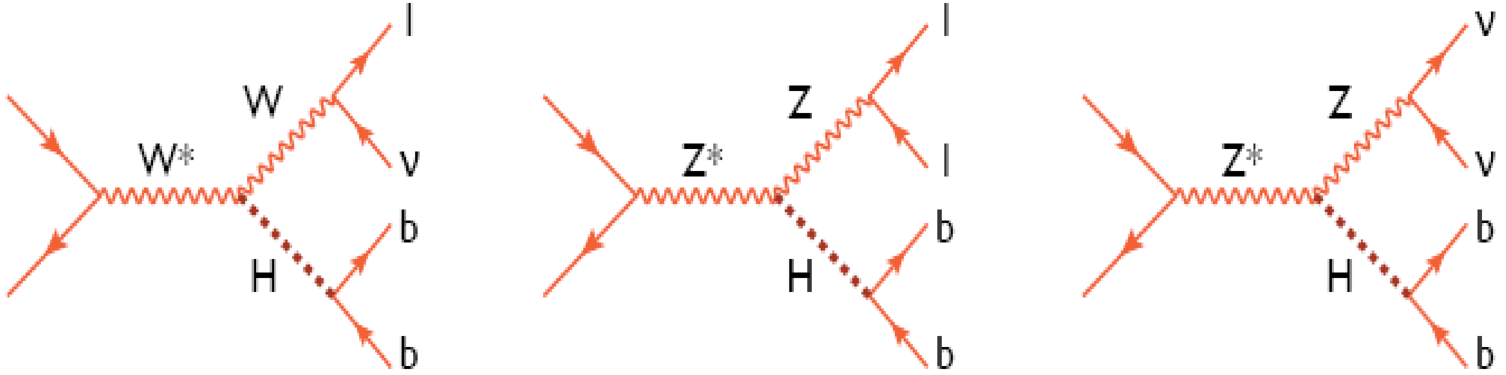


Trigger algorithms	$\epsilon(H \to bb)$	$\epsilon(\phi \to bb)$	$\epsilon(Z \to bb)$
Vertex b-tag	13%	11%	4%
Muon b-tag	5%	6%	2%

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

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

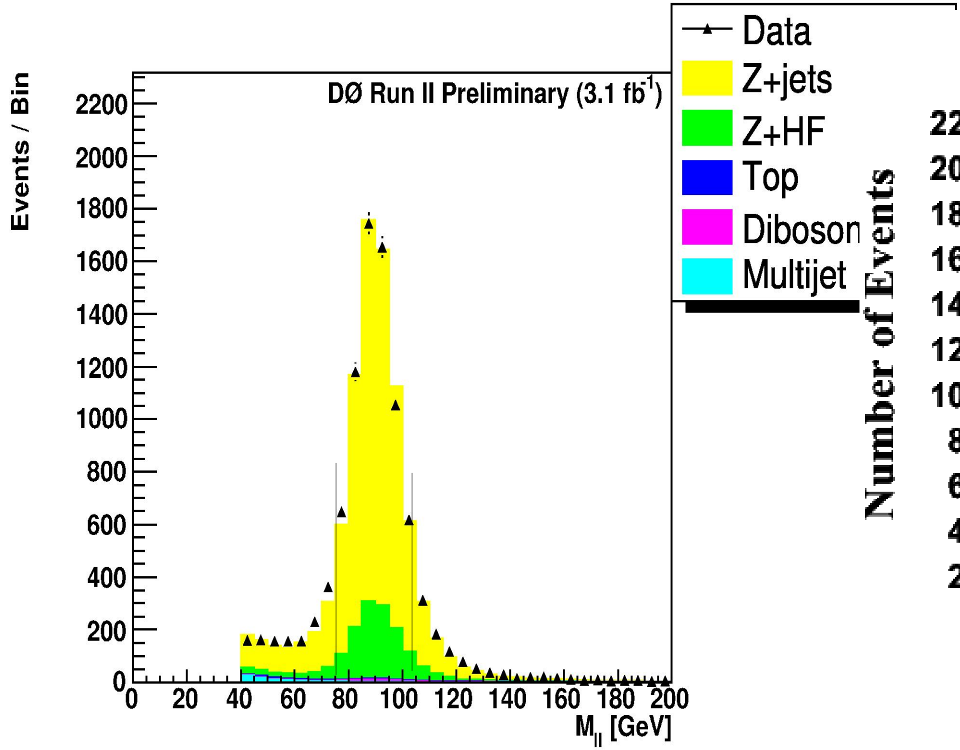
Low Mass Higgs: $ZH \rightarrow \ell^+\ell^- b\bar{b},\ \ell = e, \mu$

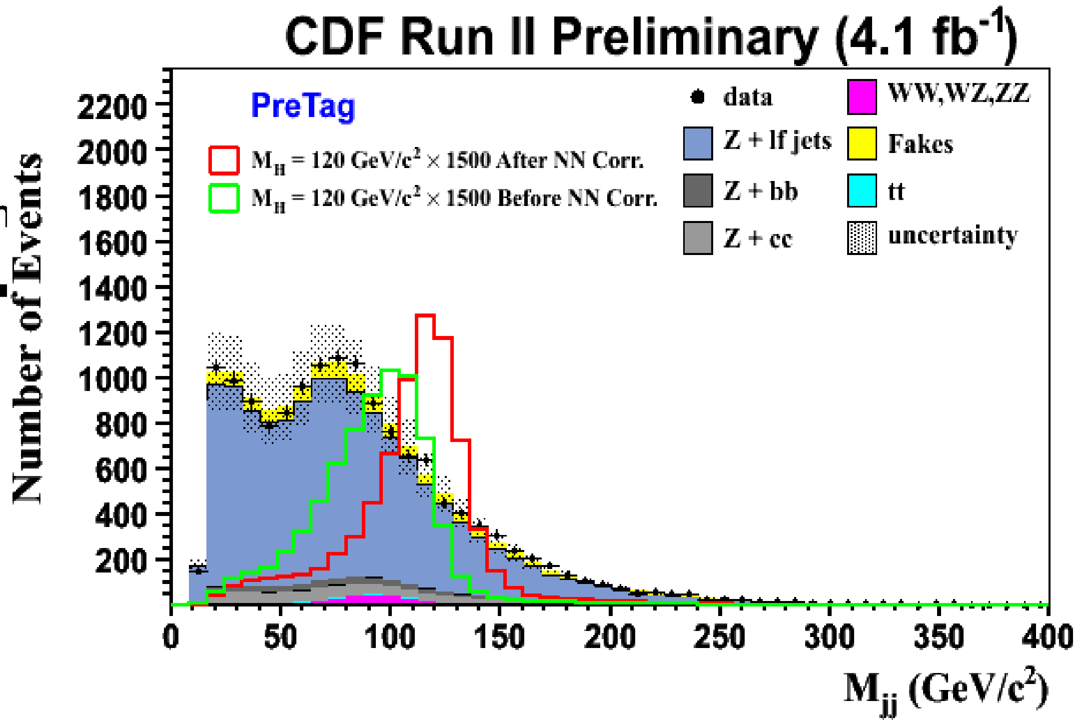
Signature: 2 high Pt leptons and 2+ b-jets

CDF: 4.1 fb^{-1} D0: 3.1 – 4.2 fb^{-1}

Major backgrounds: Z + jets/hf, top, dibosons

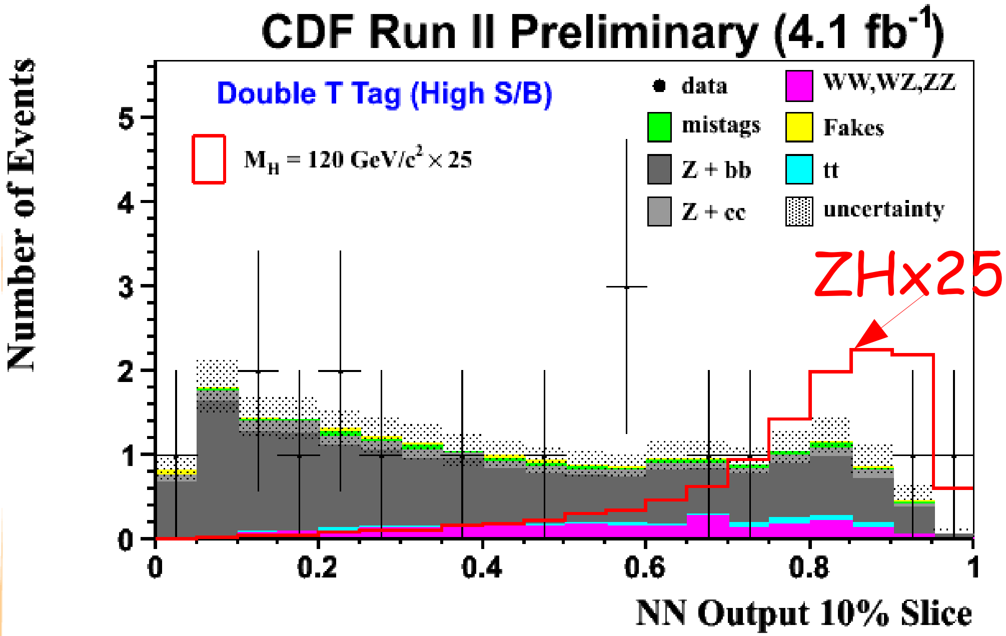
Small σxBR ~ 1 event/fb^{-1} Important to increase acceptance

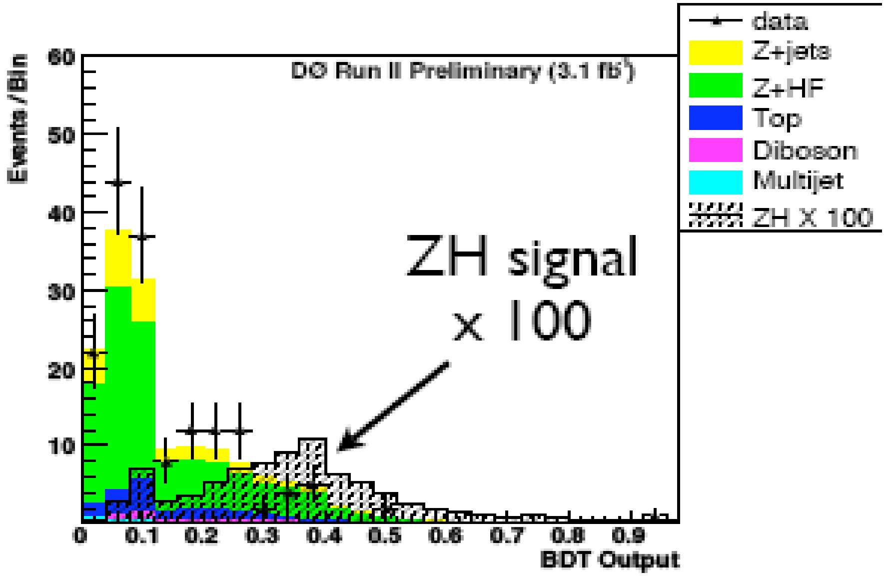




Low Mass Higgs: $ZH \to \ell^+\ell^- b\bar{b},\ \ell = e,\mu$

Use multivariate techniques to improve S/B





Analysis 115	Lumi fb^{-1}	Expected limit	Observed limit
CDF	4.1	6.8	5.91
D0 BDT	3.1	8	9.1

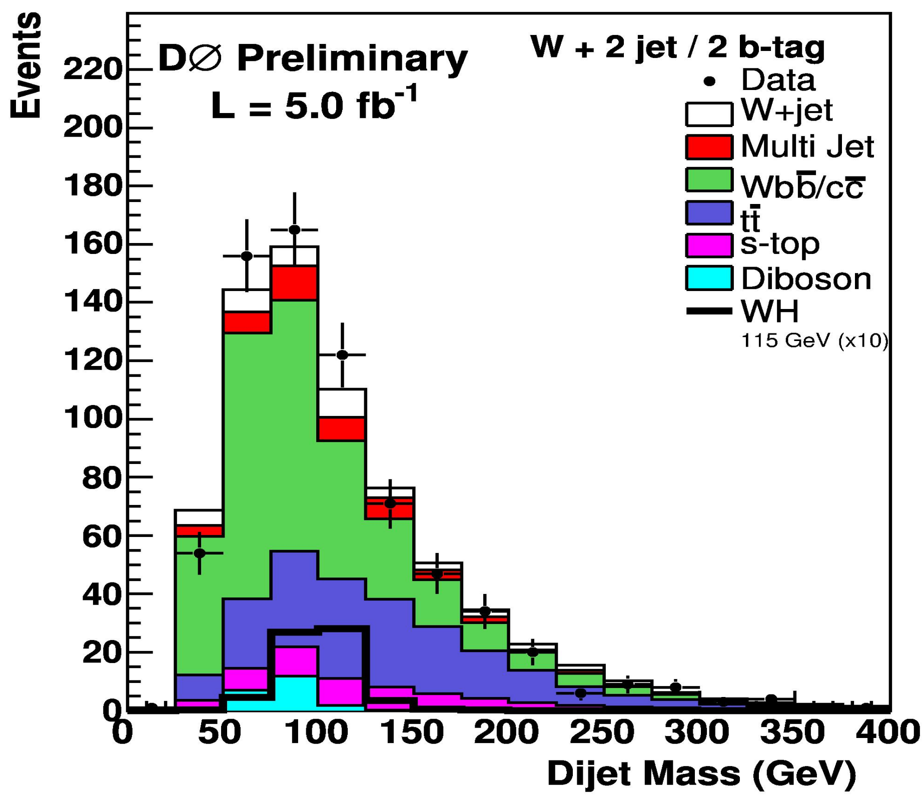
Low Mass Higgs: $WH \to \ell\nu b\bar{b},\ \ell = e,\mu$

