SM Low Mass search "secondary channels"
($H \to \gamma\gamma$, $HX \to \tau\tau jj$, $VH \to qqbb$)

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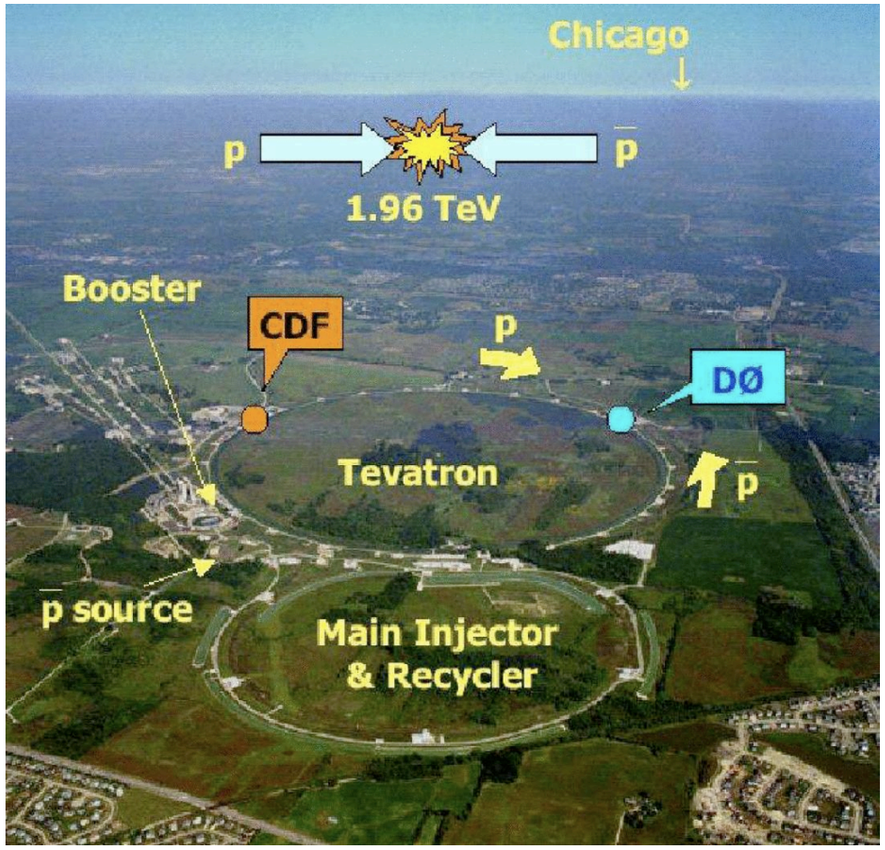
for D0 and CDF collaboration

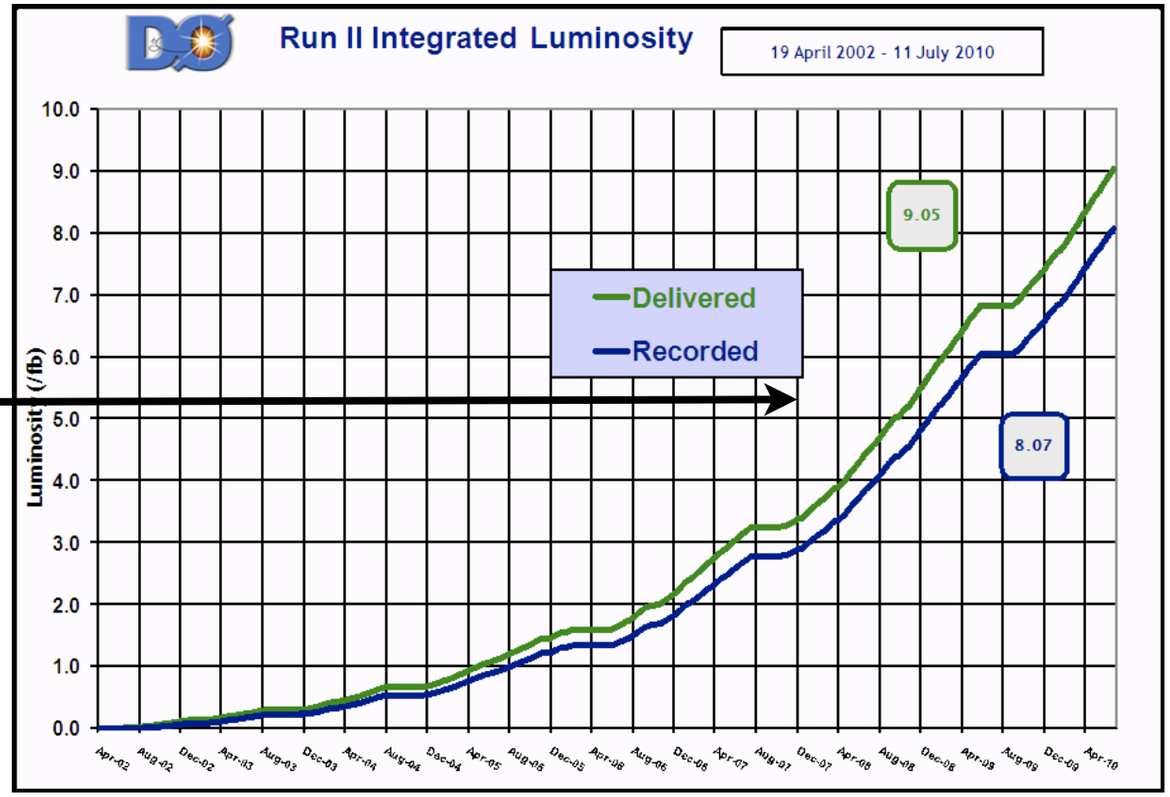
Higgshunting Workshop 07-29-2010

Outline

- Motivation
- H->γγ @ D0/CDF L=4.2/5.4 fb-1
- XH->ττjj @ D0/CDF L=4.9/2.0 fb-1
- VH->qqbb @CDF L=4.0 fb-1
- Results
- Summary

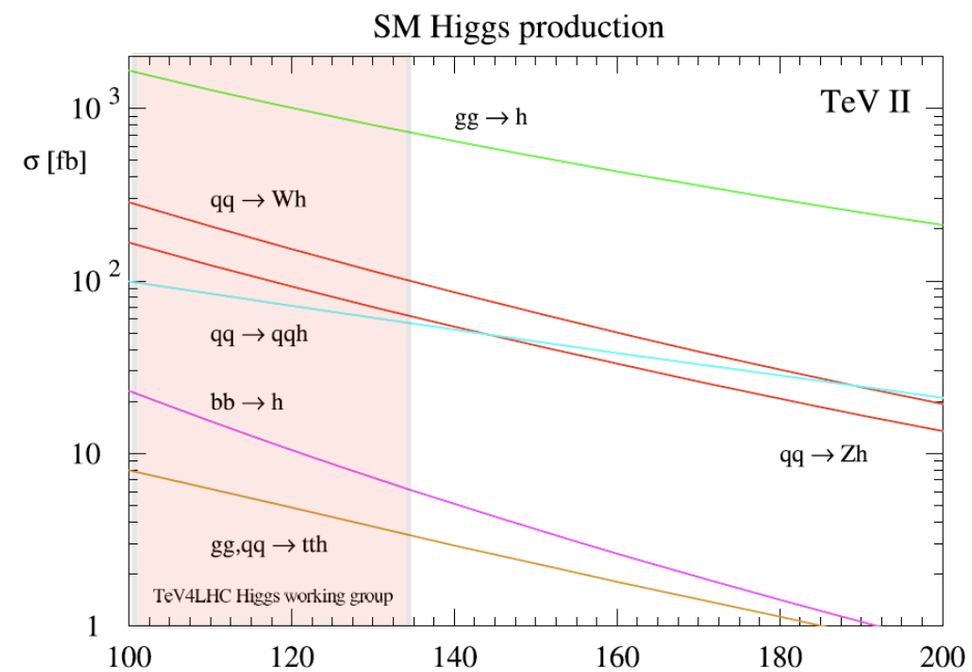


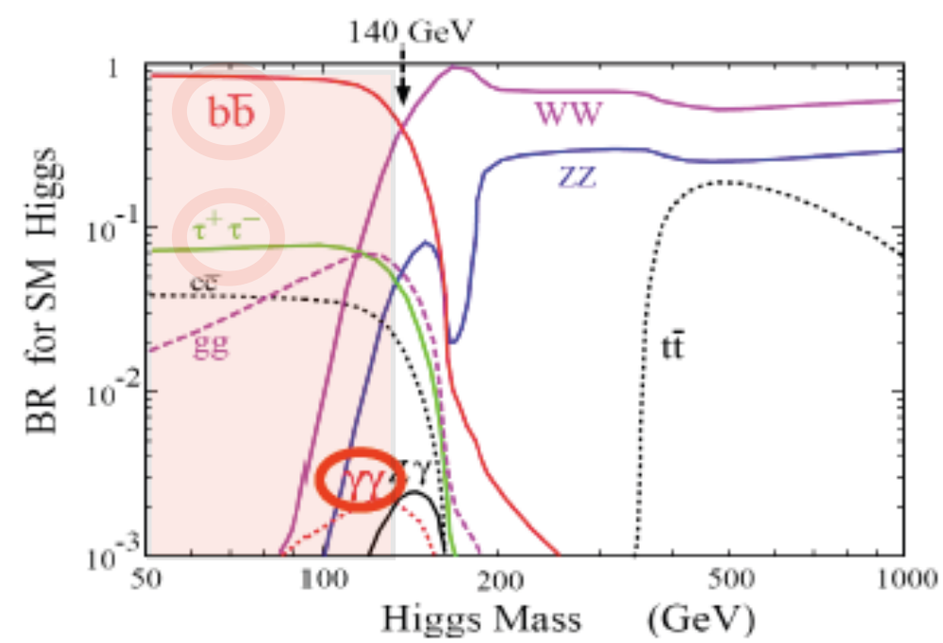
Analysis presented here 2.0-5.4 fb-1



Motivation

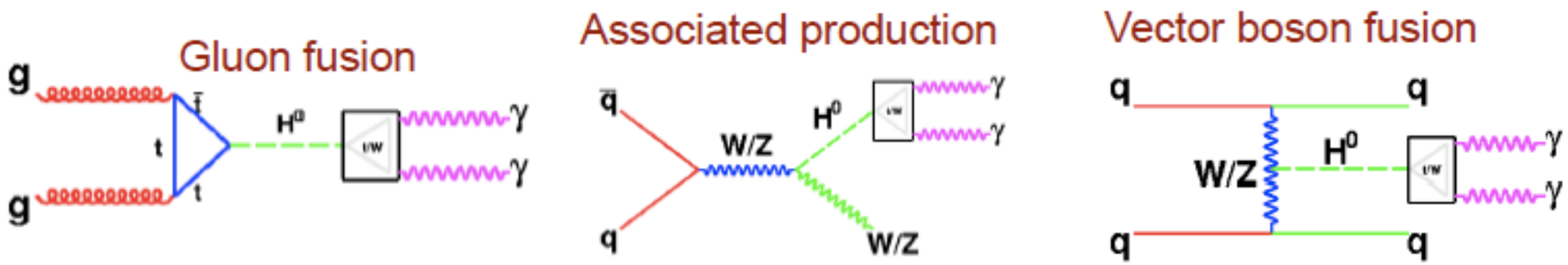
- Theoretical constraints for secondary channels are small BR of γγ/ττ
- Experimental challenges in these channels are large background and detection of γ/τ final states
- However they can add up to Higgs sensitivity
- The channels involving gamma decays of SM Higgs helps intermediate mass region
- Simultaneous search for VH/Vector Boson Fusion (VBF) signals in tau final states, sensitive at low mass
- Channels for VH->qqbb has larger BR but huge QCD bkg, can contribute in low mass





