Higgs Searches @ the Tevatron

P.A.F, September 12th 2007,

Gregorio Bernardi, LPNHE-Paris

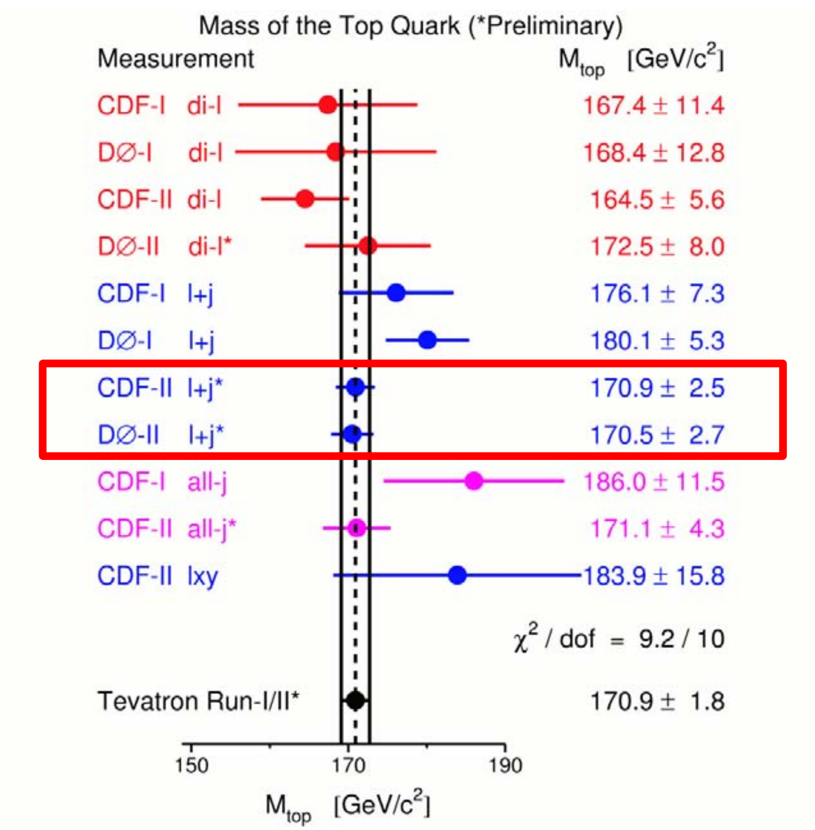
for the CDF and DØ Collaboration

- **Introduction to the Higgs Mechanism**
- **Tevatron & Detectors**
- **Standard Model Higgs Searches**
- **Discovery Prospects**
- **Beyond the S.M. Higgs Searches**
- **Conclusions**

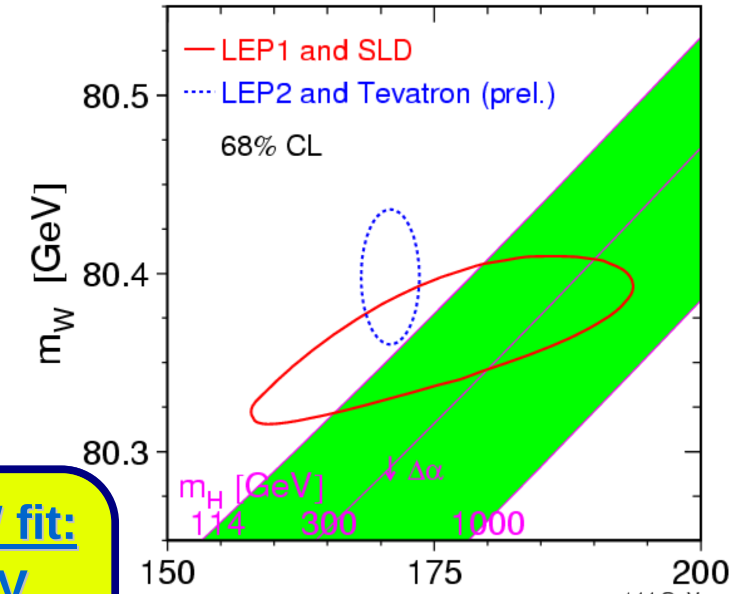
Experimental constraints on the Higgs Boson

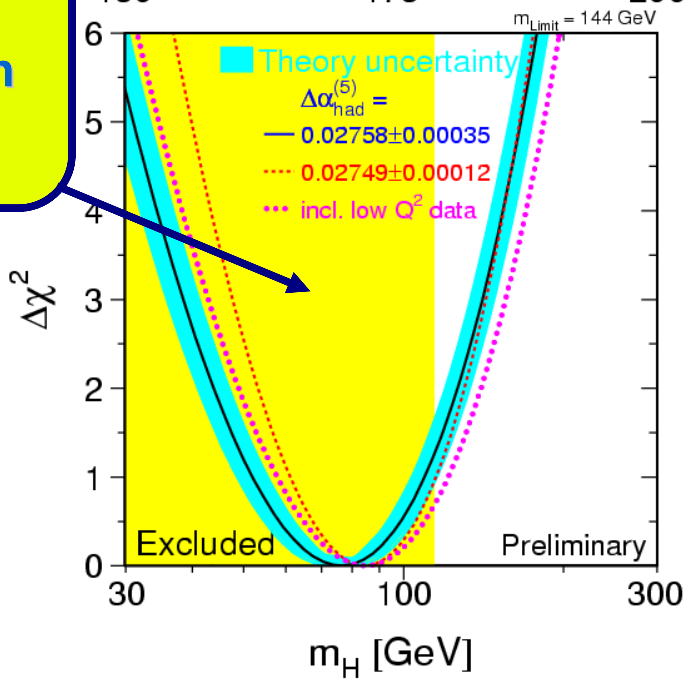
Indirect Constraints:
Top, W-boson masses

Direct searches at LEP II:
m_H>114.4 GeV @ 95% CL



Precision EW fit:
m_H<144 GeV
(<182 GeV with LEPII Limit)





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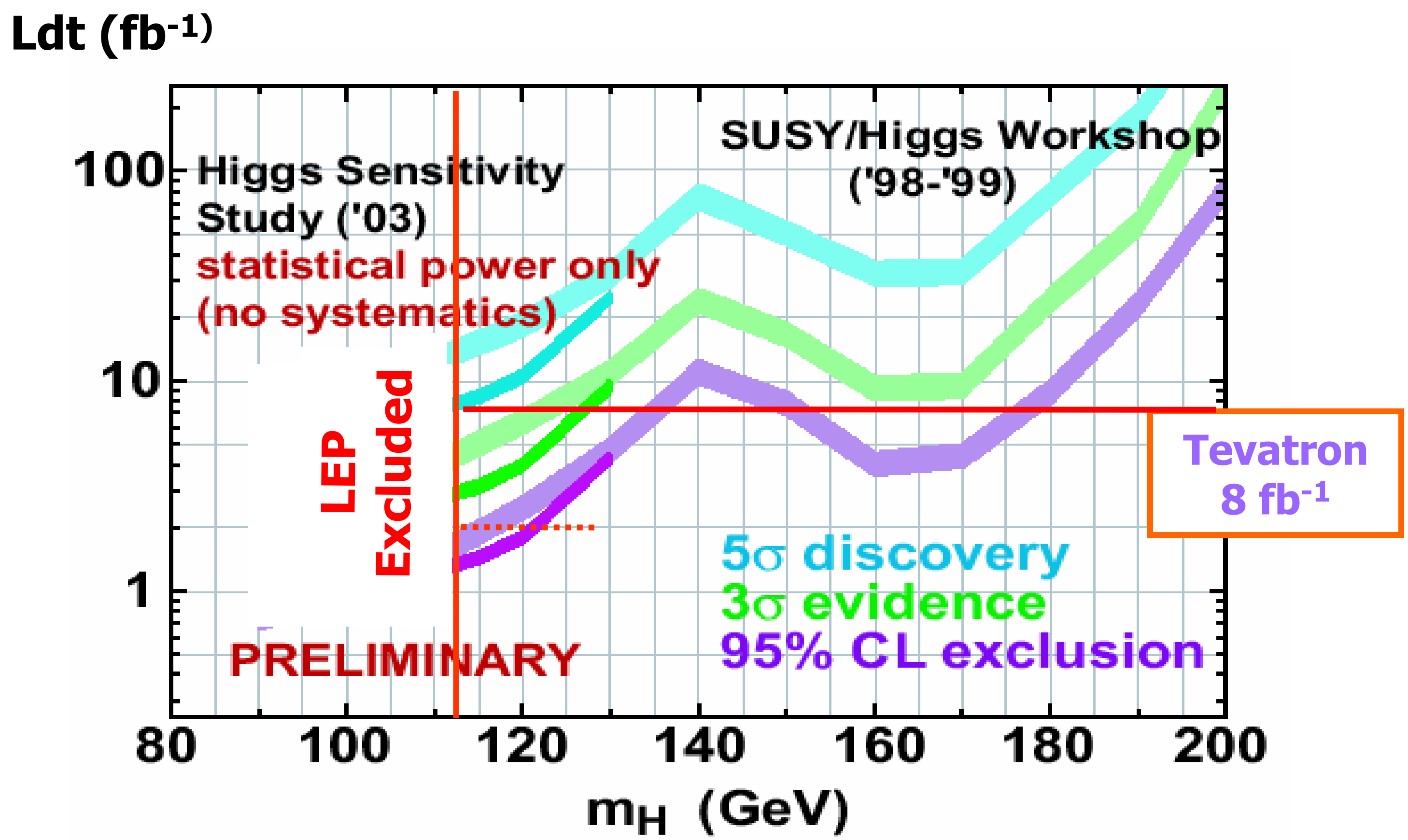
Tevatron SM Higgs Search: Outlook



In earlier studies, the Tevatron sensitivity in the mass region above LEP limit (114 GeV) was estimated to start at ~2 fb^{-1}

with 8 fb^{-1}: exclusion would be 115-135 GeV & 145-180 GeV,

Now, we are:

→ optimizing analysis techniques, understanding detectors better

→ measuring SM backgrounds (ttbar, Zbb, Wbb, WW, single top!)

→ Placing first Combined Higgs limits and compare to the prospects

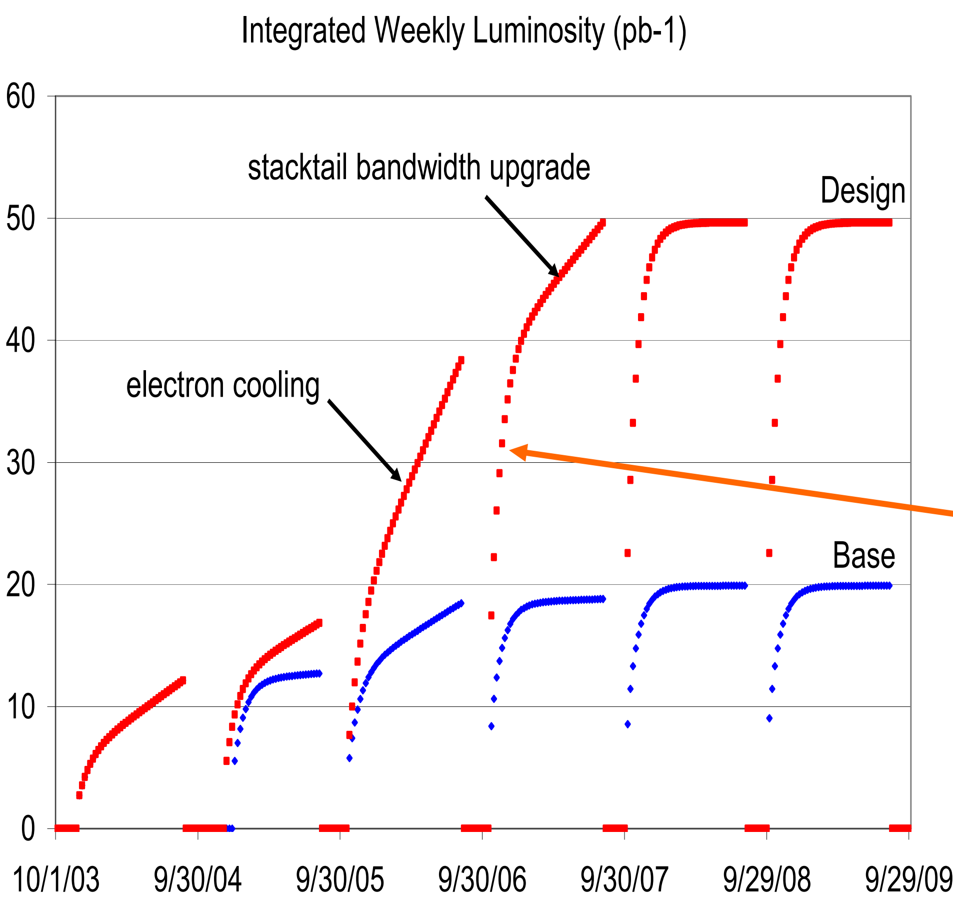
Tevatron Long Term Luminosity Plan

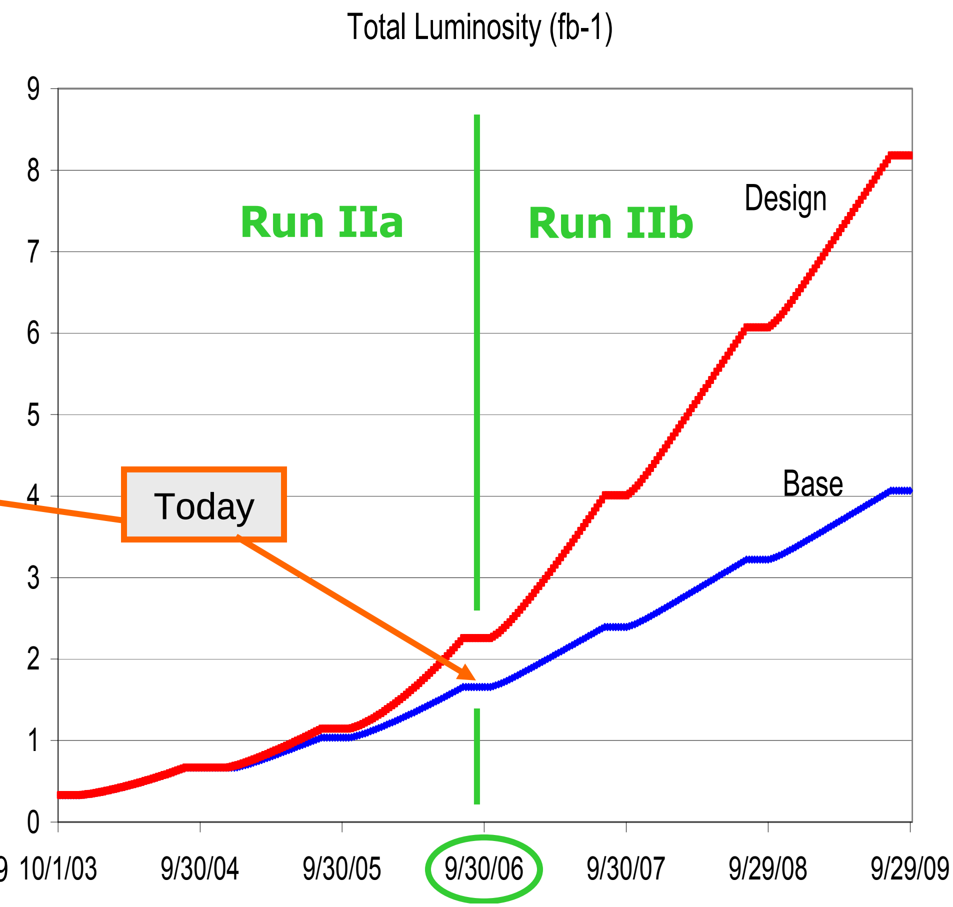
Increase in number of antiprotons
→ key for higher luminosity

Expected peak luminosity
→ $3 \cdot 10^{32}$ cm^{-2}sec^{-1} in 2007

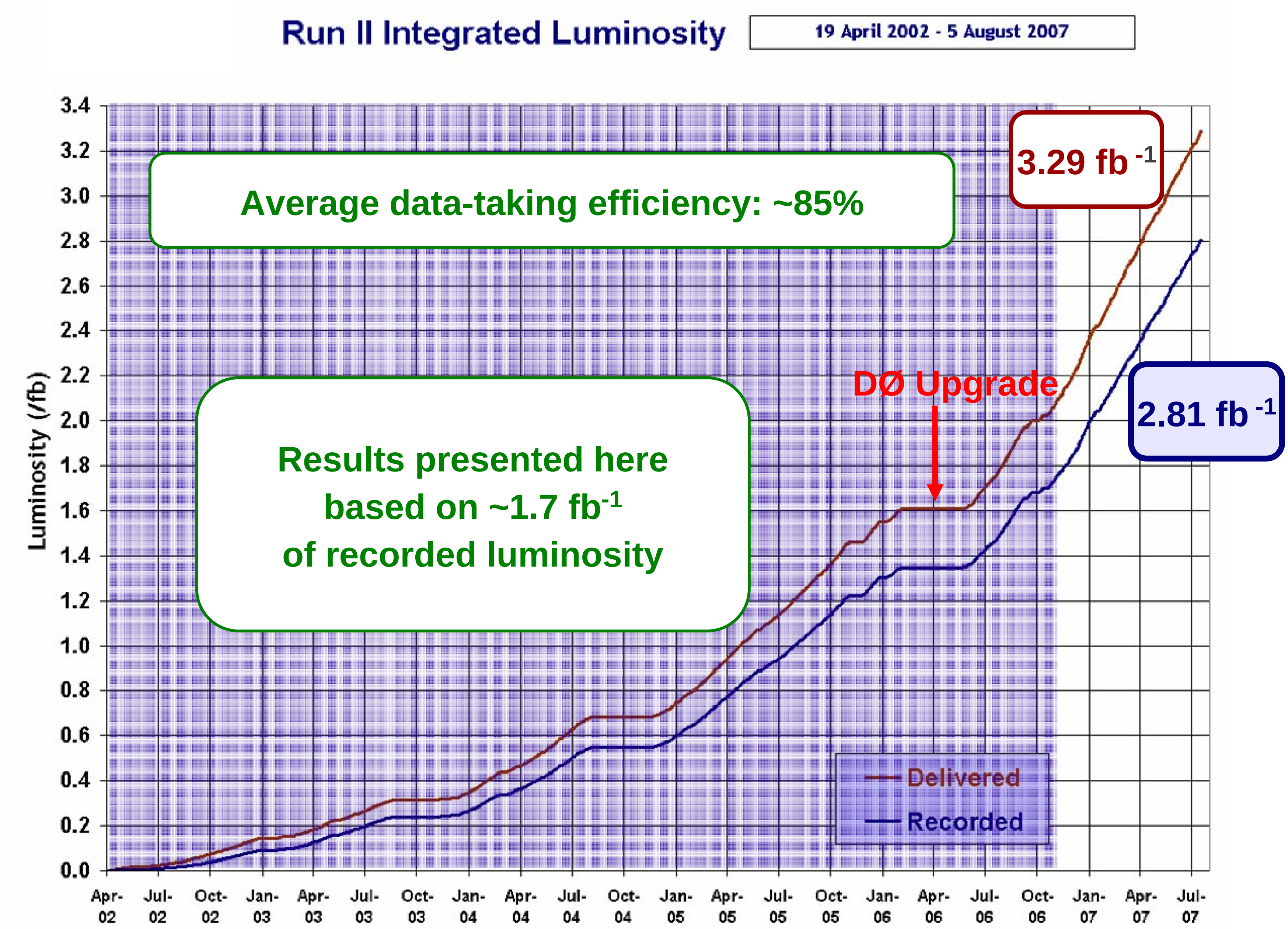
Currently expecting delivered luminosity to each experiment

→ 6- 8 fb^{-1}
by the end of 2009



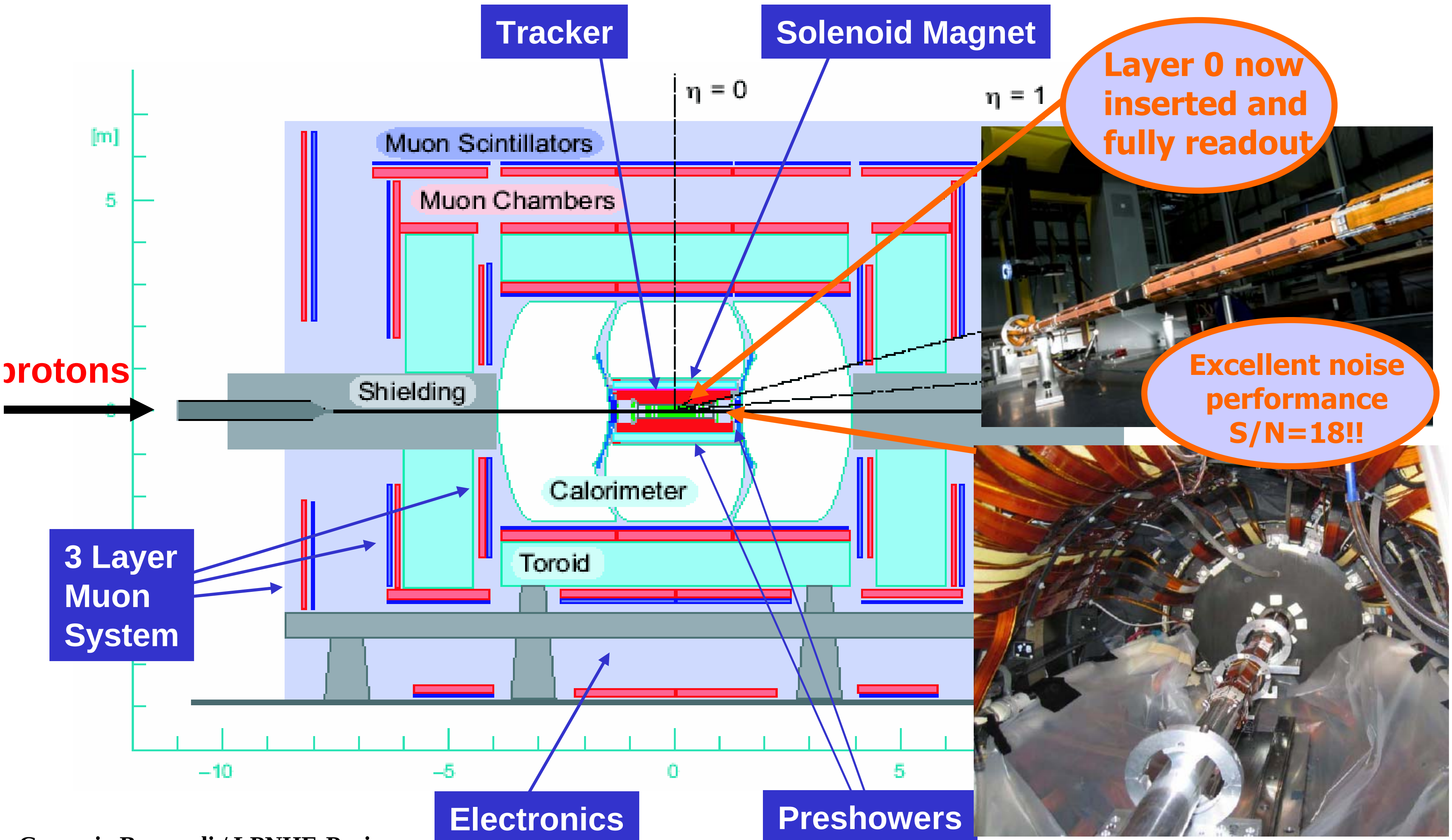


Dataset

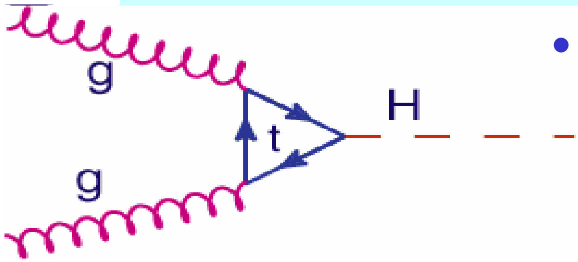

Run II Integrated Luminosity
19 April 2002 - 5 August 2007
Average data-taking efficiency: ~85%
Results presented here
based on ~1.7 fb^{-1}
of recorded luminosity
3.29 fb $^{-1}$
2.81 fb $^{-1}$
DØ Upgrade
Delivered
Recorded
Luminosity (/fb)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07