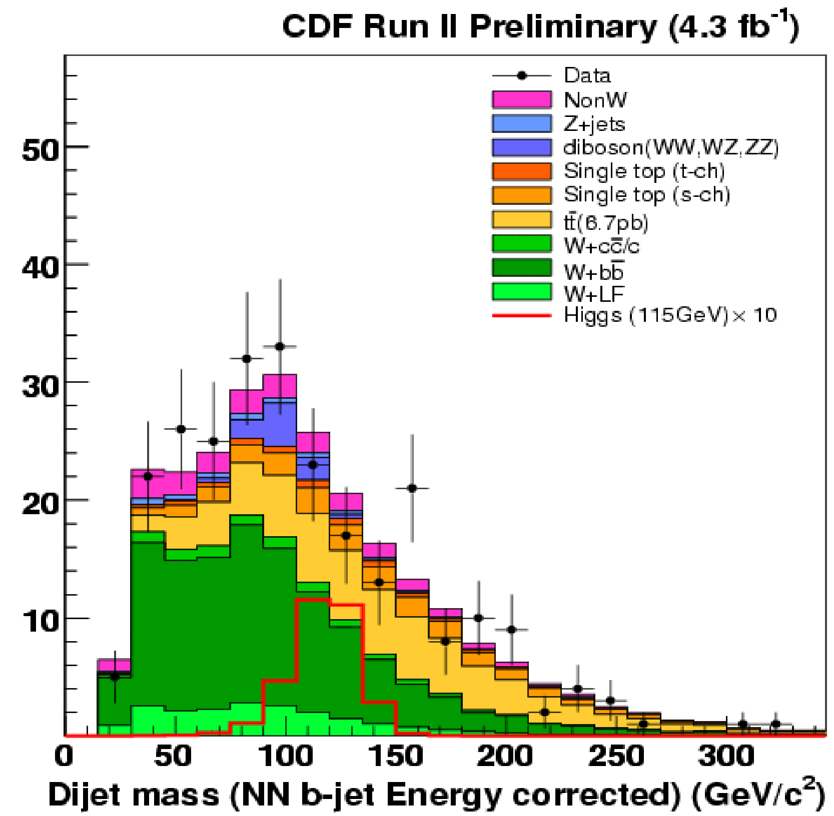
Signature: 1 high Pt lepton large MET and 2+ b-jets

CDF 4.3 fb^{-1} and D0 5.0 fb^{-1}

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

"Large" σxBR ~ 3-4 event/fb^{-1}



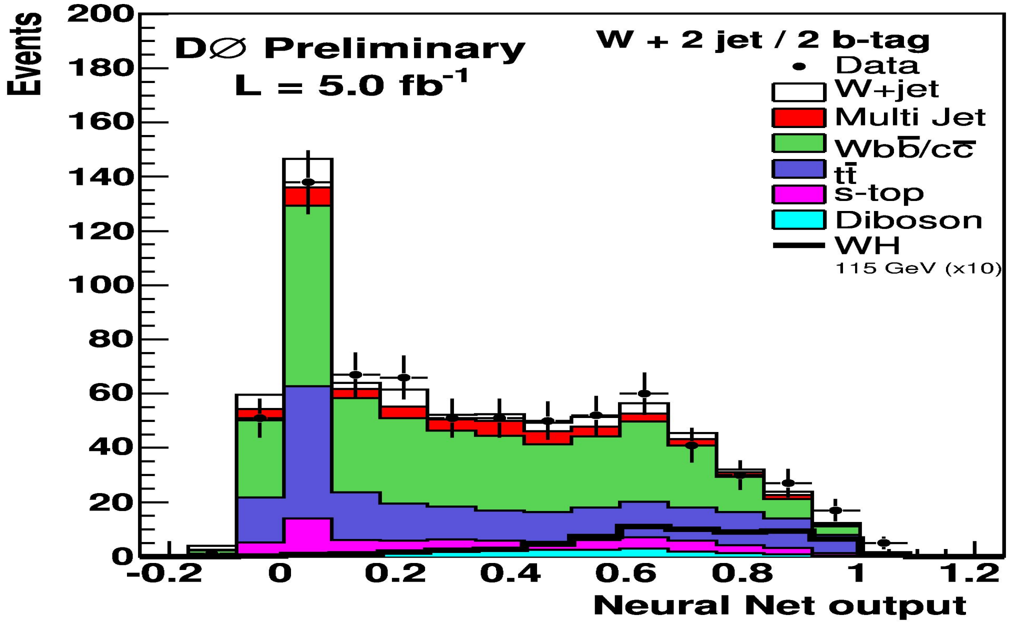


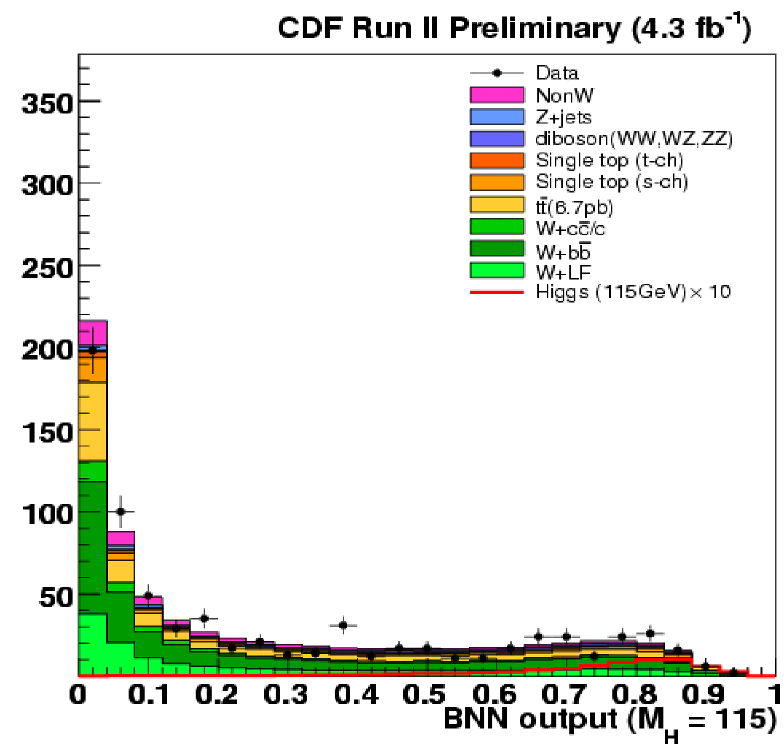
Low Mass Higgs: $WH \rightarrow \ell\nu b\bar{b},\ \ell = e, \mu$

Multivariate techniques to improve S/B:

D0: NN

CDF: Bayesian NN





Analysis M_H=115	Lumi fb^{-1}	Expected limit	Observed limit
CDF BNN	4.3	4	5.3
D0 NN	5	5.1	6.9

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

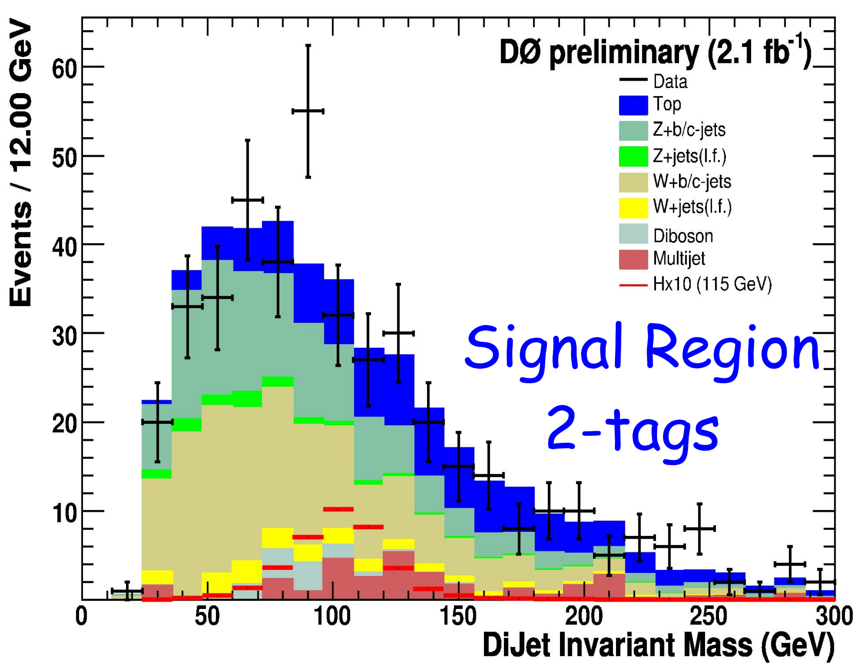
Signal acceptance ZH->vvbb and WH->~~l~~vbb (l missed)

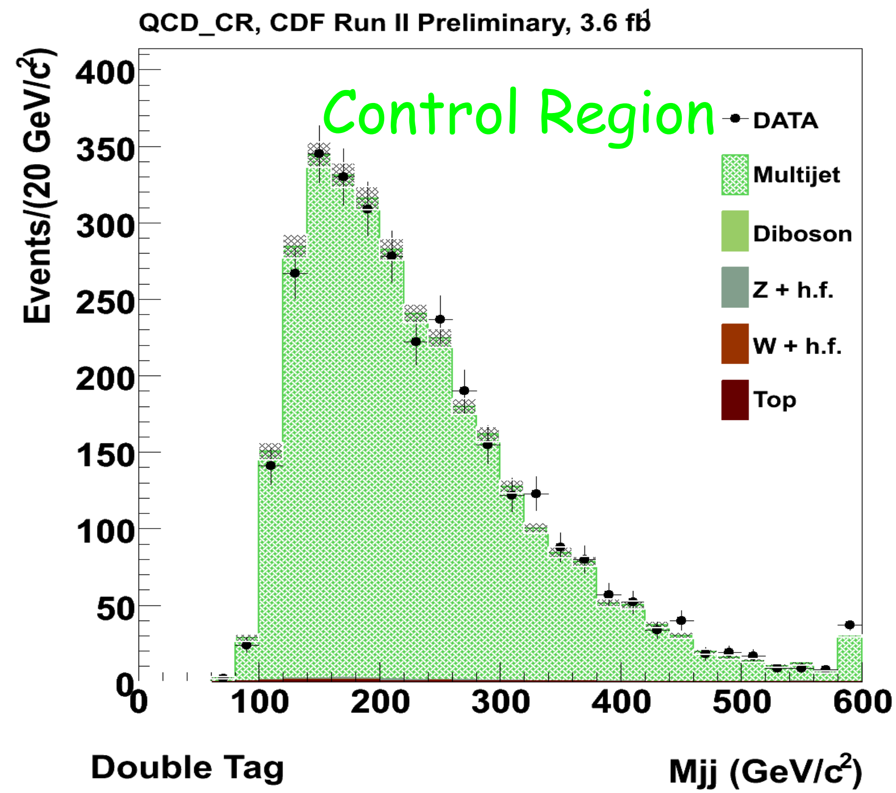
Signature: large MET and 2+ b-jets

CDF 3.6 and D0 : 2.1 fb^{-1}

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

Background modeled using data



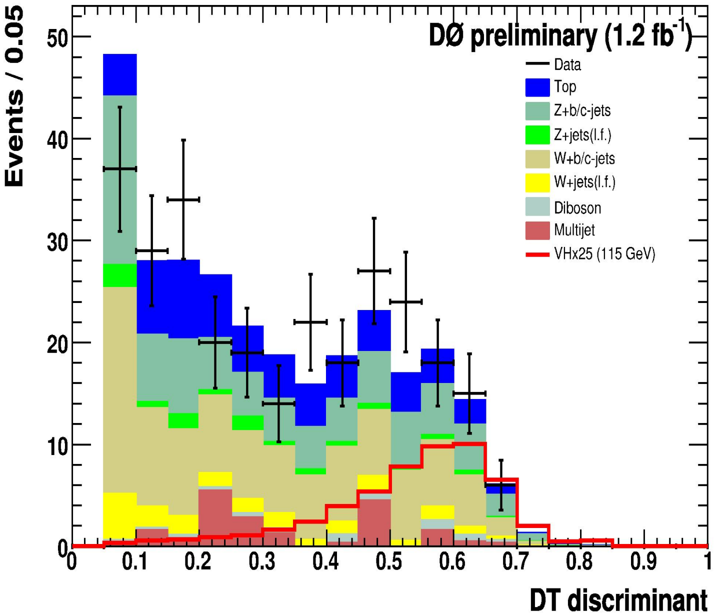


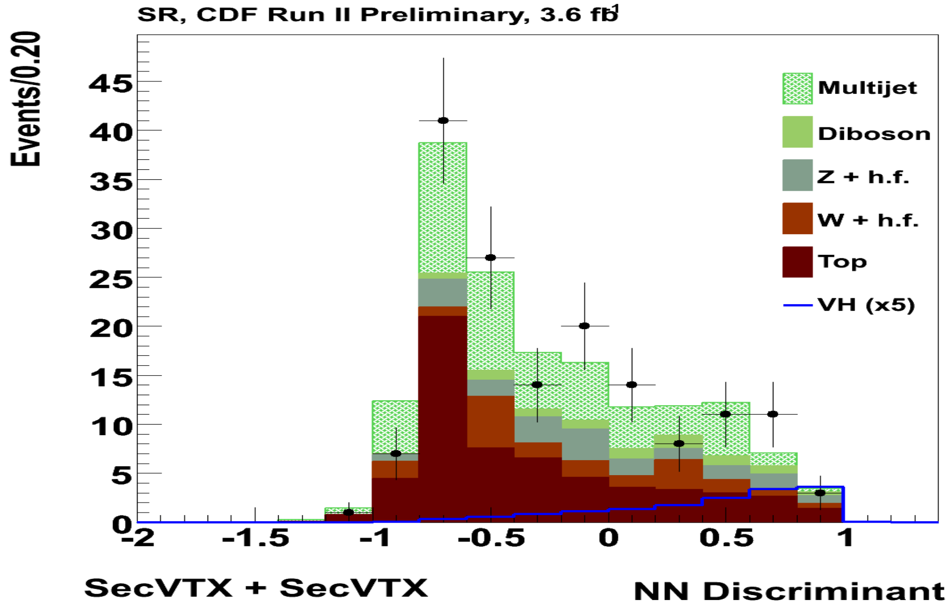
Low Mass Higgs: $VH \to \not{E}_T b\bar{b}$

Multivariate techniques to improve S/B:

D0: BDT on double tagged sample

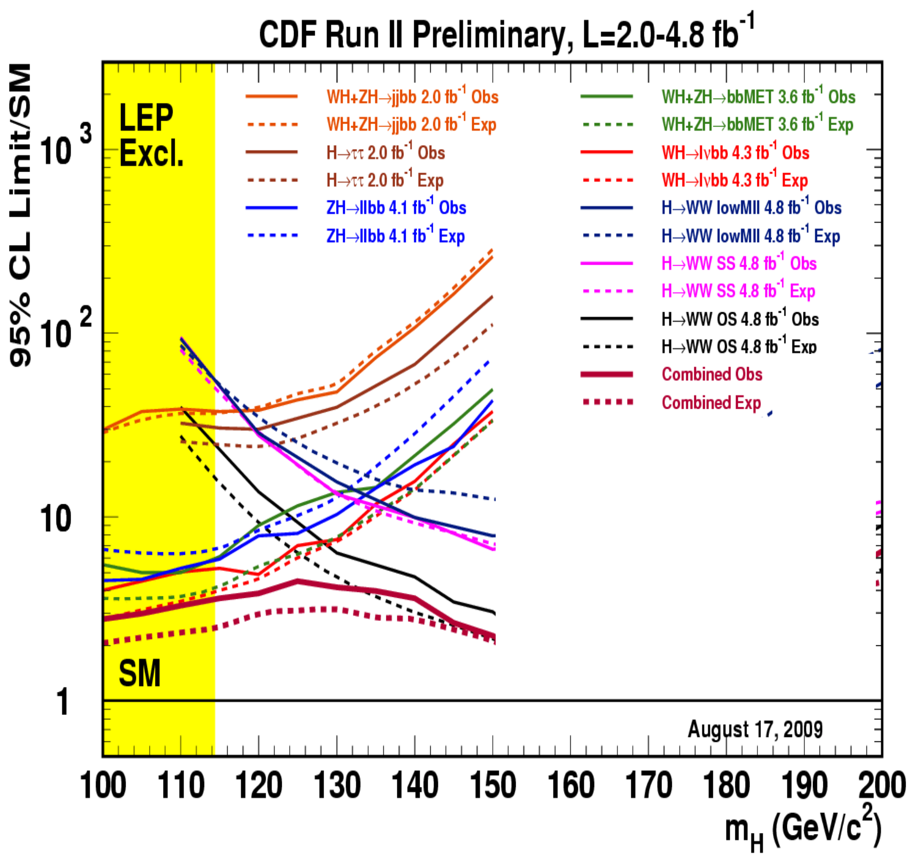
CDF: NN with separate training for 2 and 3 jets

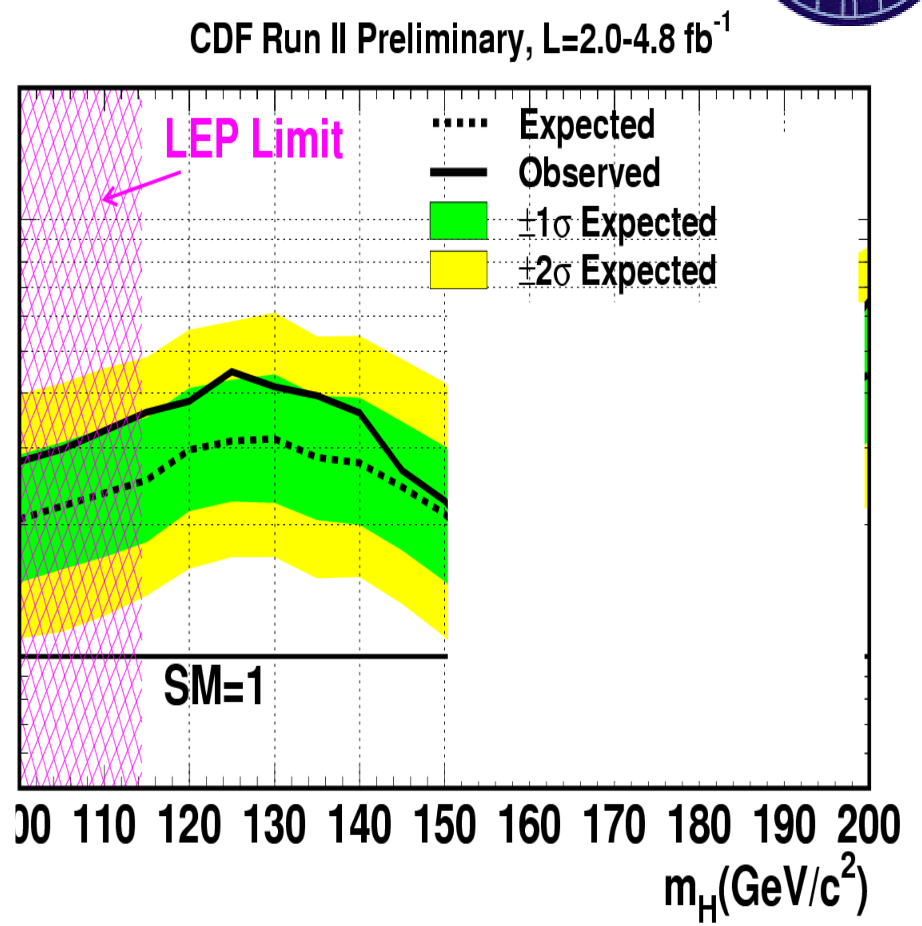




Analysis M_H=115	Lumi fb^{-1}	Expected limit	Observed limit
CDF NN	3.6	4.2	6.1
D0 BDT	2.1	8.4	7.5