H→γγ @D0/CDF

L=4.2/5.4 fb-1



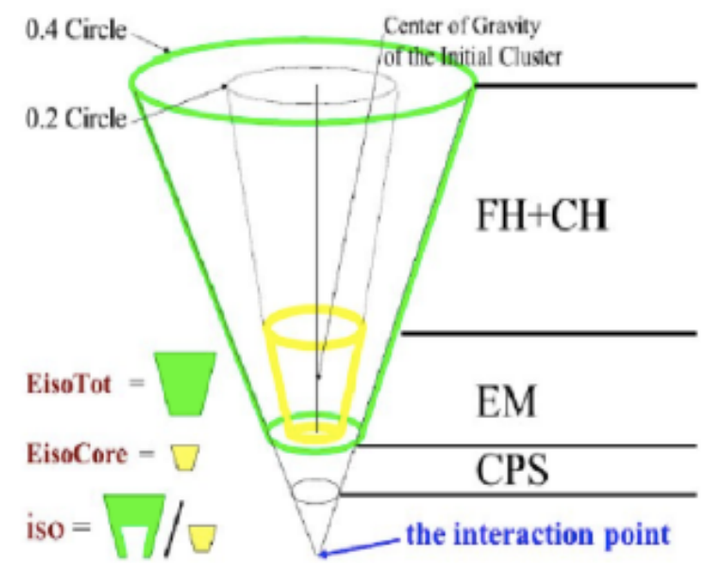
Add ~30% more signal

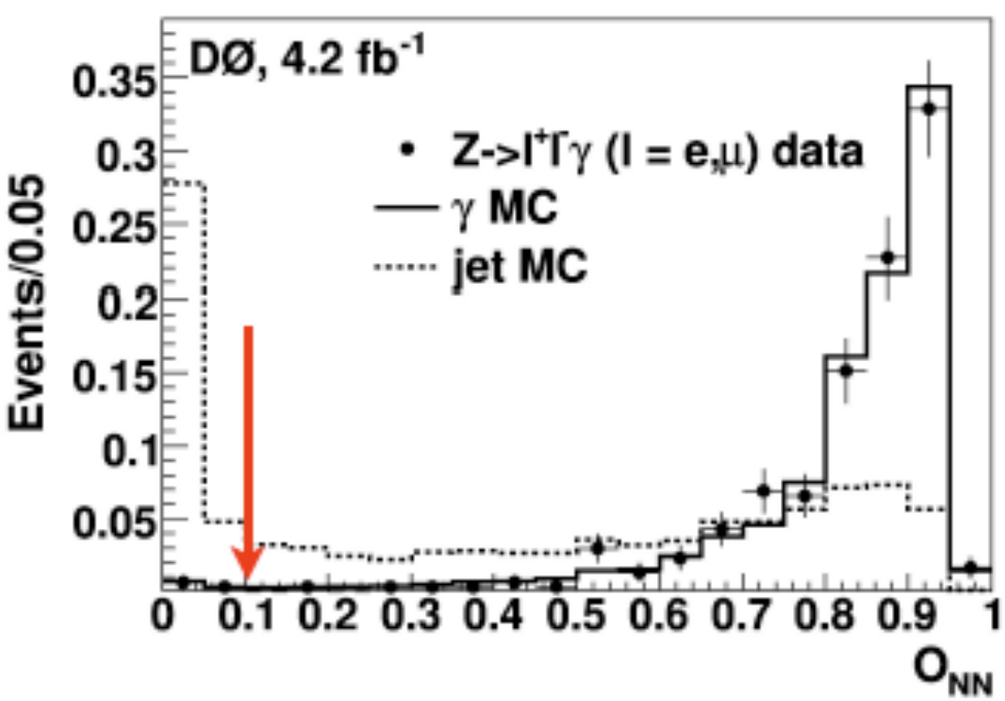
- SM Higgs decay to two photons
- Diphoton Mass observable in falling spectrum
- Photon Identification
- Calorimeter resolution
- Background model by data driven techniques

- Event Selection
- DiEM cal-only trigger suites, Single photon with high pT (50-70 GEV) threshold
- PV should be inside acceptance of tracking
- In central calorimeter
- pT>25/15 GEV (D0/CDF)
- Mgamgam > 60/30 GEV

H→γγ Preselection

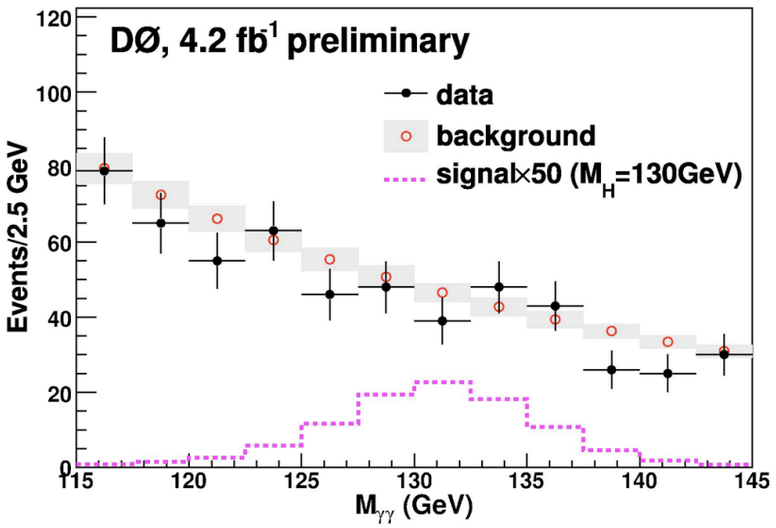
- Photon identification
- High EM fraction/cluster in shower
- Calorimeter and tracker isolation
- Transverse shower profile and no associated track
- D0 also uses a 5 variable NN cut >0.1

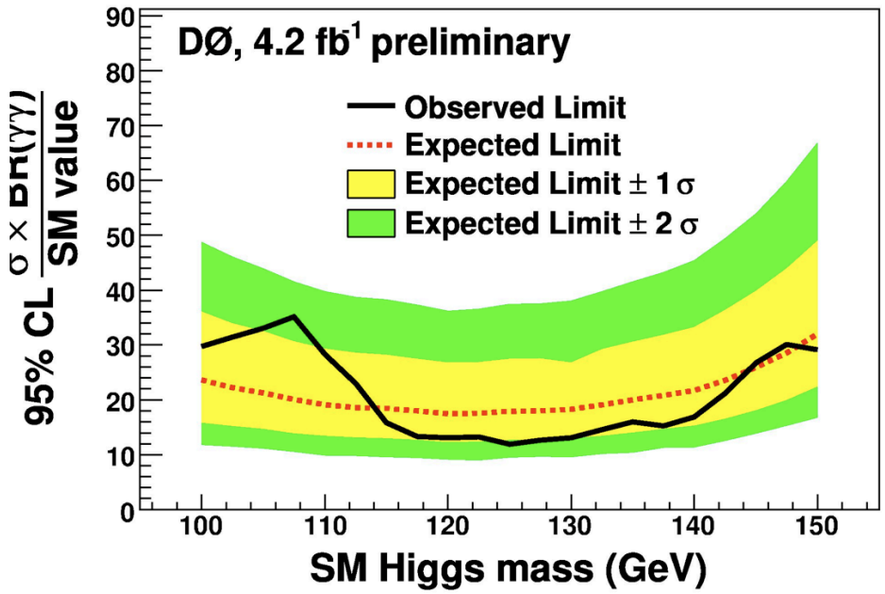




- Main Backgrounds
- Reducible backgrounds : Electrons misidentified as photons Z/γ*->ee, Jets misidentified as photons,dijet and γ+jet, using NNLO MC
- Irreducible backgrounds : direct QCD di-photon production using a sideband fitting method from data
- CDF analysis the sum of all backgrounds is taken from a inclusive sideband fitting method