The Upgraded DØ detector in Run IIb

- **Trigger: L1 Calorimeter trigger**
- **Silicon vertex detector: Layer 0**

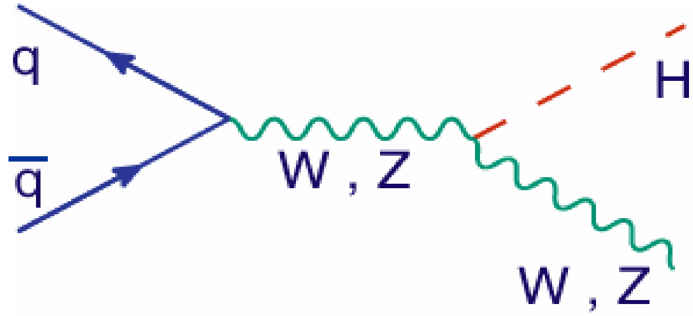


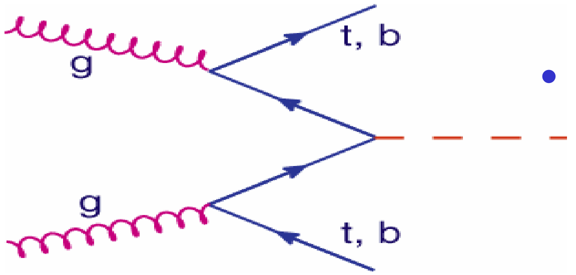
SM Higgs boson production



- **gg fusion**
  - Dominates at hadron machines
  - Usefulness depends on the Higgs decay channel

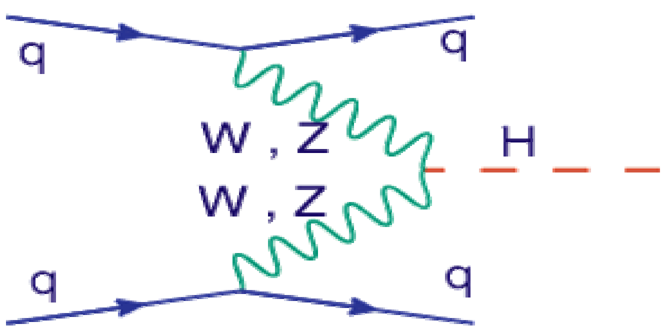
- **WH, ZH associated production**
  - Important at hadron colliders since can trigger on 0/1/2 high-p_T leptons and MET





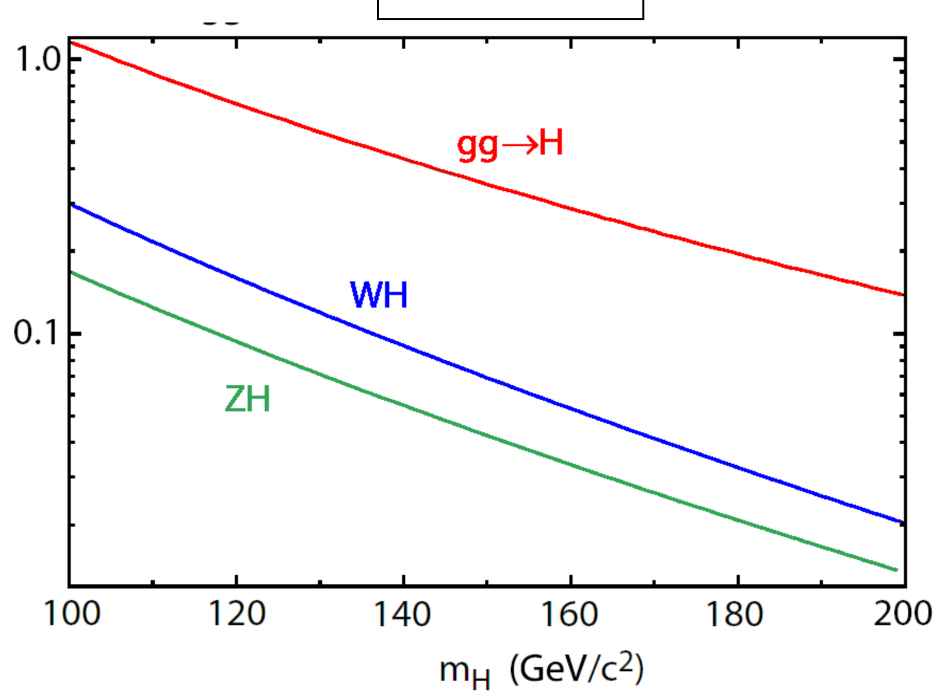
- **ttH and bbH associated production**
  - High-p_T lepton, top reconstruction, b-tag
  - Low rate at the Tevatron

- **Vector Boson Fusion**
  - Two high-p_T forward jets help to “tag” event
  - Important at LHC, being studied at DØ

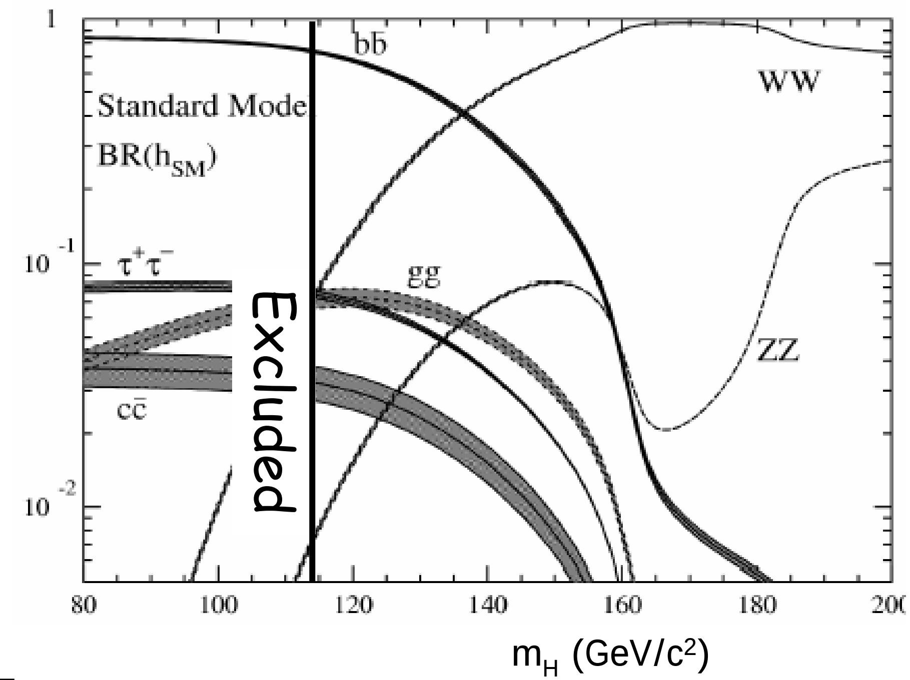


SM Higgs Production and Decays

Production



Decays



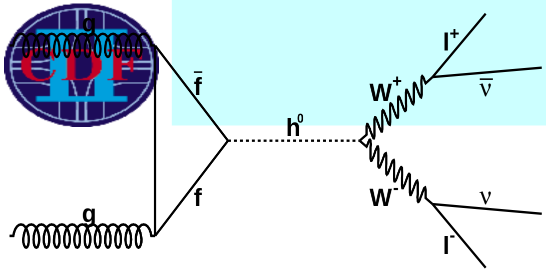
Production cross section (m_H 115-180)
→ in the 0.8-0.2 pb range for gg → H
→ in the 0.2-0.03 pb range for WH
associated vector boson production

Dominant Decays
→ $b\bar{b}$ for M_H < 135 GeV
→ WW^* for M_H > 135 GeV

Search strategy:

M_H <135 GeV: associated production WH and ZH with H→bb decay
Backgrounds: top, Wbb, Zbb…

M_H >135 GeV: gg →H production with decay to WW^* or WH→WWW^*
Backgrounds: WW, DY, WZ, ZZ, tt, tW, $\tau\tau$



H → WW* → lνlν

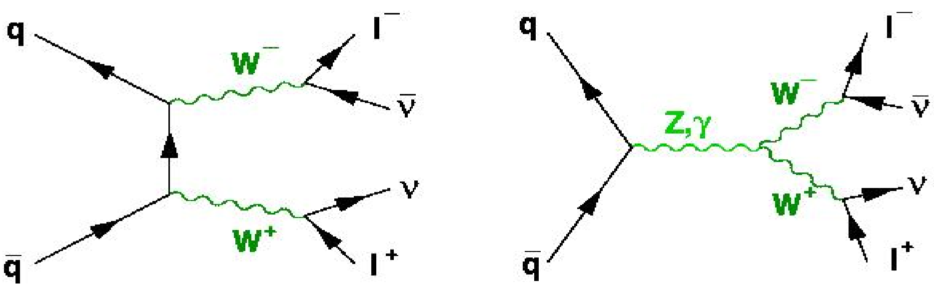
DØ analysis: L ~ 1.0 fb^{-1} in H → WW* → e-e
L ~ 0.9 fb-1 in H → WW* → mu-mu
L ~ 1.7 fb-1 in H → WW* → e-mu

Selection Strategy

- **Presection:** **lepton ID, trigger, opposite charge leptons**
- **Remove QCD and Z→l^+l^-:** **$\not{E}_T$ > 20 GeV**
- **Higgs Mass Dependent Cuts:** **Invariant Mass (M_{l+l-}); Min. Transverse Mass**
  Sum of lepton p_T^l and E_T ($\Sigma\, p_T^l + E_T$)
- **Anti tt(bar) cut:** **$H_T = \Sigma\, P_T^{jet} < 100$ GeV**
- **Spin correlation in WW pair:** **$\Delta\phi(l,l) < 2.0$**

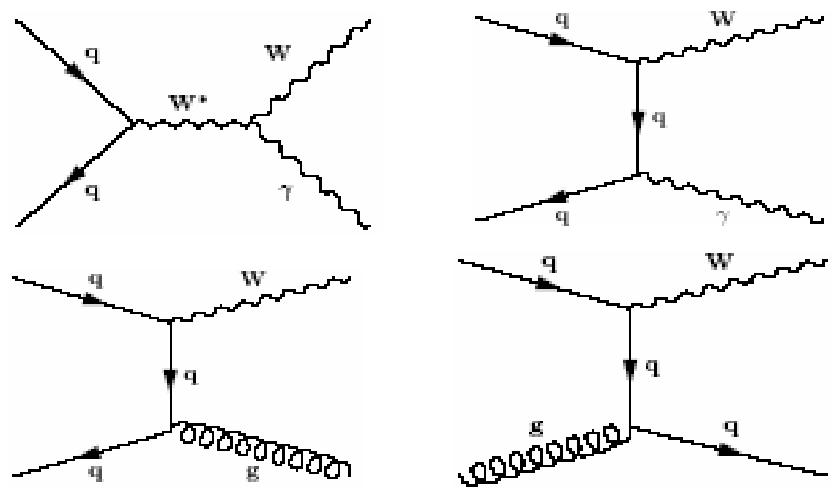
Major backgrounds

WW production



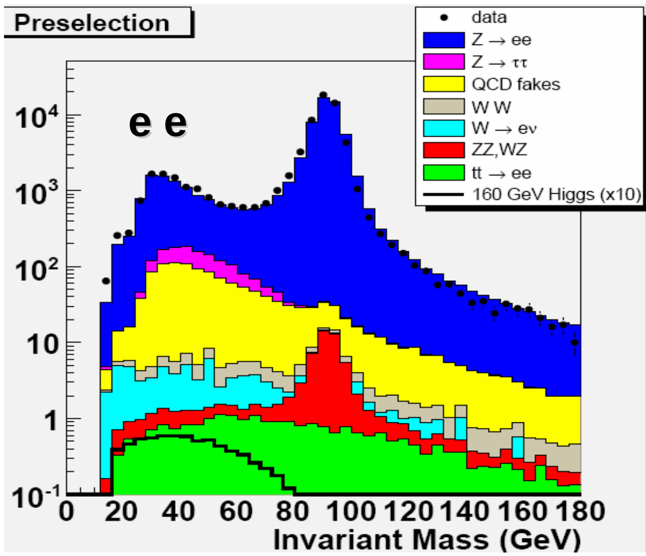
Now measured at the Tevatron by both expts.
in agreement with NLO calculation: ~13.5 pb

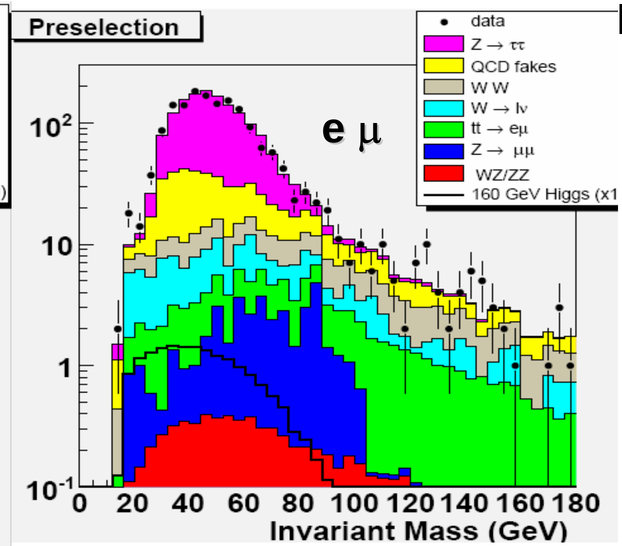
W + jet/γ production:

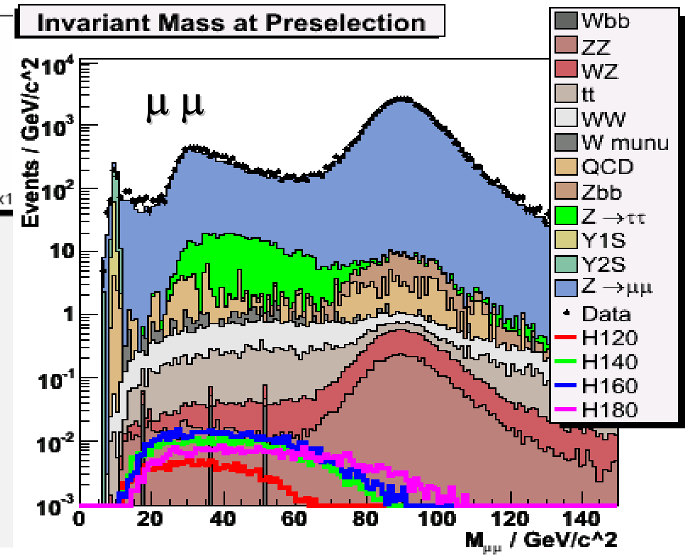


$H \rightarrow WW^* \rightarrow ee$ / $e\mu$ / $\mu\mu$ ($\sim 1\ fb^{-1}$)

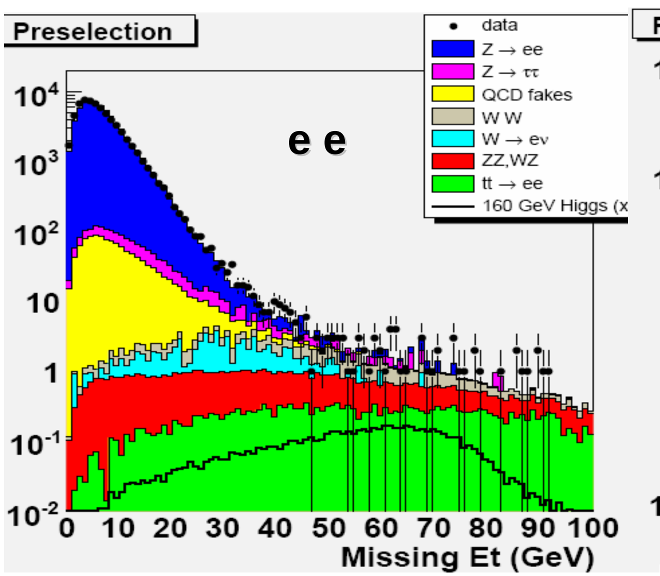
Preselection: Trigger, ID, leptons of opposite charge: $p_T^{l1} = 15$ GeV; $p_T^{l2} = 10$ GeV

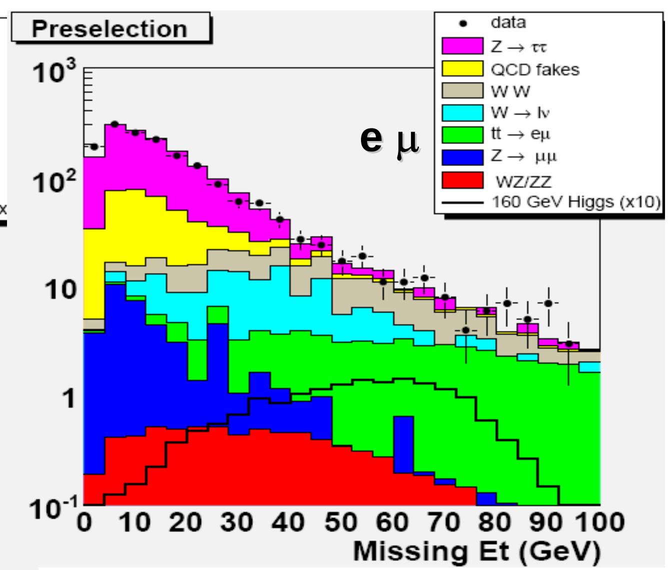


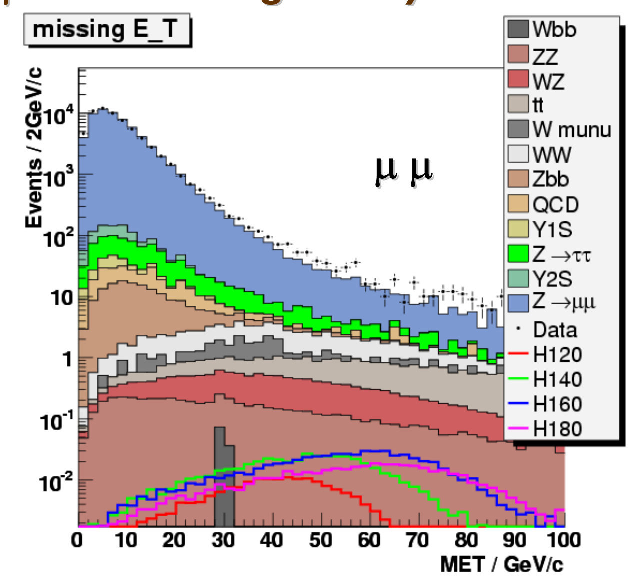




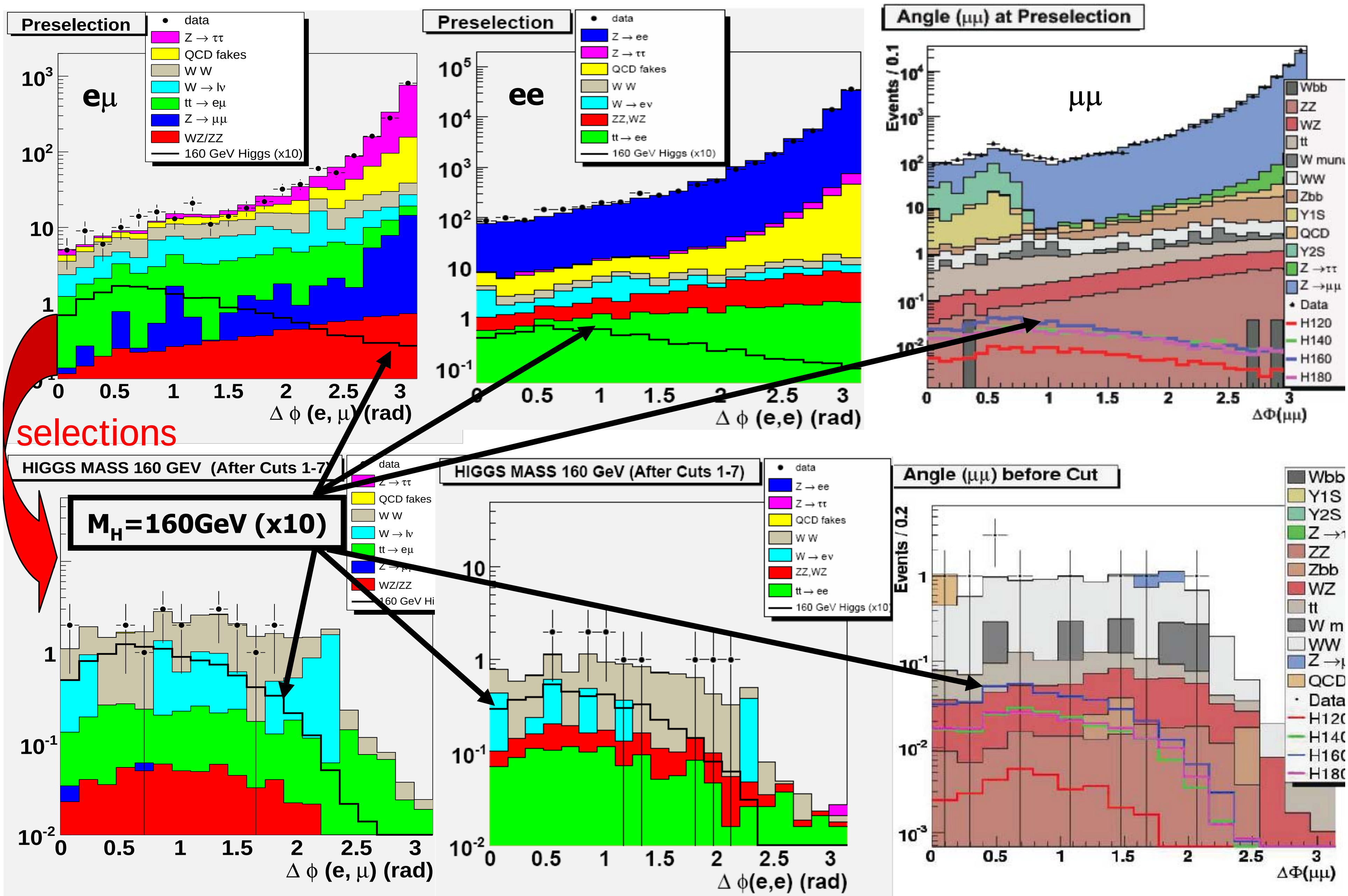
Missing Transverse Energy > 20 GeV Cut (to suppress $Z/\gamma^* \rightarrow l^+l^-$ background)





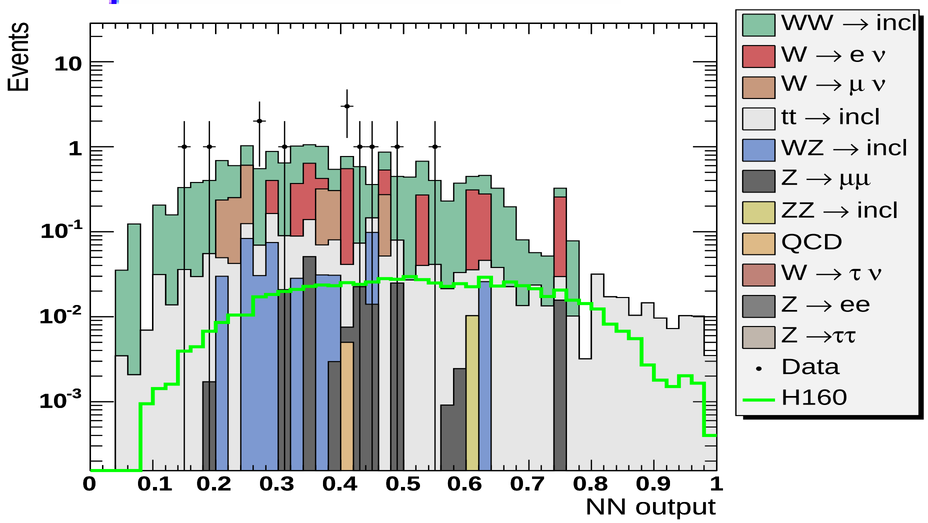


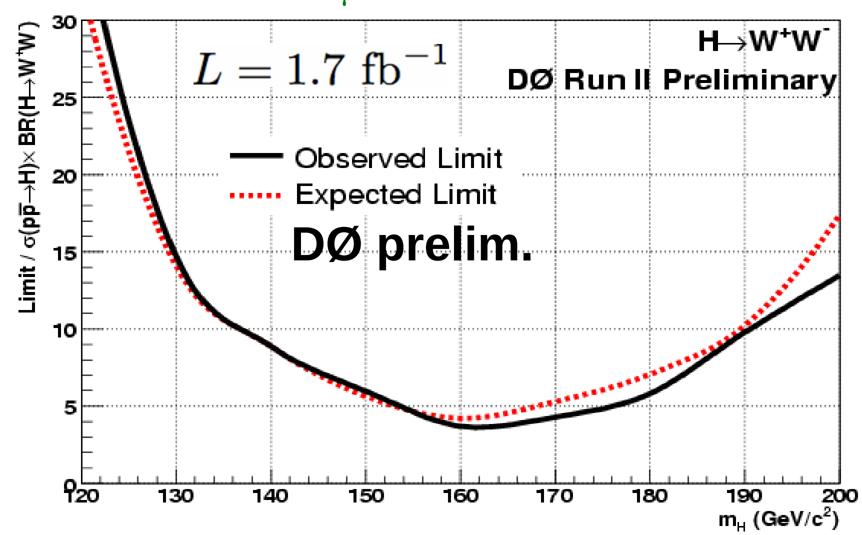
H→WW* : final selection



H→WW* / Neural Net & μτ @ Dzero

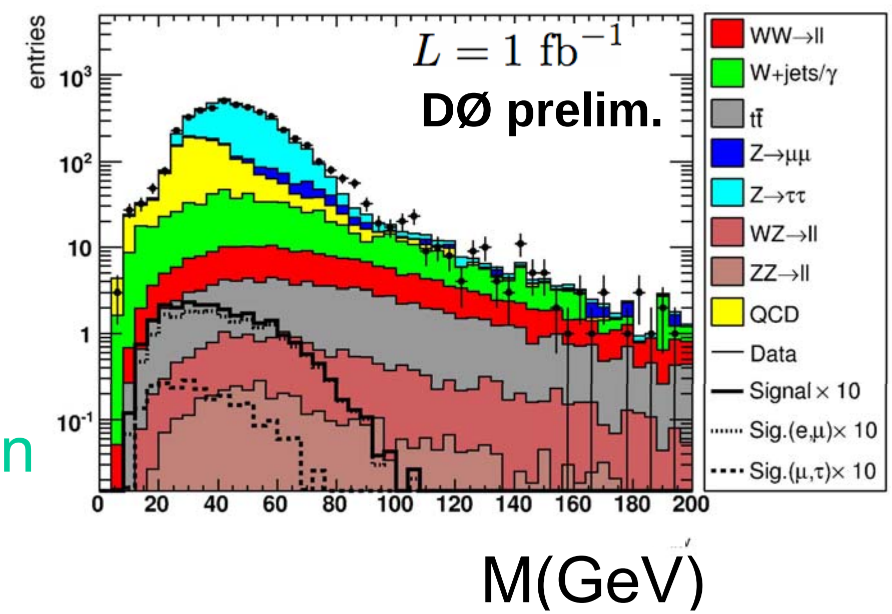
μe final state (normalised to $Z \rightarrow \tau_e \tau_\mu$)