Low Mass Higgs Combination

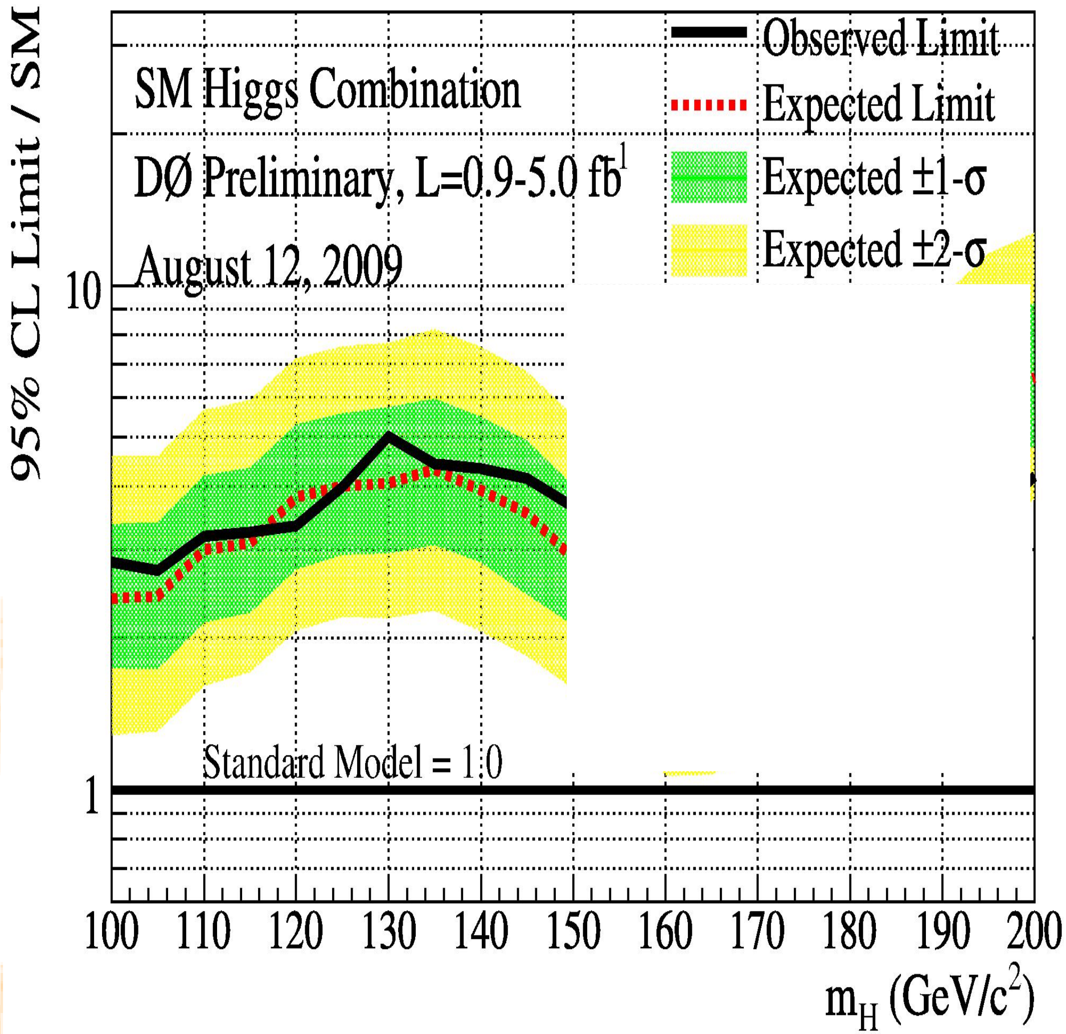




M_H=115 Expected limit 2.53

Observed limit 3.62

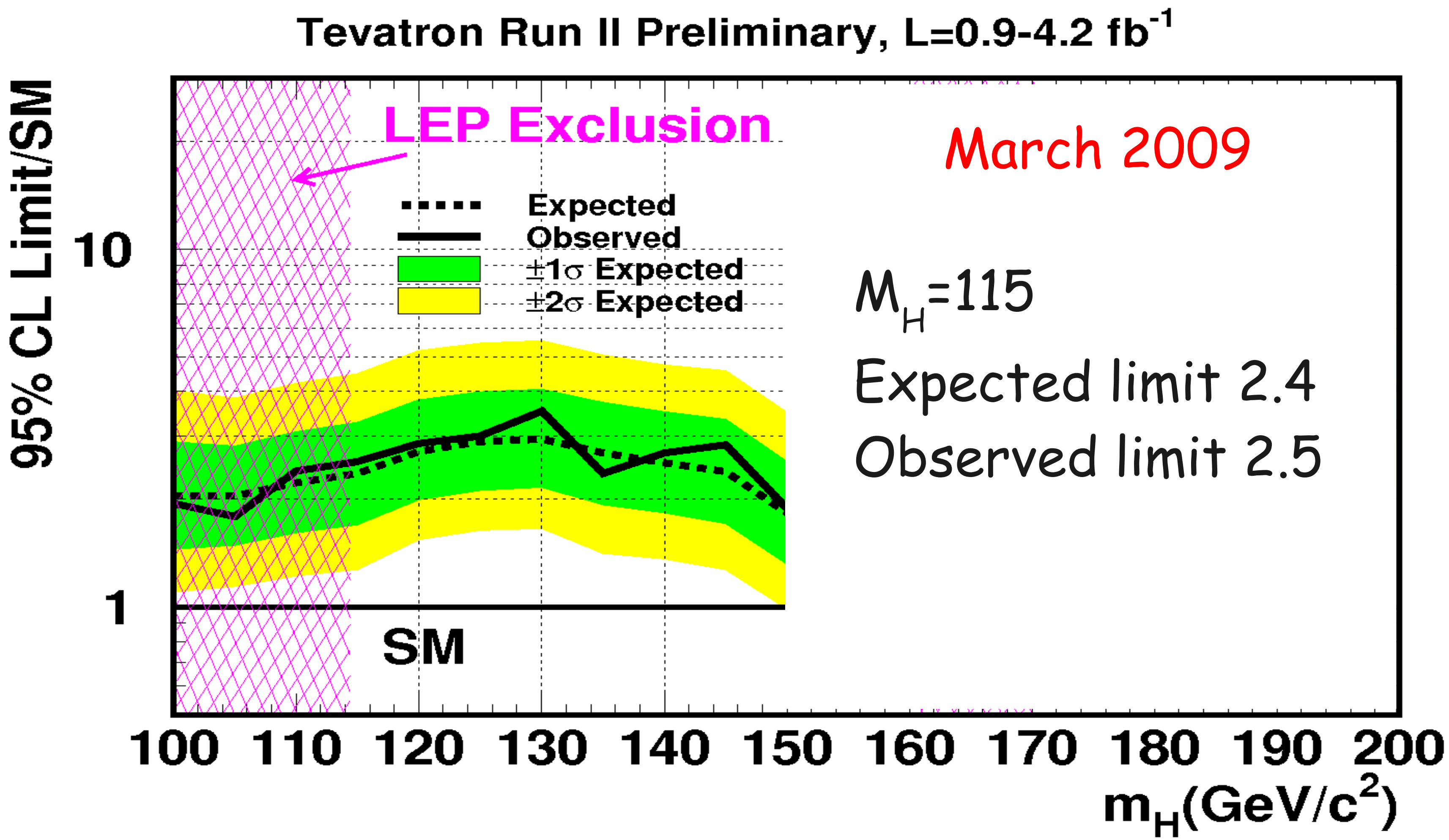
Low Mass Higgs Combination



M_H=115 Expected limit 3.1

Observed limit 3.2

Low Mass Higgs Tevatron Combination



March 2009

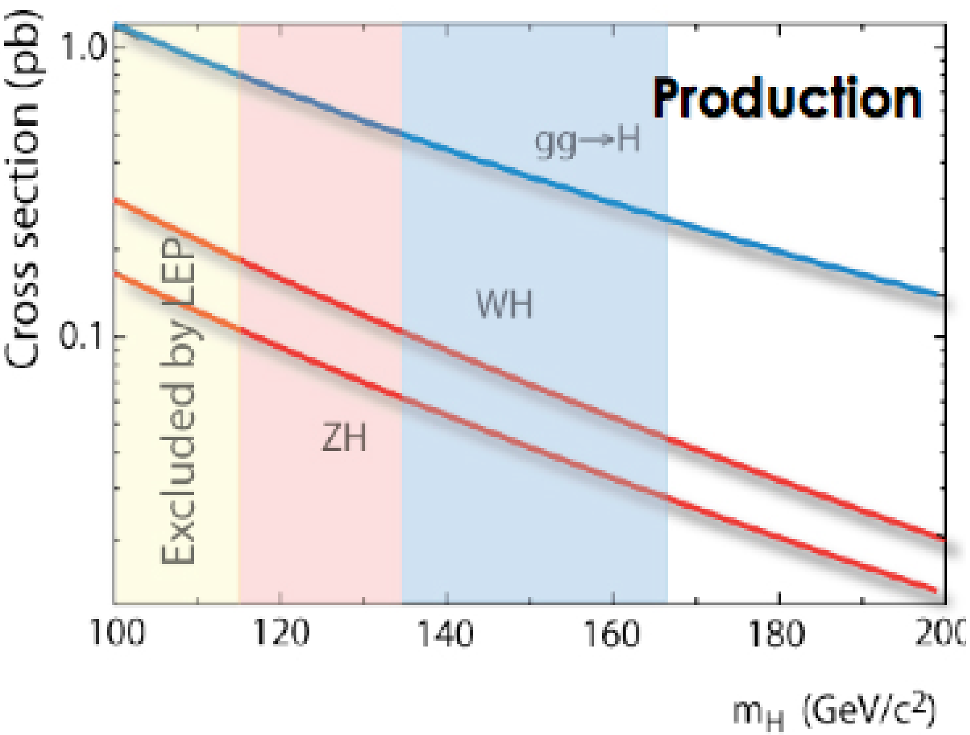
M_H=115

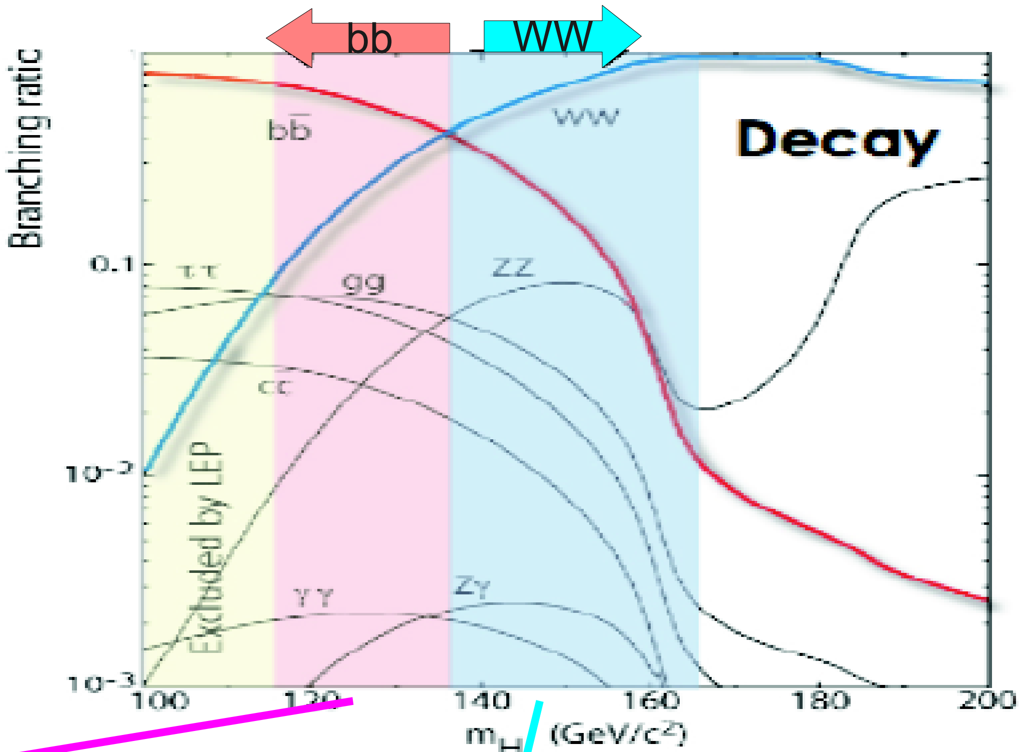
Expected limit 2.4

Observed limit 2.5

In progress a new combination.

Direct Higgs searches @Tevatron

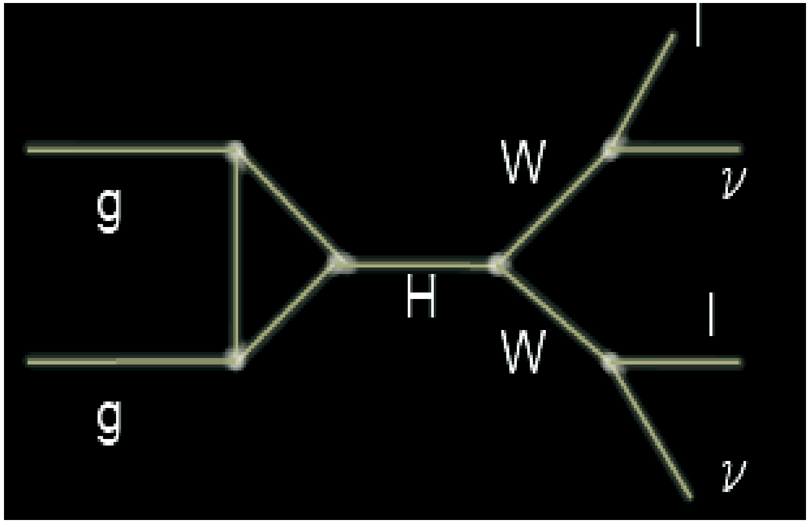




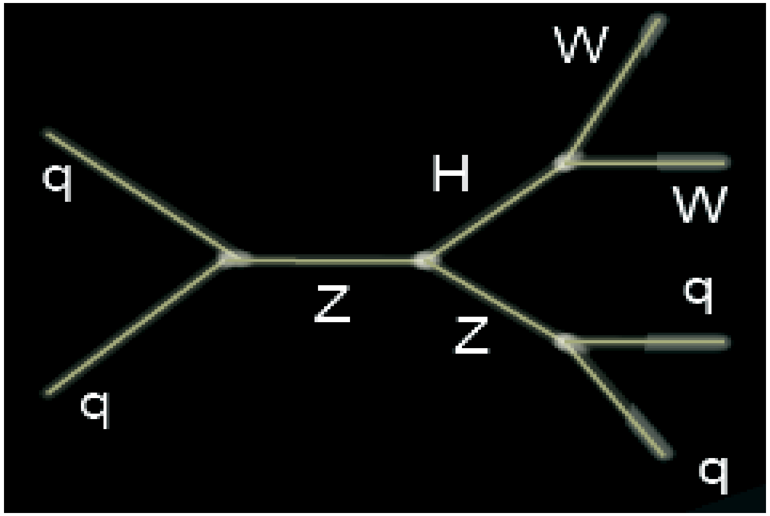
Low Mass: M_H<135 GeV/c^2 High Mass: M_H>135 GeV/c^2

High Mass Higgs: $H \rightarrow WW$

Signal:



0 jets at LO (gg->H)

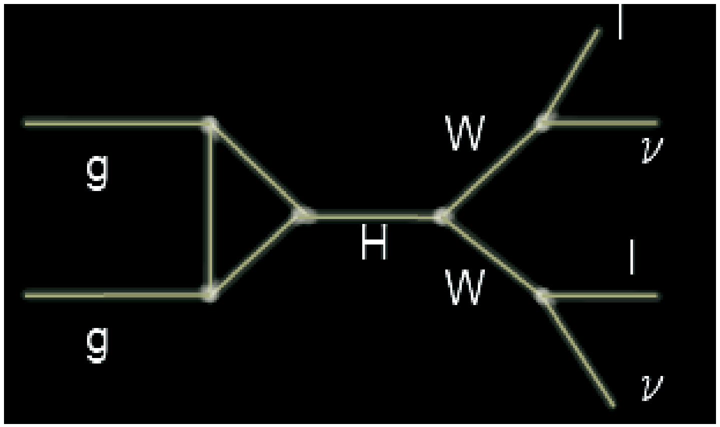


2 jets at LO (ZH/WH/VBF)

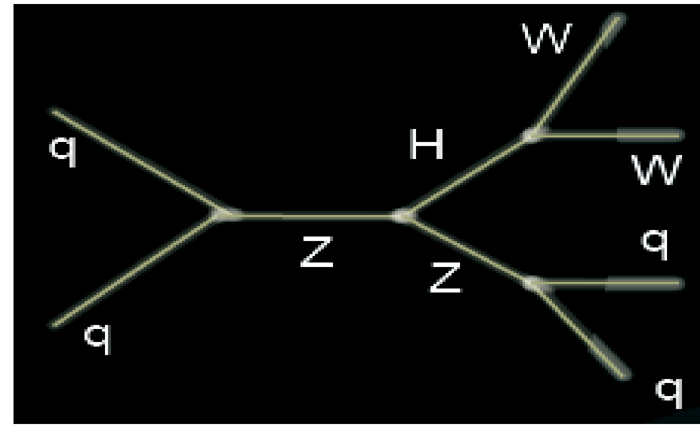
Separate in 0, 1, 2+ jets bin because of different backgrounds

High Mass Higgs: $H \to WW$

Signal:

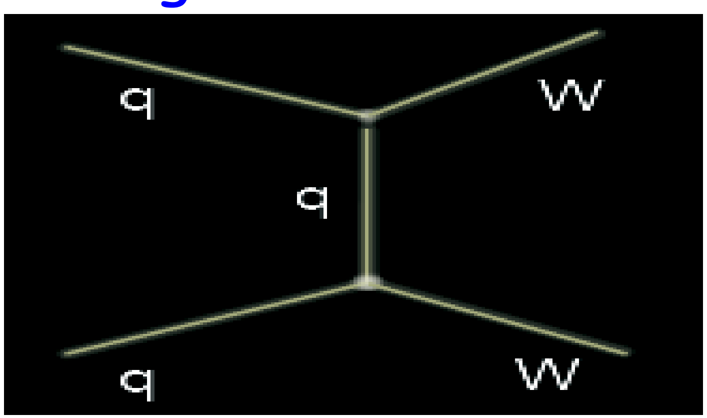


0 jets at LO (gg->H)

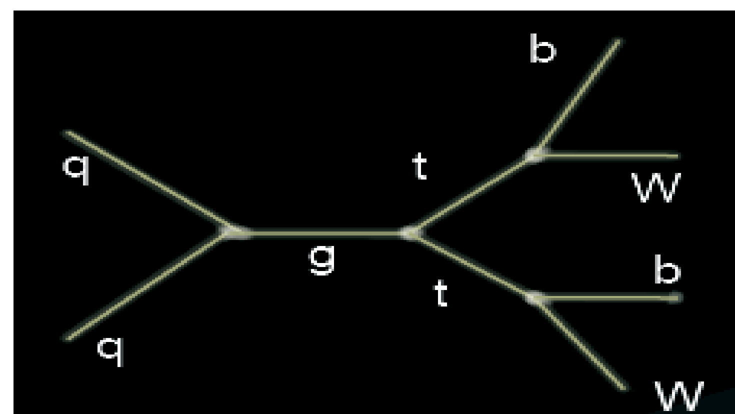


2 jets at LO (ZH/WH/VBF)

Background:



LO: WW, Drell Yan, W+γ



LO: WZ, ZZ, $t\bar{t}$

High Mass Higgs: $H \to WW$

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 $\int \mathcal{L} = 4.8\ \mathrm{fb}^{-1}$

$M_H = 165\ \mathrm{GeV}/c^2$

$t\bar{t}$	1.99	$\pm$	0.31
DY	128	$\pm$	30
WW	447	$\pm$	48
WZ	19.7	$\pm$	2.7
ZZ	29.9	$\pm$	4.1
W+jets	154	$\pm$	37
$W\gamma$	112	$\pm$	19
Total Background	893	$\pm$	79
$gg \to H$	12.6	$\pm$	1.7
WH	0.00	$\pm$	0.00
ZH	0.00	$\pm$	0.00
VBF	0.00	$\pm$	0.00
Total Signal	12.6	$\pm$	1.7
Data	950		

OS 0 Jets

CDF Run II Preliminary $\int \mathcal{L} = 4.8\ \mathrm{fb}^{-1}$

$M_H = 165\ \mathrm{GeV}/c^2$

$t\bar{t}$	145	$\pm$	24
DY	51	$\pm$	17
WW	25.6	$\pm$	5.8
WZ	5.30	$\pm$	0.73
ZZ	2.36	$\pm$	0.32
W+jets	21.9	$\pm$	5.9
$W\gamma$	2.72	$\pm$	0.67
Total Background	254	$\pm$	33
$gg \to H$	2.5	$\pm$	1.7
WH	1.90	$\pm$	0.25
ZH	0.99	$\pm$	0.13
VBF	1.04	$\pm$	0.17
Total Signal	6.4	$\pm$	1.8
Data	224		