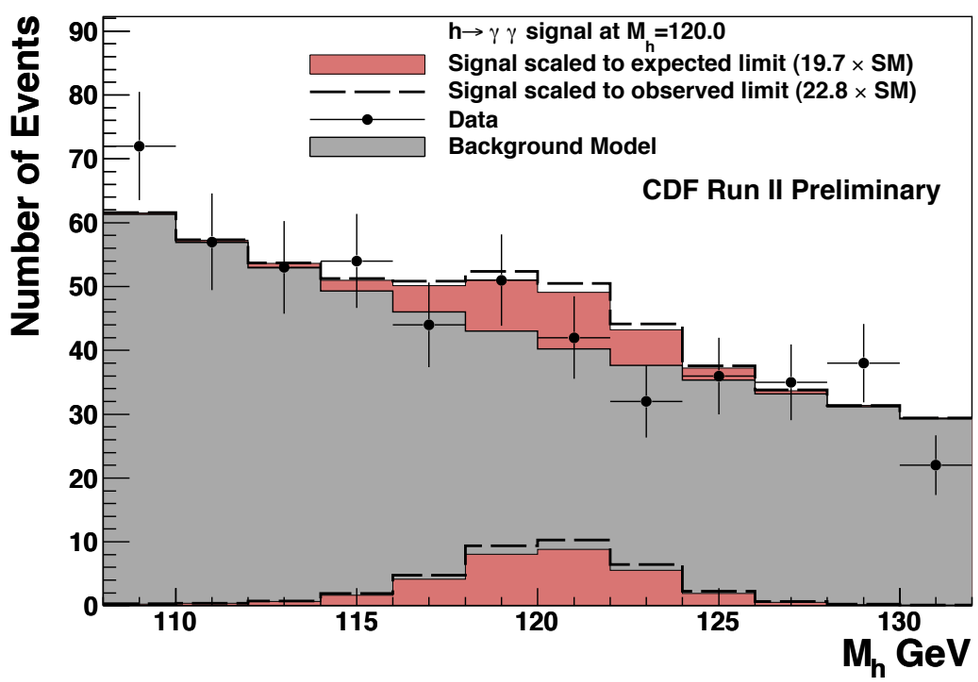
H→γγ Results @D0/CDF

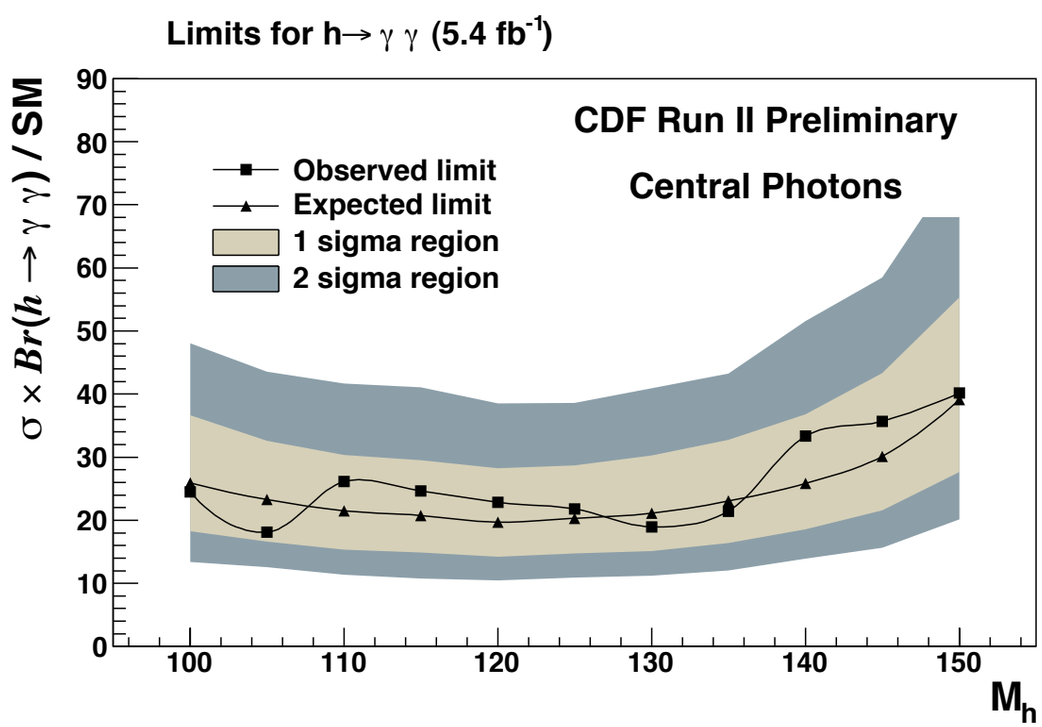




source	uncertainty
luminosity	6.1% [21]
trigger	0.1%
PDF for $h \to \gamma\gamma$ acceptance	1.7% - 2.2%
electron misidentification efficiency	19.0%
$Z/\gamma^*(ee)$ cross section	3.9%
photon identification efficiency	6.8%
background subtraction	shape
photon energy scale	shape

- Mγγ spectrum in the search region for derivation of limits 20 times than SM higgs cross section

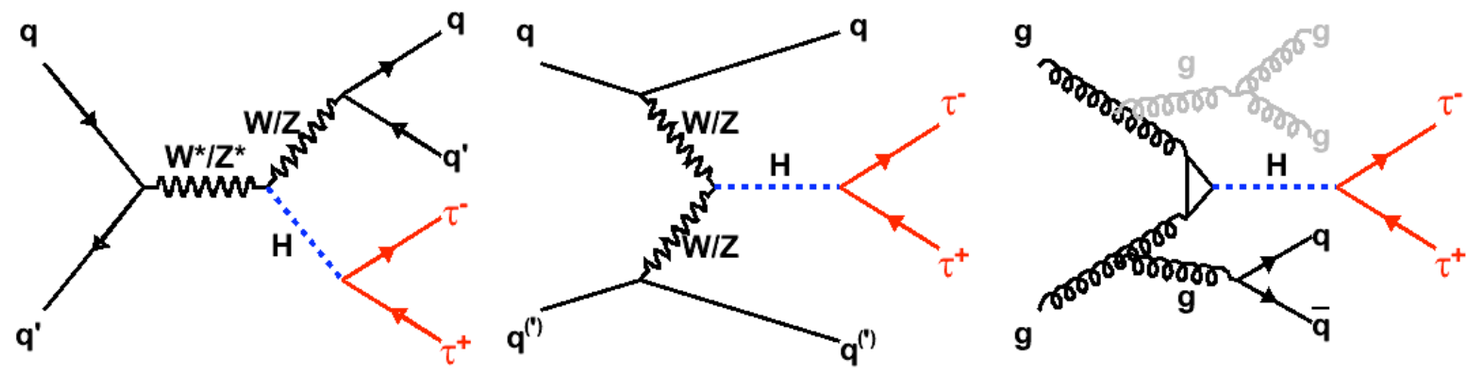




VH/VBF→ττjj @D0/CDF

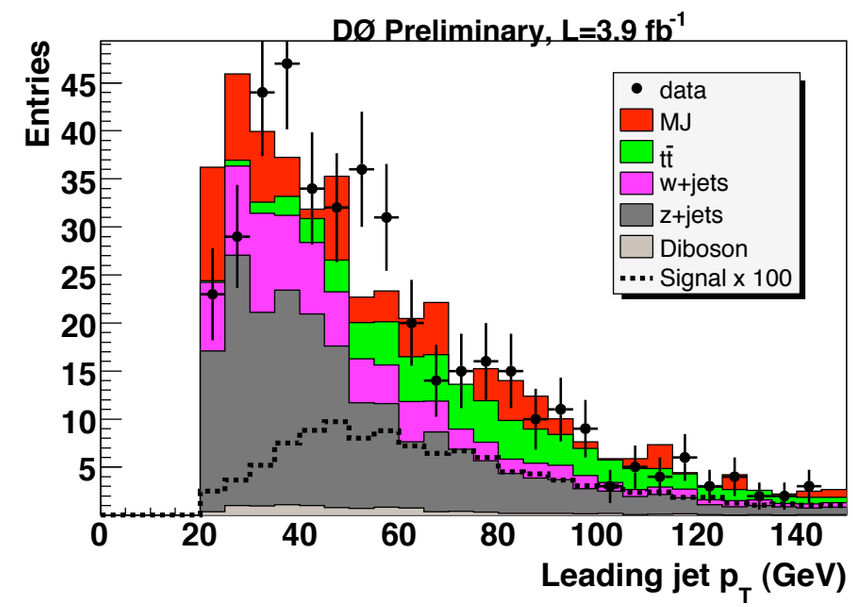
L=4.9/2.0 fb-1

- W(→ qq') H(→ τ+τ-)
- Z(→ qq) H(→ τ+τ-)
- H(→ bb) Z(→ τ+τ-)
- VBF qHq'→ q' τ+τ-q
- gg → H → τ+τ-+≥ 2jets



- Event Selection
- Only one isolated muon
- One hadronic tau candidate pT>15 GeV
- At least two jets pT>20 GeV and |η|>3.4
- Opposite sign mu-tau pair requirement
- Electron veto
- No B tagging

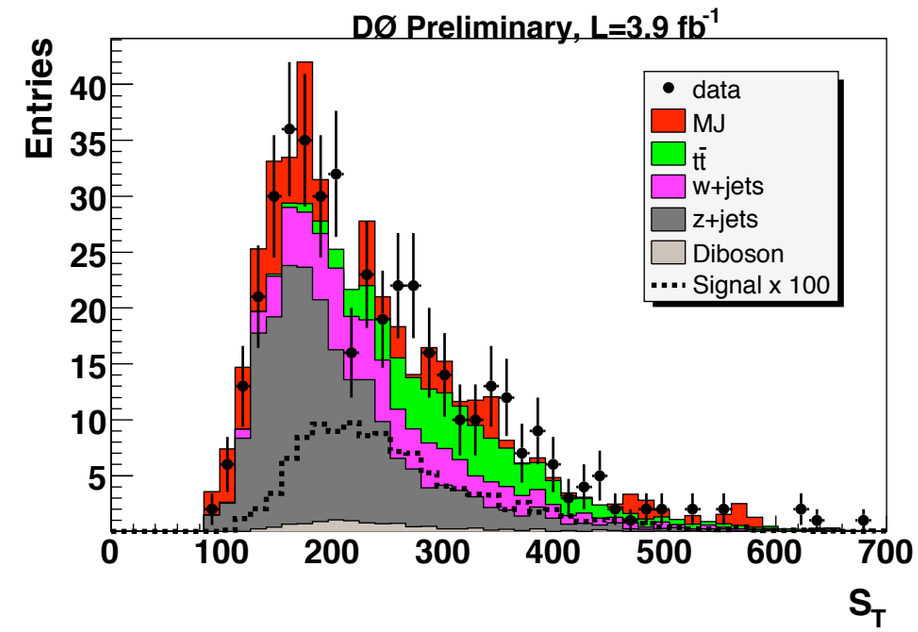
leading jet pT



ttjj Preselection @D0

ST

- After preselection Multivariate technique used for optimum sensitivity
- Variables used for BDT training showing good data montecarlo agreement