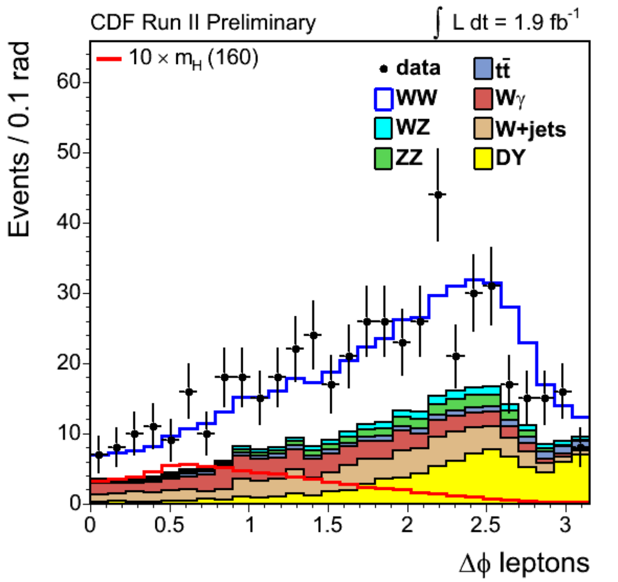


$\mu \tau_{had}$ final state

- hadronic tau reconstruction challenging at hadron collider
- $Z \rightarrow \tau_\mu \tau_{had}$ has been observed
- adds sensitivity, no NN yet, not yet Included in the combination

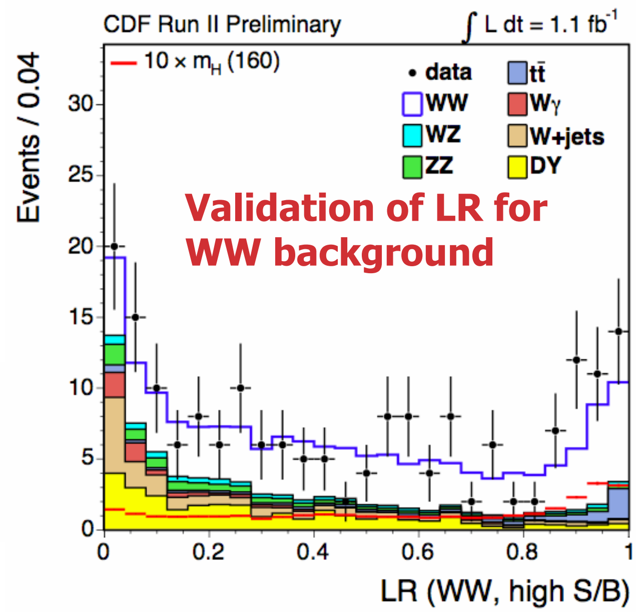


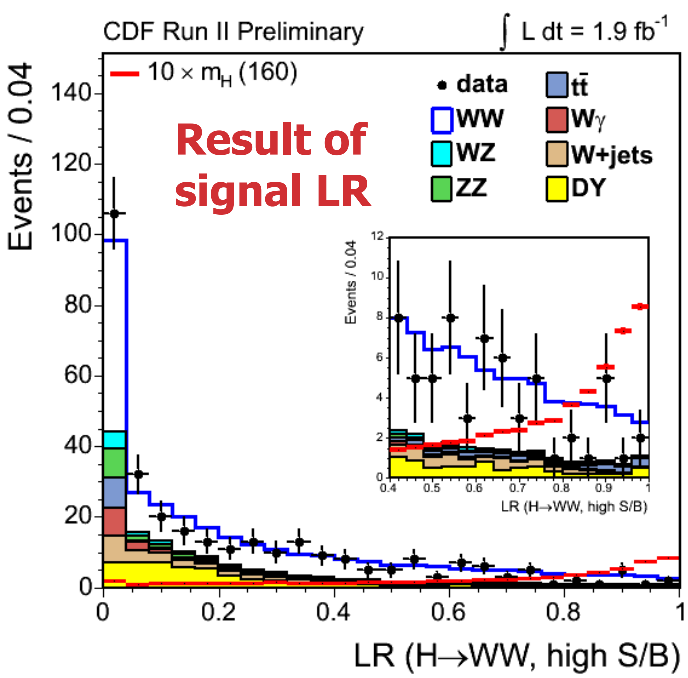
$H \rightarrow WW^*$: matrix element @ CDF



Likelihood Ratio from Matrix Element probabilities of $H \rightarrow WW$, WW, ZZ, W+fakes & conversions

$$LR = \frac{P_{Higgs}(M_H)}{P_{Higgs}(M_H) + \sum_i f_{bkg,i} P_{bkg,i}}$$





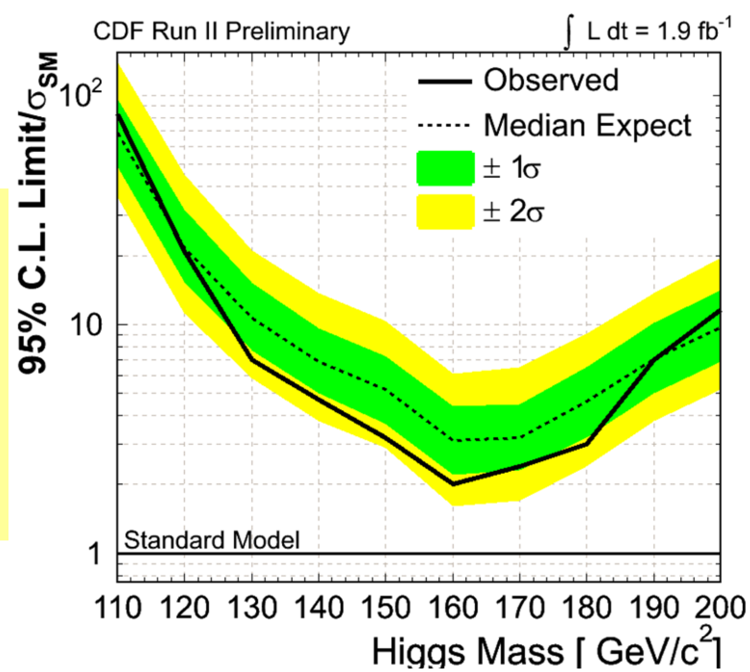
CDF new result

- **Expected limit**

< 3.1 times SM

- **Observed limit**

< 2.0 times SM

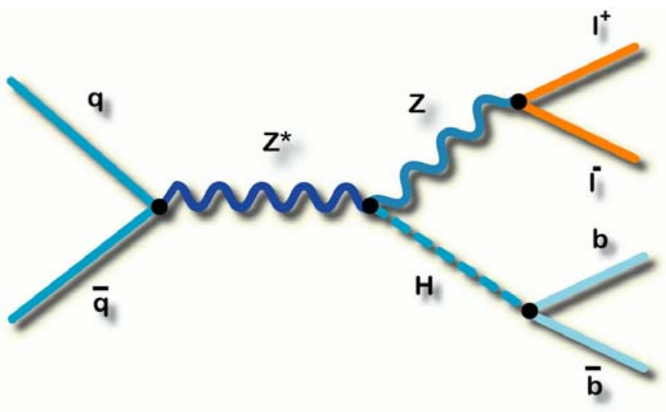


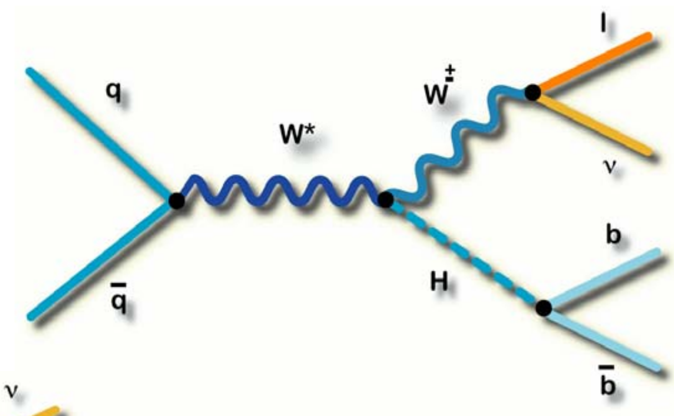
Associated Higgs Production

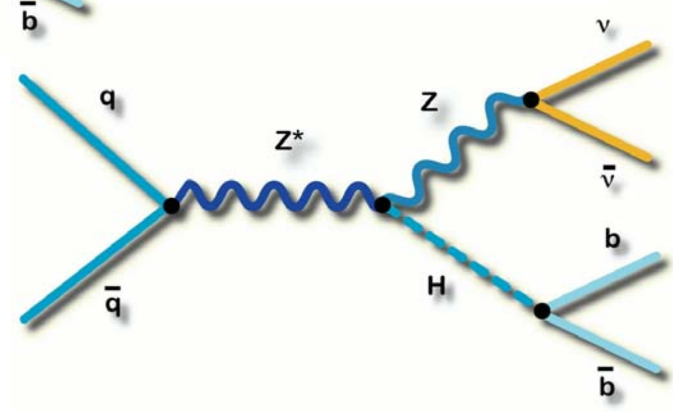
Experimental Signature

Leptonic decay of W/Z bosons provides "handle" for event

Higgs decay to two bottom-quarks helps reduce SM backgrounds





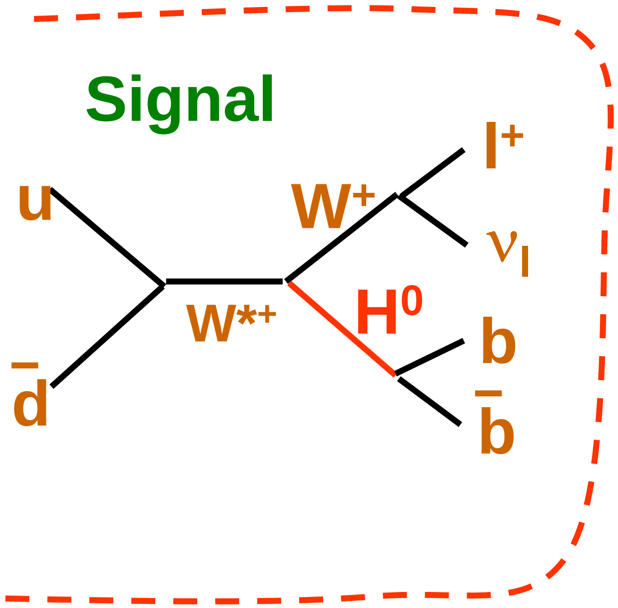


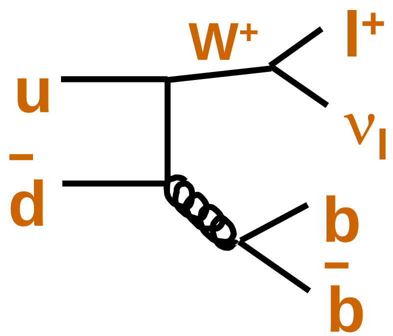
Event Yields/sensitivity for H→bb, with 1 fb^{-1}

Expected/Observed Events in 1.0fb^{-1} mH=115 GeV, 70<djMass<130 GeV				
Channel	**Signal**	**Bkgd**	**Data**	**S/ sqrt(B)**
WH→ l ν bb 2Tag	1.45	86.6	91	0.156
WH→ l ν bb 1Tag	1.48	365.2	339	0.077
WH/ZH→ MET+bb	0.83/ 0.54	55.3	63	0.184
ZH→ l l bb	0.37	19.8	17	0.083

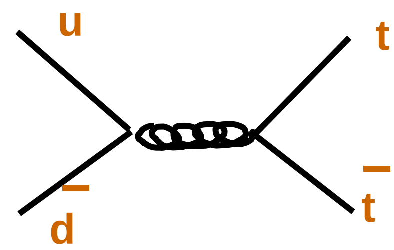
ZH→ ννbb channel has large cross efficiency from WH signal (lost/undetected lepton + hadronic tau decays: W → τν) ➔ almost as sensitive although cross-section is lower.

SM Higgs Searches @ Tevatron: WH→lνbb

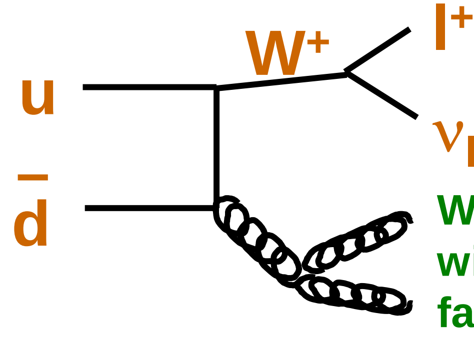




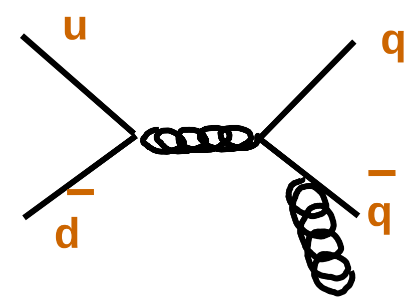
Large background (also Wcc̄)



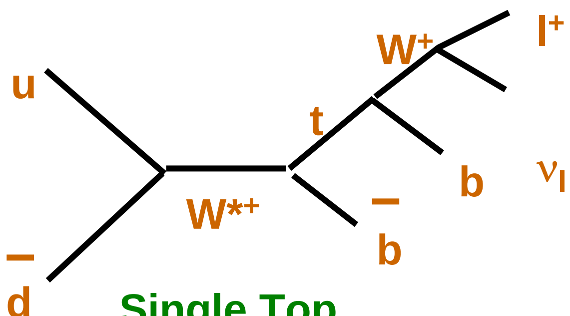
"ttbar": Jets+leptons from W decay



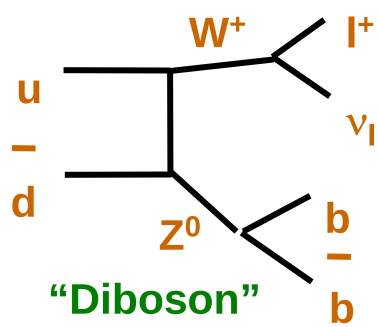
W+2 light jet with one/two false b-tag



"Non-W from QCD"



Single Top



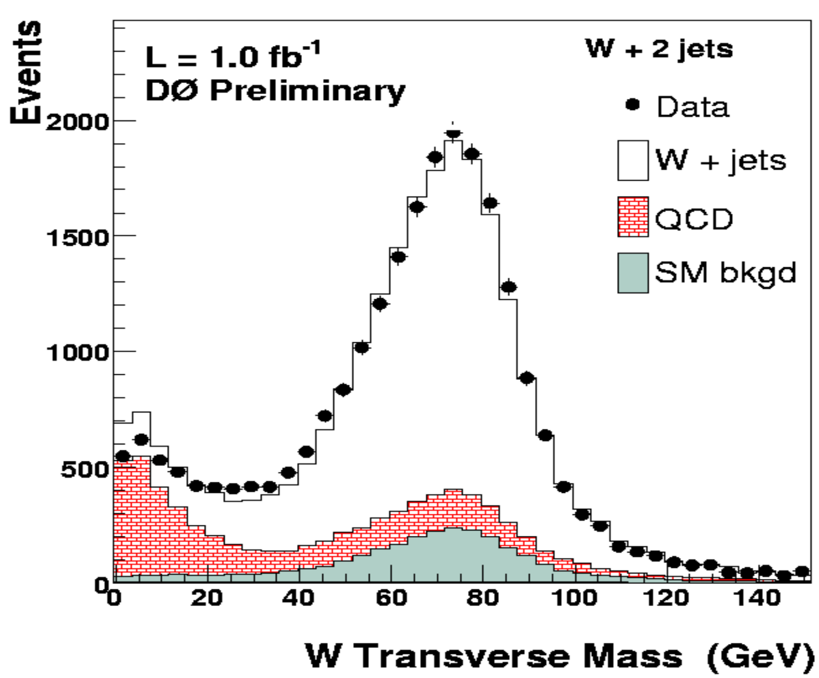
"Diboson"

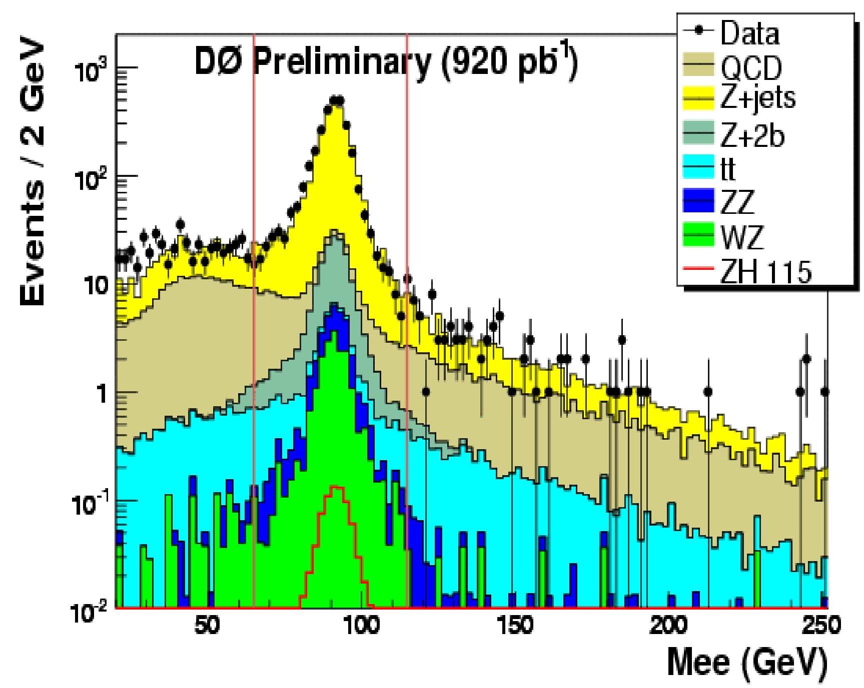
and "Non-W from EW", e.g. all Zbb processes In which one lepton is lost

Selecting W→lνbb & ZH→llbb

- Select events by utilizing vector-boson decay signatures
  - Require one(two) high-pT leptons: pT > 20(15) GeV)
  - Neutrinos manifest as missing transverse energy
    - **WH→lνbb:** MET > 20 GeV, **ZH→llbb:** MET *should be small!!*
  - Reconstruct vector boson mass
- Use "OR'ing" of muon triggers: 100% efficiency & +15% in sensitivity

$$M_W^{trans} = \sqrt{2\, p_T^l ME_T (1 - \cos(\Delta\phi))}$$

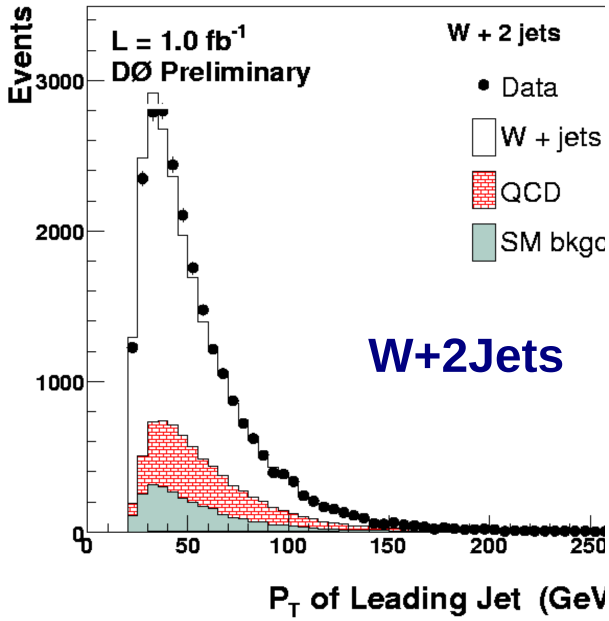


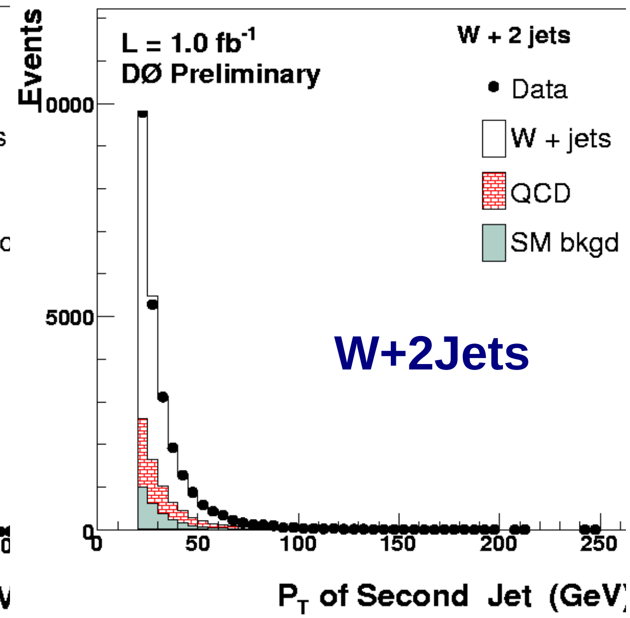


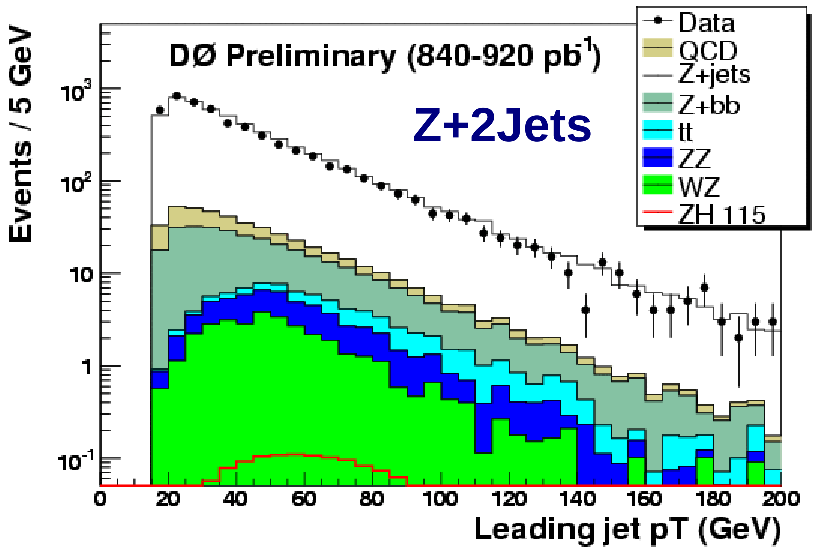
W→lν & ZH→ll + Jets

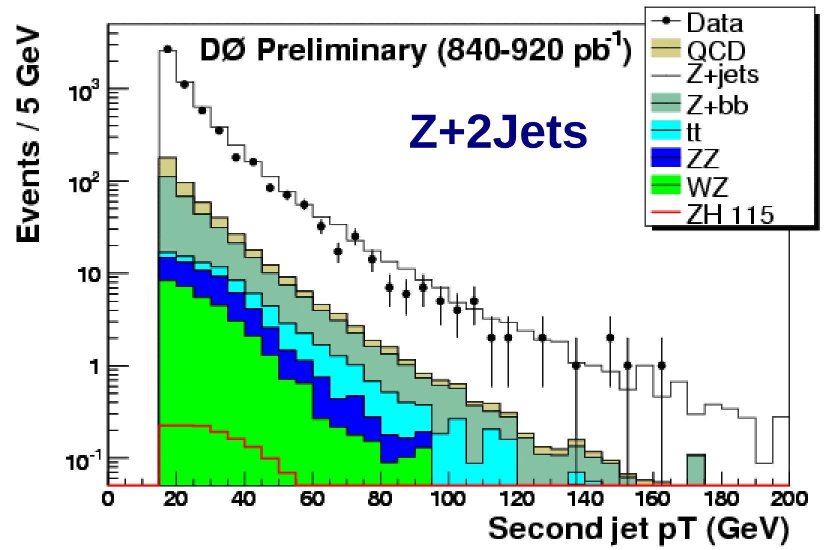
Select high-pT, central jets as a step towards a Higgs signature