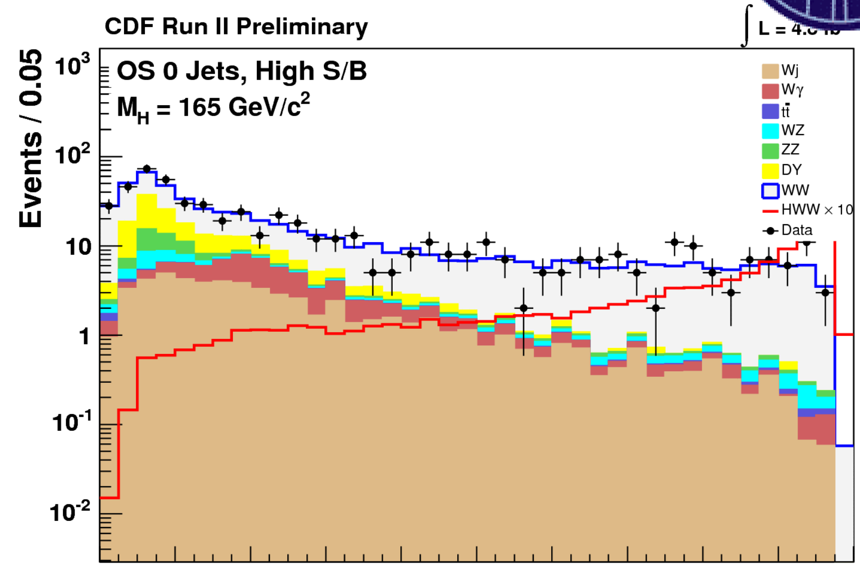
OS 2+ Jets

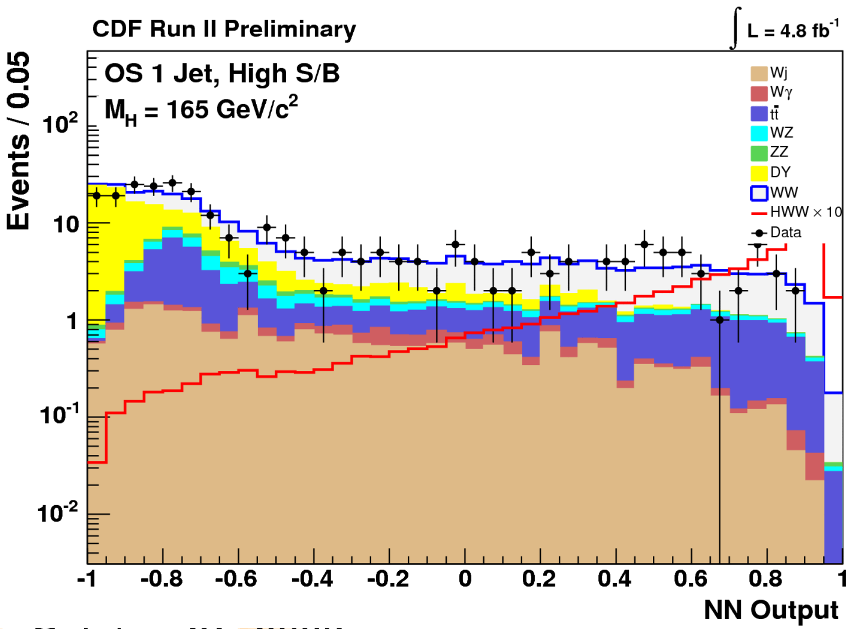
High Mass Higgs: $H \rightarrow WW$

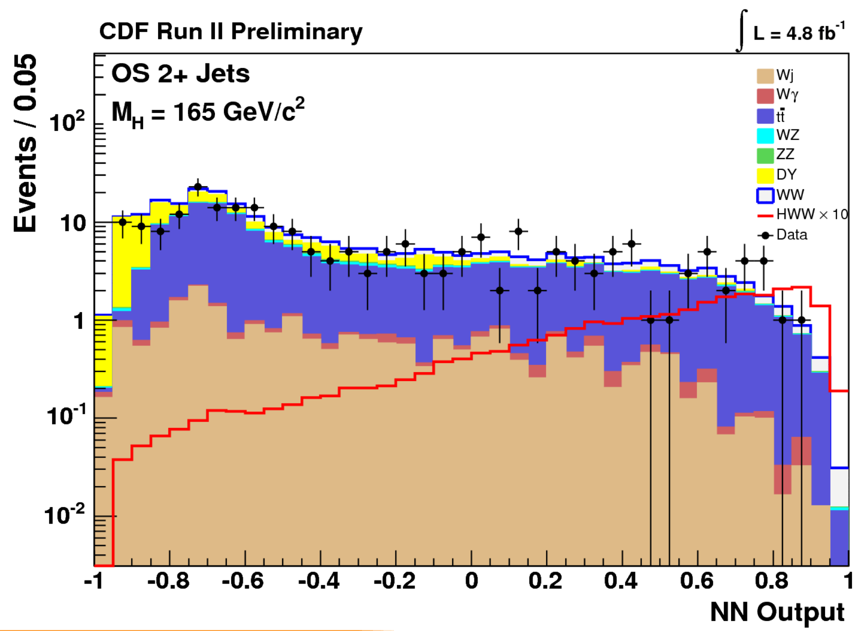
Apply selection cuts:

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

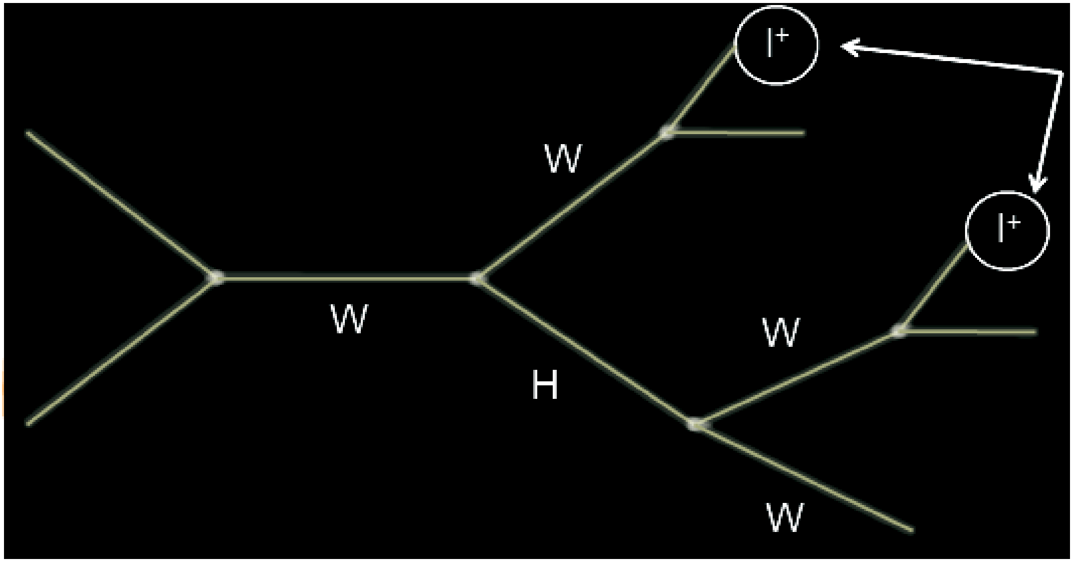
Then use combinations of ME and NN depending on jet bin







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

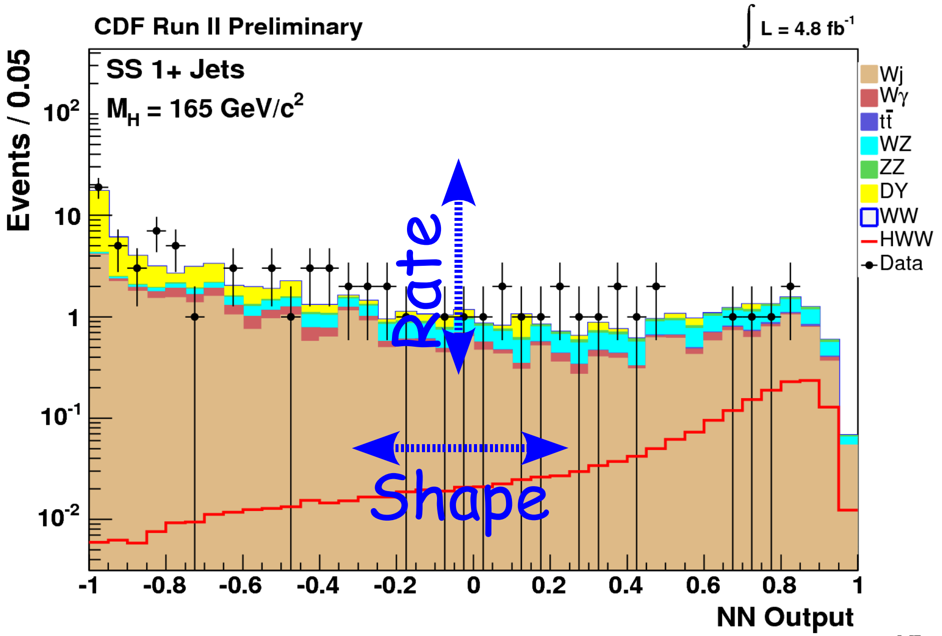
CDF Run II Preliminary	$\int \mathcal{L} = 4.8\ \mathrm{fb}^{-1}$		
$M_H = 165\ \mathrm{GeV}/c^2$			
$t\bar{t}$	0.242	±	0.068
DY	26.7	±	8.1
WW	0.039	±	0.010
WZ	9.5	±	1.3
ZZ	1.98	±	0.27
W+jets	34	±	10
$W\gamma$	4.34	±	0.99
Total Background	76	±	13
WH	1.61	±	0.21
ZH	0.261	±	0.034
Total Signal	1.87	±	0.24
Data		81	

SS 1+ Jets

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

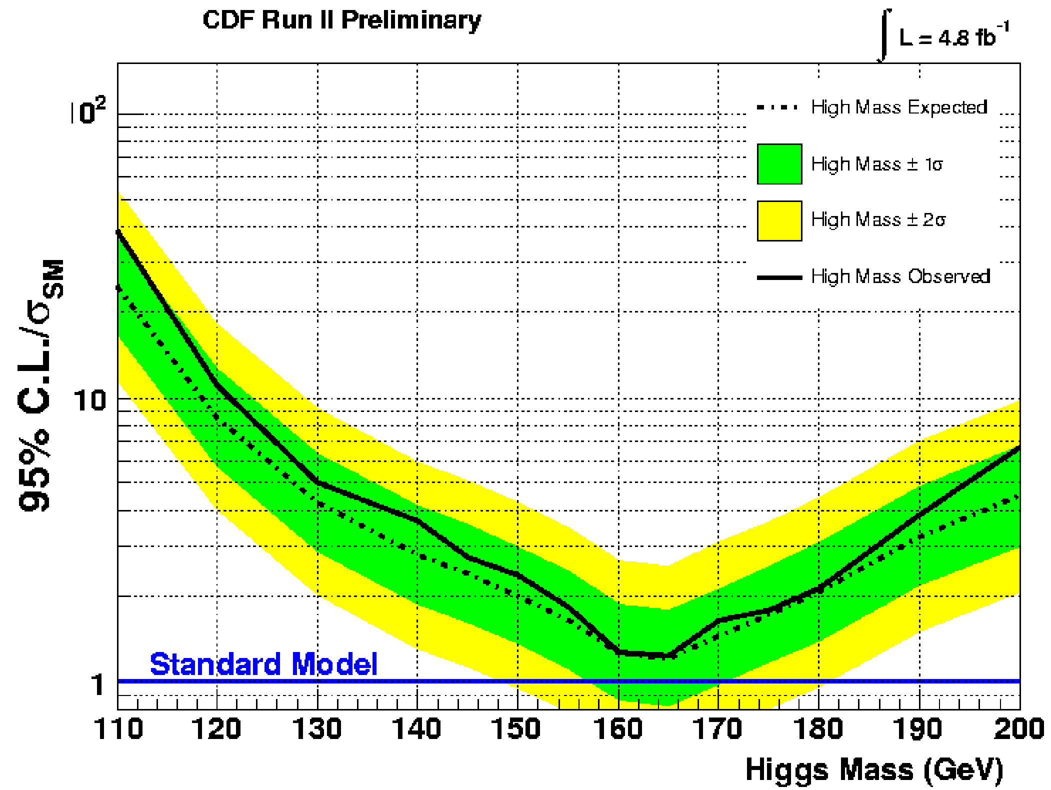
Latest gg->H cross section (Florian and Grazzini)

- ✔ 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	2.06	2.63
1 jet	2.65	1.82
2+ jets	3.49	5.07
SS +jet	6.2	5.72
Combined	1.26	1.27



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

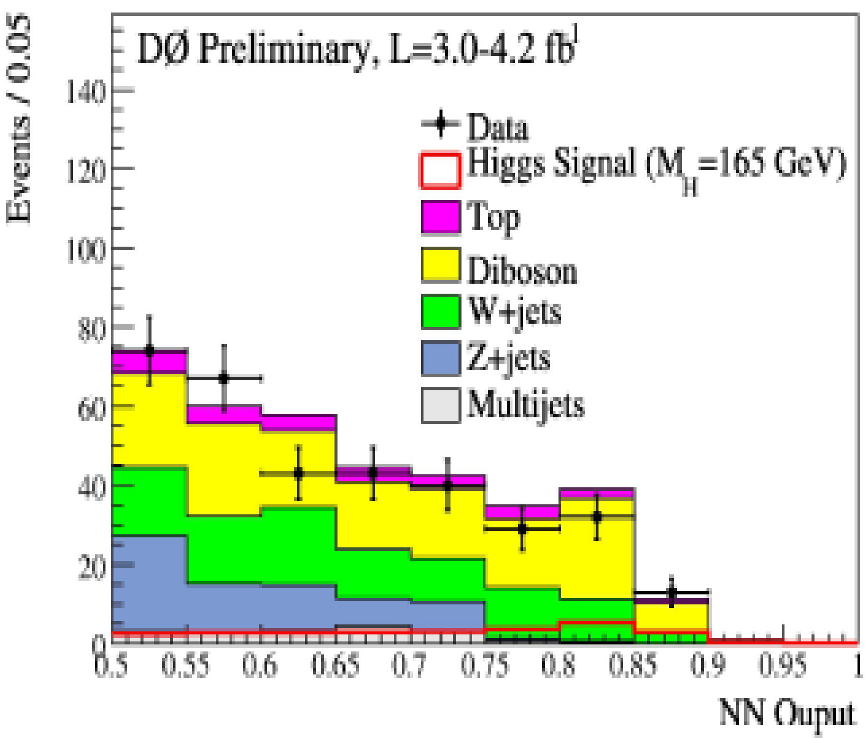
Analysis separated by lepton type: ee, μμ, eμ

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

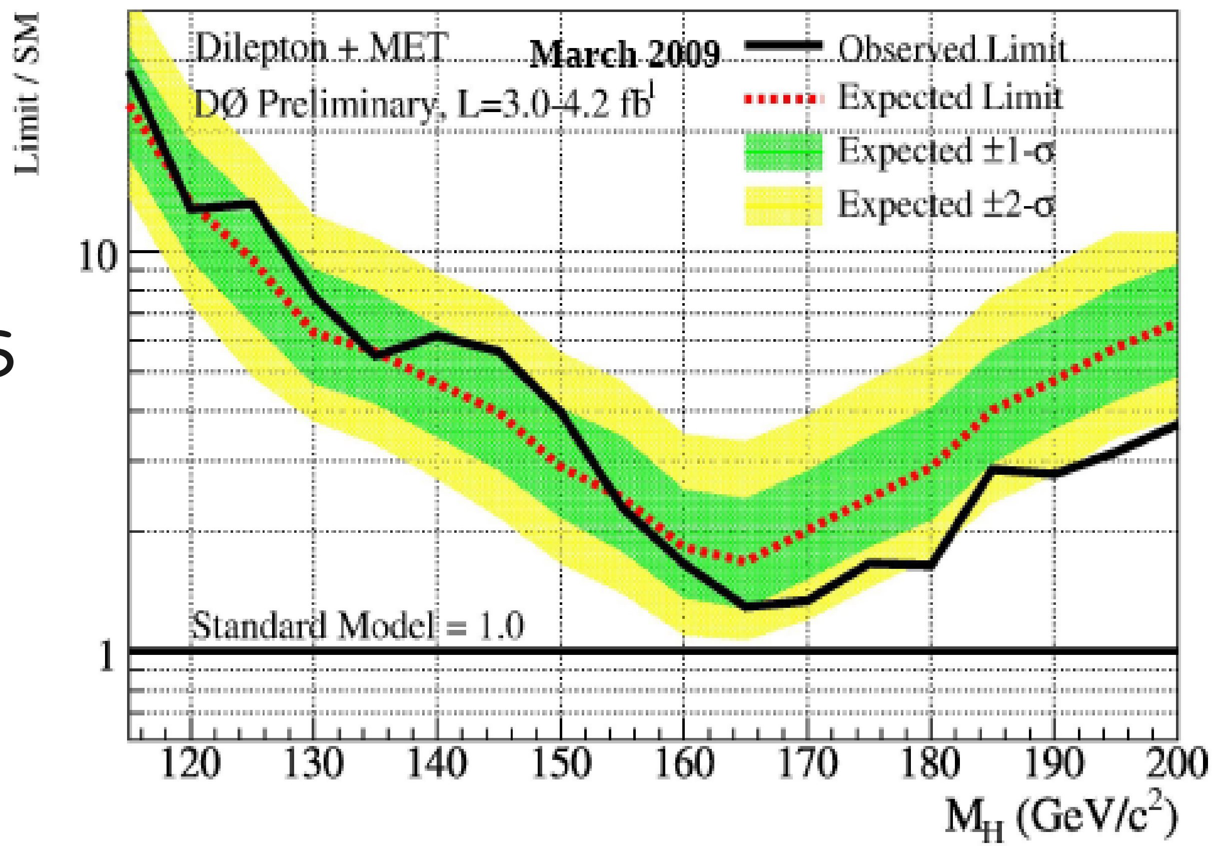
Use the same systematic of CDF, same inputs