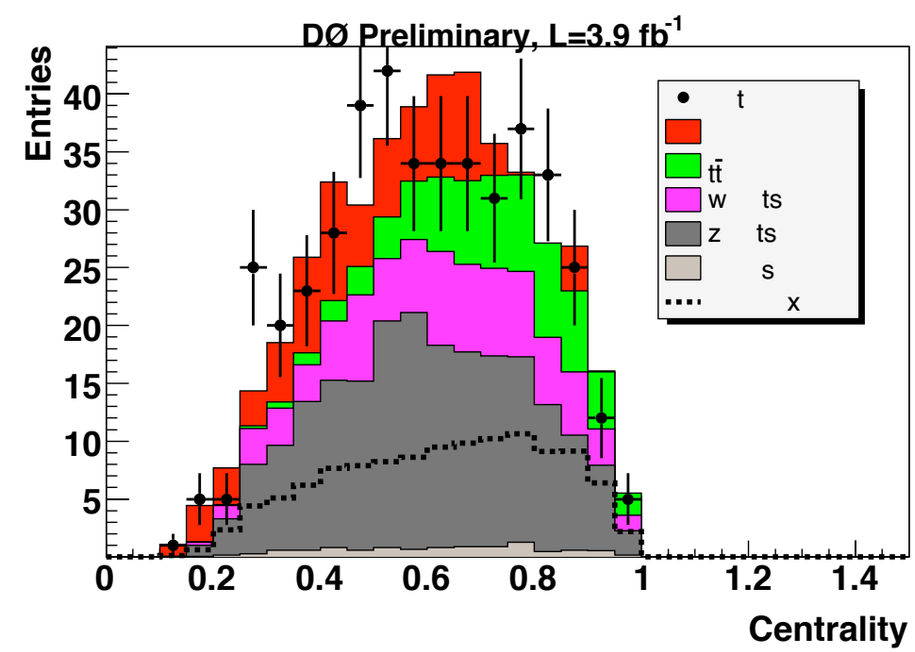


Event Yield

Data	ΣBknd	$t\bar{t}$	W+jets	Z+jets	DB	MJ
433	439.9	66.7	81.5	222.7	10.2	80.7

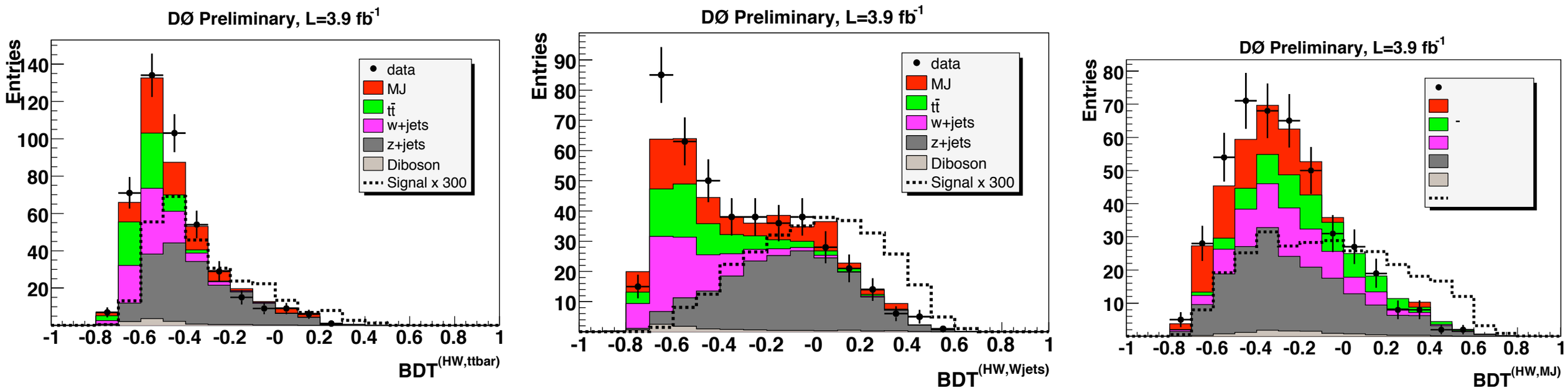
Process	ZH	HZ	HW	VBF	GGF
Event yield	0.11	0.23	0.72	0.12	0.15

centrality



BDTs for ττjj selection @D0

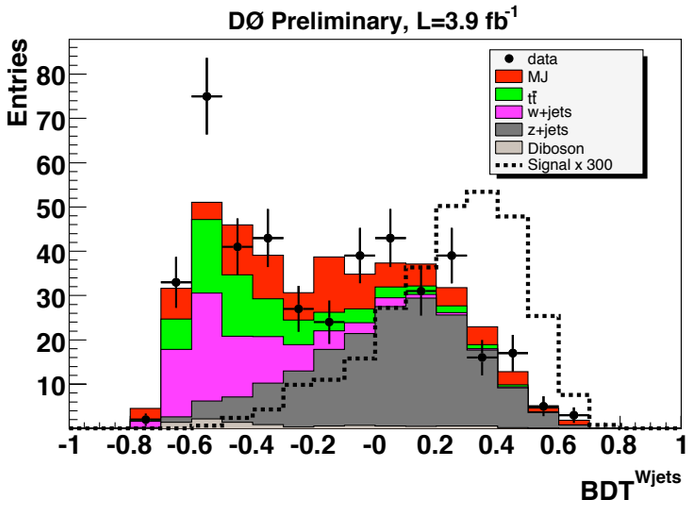
- 32 Boosted Decision Trees for four signals to four bkgd BDTs output in two mass regions
- 17 variables used for each BDT
- Final selection cut on average on maxBDT of ttbar,wjets and MJ BDTs
- Look at the average BDT of zjets as final variable.

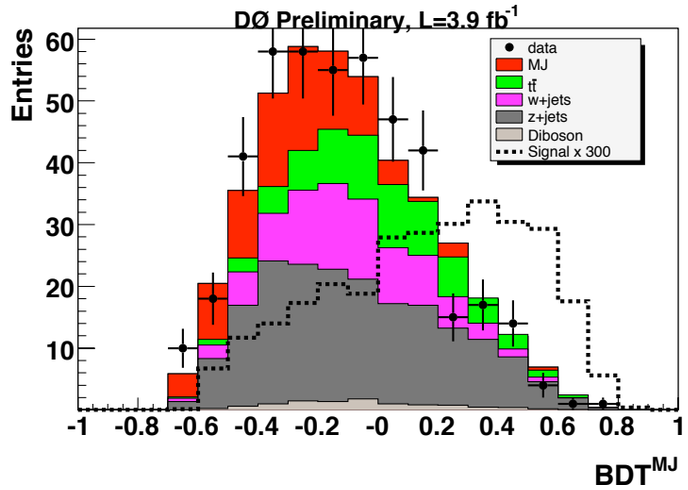


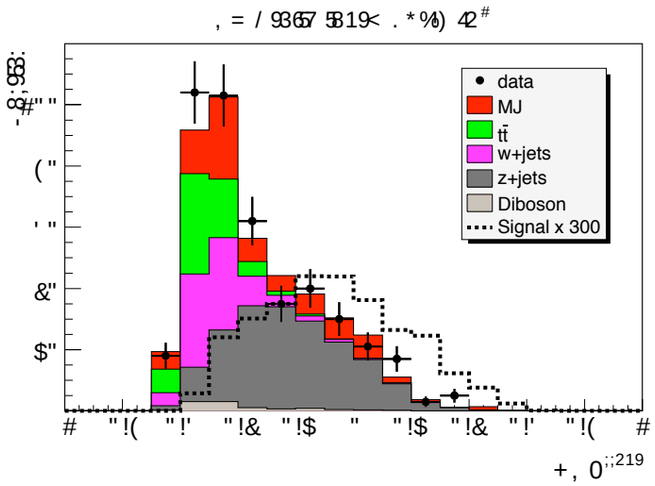
- BDT training WH signal vs different backgrounds

BDTs for ττjj@D0

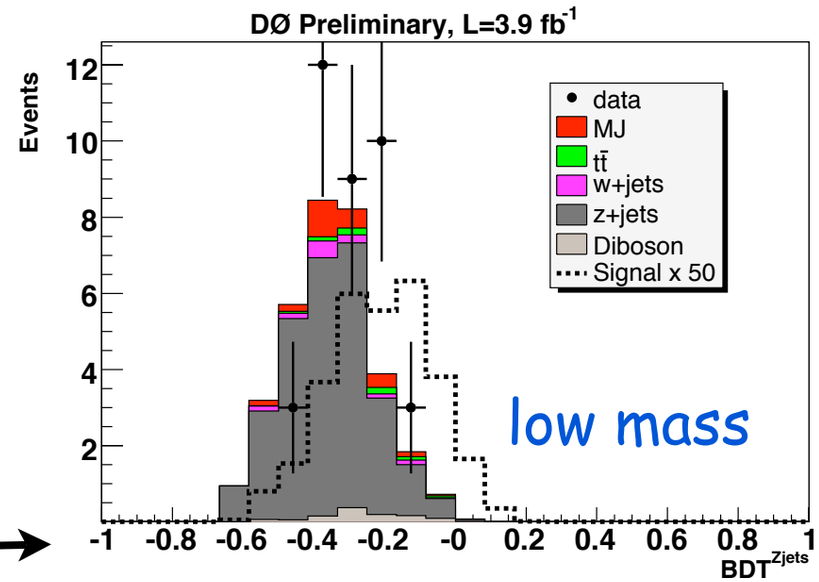
L=4.9 fb-1

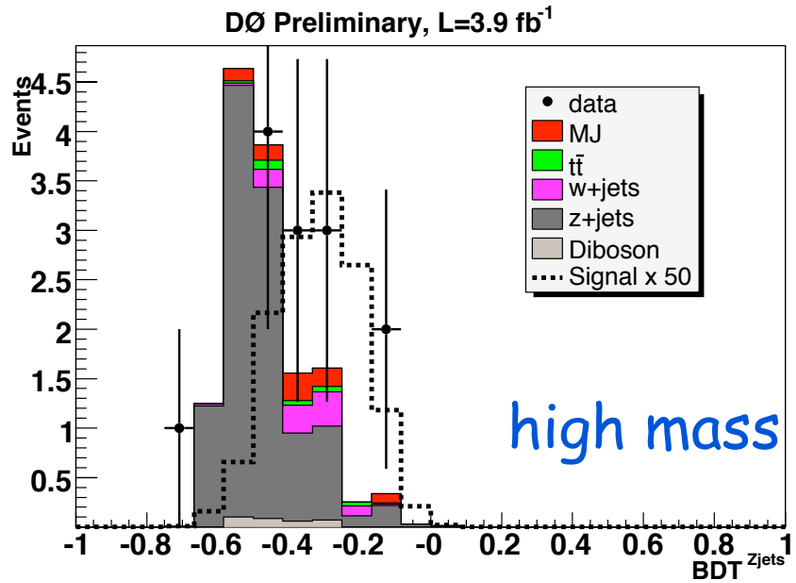






- MaxBDT Signal trained against different backgrounds
- Final distribution average Zjets BDT for limit setting
- Major systematics
- Tau ES 4.5% Lumi 6.1% QCD 15% Cross sec 10% JES 7.5%