- **WH→lνbb:** pT>20 GeV
  |η|<2.5
- **ZH→llbb:** pT>15 GeV
  |η|<2.5





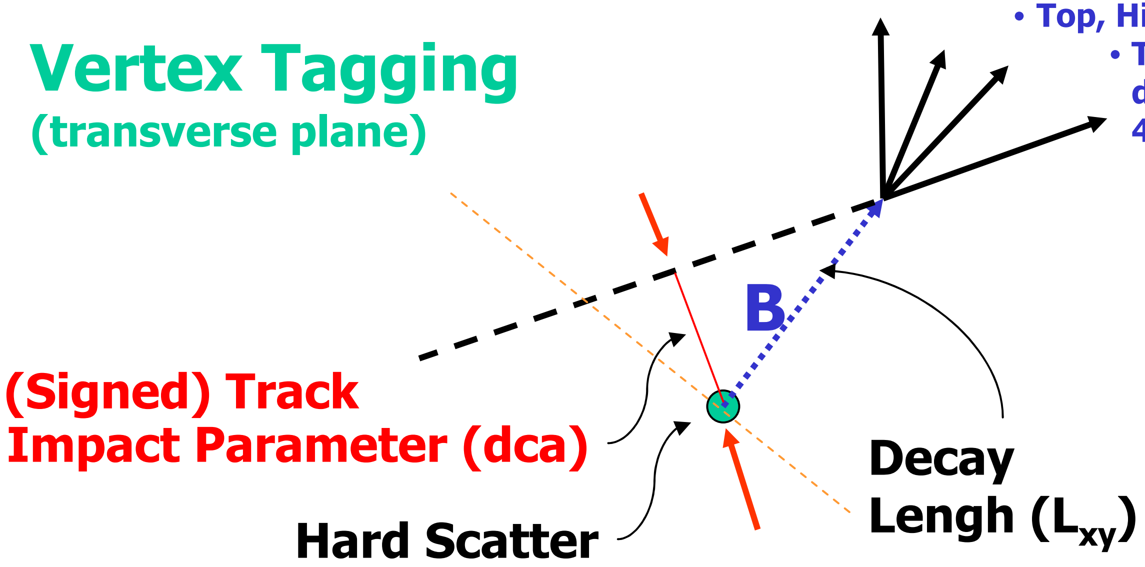


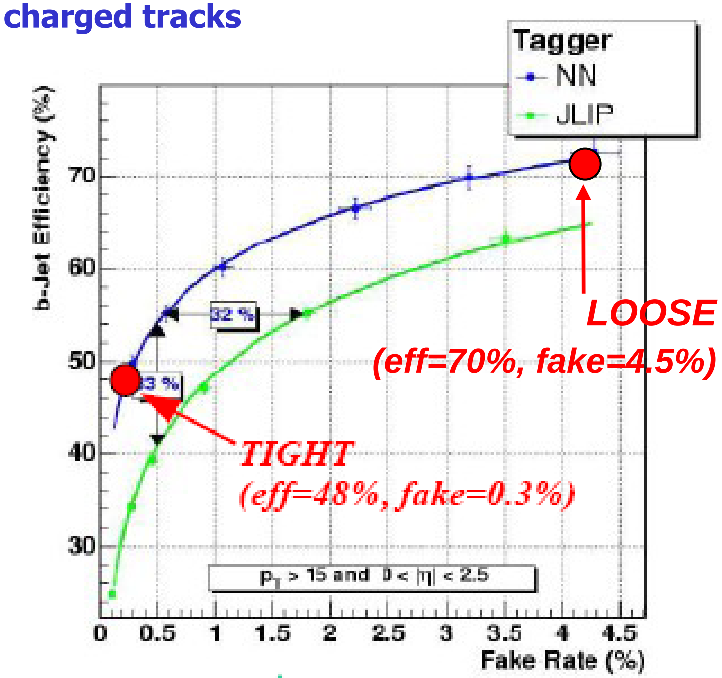


Tagging b-quarks (B-hadrons)

Vertex Tagging
(transverse plane)

- Top, Higgs have 2 b-quark jets→ contains a B hadron
  - Travels some distance from the vertex before decaying -With charm cascade decay, about 4.2 charged tracks





Several mature algorithms used:

3 main categories:

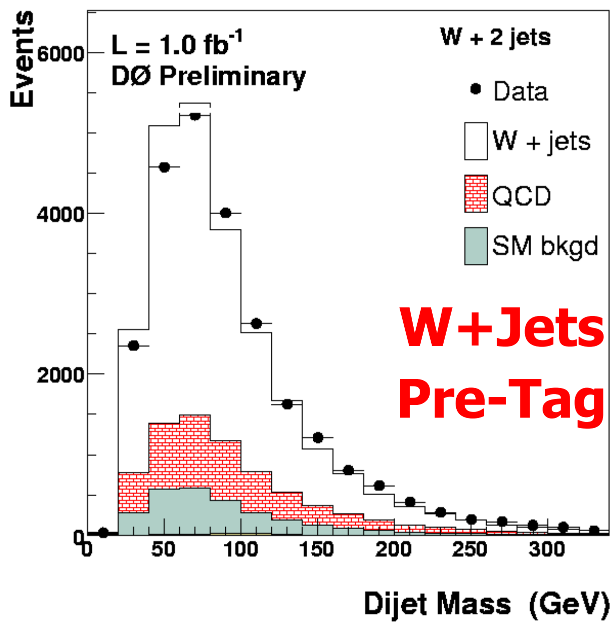
- Soft-lepton tagging
- Impact Parameter based → Impact Parameter Resolution
- Secondary Vertex reconstruction → Decay Length Resolutin

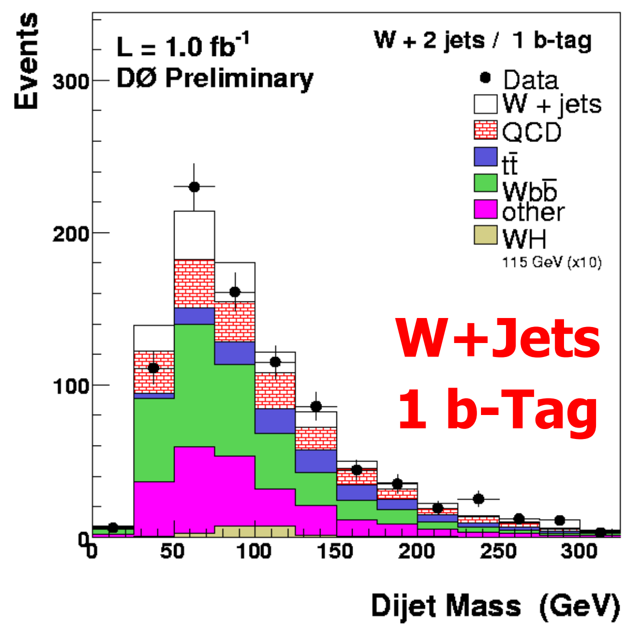
Combine in Neural Network:

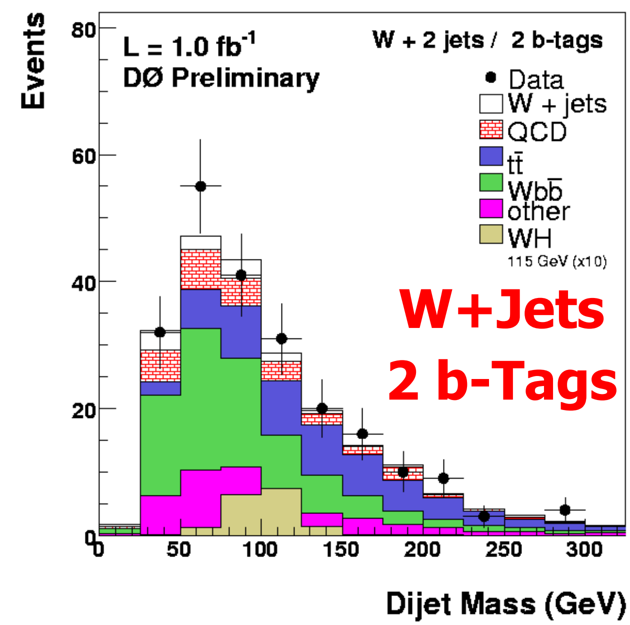
- vertex mass
- vertex number of tracks
- vertex decay length significance
- chi2/DOF of vertex
- number of vertices
- two methods of combined track impact parameter significances

Can analyze separately one b-tag (allowing low mistag) and two b-tag events (allowing larger mistag) to optimize sensitivity

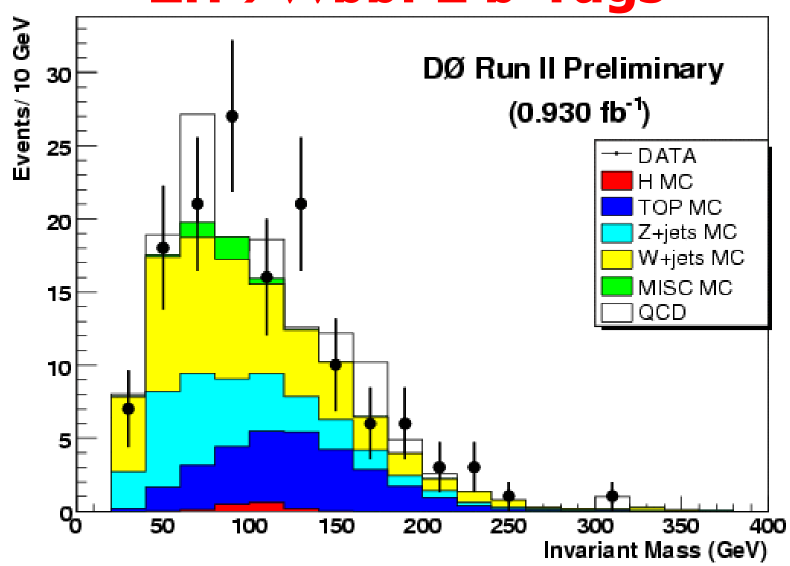
Selecting H→ bb Events



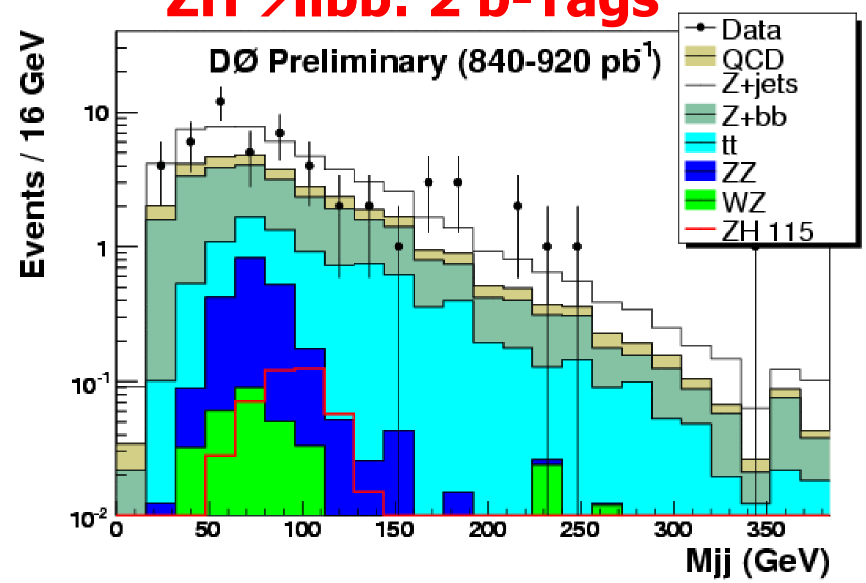




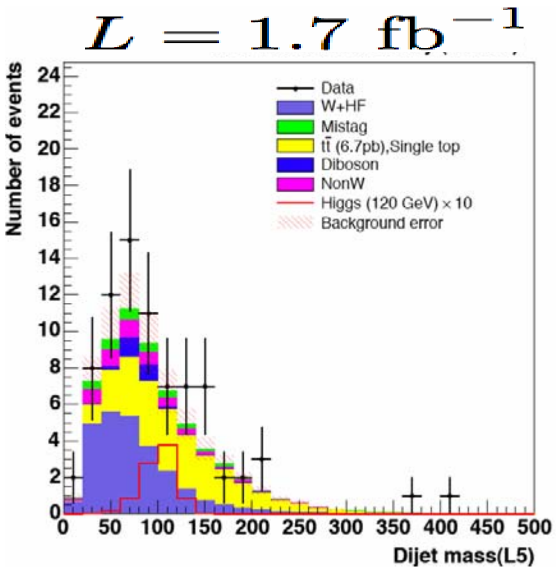
ZH→ννbb: 2 b-Tags



ZH→llbb: 2 b-Tags

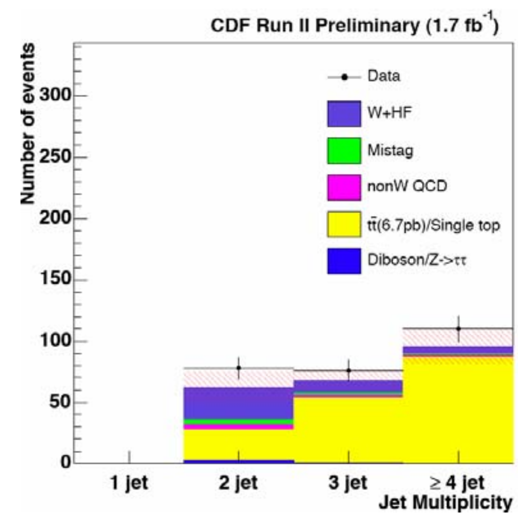


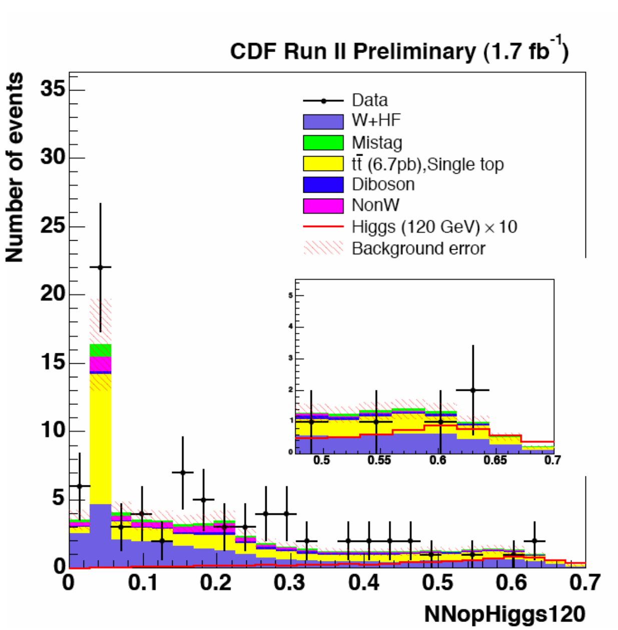
WH→lνbb / Neural Net @CDF

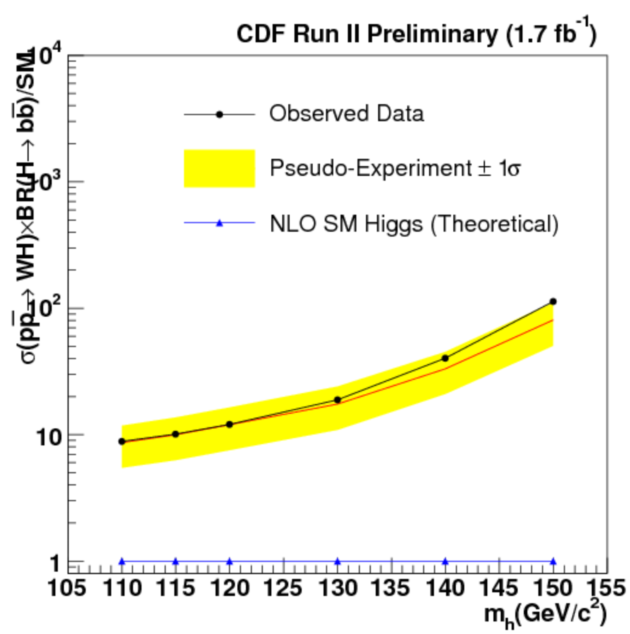


Neural Network trained on event kinematics

two exclusive samples using different b tagging algorithms







m_H = 115 GeV

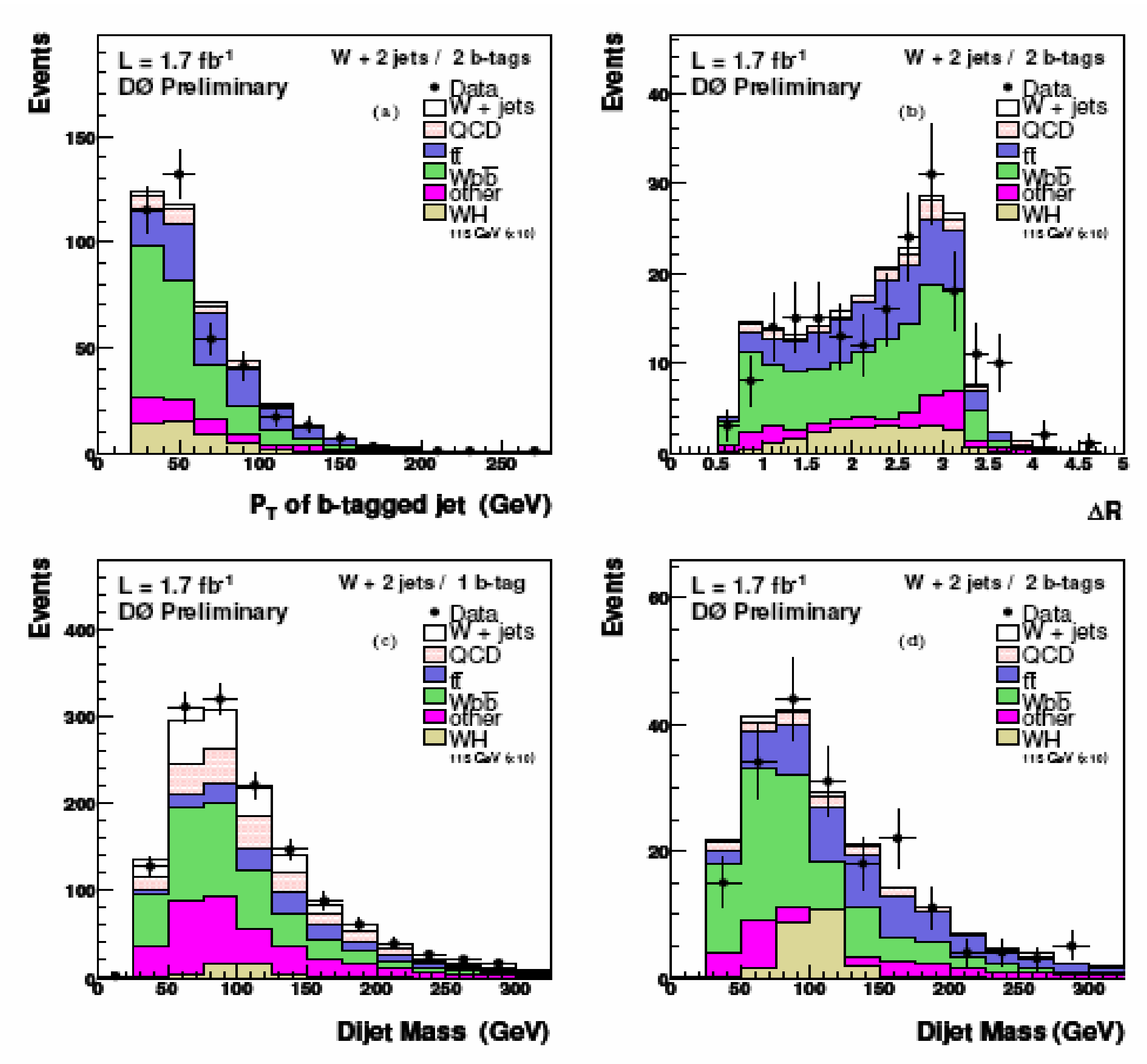
$$\frac{\sigma_{95}(L = 1.7\ \mathrm{fb}^{-1})}{\sigma_{95}(L = 1.0\ \mathrm{fb}^{-1})} \simeq 1.7$$

Sensitivity increased linearly with luminosity:

- more b tagging channels
- Neural Net

WH→lνbb @ Dzero

1 'tight' b-tag   2 'loose' b-tags



$$L = 1.7 \text{ fb}^{-1}$$

Four samples:

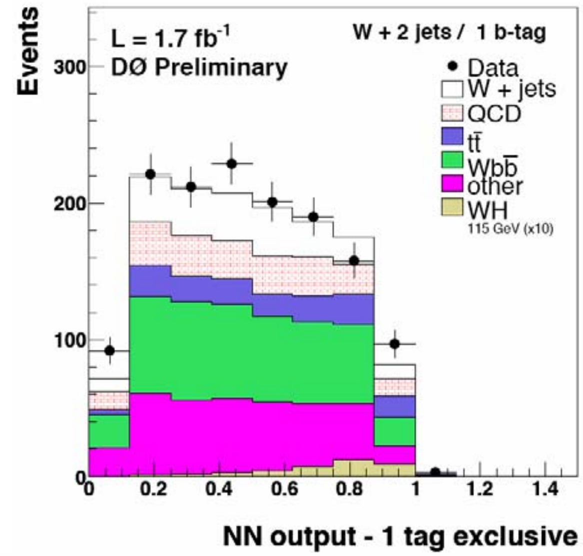
- electron, muon
- 1 b tag, 2 b tags

major background:

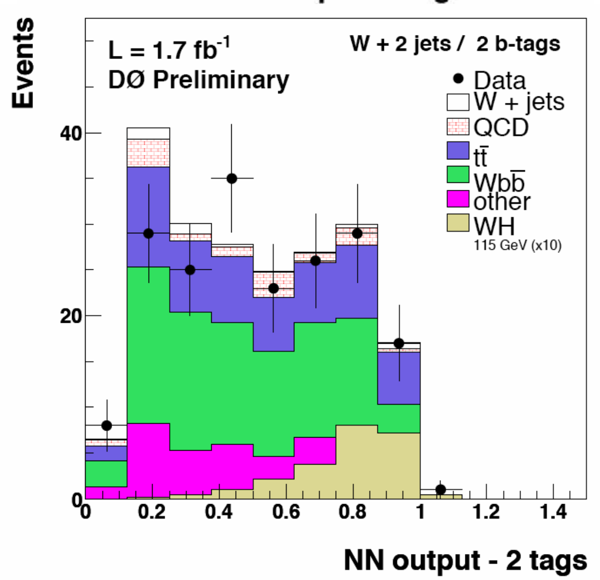
- W plus b-jets
- top pairs

variables used to train Neural Net

WH→lνbb / Neural Net @ Dzero

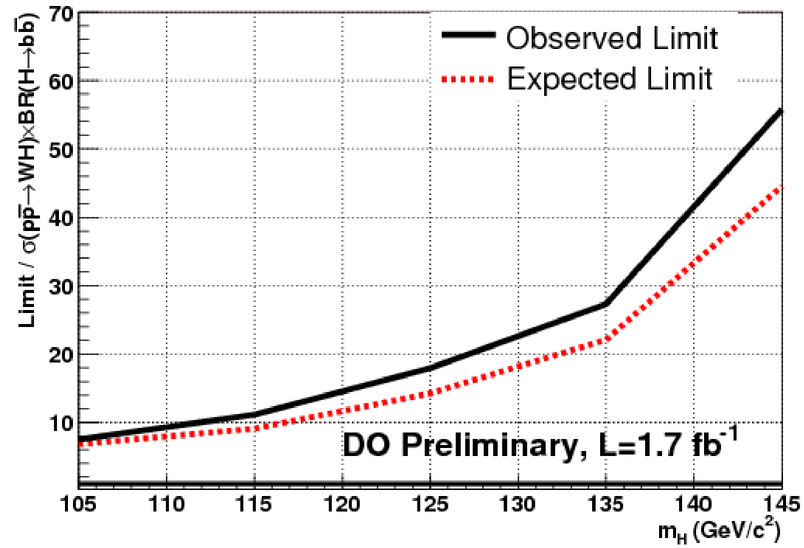


1 b-tag (excl.)