M_H=165

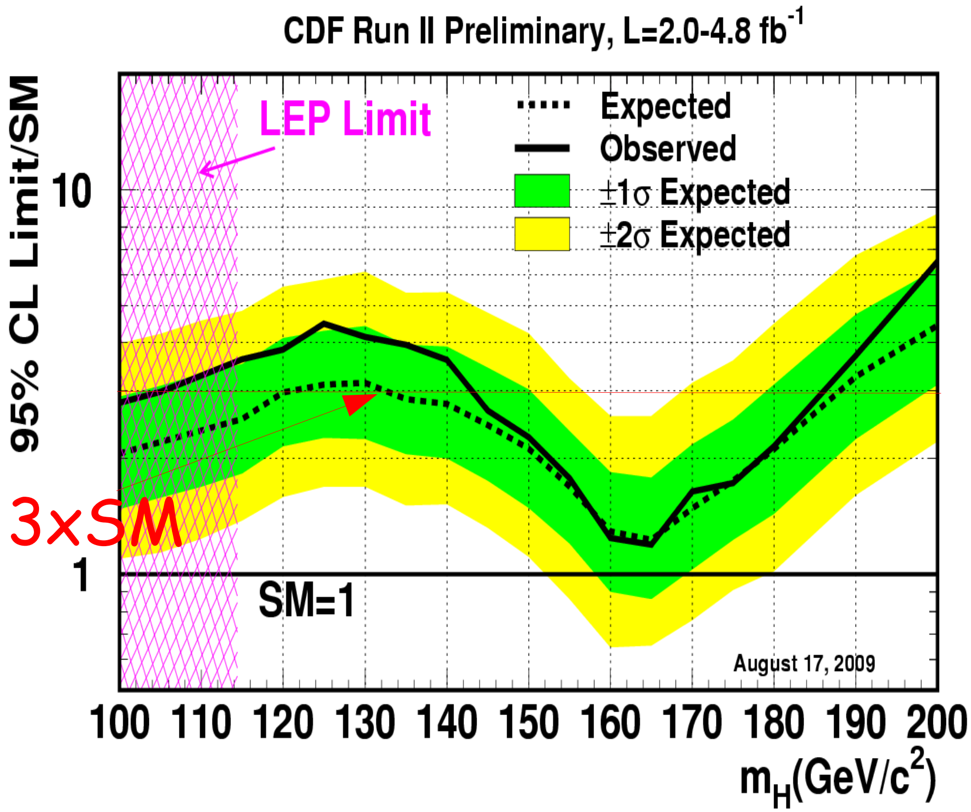
expected limit 1.7

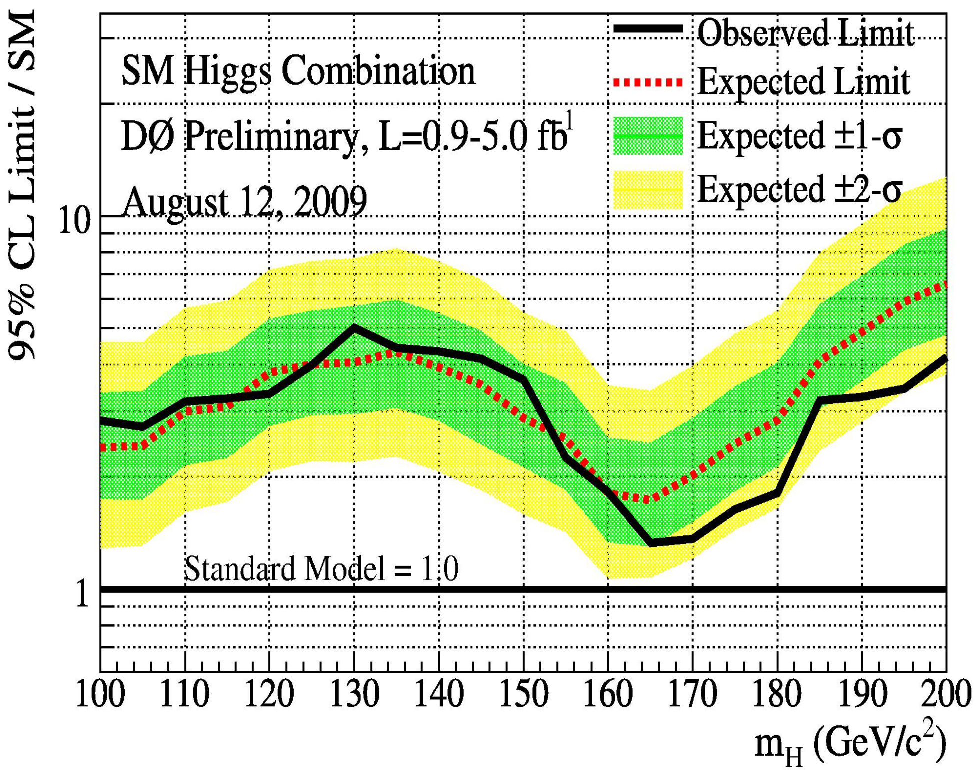
observed limit 1.3

It does not include SS



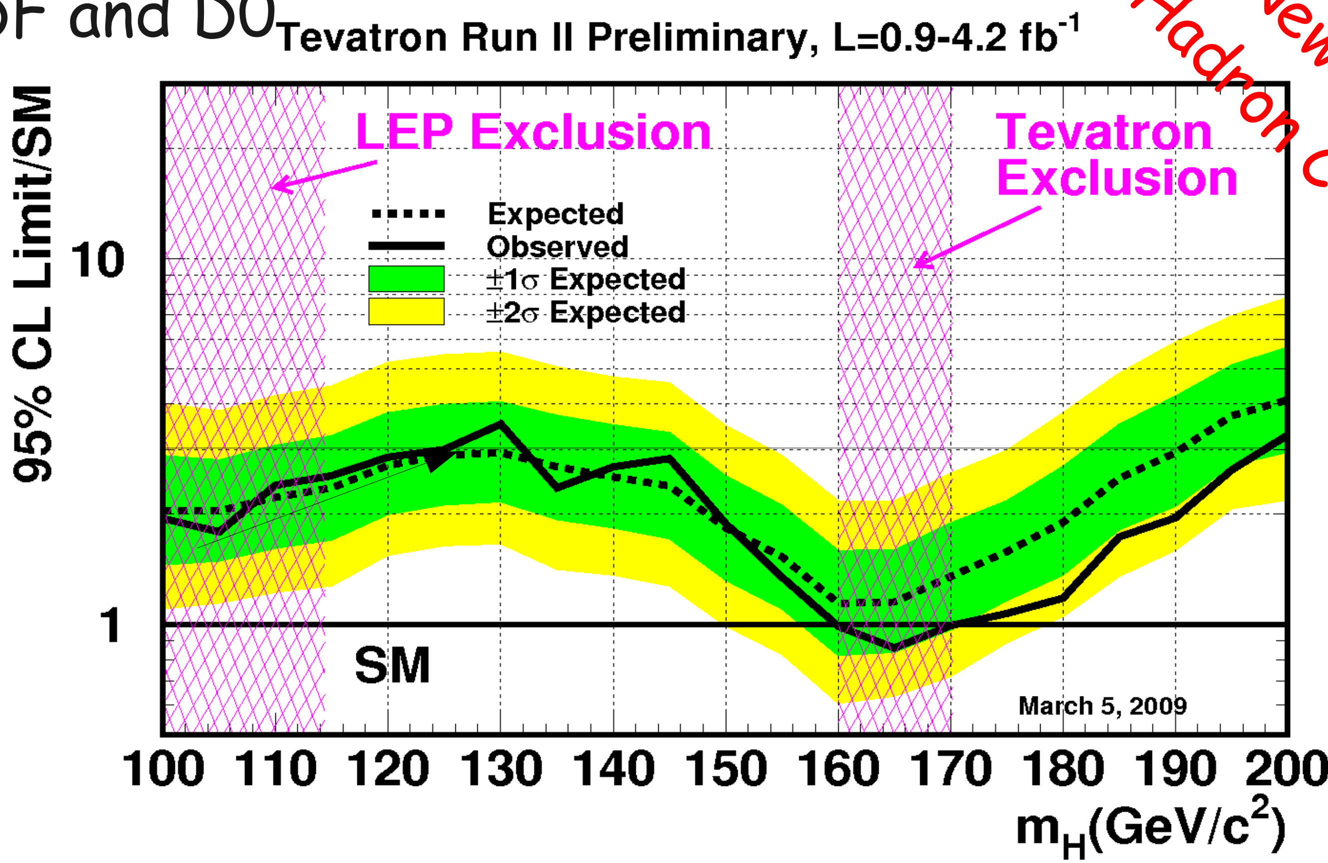
CDF and D0 Combinations





Tevatron Combination

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

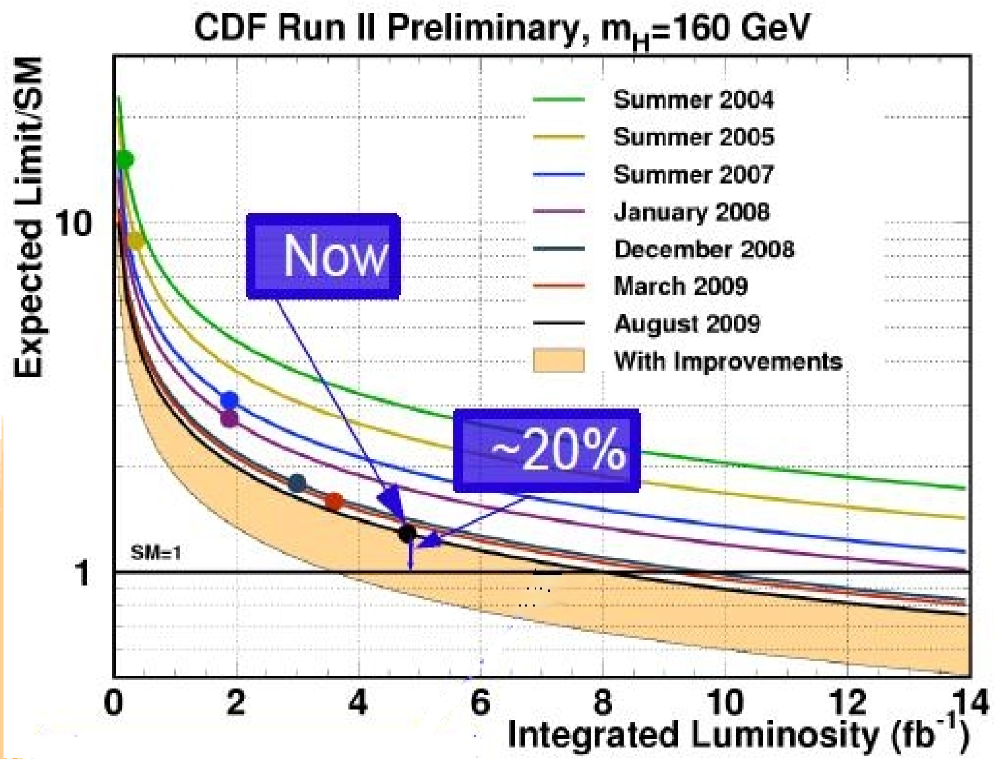


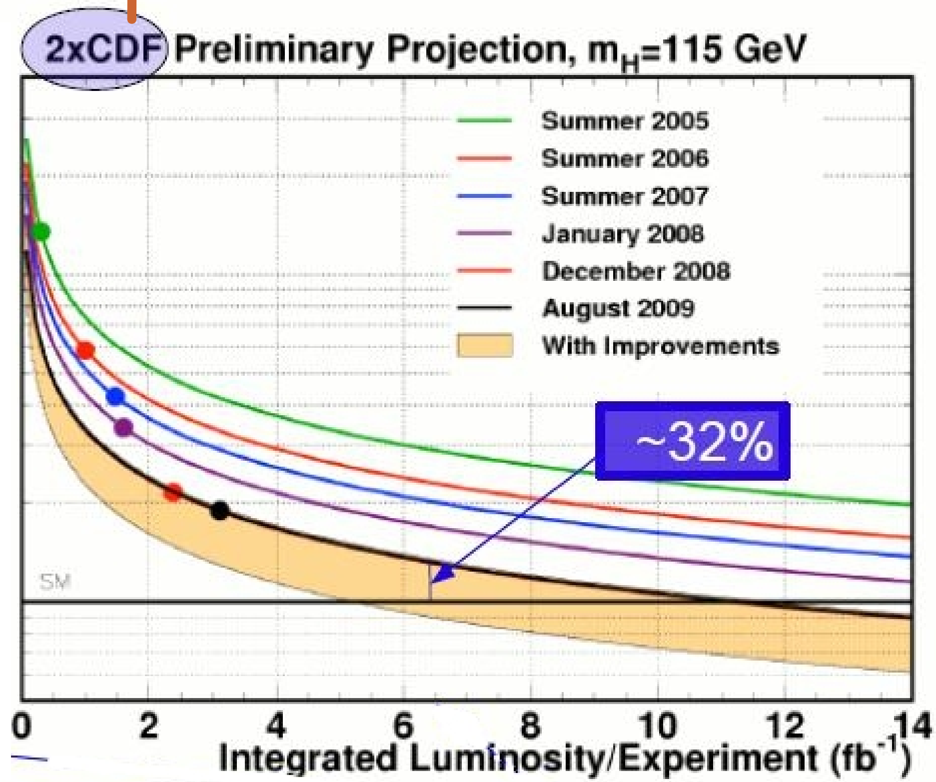
New Combination expected for Hadron Collider Physics Symposium

Old!