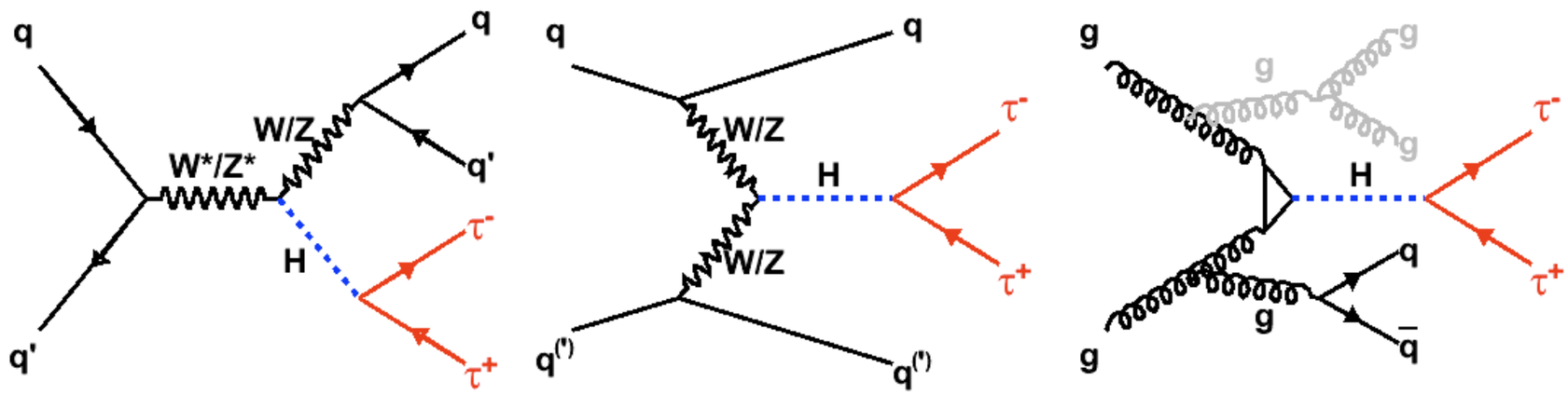




VH/VBF→ττjj @ CDF

L=2 fb-1

- W(→ qq') H(→ τ+τ-)
- Z(→ qq) H(→ τ+τ-)
- VBF qHq' → q' τ+τ-q
- gg → H → τ+τ-± 2jets



- Event Selection

- Exact 1 Lepton: Central (|η| < ~1.0) isolated electron or muon with Pt > 10 GeV
- Exact 1 Hadronic Tau: Central hadronic τ (|η| < 1.0, 1 or 3 track in signal cone) with visible Pt > 15 GeV
- OS requirement: Lepton and Hadronic τ candidates have to be opposite sign
- At least 2 Jets: Et > 15 GeV and |η| < 2.5
- Z boson veto (for Z→ee/μμ)

Event Yield @ CDF

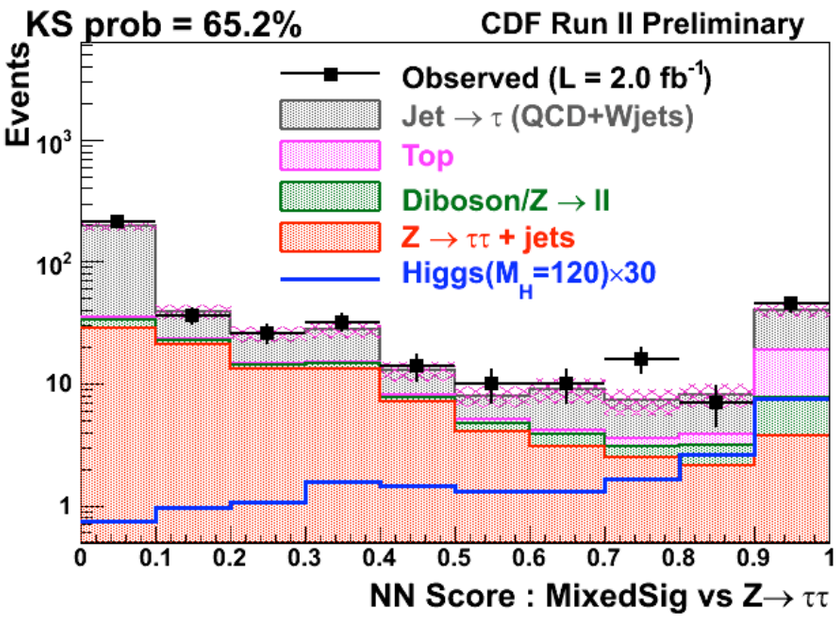
- Signal Yield

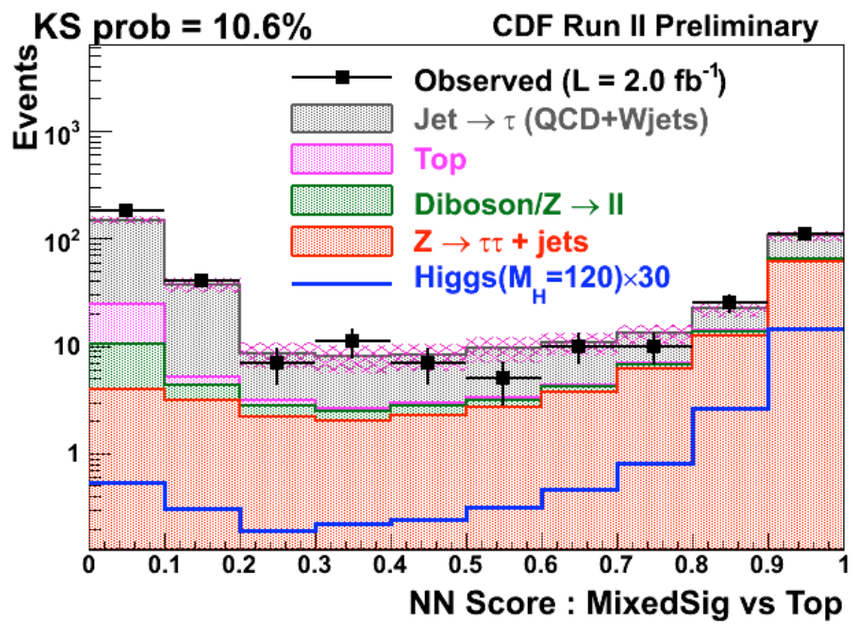
$2fb^{-1}$	M_H=110	M_H=115	M_H=120	M_H=130	M_H=140	M_H=150
WH	0.25(1.5%)	0.21(1.5%)	0.18(1.6%)	0.11(1.7%)	0.06(1.8%)	0.025(1.9%)
ZH	0.16(1.5%)	0.14(1.6%)	0.11(1.6%)	0.07(1.8%)	0.04(1.9%)	0.017(2.0%)
VBF	0.14(1.4%)	0.13(1.4%)	0.12(1.5%)	0.09(1.6%)	0.05(1.7%)	0.024(1.9%)
ggH	0.28(0.18%)	0.28(0.21%)	0.26(0.24%)	0.18(0.26%)	0.11(0.3%)	0.052(0.33%)
Total	0.83±0.01	0.76±0.01	0.67±0.01	0.45±0.004	0.26±0.002	0.12±0.001

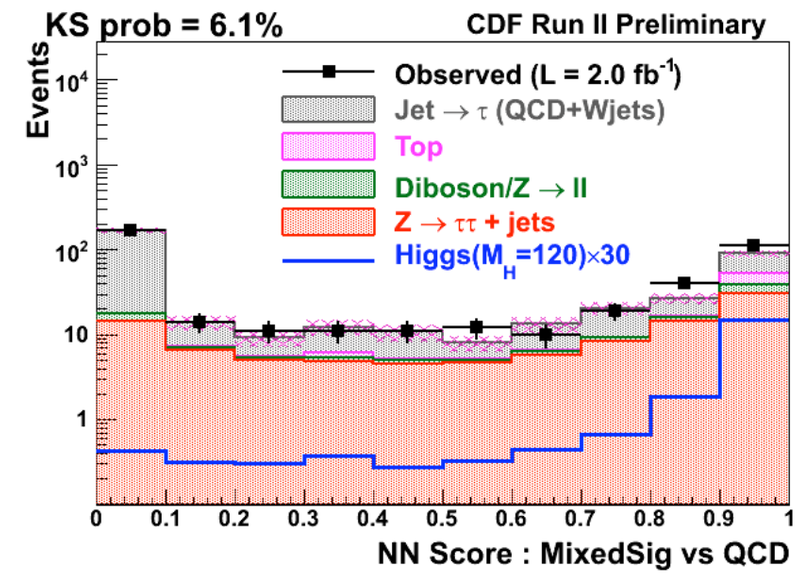
- Background Yield

Source	Model	$e/\mu + \tau_h +$ 0jet	$e/\mu + \tau_h +$ 1jet	$e/\mu + \tau_h + \geq$2jet	Grand Total
Z→ $\tau\tau$+$jets$	ALPGEN	2746.8±260.7	465.1±108.3	99.1±25.9	3310.9±394.8
Z→ ll+$jets$	ALPGEN	216.9±23.0	48.3±7.8	11.7±2.2	276.8±32.2
$t\bar{t}$	PYTHIA	0.10±0.02	2.2±0.4	16.9±2.7	19.3±3.0
Diboson	PTYHIA	21.9±3.0	7.6±1.1	4.6±0.8	34.0±4.8
$jet \rightarrow \tau_{had}$	SS data	3269±57.2	876±29.6	220±14.8	4365±66.1
Add-on $W + jets$	ALPGEN	414.9±61.7	99.6±14.9	21.5±3.2	536.1±79.6
Total Background		6669.6±290.8	1498.8±116.8	373.8±32.4	8542.1±422.8
		Control Region	Control Region	Signal Region	-
Observed (2 fb^{-1})		6653	1571	410	8634

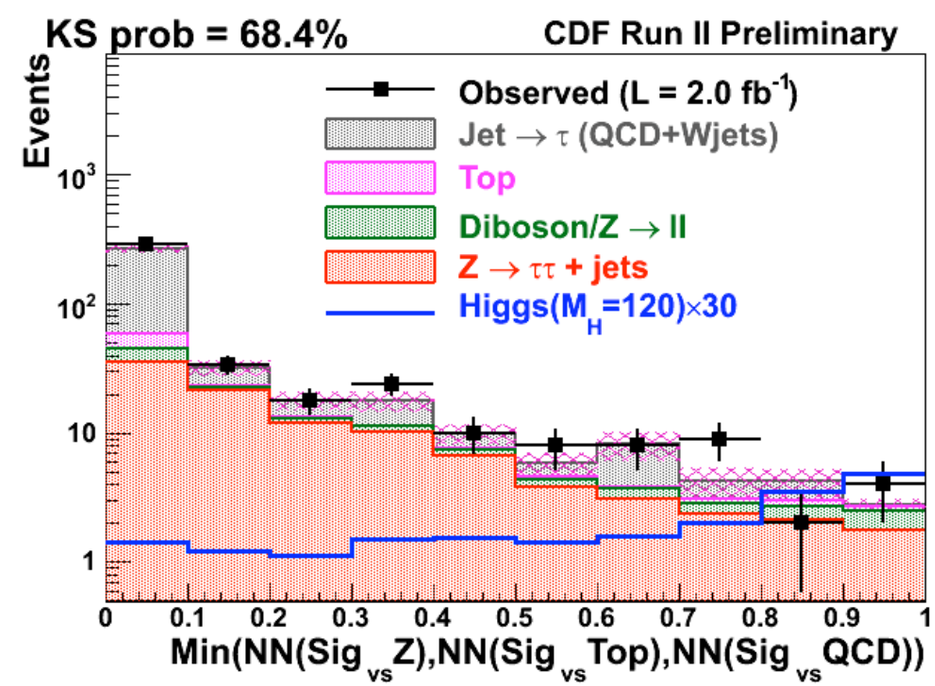
NNs selection @ CDF







- Three NNs trained with mixed Signal vs zee,top, qcd backgrounds
- Final discriminator minimum of three NNs
- Major Systematics
- JES 15% Lumi 6.0% tau ID 3%
- Signal 10-22%