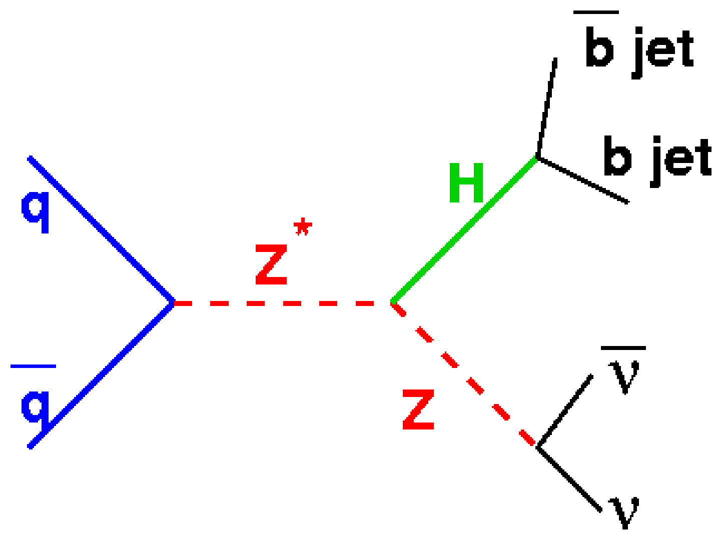
2 b-tags

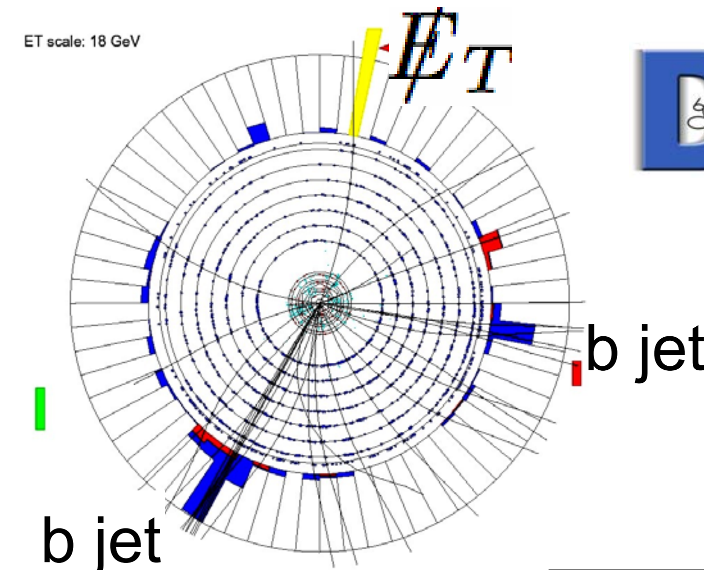
Limit setting using
NN output distributions

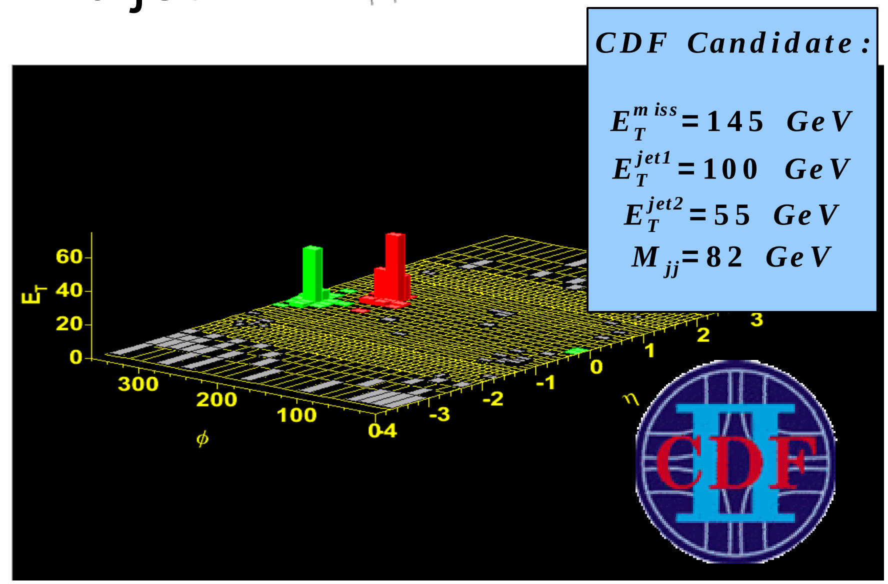


m_H = 115 GeV	CDF exp / obs	DØ exp / obs
σ_{95}/SM	10.0 / 10.1	9.1 / 11.1

ZH→ννbb (WH→ℓνbb) searches







Basic selection:

- two acoplanar jets
- ≥ 1 tagged b-jets (CDF)
  2 tagged b-jets (DØ)
- E_T^{miss} > 70 GeV (CDF)
  50 GeV (DØ)

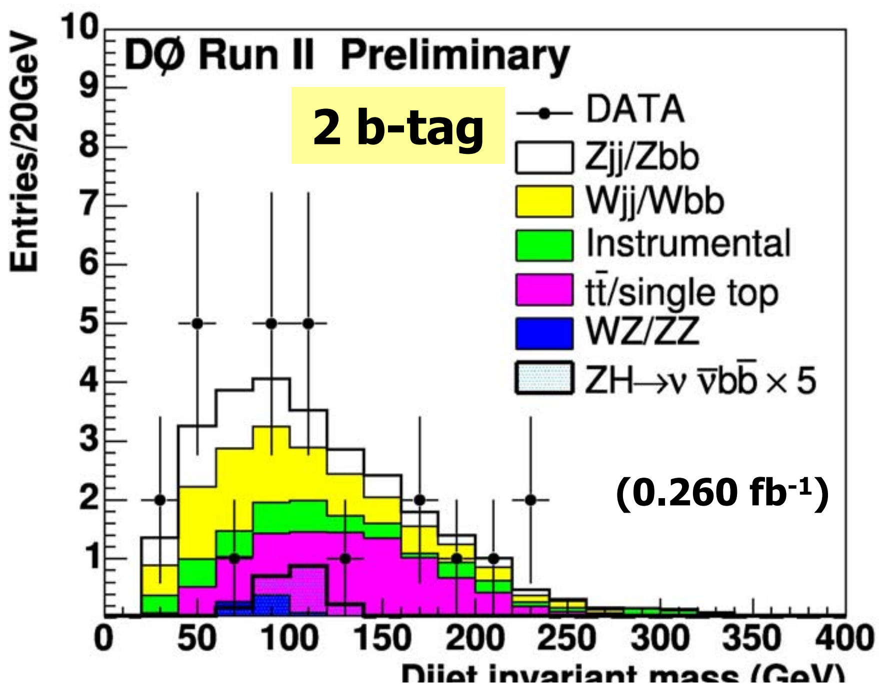
ZH →ννbb / Dijet mass

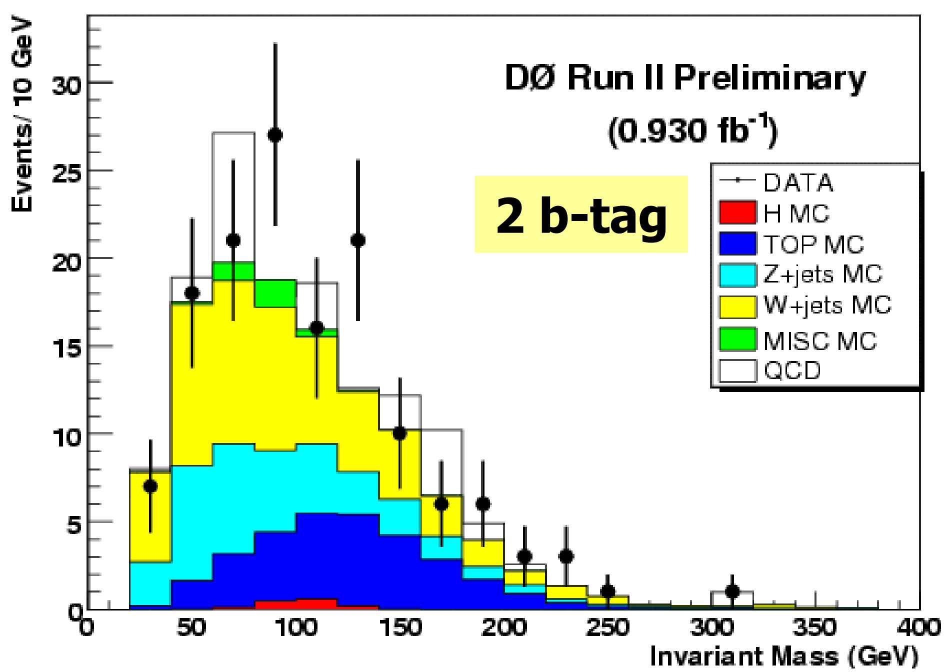
- **Improved event selection includes:**
  - **Two acoplanar jets with:**
  - **E_T > 20 GeV**
  - **E_T^{miss} > 50 GeV**
  - **Sum of scalar jet E_T < 240 GeV**

Same analysis used for WH → lνbb with missed lepton→ improves the combined WH limit

Bkgd. composition (%)	
Wjj/Wbb	30
Zjj/Zbb	20
Instrumental	15
Top	32
WZ/ZZ	3

Increased statistics compared to our previous result on 0.26 fb^{-1}





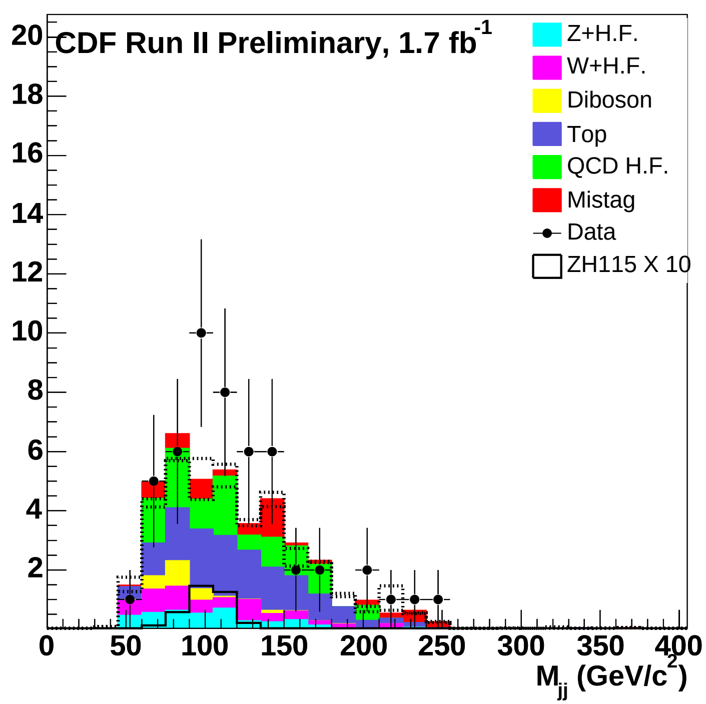
ZH→ν ν bb / @CDF

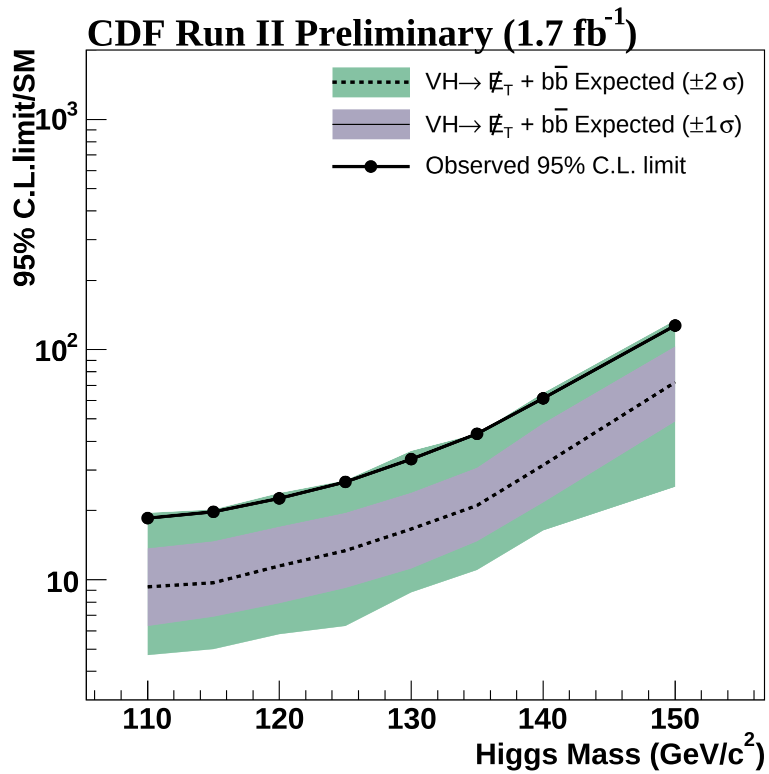
Backgrounds :
- W+heavy flavour jets
- Z +heavy flavour jets
- top pairs

Similar expected sensitivity as WH channel:

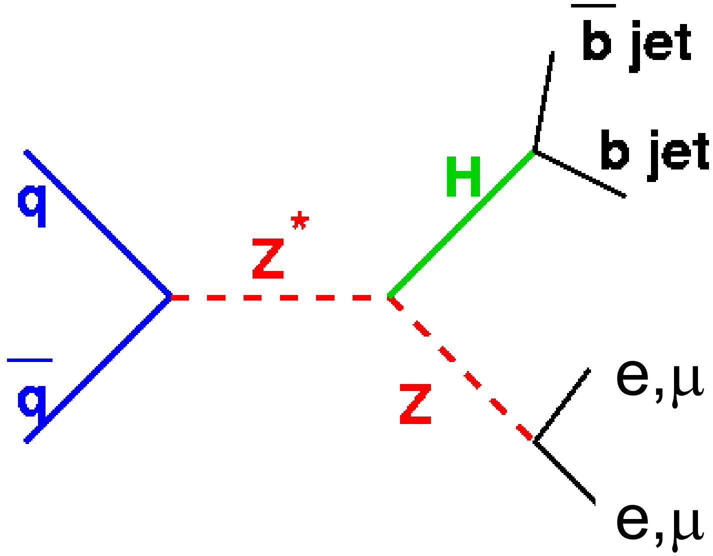
m_H=115 GeV: σ_{95}/SM= 9.7 (exp)
=19.7 (obs)

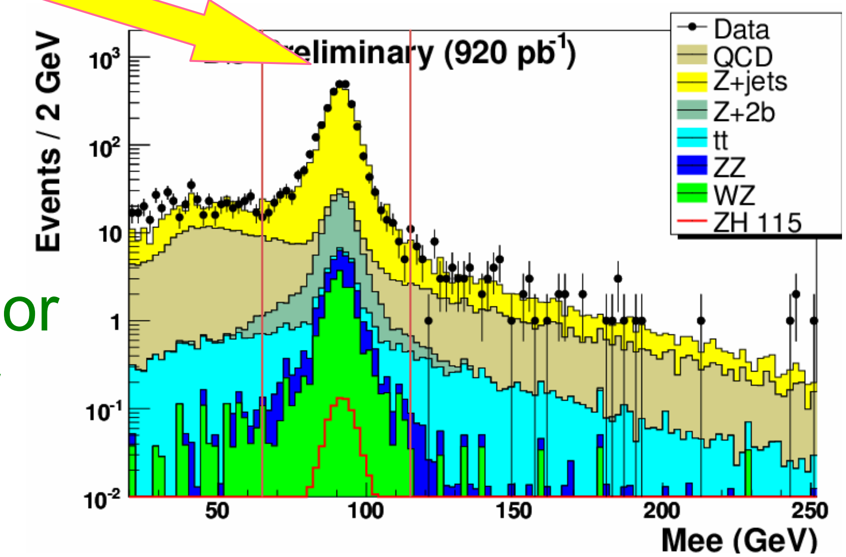
Dijet Mass, SR, L+L $L = 1.7\ \mathrm{fb}^{-1}$





ZH → l l bb



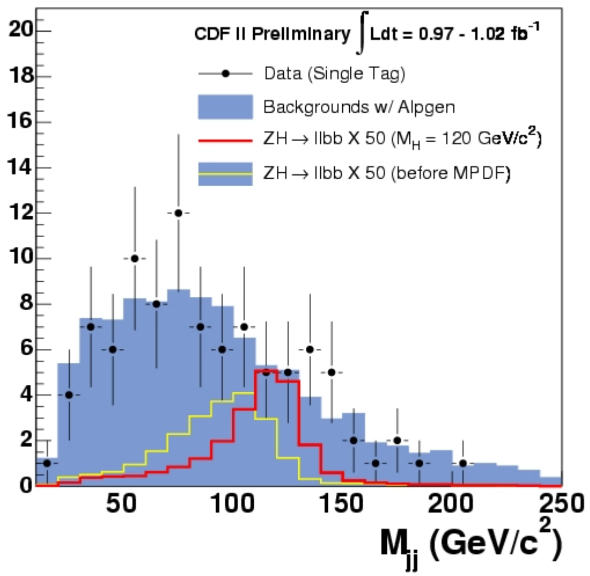


Basic selection:

-require two isolated muons or electrons in Z mass window

-one or two tagged b jets

ZH → l l bb / 2D NN @ CDF



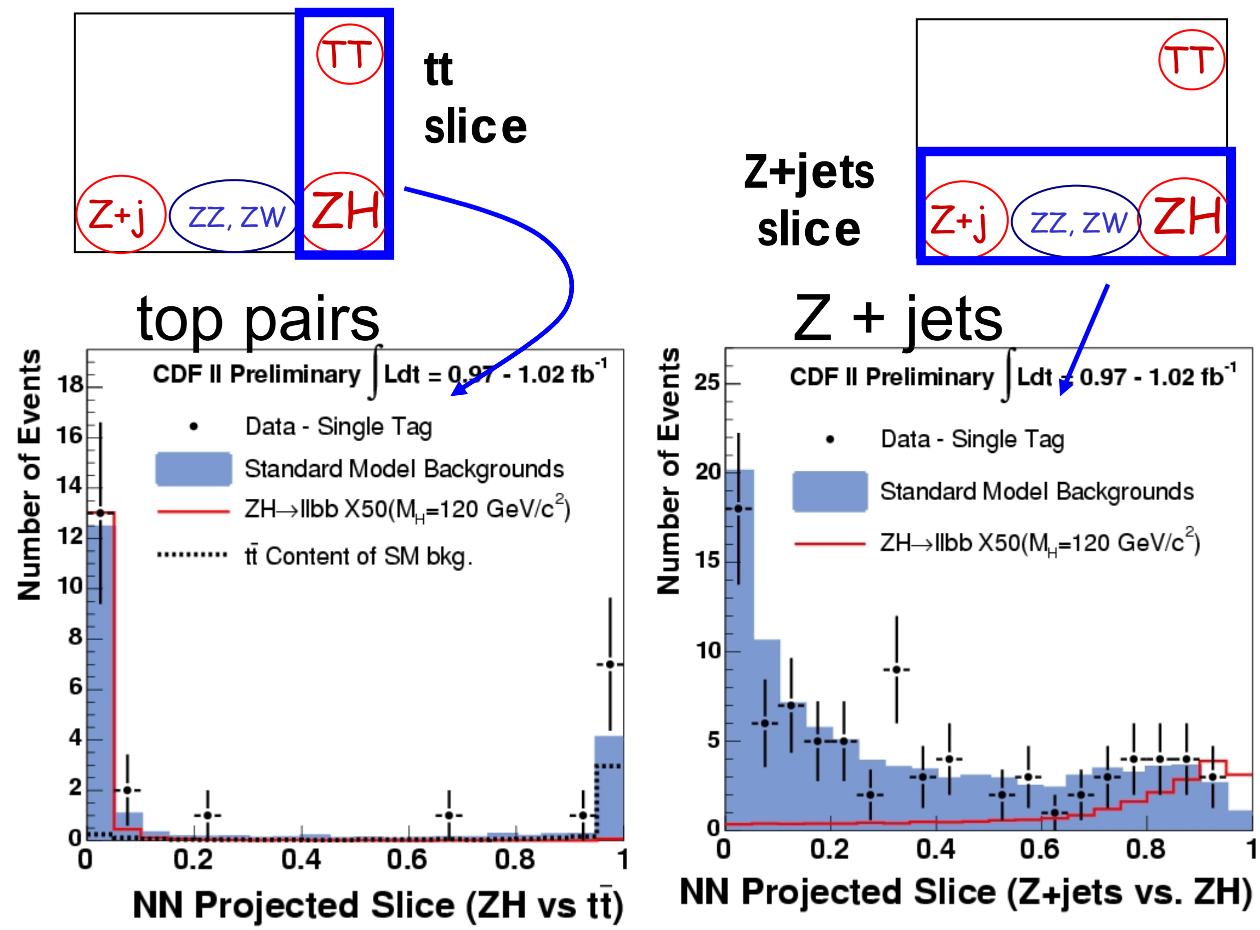
Reduce backgrounds:

- split data into 2 loose b-tags and 1 tight single b-tag

improve dijet mass resolution

- Corrects jets based on their MET projection
  - no real MET in Z+jets
- Improves dijet mass resolution
  - from 17% to 10%
- Results in 30% effective luminosity increase

Separate NN trained to reject 2 main backgrnd processes:



M=115 GeV: CDF $\sigma 95/SM$ = 16(exp), 16(obs)

Dzero $\sigma 95/SM$ = 18(exp), 20(obs)

Limit Setting

LEP: low background, small systematics
Tevatron/LHC: high background, large systematics

Background only (b) and signal plus background (s+b) hypotheses are compared to data using Poisson likelihoods.

Probability density function is obtained through Gaussian smearing.

Systematic uncertainties are included in the likelihood (‘profile likelihood’)

Background is constrained by maximising profile likelihood (‘sideband fitting’).