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

Future Prospects





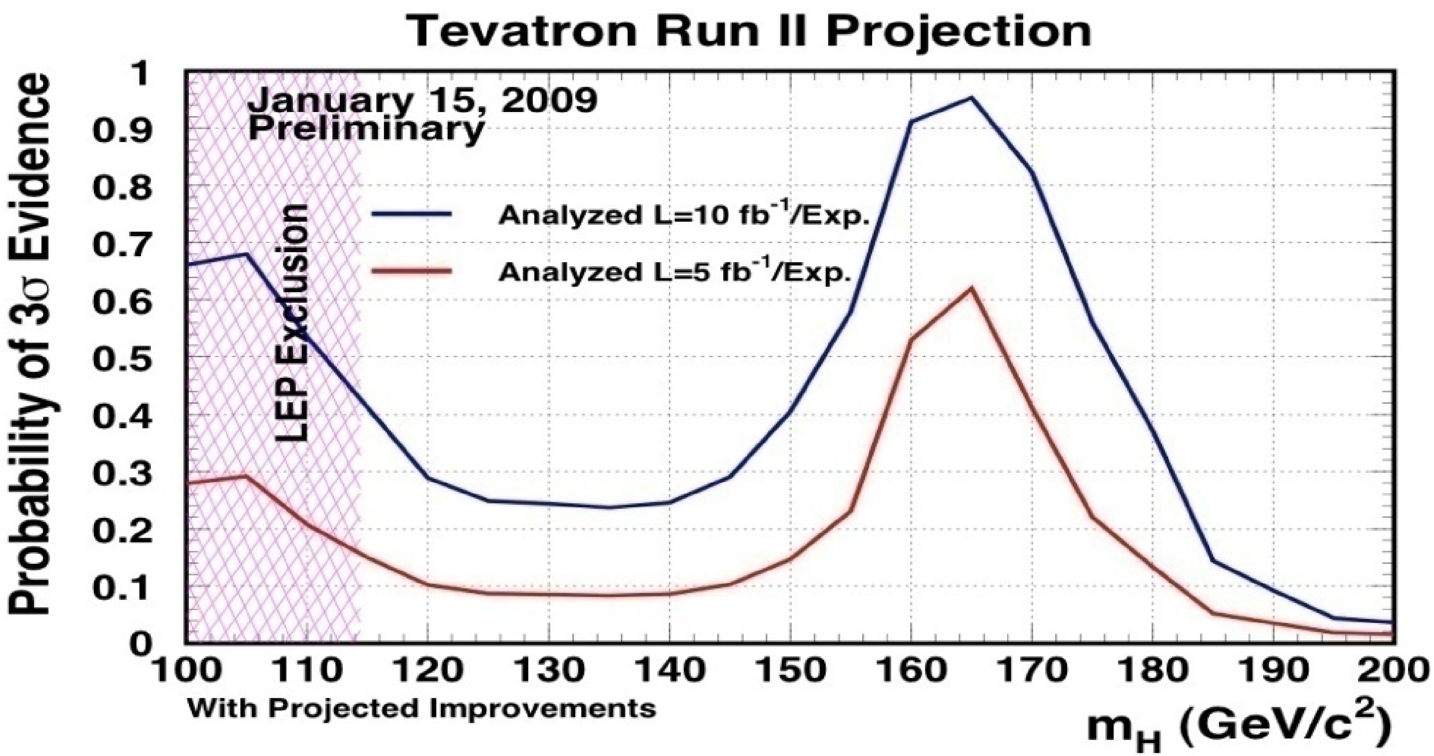
Additional improvements:
- lower Met cut for WW can open door to H->ZZ
- include W->tau
- include 3 lepton events

More challenging:
- need to improve around 30% on most important analysis
- add new triggers

Efficiency respect to double tag events

Conclusions

- CDF and D0 are making a lot of progress in Higgs searches
- More data are coming, the results are improving more that $1/\sqrt{N}$