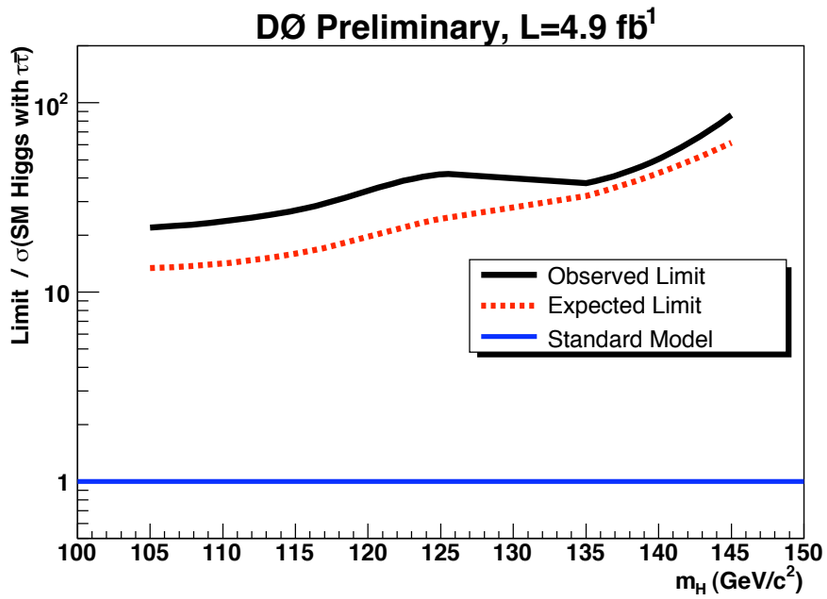
Limits

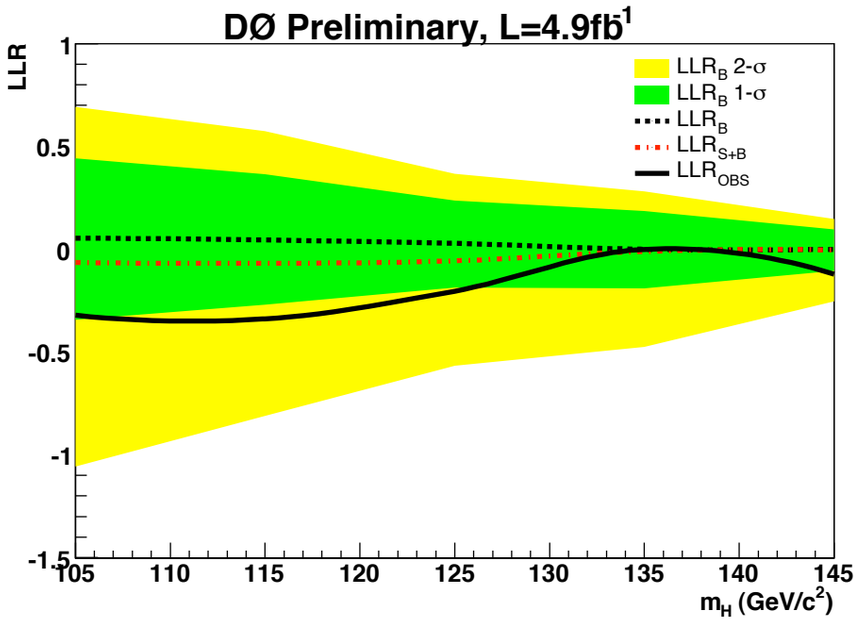
Good agreement with background prediction. No significant excess in signal region

D0 uses modified frequentist approach to set 95% CL LLR plots shown below

D0 sets limits for combined ττjj analysis expected limit range 24-120

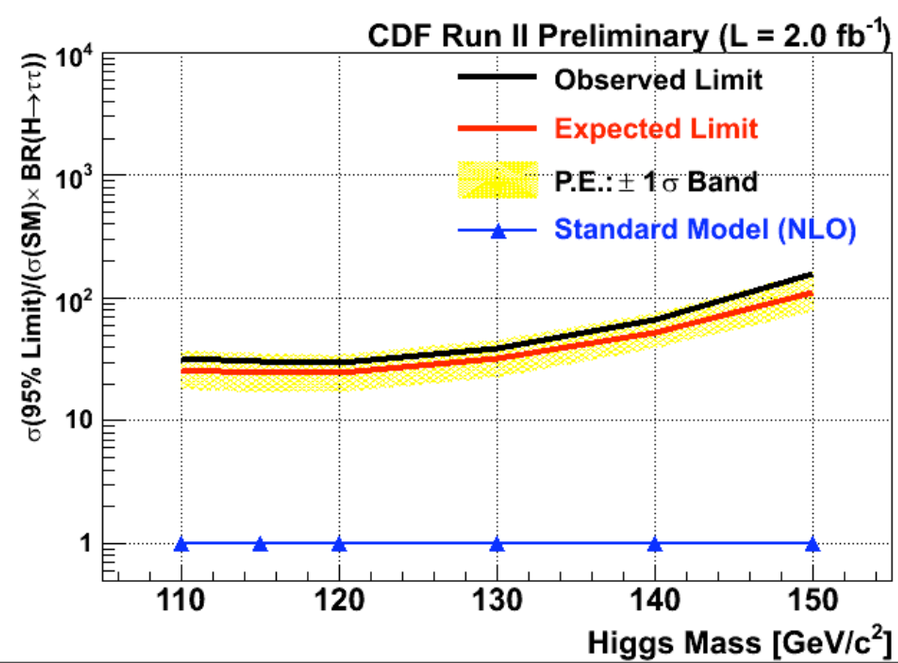
D0 ττ





- CDF uses a Bayesian approach
- CDF sets limits for ττjj analysis with 2 fb-1 data
- The expected limit ranges from 24.2 to 111.7

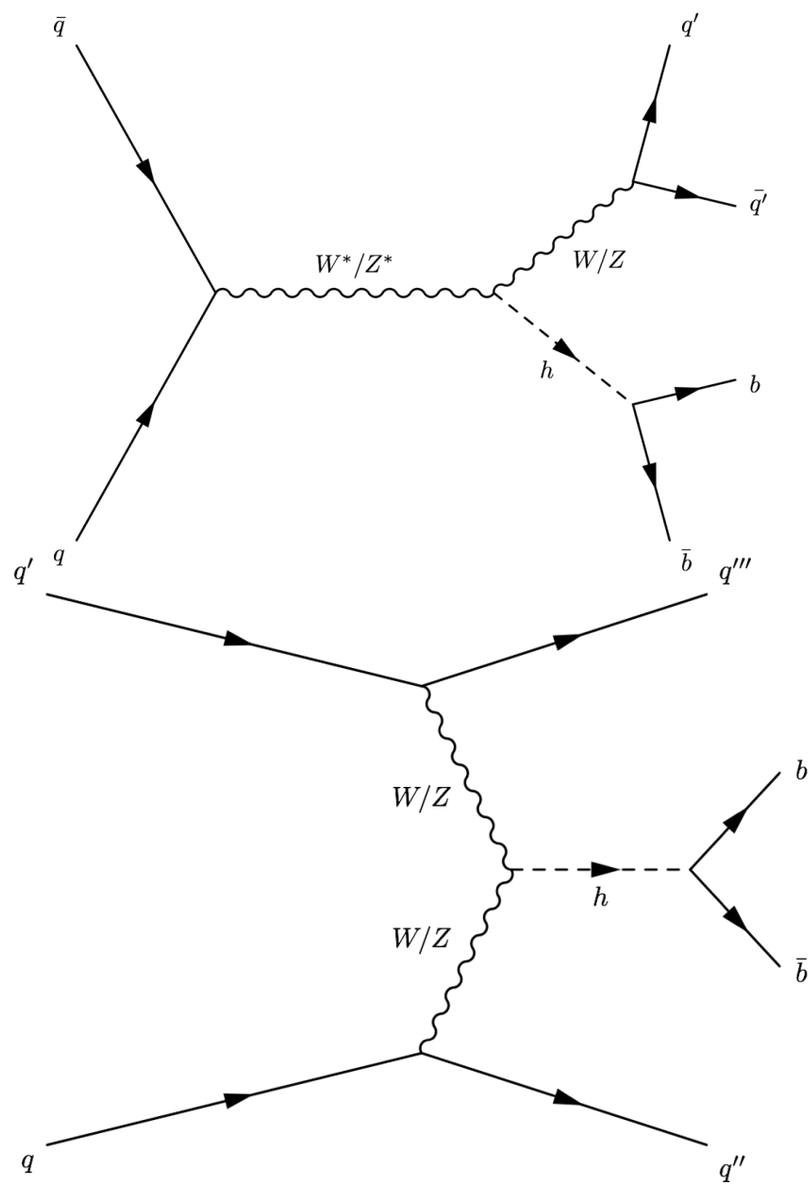
Mass	Expected Median	Expected Mean (RMS)	Observed
110	$25.8^{+11.5}_{-7.5}$	27.4(10.1)	32.5
115	$24.8^{+10.5}_{-7.5}$	26.1(9.4)	30.5
120	$24.2^{+10.0}_{-7.0}$	25.6(9.0)	30.0
130	$32.3^{+13.1}_{-9.5}$	34.6(13.1)	39.5
140	$52.8^{+22.5}_{-13.5}$	55.2(20.2)	67.5
150	$111.7^{+49.5}_{-33.0}$	119.0(42.3)	159.0



VH/VBF→qqbb@CDF

L=4.0 fb-1

- Large signal yield as it profits from the largest cross-section x branching ratio
- Complete event information. No missing energy to infer
- large QCD background