Combining the results

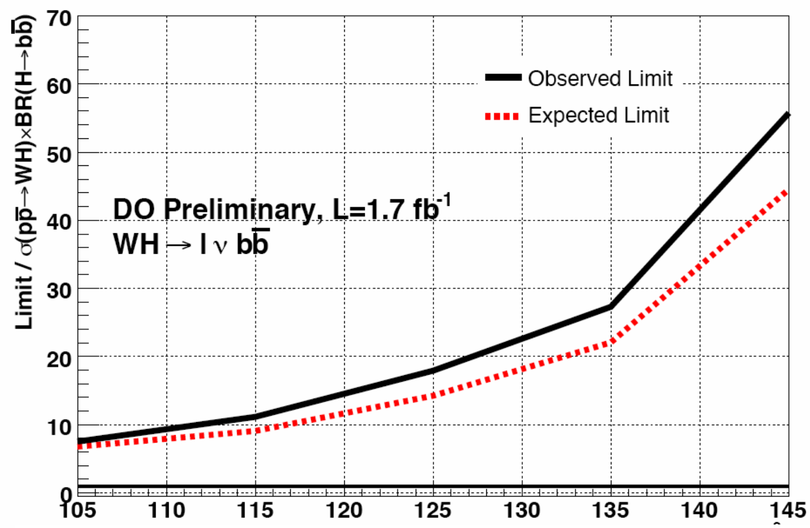
Tevatron experiments use LEP CL_s (modified frequentist) and Bayesian methods

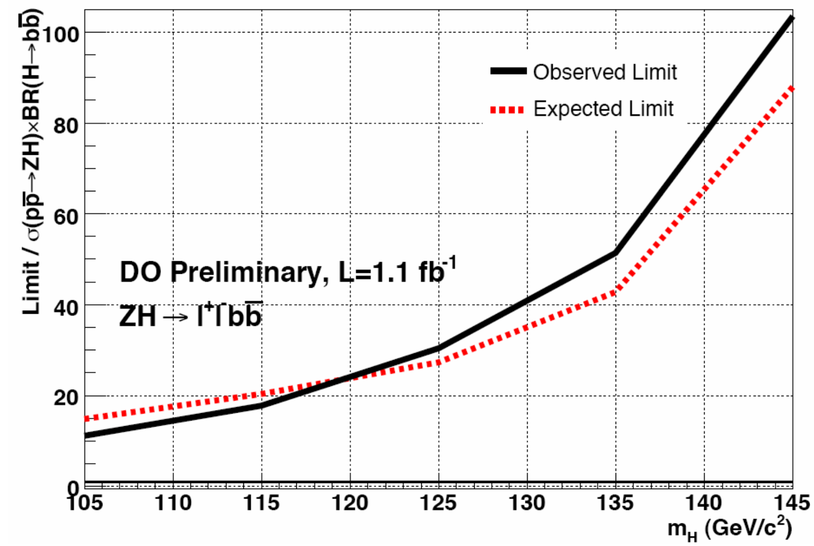
Systematics, including correlations, taken into account:

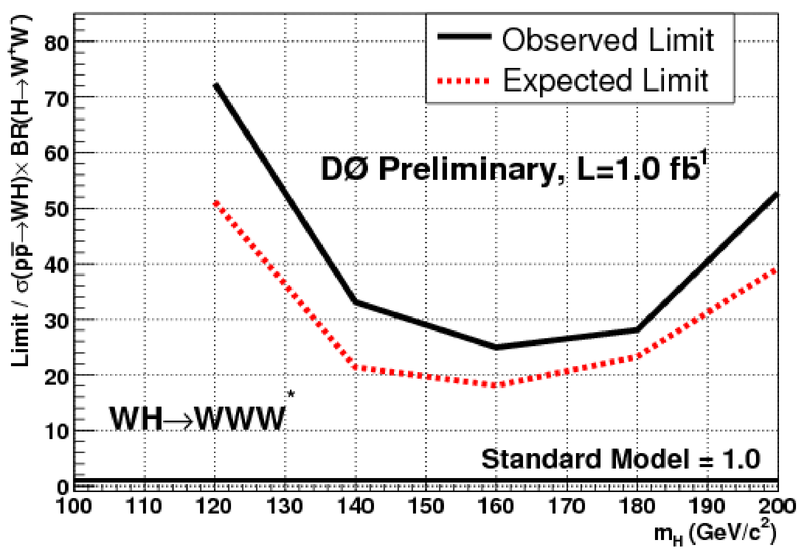
Main systematics (depending on channel):
- luminosity and normalisation
- QCD background estimates
- input background cross-sections
- jet energy scale and b-tagging
- lepton identification

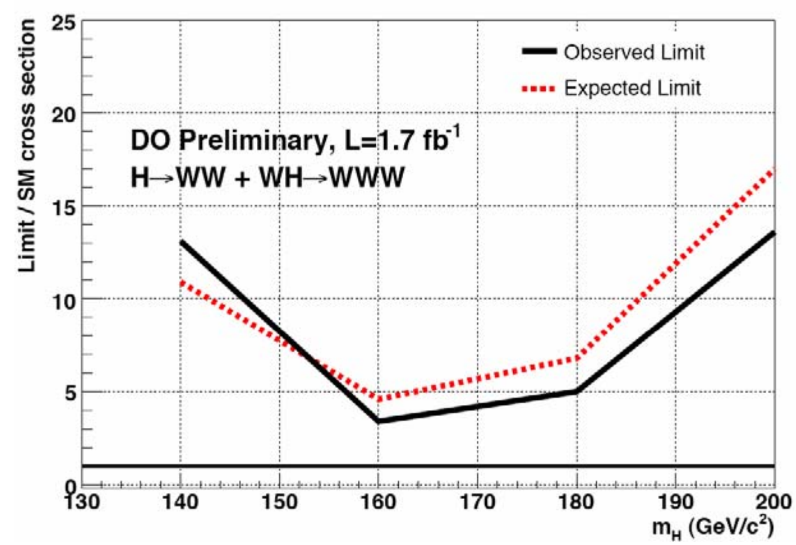
Limit setting approaches agree to within 10%

DØ Channels

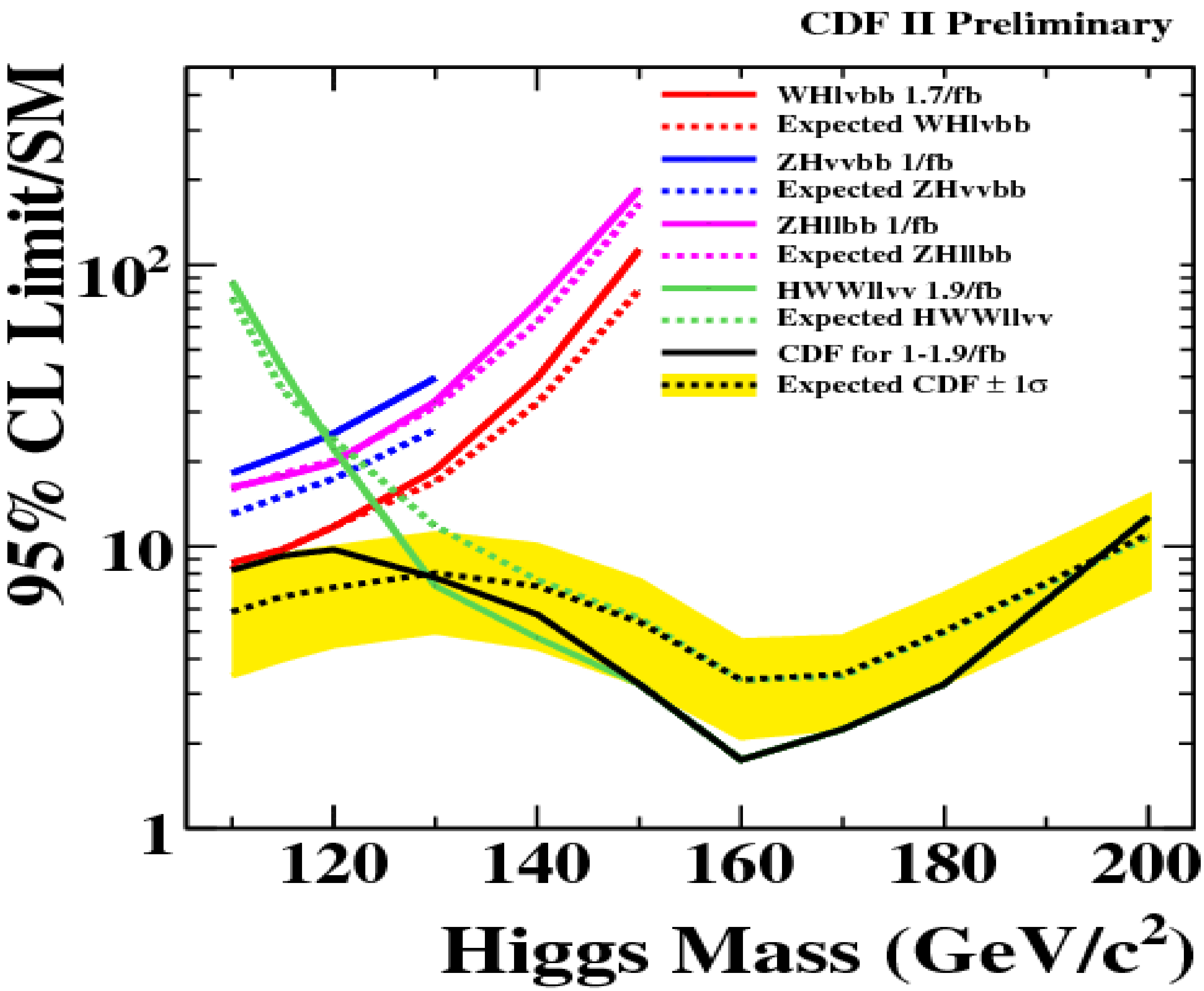

Observed Limit
Expected Limit
DO Preliminary, L=1.7 fb-1
WH → l ν bb̄
Limit / σ(pp̄→WH)×BR(H→bb̄)
0 10 20 30 40 50 60 70
105 110 115 120 125 130 135 140 145


Observed Limit
Expected Limit
DO Preliminary, L=1.1 fb-1
ZH → l+l-bb̄
Limit / σ(pp̄→ZH)×BR(H→bb̄)
0 20 40 60 80 100
105 110 115 120 125 130 135 140 145
mH (GeV/c2)


Observed Limit
Expected Limit
DØ Preliminary, L=1.0 fb-1
WH→WWW*
Standard Model = 1.0
Limit / σ(pp̄→WH)× BR(H→W+W-)
0 10 20 30 40 50 60 70 80
100 110 120 130 140 150 160 170 180 190 200
mH (GeV/c2)

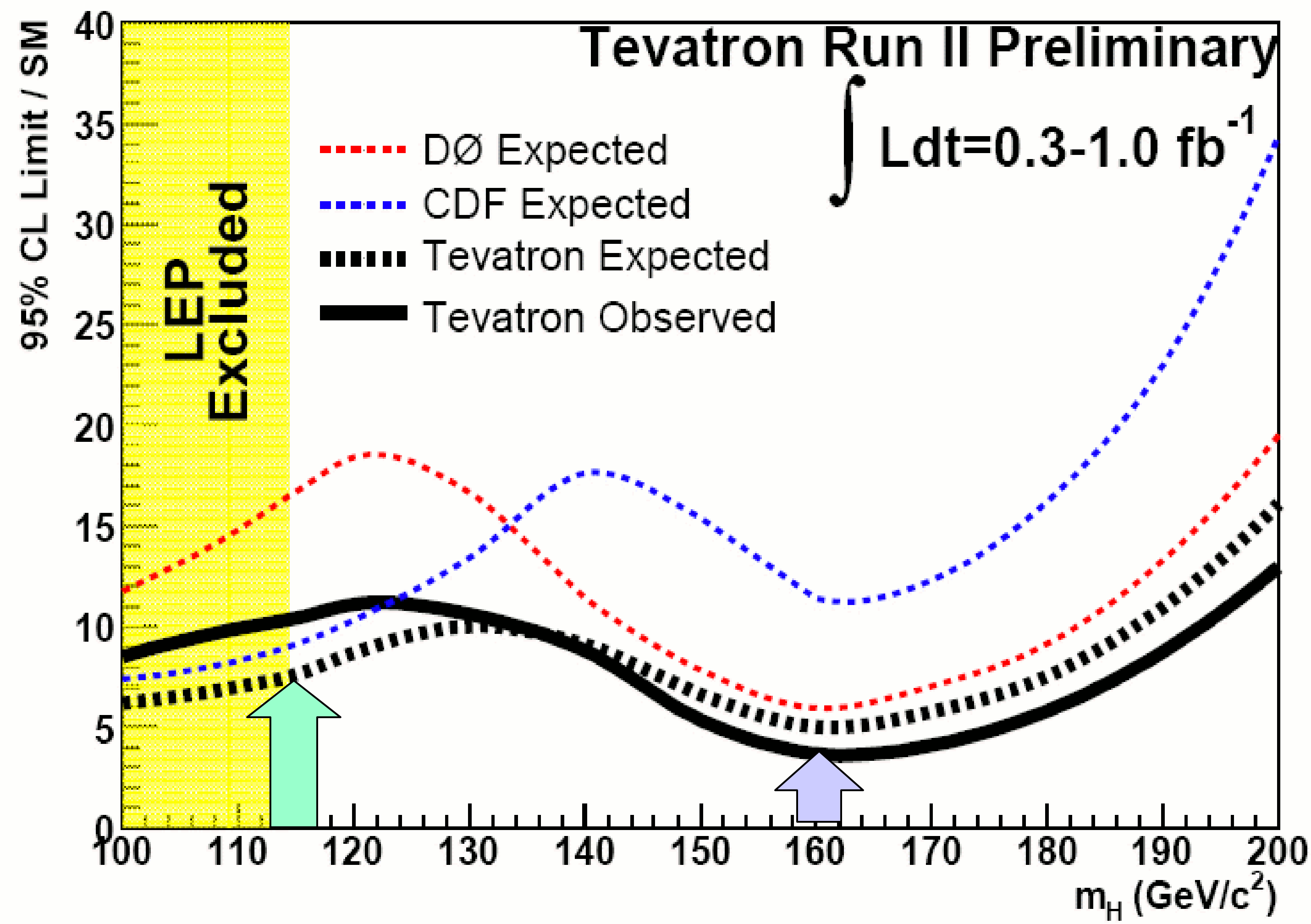

Observed Limit
Expected Limit
DO Preliminary, L=1.7 fb-1
H→WW + WH→WWW
Limit / SM cross section
0 5 10 15 20 25
130 140 150 160 170 180 190 200
mH (GeV/c2)

CDF Combination



- new CDF ννbb result not included yet

SUMMER 2006

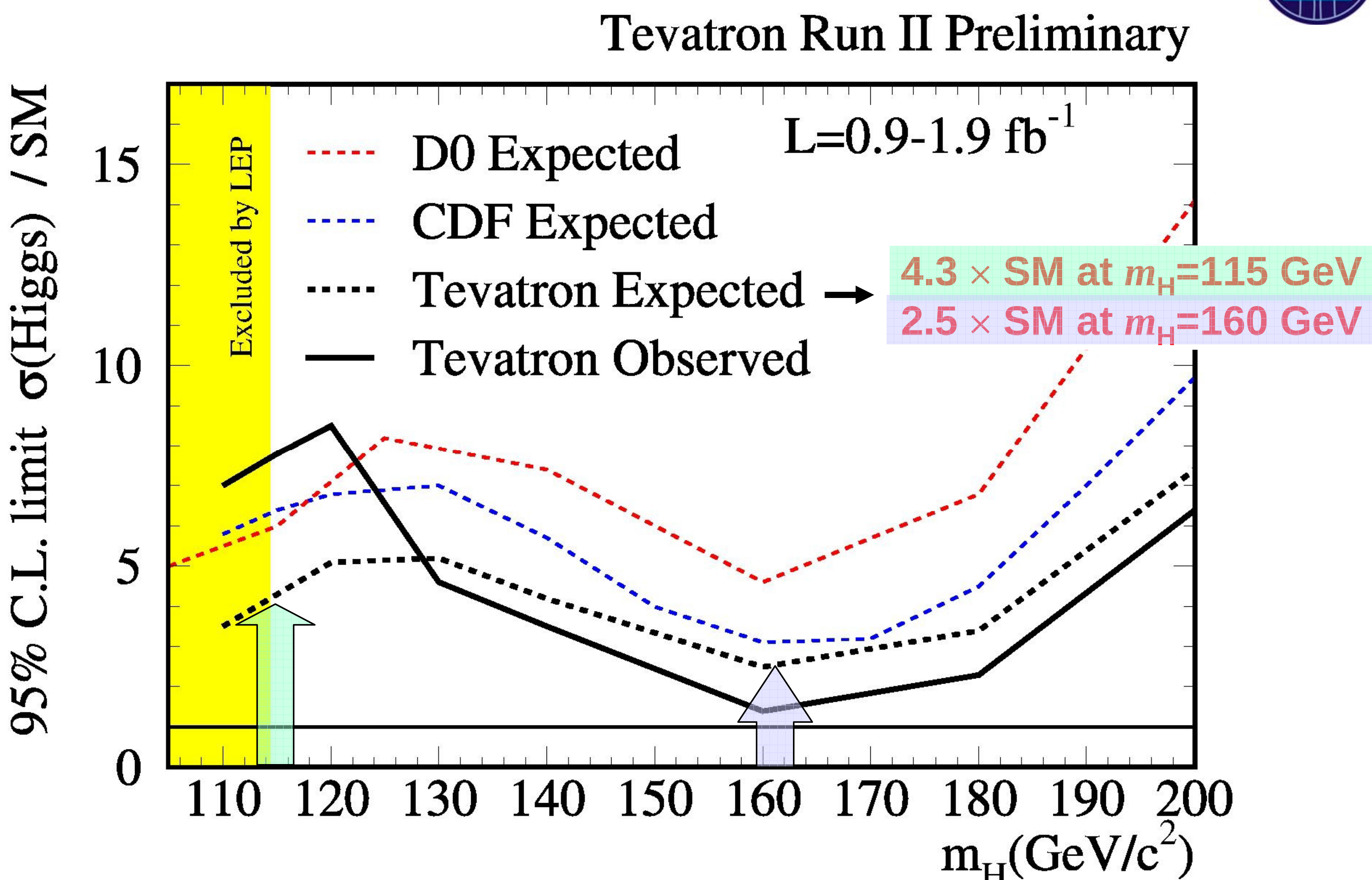


7.6 × SM at m_H=115 GeV

Expected Ratios to SM

5.0 × SM at m_H=160 GeV

SUMMER 2007



Observed limit at m_H= 160 Gev: 1.4 x SM expect.

➔ could be excluded at Moriond 2008

SM Higgs Summary

First time with essentially complete result

All channels have been analyzed with >1 fb^{-1} of data

Full impact of systematics uncertainties is included

Analyses are steadily improving due to optimization

Combined limit looks very promising

High mass region benefits a lot from H→WW* type analyses (H and WH production), but low mass as well, as low as 120 GeV➔ enhanced sensitivity at low mass.

Our outlook for the future looks very interesting

LHC experiments has work hard to get the signal before Tevatron, if the Higgs is light (<130 GeV)

But the Tevatron has insight also if it is close to 160 GeV and can exclude at 95%CL from 115 to 185 GeV.

Barring accidents, the Tevatron could have evidence by 2009-2010, if it's there as the Standard Model predicts

If not, maybe it is a Supersymmetric Higgs !

Higgs Bosons in the MSSM

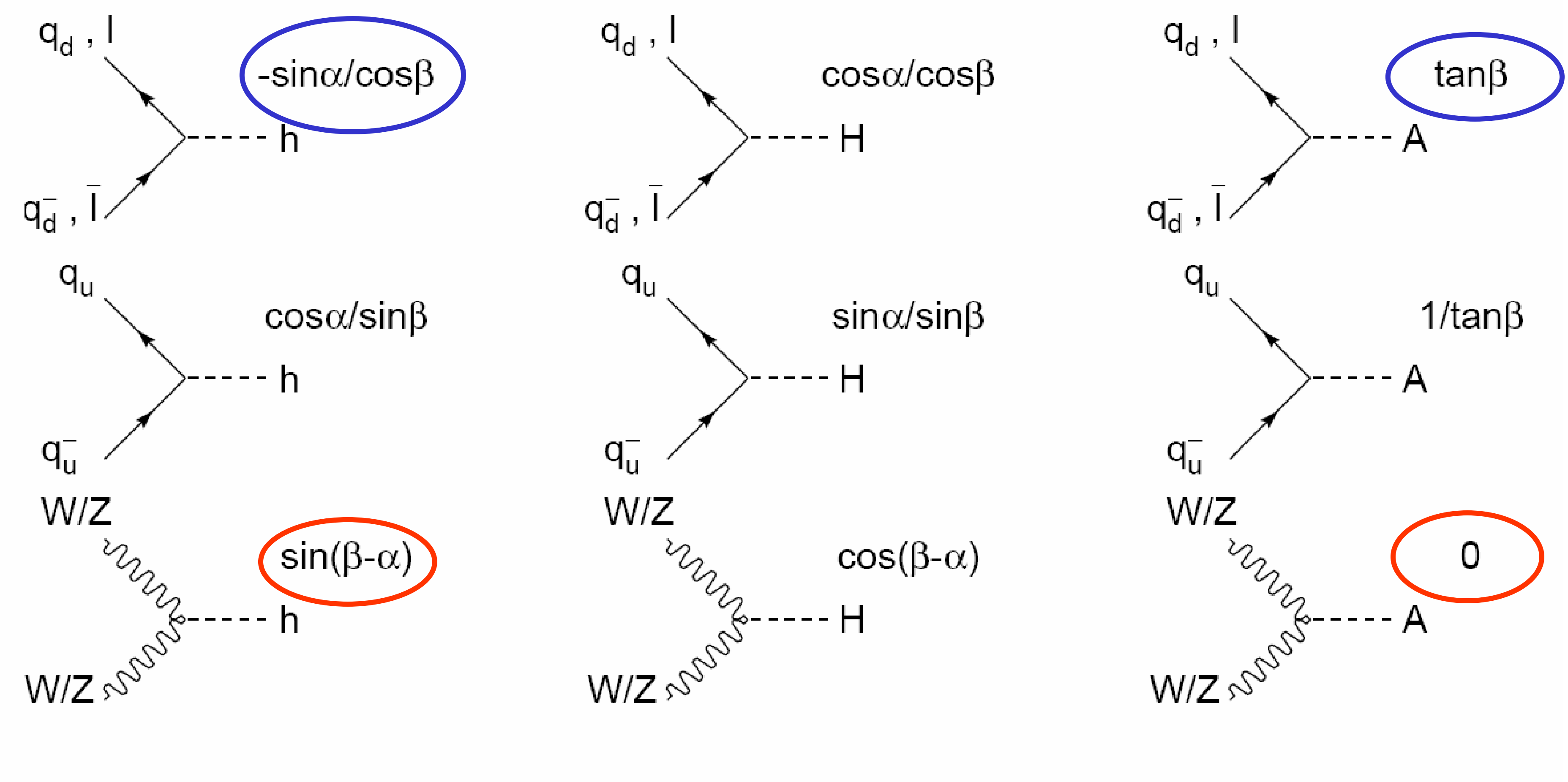
Minimal Super-Symmetric Model

- **Two Complex Higgs Doublets needed to avoid anomalies**
- **Eight Degrees of Freedom minus $W^{+,-}$, Z^0 longitudinal polarization states → five scalars predicted: h, H, A, H^+, H^-**
- **CP-conserving models: h, H are CP-even, A is CP-odd**
- **At tree-level, two independent Parameters:**
  - **m_A**
  - **$\tan\beta$ = ratio of VEV's**
  - **M_{SUSY} (parameterizes squark, gaugino masses)**
  - **X_t (related to the trilinear coupling A_t) → stop mixing)**
  - **M_2 (gaugino mass term)**
  - **μ (Higgs mass parameter)**
  - **m_{gluino} (comes in via loops)**

These 5 parameters intervene via radiative corrections, we study 2x2 scenarios →
(cf M. Carena et al., hep-ph/051123)

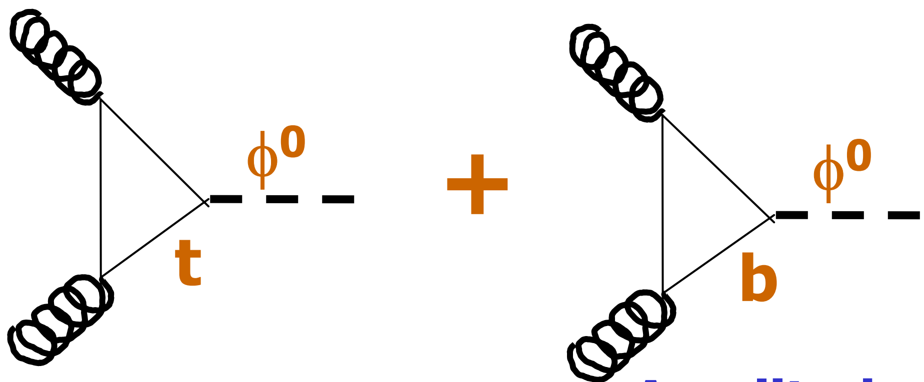
	m_h-max	no-mixing
M_{SUSY}	1 TeV	2 TeV
X_t	2 TeV	0
M_2	200 GeV	200 GeV
μ	±200 GeV	±200 GeV
m_g	800 GeV	1600 GeV

Couplings of MSSM Higgs Relative to SM



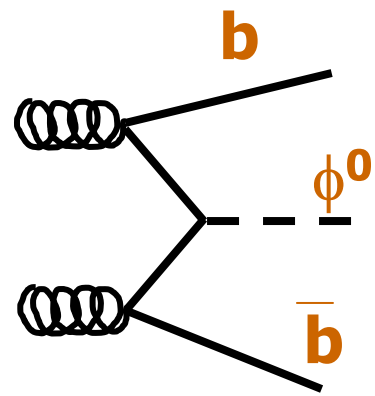
W and Z couplings to H, h are suppressed relative to SM (but the sum of squares of h^0, H^0 couplings are the SM coupling). Yukawa couplings can be enhanced at high tanβ

MSSM Higgs Production Mechanisms



Amplitude $\propto$ 1/tanβ
suppressed!

Amplitude $\propto$ tanβ
enhanced!



Amplitude $\propto$ tanβ
enhanced!