http://www-cdf.fnal.gov/physics/new/hdg/hdg.html

http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

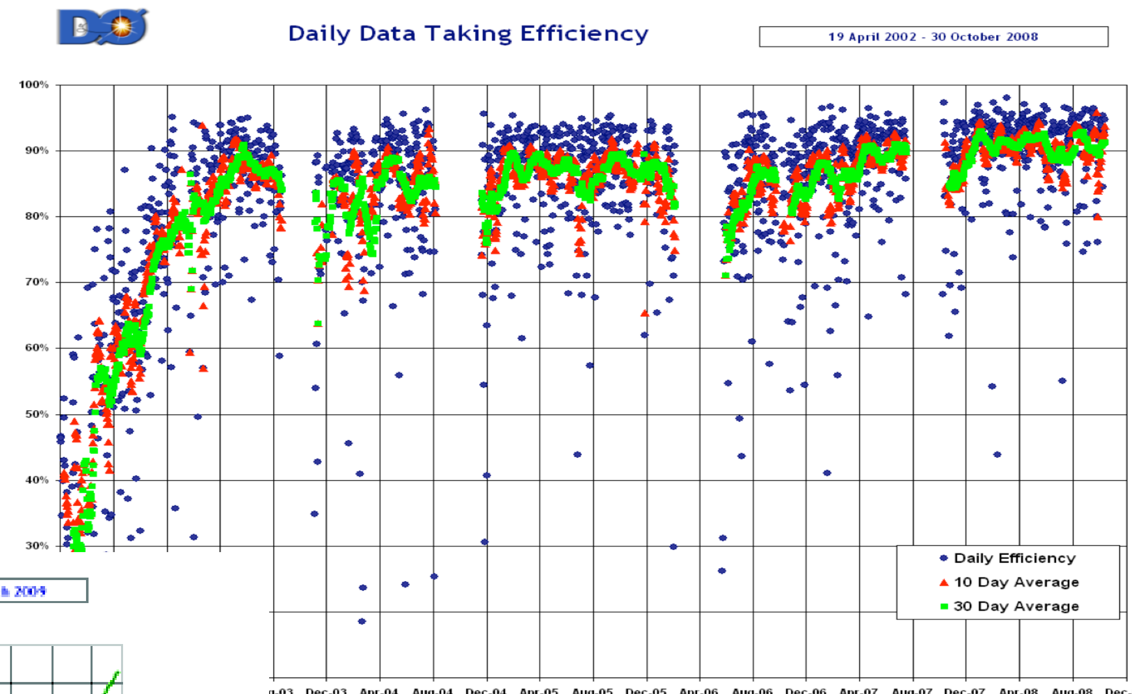
BACKUP

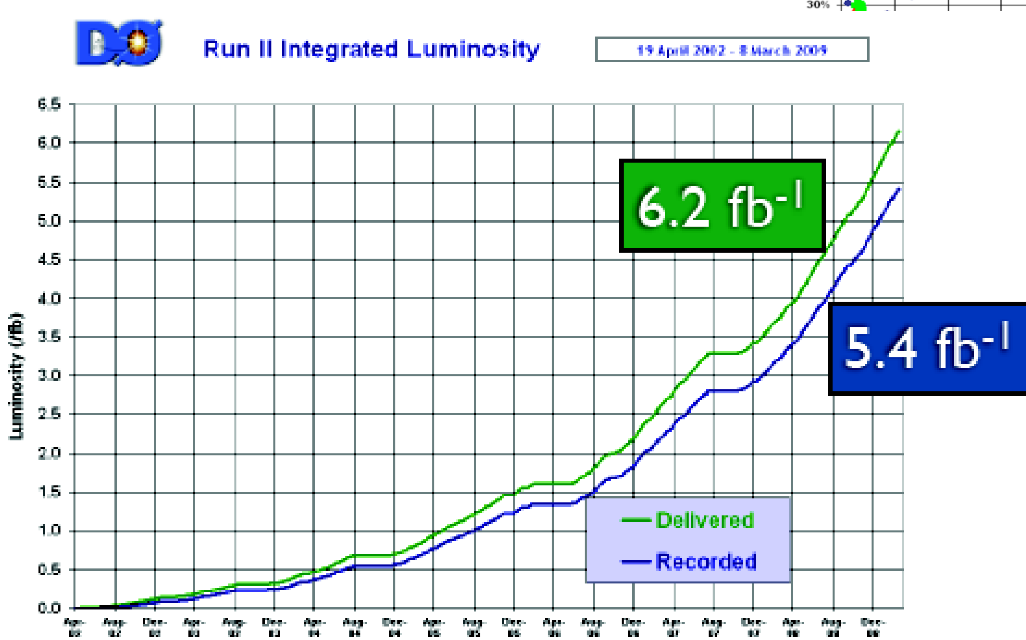
Detectors Status: DZero

Stable operations

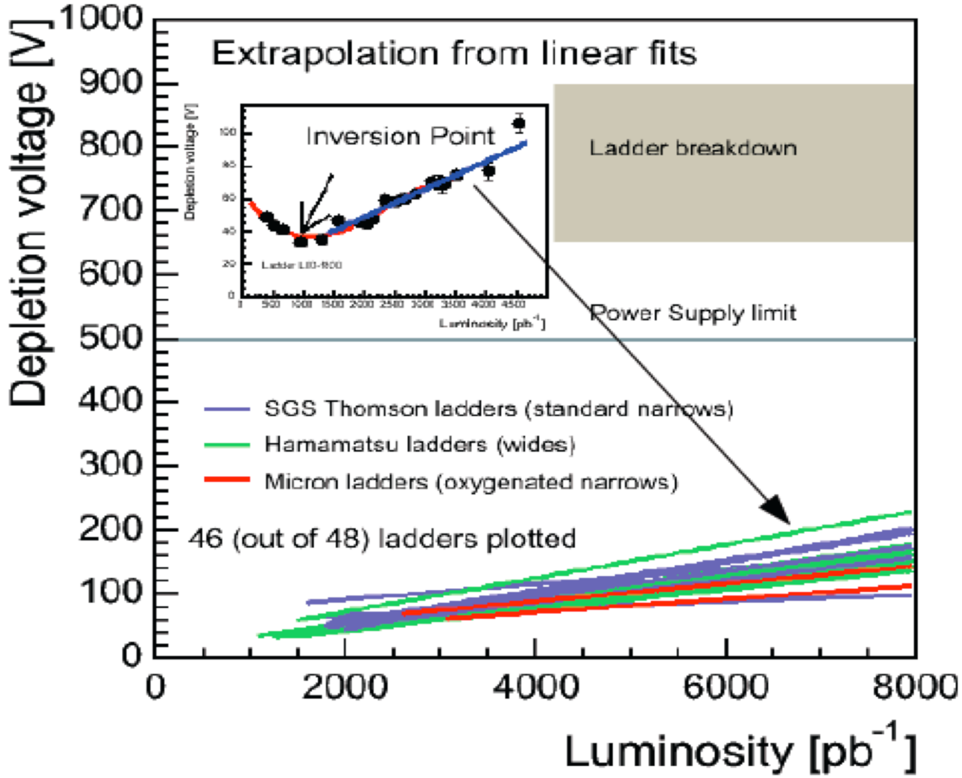
~90% efficiency

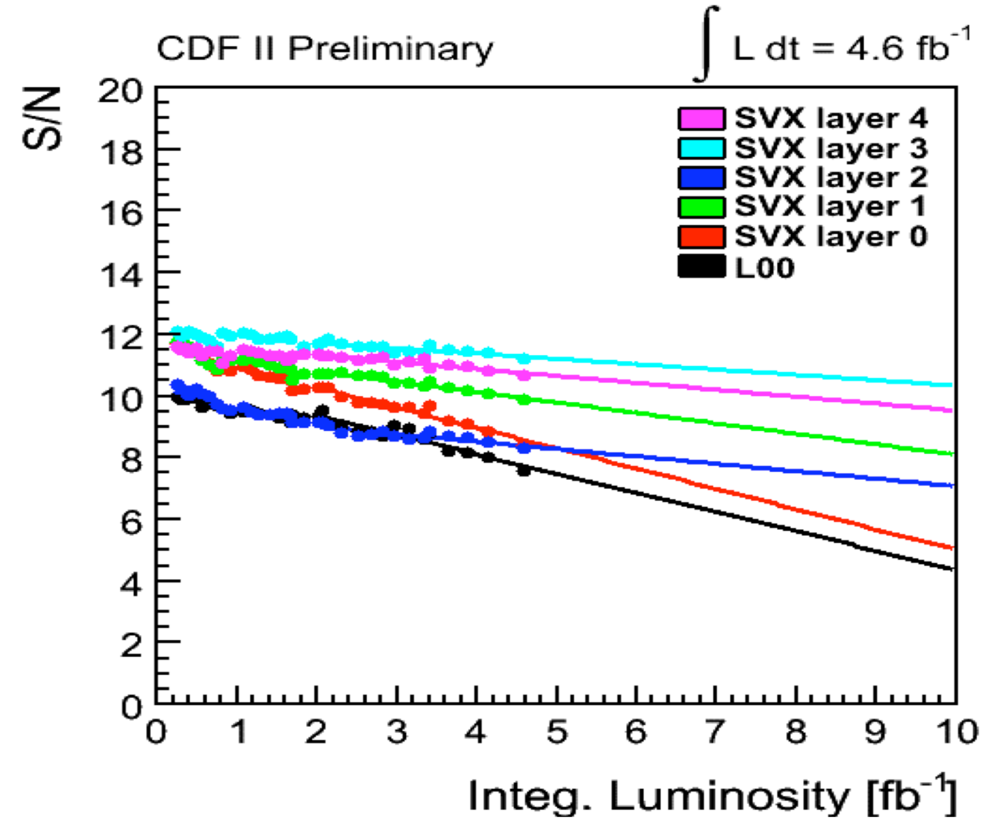
Up to now on tape 5.4fb^{-1}





Detectors health: CDF



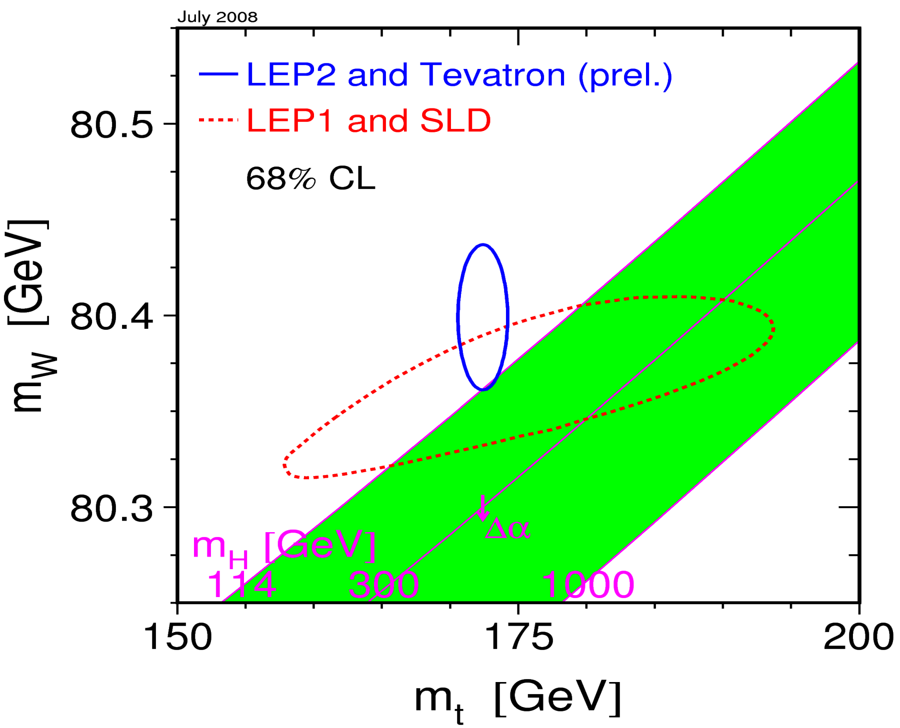


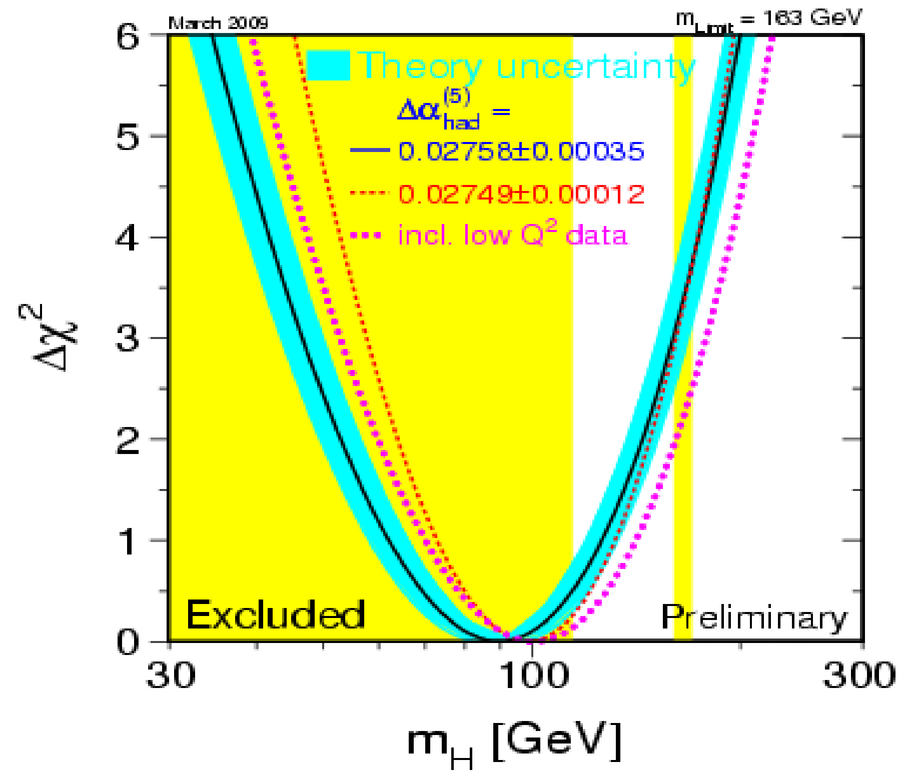
- Is radiation damage going to limit the operational lifetime of SVX?
  - Study performed recently and answer: NO
- ~ 5-6 (S/N) good for physics
- ~ 3 (S/N) Run I able to do high P_T b-tagging

Cornering the Higgs

http://lepewwg.web.cern.ch/LEPEWWG/

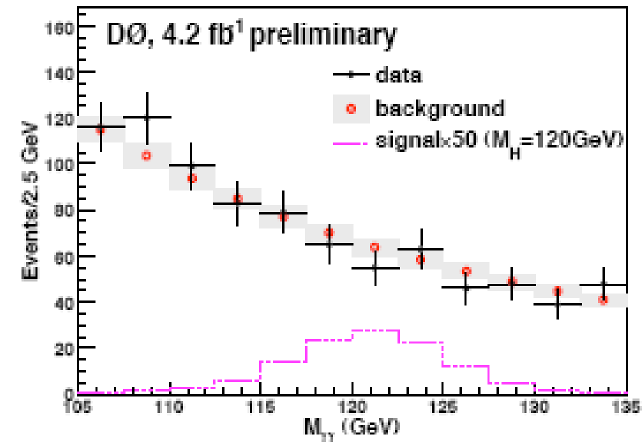
While this is not a proof that the Standard-Model Higgs boson actually exists, it does serve as a guideline in what mass range to look for it.





Low Mass Higgs: $H \to \tau\tau$ $H \to \gamma\gamma$

- DØ recently updated $H \to \gamma\gamma$ with 4.2 fb^{-1}.
  - ➡ QCD diphoton backgrounds modeled using data.

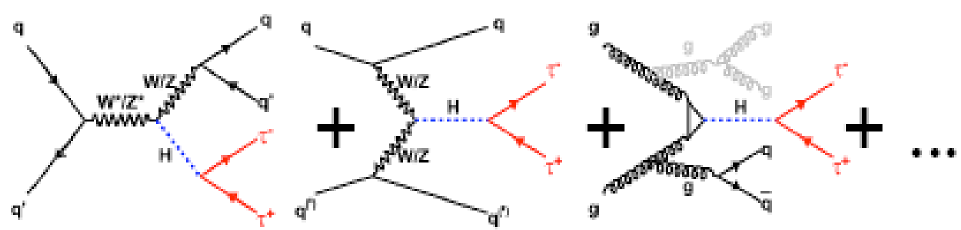


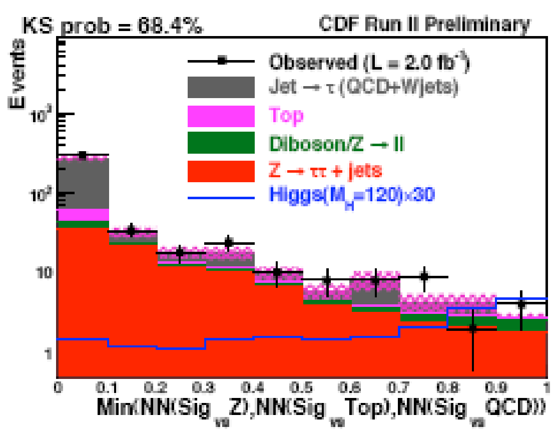
- Search for Higgs in ±15 GeV diphoton mass window.

M_H = 115 GeV
Exp: 18 Obs: 13

- No excess is seen. Limit also interpreted in fermiophobic Higgs scenario.

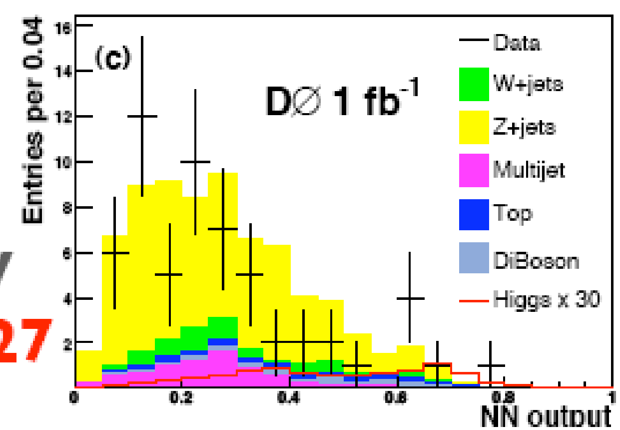
- Both CDF and DØ have inclusive Higgs + X → tau + X searches.
  - ➡ CDF uses 2.0 fb^{-1}. DØ uses 1.0 fb^{-1}.





M_H = 115 GeV
Exp: 25 Obs: 31

M_H = 115 GeV
Exp: 28 Obs: 27



Higgs production x-sections

Simone Pagan Griso Moriond

New ggH signal x-sections by Florian at Grazzini (arXiv:0901.2427)

included NNLL σ(gg→H), latest MSTW2008 pdf, 2-loop ewk corrections, exact b-quark treatment @ NLO

M_H (GeV/c^2)	$\sigma_{gg\to H}$ (pb)	σ_{WH} (pb)	σ_{ZH} (pb)	σ_{VBF} (pb)	$\mathrm{Br}_{\mathrm{H\to WW}}$
110	1.413	0.208	0.124	0.084	0.044
120	1.093	0.153	0.093	0.072	0.132
130	0.858	0.114	0.071	0.061	0.287
140	0.682	0.086	0.054	0.052	0.483
145	0.611	0.075	0.048	0.048	0.573
150	0.548	0.065	0.042	0.045	0.682
155	0.492	0.057	0.037	0.041	0.801
160	0.439	0.051	0.033	0.038	0.901
165	0.389	0.044	0.029	0.035	0.957
170	0.349	0.039	0.026	0.033	0.965
175	0.314	0.034	0.023	0.031	0.951
180	0.283	0.031	0.021	0.028	0.935
190	0.231	0.024	0.017	0.024	0.776
200	0.192	0.019	0.014	0.021	0.735

H->WW Systematics 0-Jet bin

0 Jet Uncertainties	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet	$gg \to H$	WH	ZH	VBF
Cross Section											
Scale								10.9%			
PDF Model								5.1%			
Total	*10.0%*	*10.0%*	*10.0%*	15.0%	5.0%	10.0%		12.0%			
Acceptance											
Scale (leptons)								2.5%			
Scale (jets)								4.6%			
PDF Model (leptons)	1.9%	2.7%	2.7%	2.1%	4.1%	2.2%		1.5%			
PDF Model (jets)								0.9%			
Higher-order Diagrams	**5.5%**	**10.0%**	**10.0%**	10.0%	**5.0%**	**10.0%**					
Missing Et Modeling	1.0%	1.0%	1.0%	1.0%	20.0%	1.0%		1.0%			
Conversion Modeling						20.0%					
Jet Fake Rates (Low S/B) (High S/B)							 21.5% 27.7%				
MC Run Dependence	3.9%			4.5%		4.5%		3.7%			
Lepton ID Efficiencies	2.0%	1.7%	2.0%	2.0%	1.9%	1.4%		1.9%			
Trigger Efficiencies	2.1%	2.1%	2.1%	2.0%	3.4%	7.0%		3.3%			
Luminosity	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%		5.9%			

H->WW Systematics 1-Jet bin

1 Jet Uncertainties	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet	$gg \to H$	WH	ZH	VBF
Cross Section											
Scale								10.9%			
PDF Model								5.1%			
Total	*10.0%*	*10.0%*	*10.0%*	15.0%	5.0%	10.0%		12.0%	5.0%	5.0%	10.0%
Acceptance											
Scale (leptons)								2.8%			
Scale (jets)								-5.1%			
PDF Model (leptons)	1.9%	2.7%	2.7%	2.1%	4.1%	2.2%		1.7%	1.2%	0.9%	2.2%
PDF Model (jets)								-1.9%			
Higher-order Diagrams	**5.5%**	**10.0%**	**10.0%**	10.0%	**5.0%**	**10.0%**			*10.0%*	*10.0%*	*10.0%*
Missing Et Modeling	1.0%	1.0%	1.0%	1.0%	20.0%	1.0%		1.0%	1.0%	1.0%	1.0%
Conversion Modeling						20.0%					
Jet Fake Rates (Low S/B) (High S/B)							 22.2% 31.5%				
MC Run Dependence	1.8%			2.2%		2.2%		2.6%	2.6%	1.9%	2.8%
Lepton ID Efficiencies	2.0%	2.0%	2.2%	1.8%	2.0%	2.0%		1.9%	1.9%	1.9%	1.9%
Trigger Efficiencies	2.1%	2.1%	2.1%	2.0%	3.4%	7.0%		3.3%	2.1%	2.1%	3.3%
Luminosity	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%		5.9%	5.9%	5.9%	5.9%

H->WW Systematics 2-Jet bin

$\geq$ 2 Jets Uncertainties	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet	$gg \rightarrow H$	WH	ZH	VBF
Cross Section											
Scale								10.9%			
PDF Model								5.1%			
Total	*10.0%*	*10.0%*	*10.0%*	15.0%	5.0%	10.0%		12.0%	5.0%	5.0%	10.0%
Acceptance											
Scale (leptons)								3.1%			
Scale (jets)								-8.7%			
PDF Model (leptons)	1.9%	2.7%	2.7%	2.1%	4.1%	2.2%		2.0%	1.2%	0.9%	2.2%
PDF Model (jets)								-2.8%			
Higher-order Diagrams	**10.0%**	**10.0%**	**10.0%**	10.0%	**10.0%**	**10.0%**			*10.0%*	*10.0%*	*10.0%*
Missing Et Modeling	1.0%	1.0%	1.0%	1.0%	20.0%	1.0%		1.0%	1.0%	1.0%	1.0%
Conversion Modeling						20.0%					
b-tag Veto				7.0%							
Jet Fake Rates							27.1%				
MC Run Dependence	1.0%			1.0%		1.0%		1.7%	2.0%	1.9%	2.6%
Lepton ID Efficiencies	1.9%	2.9%	1.9%	1.9%	1.9%	1.9%		1.9%	1.9%	1.9%	1.9%
Trigger Efficiencies	2.1%	2.1%	2.1%	2.0%	3.4%	7.0%		3.3%	2.1%	2.1%	3.3%
Luminosity	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%		5.9%	5.9%	5.9%	5.9%