- Event Selection
- Pass CDF multi-jet trigger and good run selection
- Veto lepton events
- Selected events should have 4 or 5 jets with $E_T > 15$ GeV
- Events should have small missing transverse energy significance to reduce contribution from ttbar background
- Among the first 4 leading jets, exactly two jets must be tagged as b-jets
- The event SumEt (based on the sum of the transverse energy of the selected jets) must be greater than 220 GeV. This cut is to improve the signal to QCD multi-jet background significance

Preselection qqbb @CDF

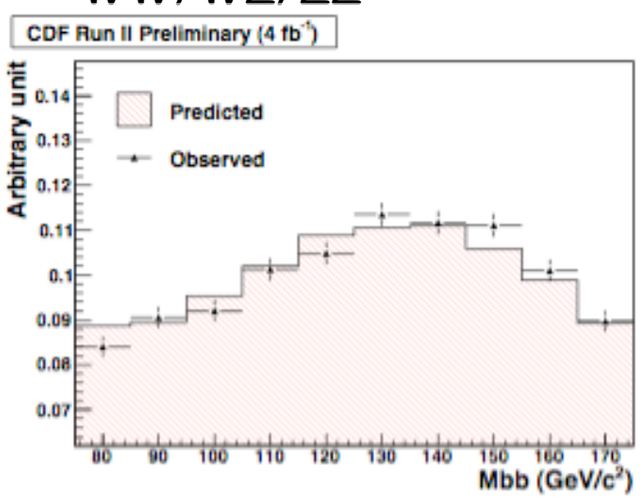
- VH Signal Region: $75 < M_{bb}$ 175 GeV/c^2 & $50 < M_{qq} < 120$ GeV/c^2
- VBF Signal Region: $75 < M_{bb}$ 175 GeV/c^2 & $M_{qq} > 120$ GeV/c^2
- Backgrounds:
- QCD (98%)

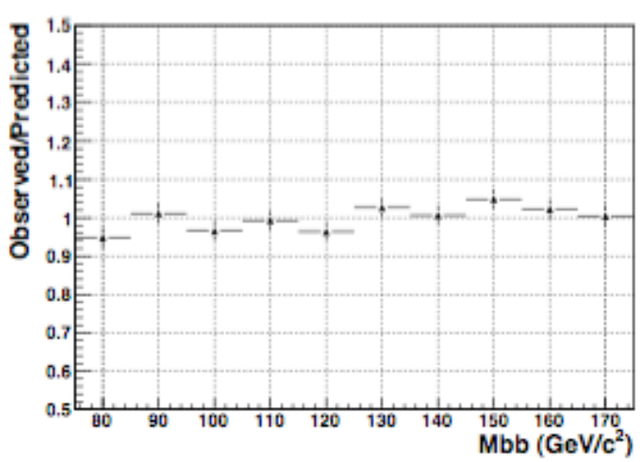
- ttbar Z + jets (where Z decays to b/c quarks)
- Single-Top
- W + bb/cc jets
- WW/WZ/ZZ

CDF Run II Preliminary (4 fb^{-1})
Expected number of background events which pass the trigger, event selection and have two b-tags (SecVtx-SecVtx [SS] or SecVtx-SetProbJ [SJ]).

Signal regions	VH (WH+ZH)		VBF	
Backgrounds	SS	SJ	SS	SJ
$t\bar{t}$	281.7	115.3	177.3	75.7
single-top	44.1	17.7	17.2	10.0
$W + bb/cc$	27.9	12.0	4.8	3.3
$Z(bb, cc)$+jets	127.5	55.4	135.0	62.9
Diboson	11.4	8.5	5.3	3.8
Data	16857	9341	17776	9518

Signal regions	WH		ZH		VBF	
Higgs Mass (GeV/c^2)	SS	SJ	SS	SJ	SS	SJ
115	5.1	1.9	3.7	1.3	3.4	1.3



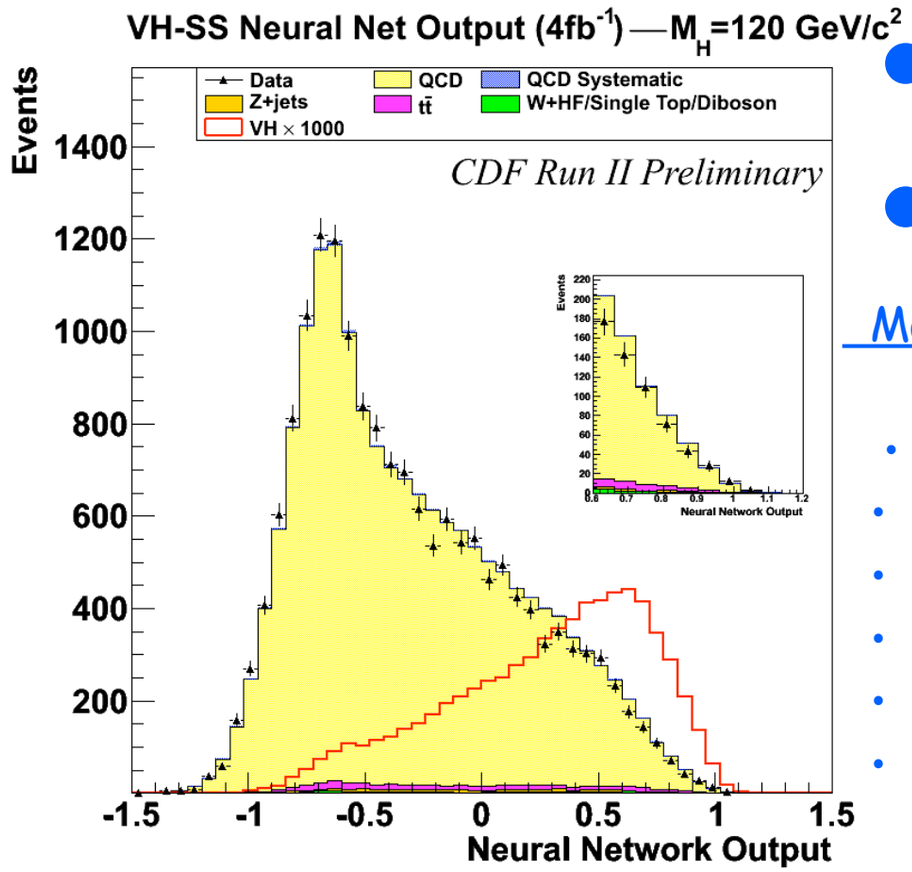


As no evidence for Higgs boson was found, we extract cross-section upper limits at 95% Confidence Limits (CL). For this analysis, four orthogonal channels were studied:

1. •VH where both b-jets are tagged by tight SecVtx
2. •VH where one b-jet is tagged by tight SecVtx and the other by JetProb(1%)
3. •VBF where both b-jets are tagged by tight SecVtx
4. •VBF where one b-jet is tagged by tight SecVtx and the other by JetProb(1%)

The results from the 4 channels are combined which gives a better result than the individual channels.

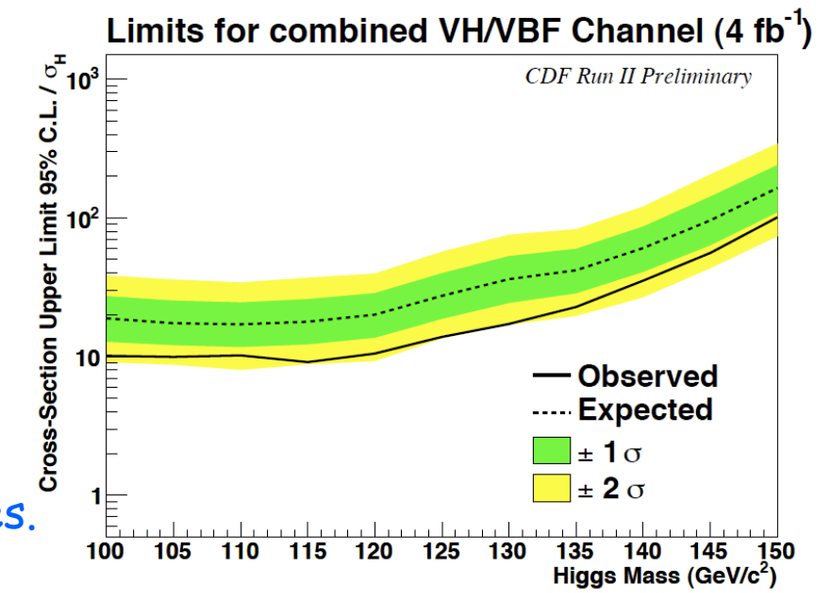
Limits qqbb@CDF

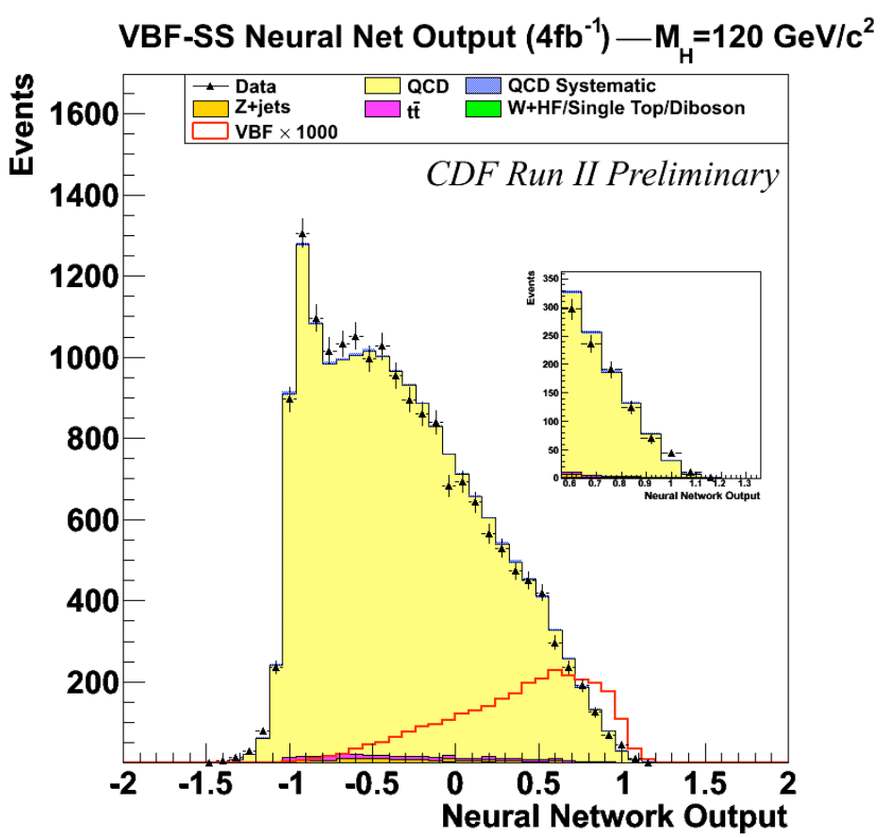


- Good DATA-MC agreement
- Put a limit on SM Higgs production cross section*BR

Major Systematics Sources

- QCD Modelling
- Luminosity
- b-tag scale factor
- Jet Energy Scale
- Initial & fnal state radiation.
- Parton distribution uncertainties.