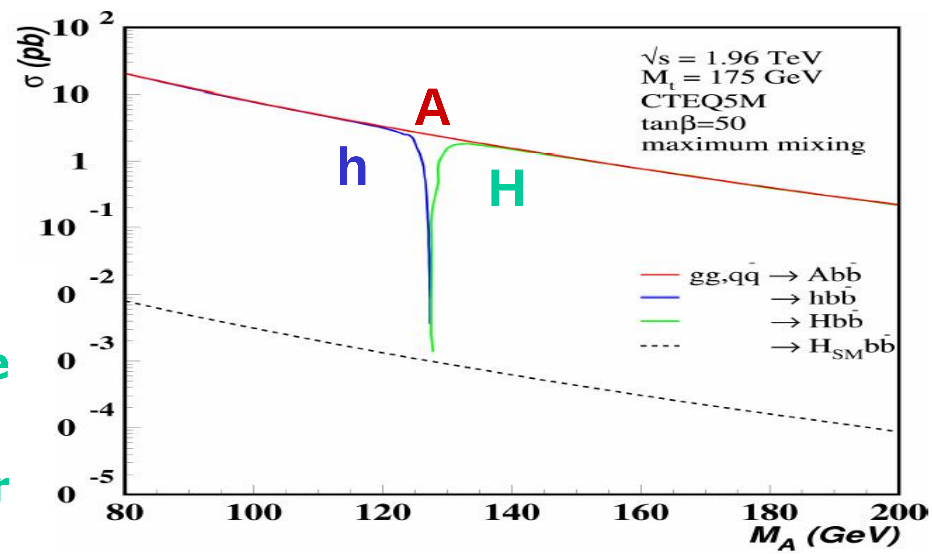
at high tanβ, σ(h,A+X) $\propto$ tan$^2\beta$

Interesting feature of many MSSM scenarios: [m_h, m_H] $\approx$ m_A at high tanβ

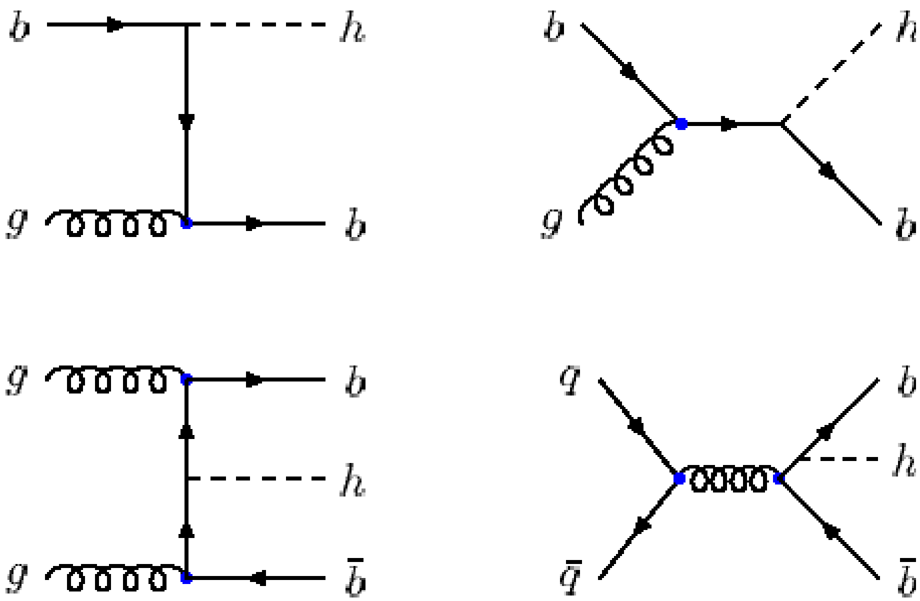
Br($A^0 \to bb$) ~ 90% and Br($A^0 \to \tau^+\tau^-$) ~ 10% almost independent of tanβ (some gg too).

Our two benchmark scenarios:

- m_h-max: Higgs boson mass m_h close to the maximum possible value for a given tanβ
- no-mixing: vanishing mixing in stop sector → small mass for h.



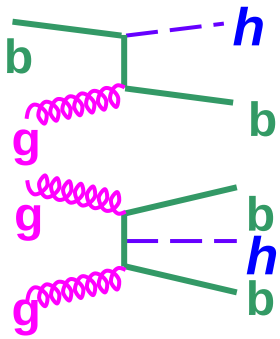
Associated SUSY-Higgs Production



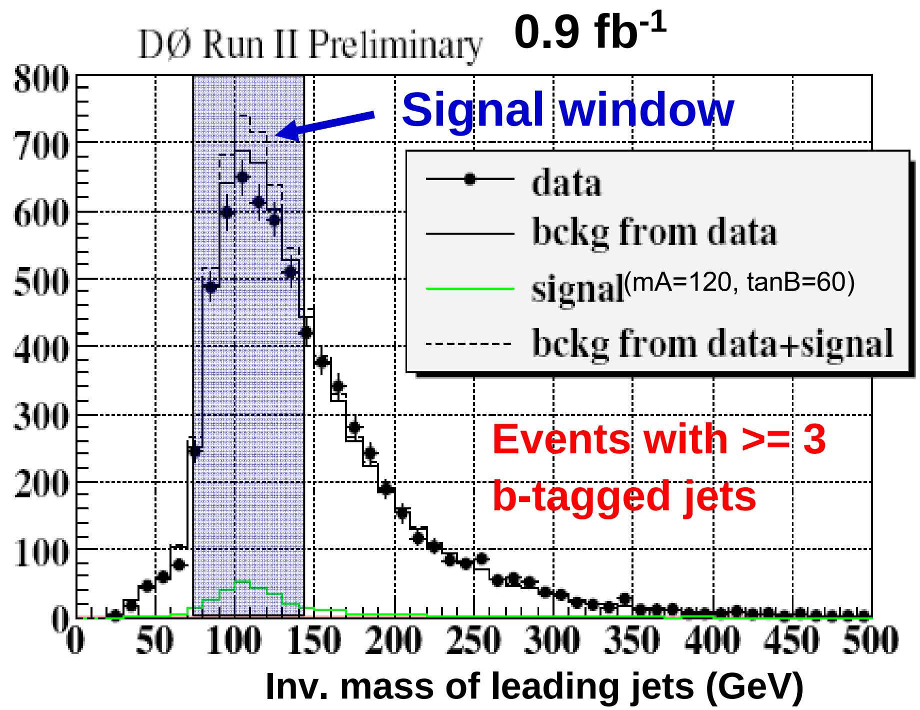
Experimental Signature

- ✗ Higgs decays to two high-pT b-quark jets
- ✗ One or two extra associated b-quarks define final state
- ✗ Search for peak in dijet invariant mass spectrum

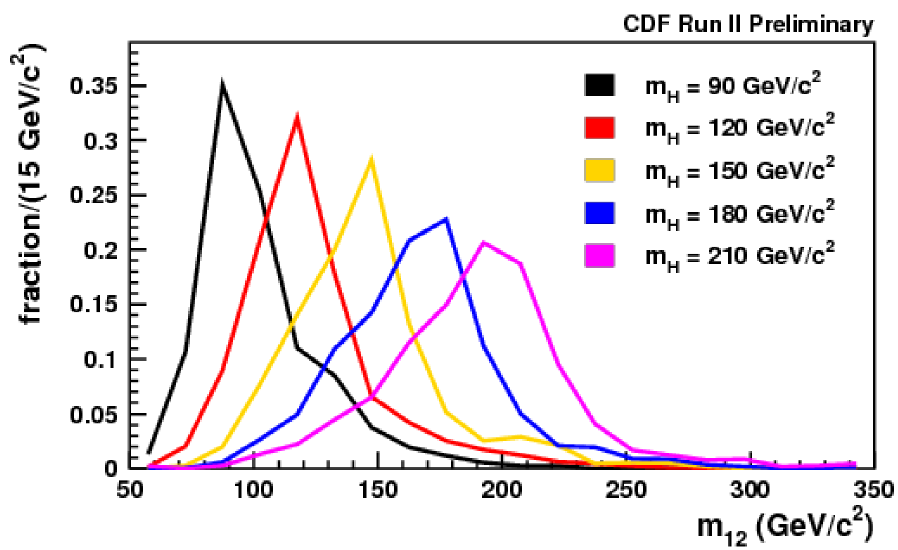
h→bb+b[b] Search



and *h → bb*



- Select at least three b-tagged jets with p_T> 40, 25, 15 GeV
  - Invariant mass of two leading jets peaks at Higgs mass
- Backgrounds estimated from data
  - Shape taken from double-tagged dijet mass spectrum
  - Rate normalized outside signal window for each point in m_A and tanβ plane
- Important mass-width effect
- Reasonable agreement between data and predicted background ➔ proceed to set upper limits on MSSM hb(b) production

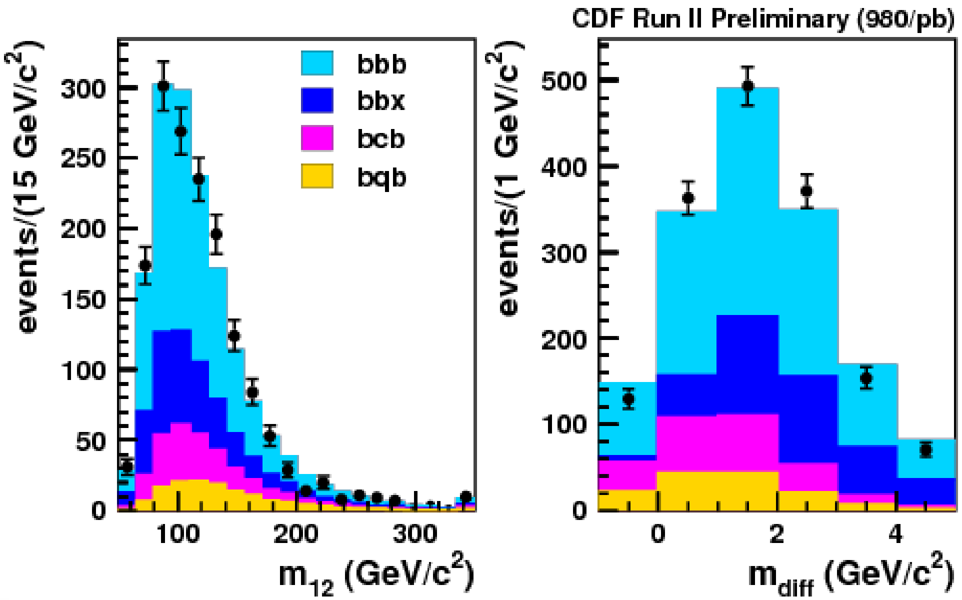


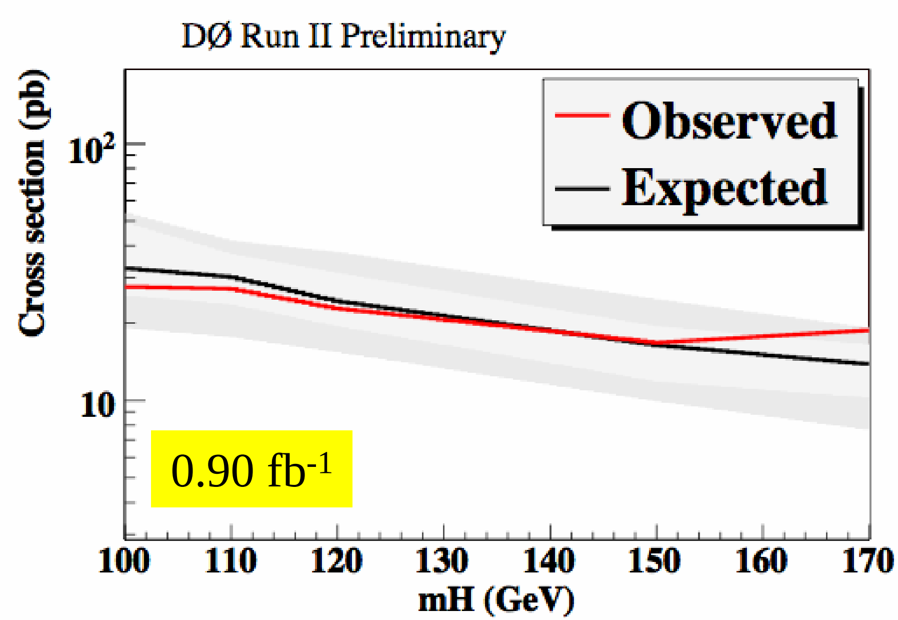
hb (b) → bb b(b) Search

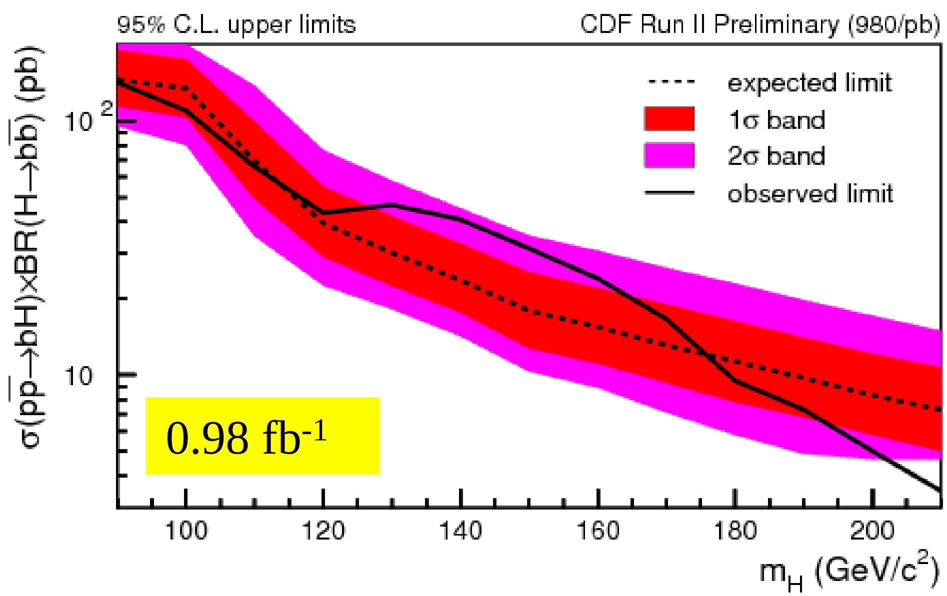
CDF uses two useful discriminators

- m_{12} (invariant mass, 2 leading jets)
- $m_{diff} = \underbrace{M^{jet1}_{vertex}}_{\text{mass of the tracks assigned to jet from the displaced vertex}} + M^{jet2}_{vertex} - M^{jet3}_{vertex}$

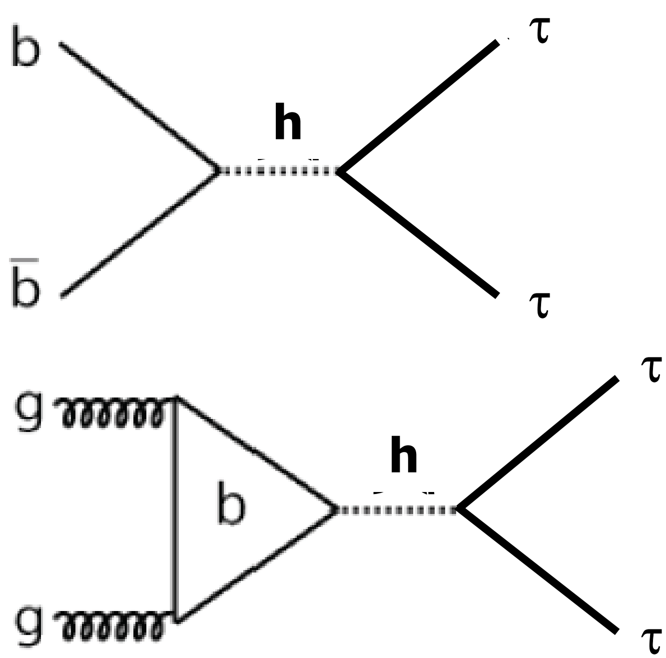
mass of the tracks assigned to jet from the displaced vertex







Di-Tau SUSY-Higgs Decays



Experimental Signature

Higgs decays to two tau leptons

Further decays of tau leptons defines final states

$gg \rightarrow h,A \rightarrow \tau^+\tau^-$ Channel

- Large production cross-section
- Tau leptons are distinct from QCD background
- b(b) $\tau^+\tau^-$ channel is possible too – we're working on it.
- Useful $\tau^+\tau^-$ decay modes → one hadronically decaying τ and e-mu channel (low BR, but low bckgd)
- Final state: opposite sign tau pair and missing transverse energy

• Signal would stand out as enhancement from background in the visible mass, M_{vis}=sqrt $(p_{\tau,1}+p_{\tau,2}+\not{p}_t)2$

• Standard Model backgrounds

Z: irreducible background
$Z/\gamma^* \rightarrow ee/\mu\mu$, multi-jet, $W \rightarrow l\nu$+jet
(rejected with M_W<20 GeV)
Di-boson (WW,WZ,ZZ)

Mode	Fra (%)	Comments
$\tau_e\tau_e$	3	Large DY bg
$\tau_\mu\tau_\mu$	3	Large DY bg
$\tau_e\tau_\mu$	6	Small QCD bg
$\tau_e\tau_h$	23	Large BR, medium bg
$\tau_\mu \tau_h$	23	Large BR, medium bg
$\tau_h\tau_h$	41	Large QCD bg

Data/Background:

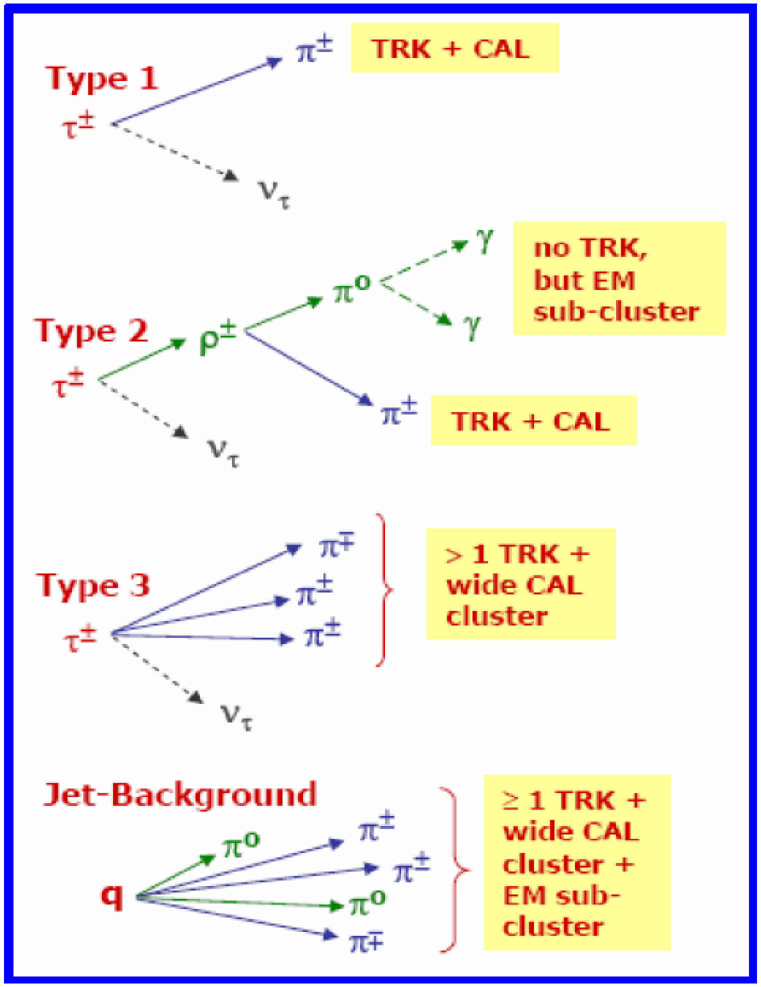
• Data Sample, L =1 fb^{-1}, recorded by single Muon Trigger

• Standard Model background is simulated using Pythia 6.2

• multi-jet background determination from data: $\mu+\tau_h$: inverted lepton isolation criteria

Tau Identification at DØ

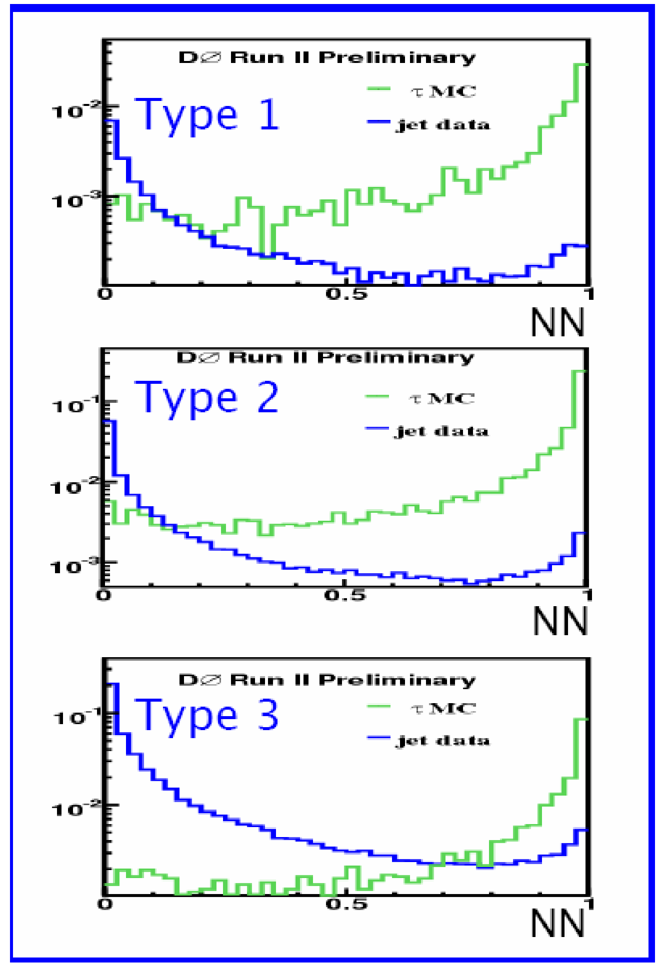
- ✗ **Neural network-based ID**
- ✗ **3 NNs for 3 distinct tau types:**



Performance for p_T>15 GeV

Agreement with Z → tau-tau decays

Factor ~40 reduction in bkgd for 30% loss in tau signal



h➔ τ+τ− Search

Similar analysis at CDF and Dzero:

use Mvisible=sqrt (pτ,1+pτ,2+p̸t)2

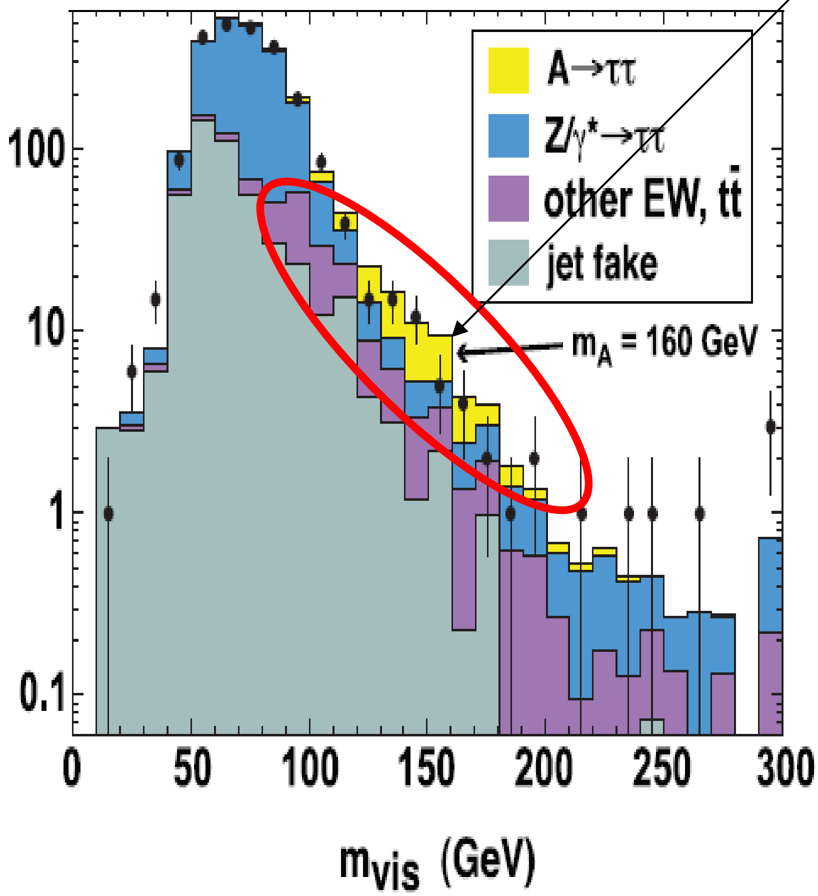
CDF: Combines e+h, μ+h, e+μ tau decays

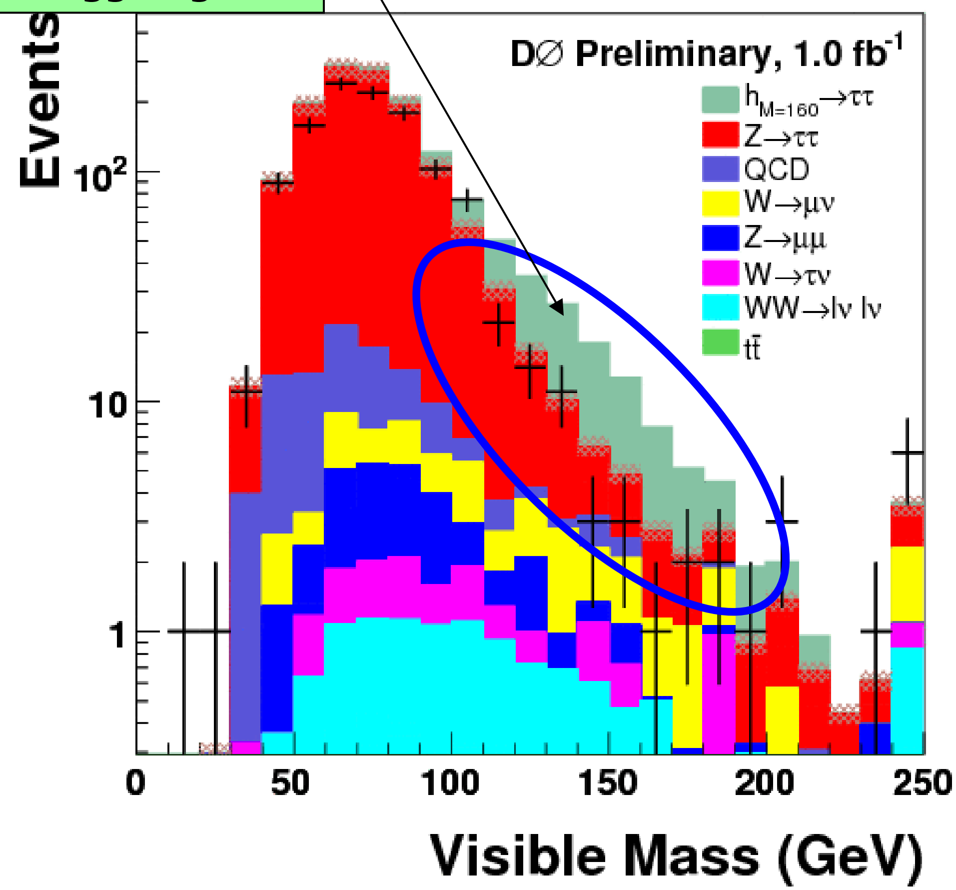
Some excess in m_{vis} in e+h, μ+h

Best fit: m_h=160 GeV, tanβ~50

➔Not seen at DO!