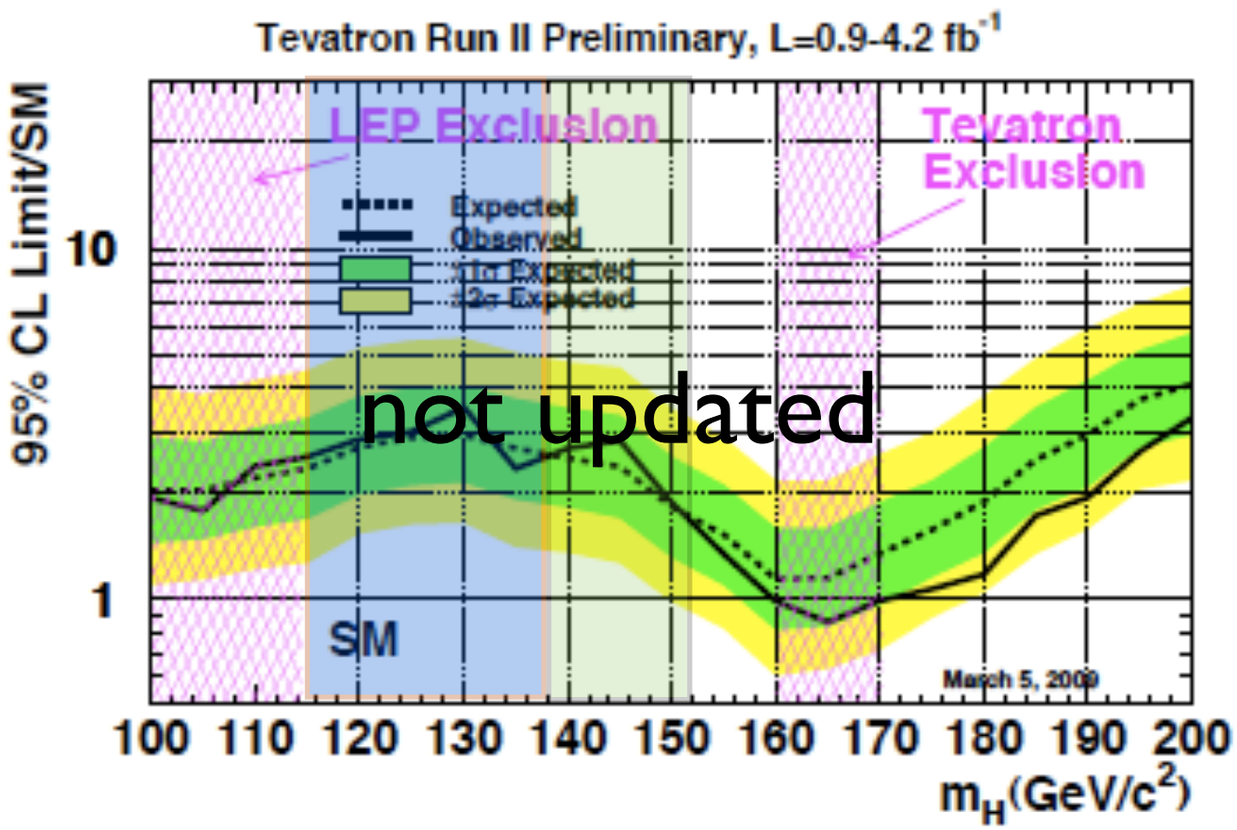
CDF Run II Preliminary

Expected and observed 95% CL upper limits for the combined VH and VBF channels using 4fb^{-1} of $p\bar{p}$ data collected by the CDF detector. The limits are normalised to the expected Higgs cross-section.

Higgs mass (GeV/c^2)	-2σ	-1σ	Median (σ/σ_H)	$+1\sigma$	$+2\sigma$	Observed
100	9.1	12.8	18.8	27.2	38.5	10.1
105	8.7	12.1	17.4	25.2	35.8	9.9
110	8.0	11.7	17.1	24.5	34.2	10.2
115	8.8	12.2	17.8	25.9	36.9	9.1
120	9.3	13.7	20.0	28.5	39.5	10.5
125	13.5	18.7	27.3	39.8	57.0	13.8
130	17.0	24.4	36.1	52.8	75.4	17.2
135	19.6	28.6	41.9	59.7	82.7	22.7
140	26.7	40.7	60.4	86.6	120.2	35.2
145	43.4	63.5	95.7	142.1	205.3	55.8
150	73.8	109.9	164.1	240.3	341.9	101.0

Summary

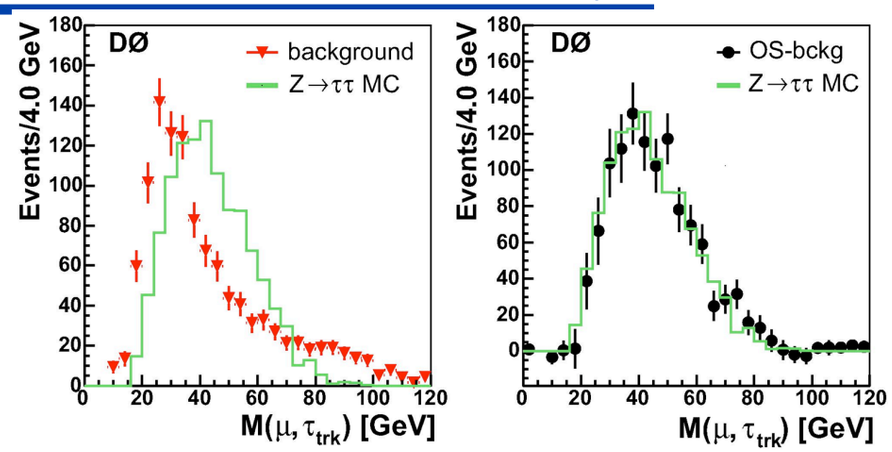
- Presented results from Higgs search at Tevatron with secondary search channels
- These channels were included in the combined CDF D0 limits shown below.
- Sensitive at low and intermediate mass region
- With more data results will be updated. Stay tuned.

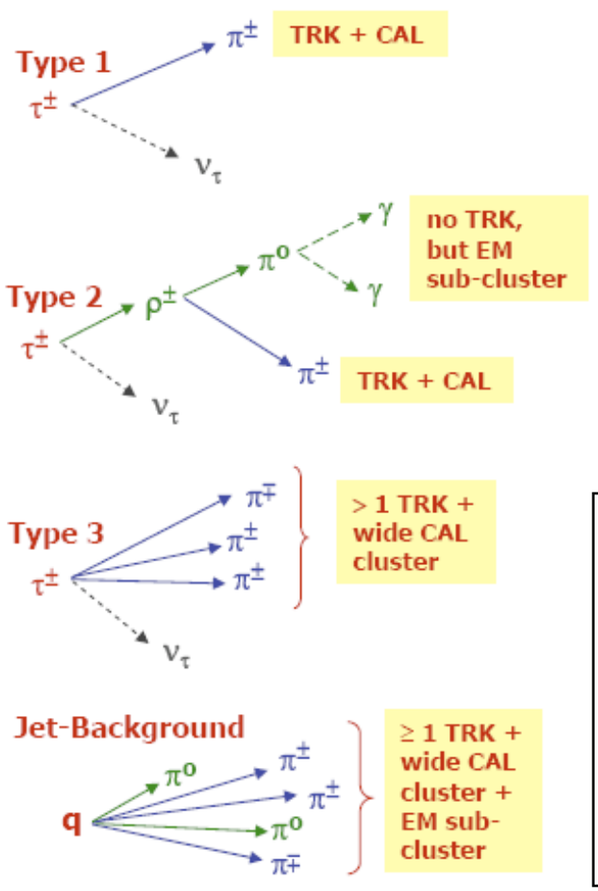


- BACKUP

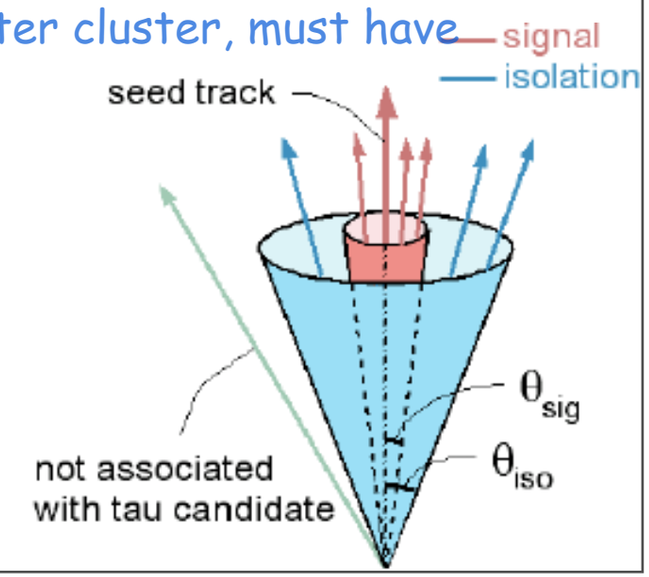
τ identification D0 & CDF

- Hadronic tau decay
- $Z \to \tau\tau$ Cross Section
- CDF measured in $\tau_e \tau_h$ channel
  ε*BR = 265 ±20 (stat) ±21 (syst)
- D0 $\tau_\mu \tau_{h,e}$
  ε*BR = 237 ±15 (stat) ±18 (syst)





CDF: Start with a calorimeter tower, ET > 6 GeV.
Add up to 6 contiguous towers with ET > 1 GeV.
Associate tracks with the calorimeter cluster, must have at least one track with pT > 6 GeV.
Tau cone defined by seed track, half angle, θsig = 50 – 175 mrad, depends on cluster energy.
Isolation annulus
1 or 3 tracks, charge = 1, in θsig
Reconstruct π0's.
Require M(tracks,π0's) < 1.8 GeV



D0: Start with calorimeter cluster, simple cone algorithm, cone size R = 0.3. Isolation cone, R = 0.5, require rms < 0.25 where rms = Energy weighted width of cluster = Associate EM subclusters: Nearest neighbour algorithm in 3rd EM layer, EM cells in other layers
Associate up to 3 tracks with pT > 1.5 GeV to the tau