Simulated Susy Higgs signal





Gre

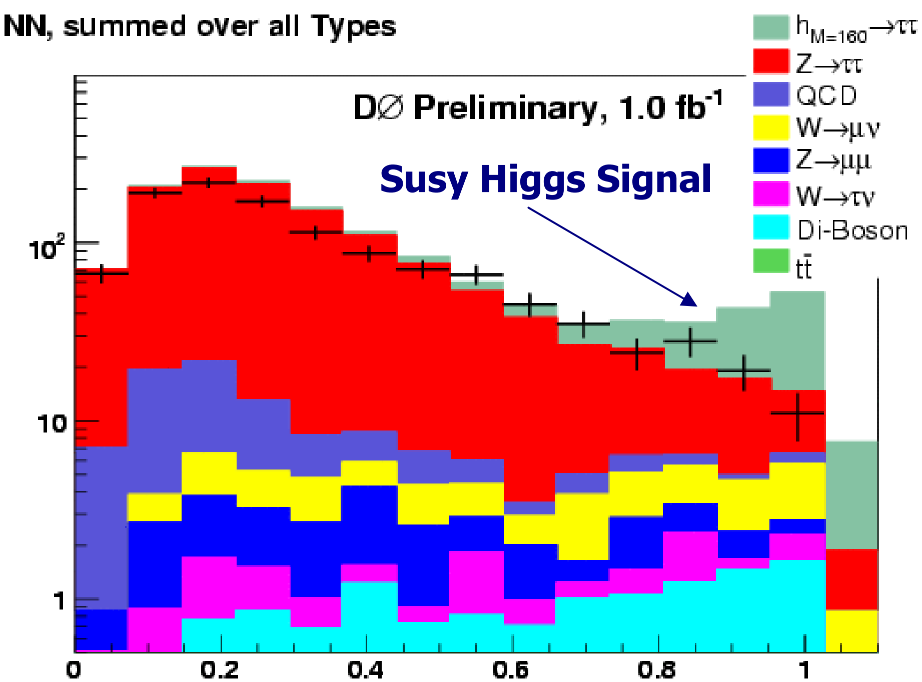
h→ $\tau^+\tau^-$ Search @ Dzero

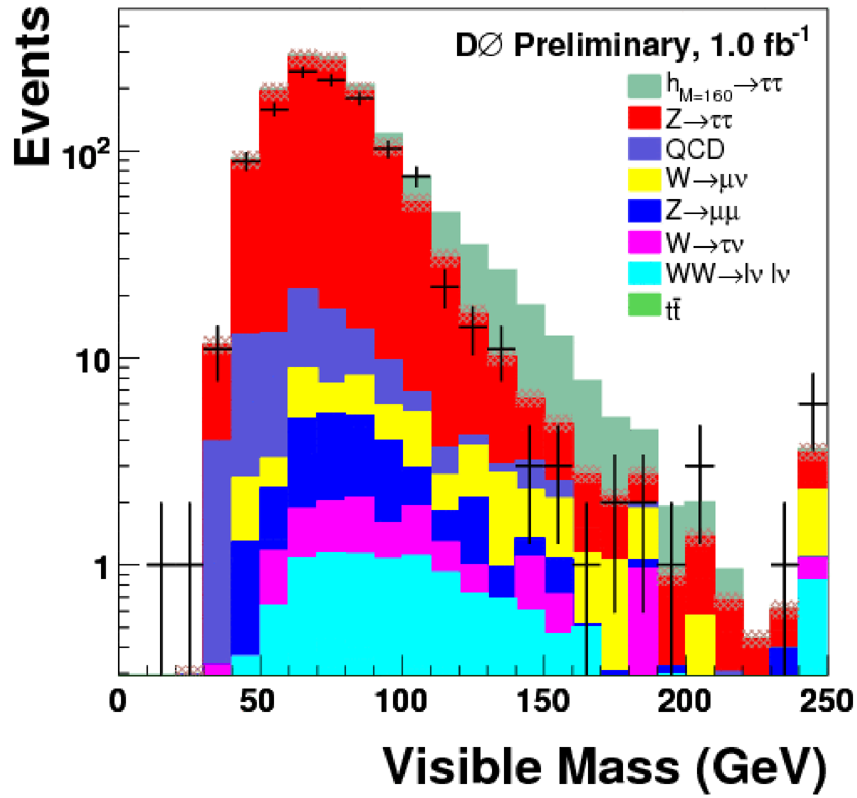
h→ $\tau^+\tau^-$ → $\mu\nu\nu + \tau_\eta$

Largest bkgds: Z→ $\tau^+\tau^-$, QCD-jet fakes

- ✗ NN>0.9, DR(η,φ)>0.5
- ✗ M^{vis}_W > 20 GeV to remove W bkgd

$$M_W^{vis} = \sqrt{2 E_\mu ME_\tau \frac{p^\mu}{p_T^\mu}(1-\cos(\Delta\phi))}$$





Mass-dependent NN optimization for signal/bkgd separation

(M^{vis}, mu, tau kinematic variables)

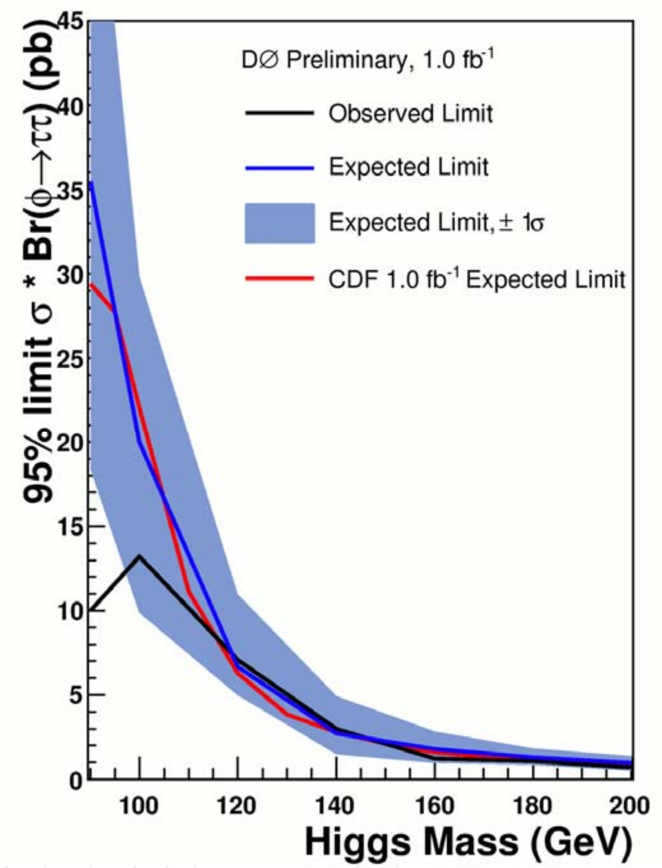
h➔ τ+τ− Search

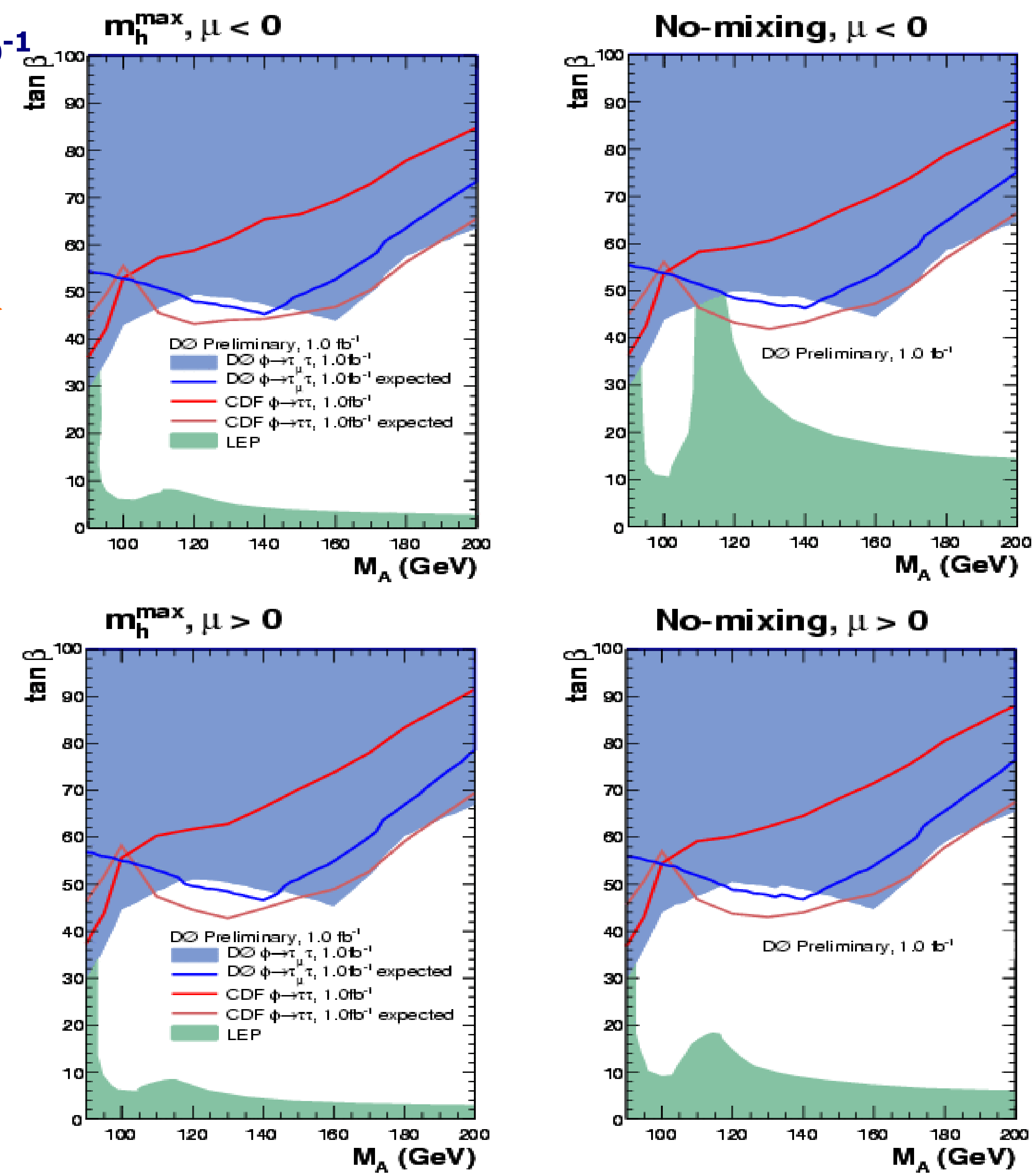
DØ/CDF preliminary results on 1.0fb^{-1}

95% CL limits, interpreted in:

σ x **Br(h➔ ττ)**

MSSM parameter space





Greg

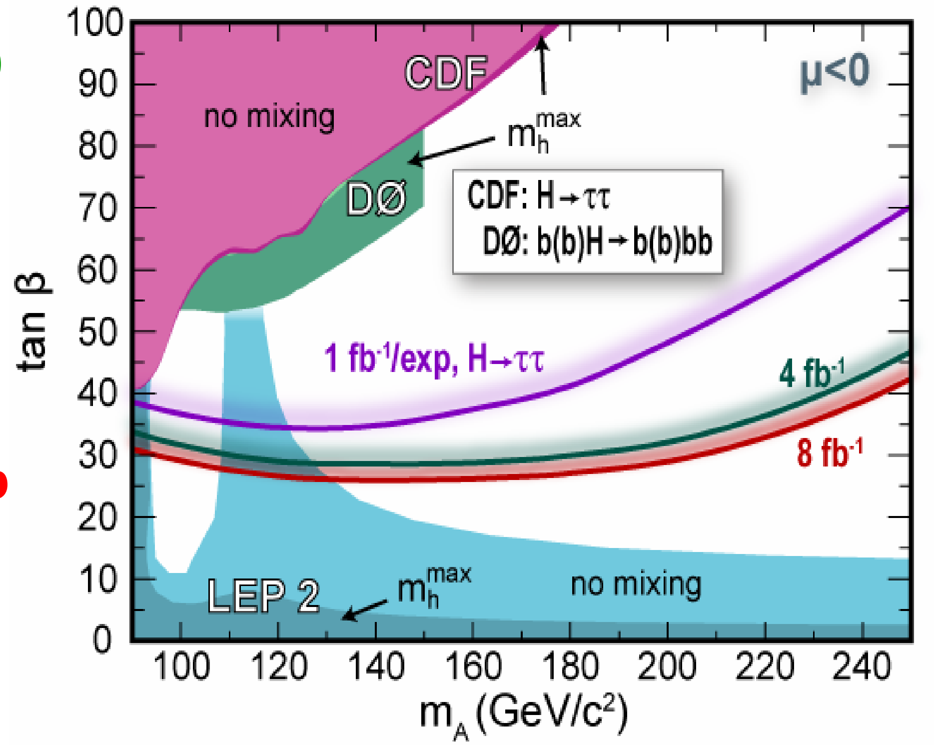
MSSM Higgs Summary and Outlook

After the published bh→bbb search on low statistics , new searches for MSSM Neutral Higgs Bosons in bbb and ττ final states have been performed using 1 fb^{-1} data taken by CDF and DØ in Run II

No significant indication for a signal has been found, but hints must be studied with more statistics. So far, upper limits were derived at 95% CL

results are comparable in sensitivity between CDF and DØ

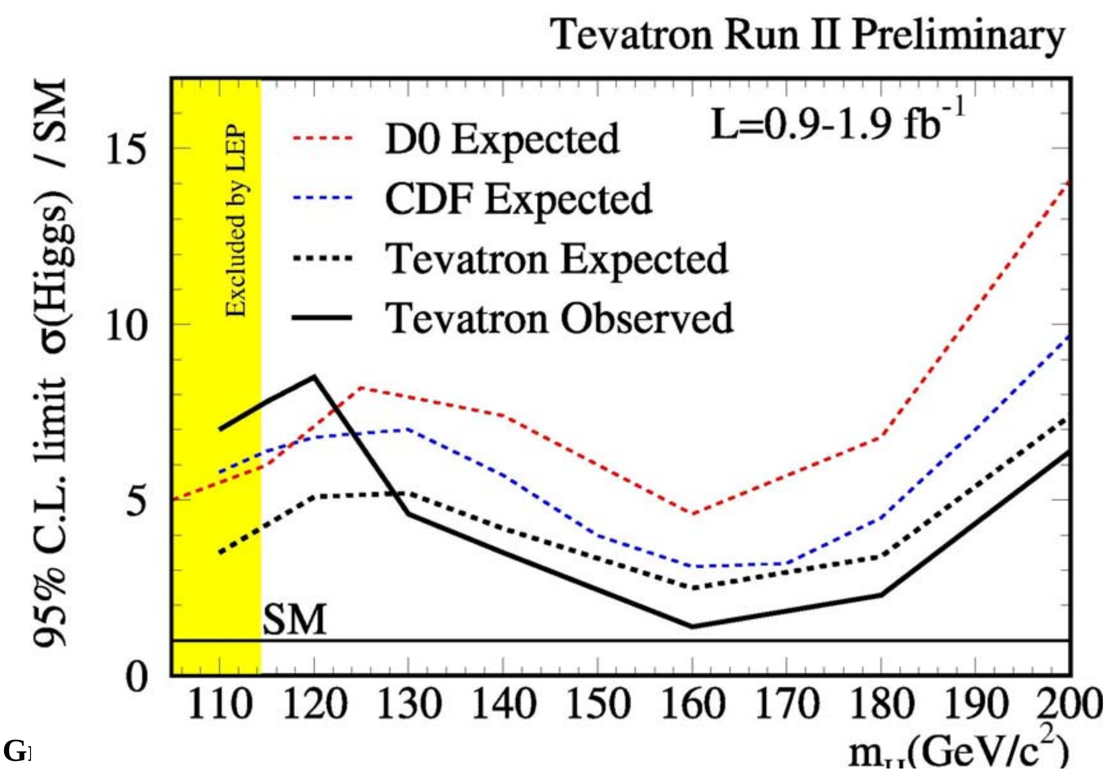
- Susy Combination with hb(b)→bbb(b) has been performed on low statistics → will be updated for Moriond 2008
- Updates with 2-3 fb^{-1} in progress
- With some sensitivity progress MSSM Higgs could be, by 2009, well constrained in some of these models up to 180 GeV, since, for instance, LEP exclude them up to 15-20 in tan b in the no-mixing scenario

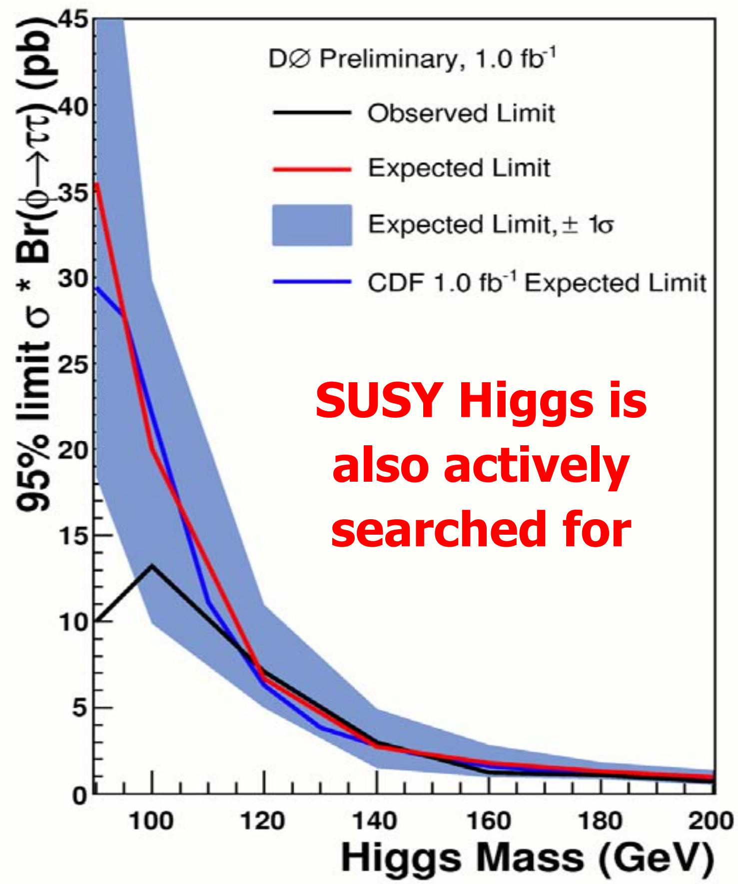


Conclusions

Higgs physics in Run II of the Tevatron looks promising: exciting time in front of us

High luminosity and improved analyses allow to push our sensitivity further : ≥3σ evidence for Higgs is probably reachable if Higgs is light or near 160 GeV





Backup Slides

SM Backgrounds

- Electroweak background: W(+jets), Z(+jets), WW, WZ, ZZ, also tt and single top

kinematic distributions using Monte Carlos:
PYTHIA (LO + parton shower)
ALPGEN (LO+MLM parton shower/matrix element matching)
COMPHEP (LO, fixed order matrix element)
MCFM (NLO)
MC@NLO (NLO)

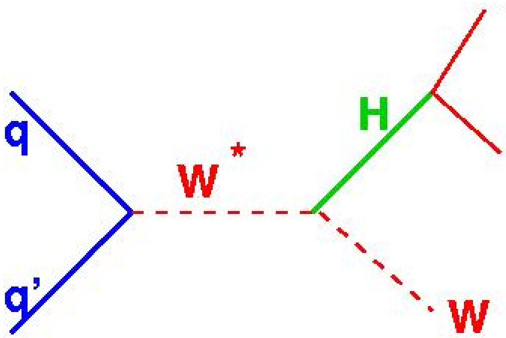
normalised using (N)NLO cross-sections and K factors
verified by data

Jet production (QCD) and instrumental background

➔ data using control samples and/or PYTHIA

Typical signal/background ratio of 1/100 in final distributions:
requires advanced analysis techniques (e.g. NN, Limit Setting..)

WH → WWW* → lν lν X @ Dzero

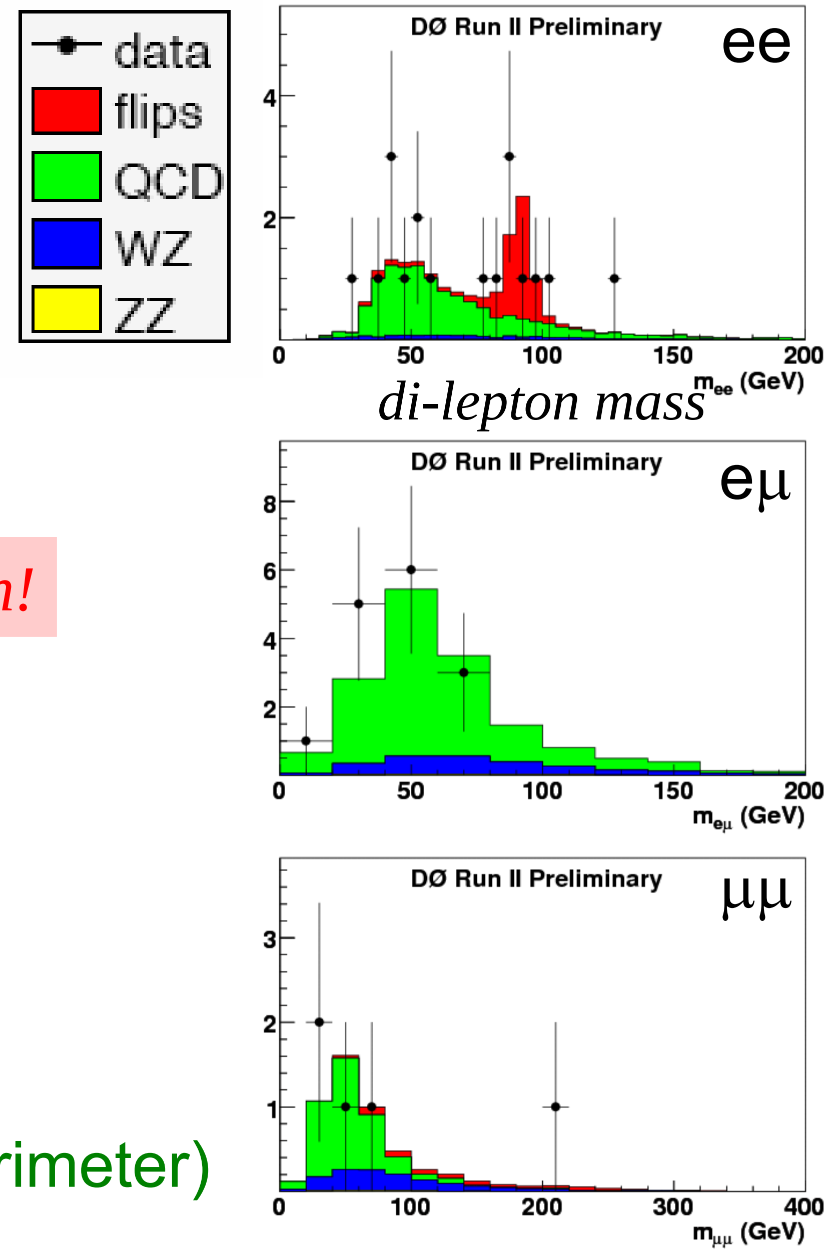


W → **hadrons**

W → ***e* or μ**

same charge

W → ***e* or μ**



di-lepton mass

Selection:

- 2 isolated leptons (p_T > 15 GeV) (electrons and/or muons) *like-sign!*
- kinematic likelihood selection

$$\Delta\phi_{\ell\ell}\ ,\ m_{\ell\ell},\ \not{E}_T \text{ or } \Delta\phi^{min}_{\ell \not{E}_T}$$

"flips": charge mis-identification estimated from data:

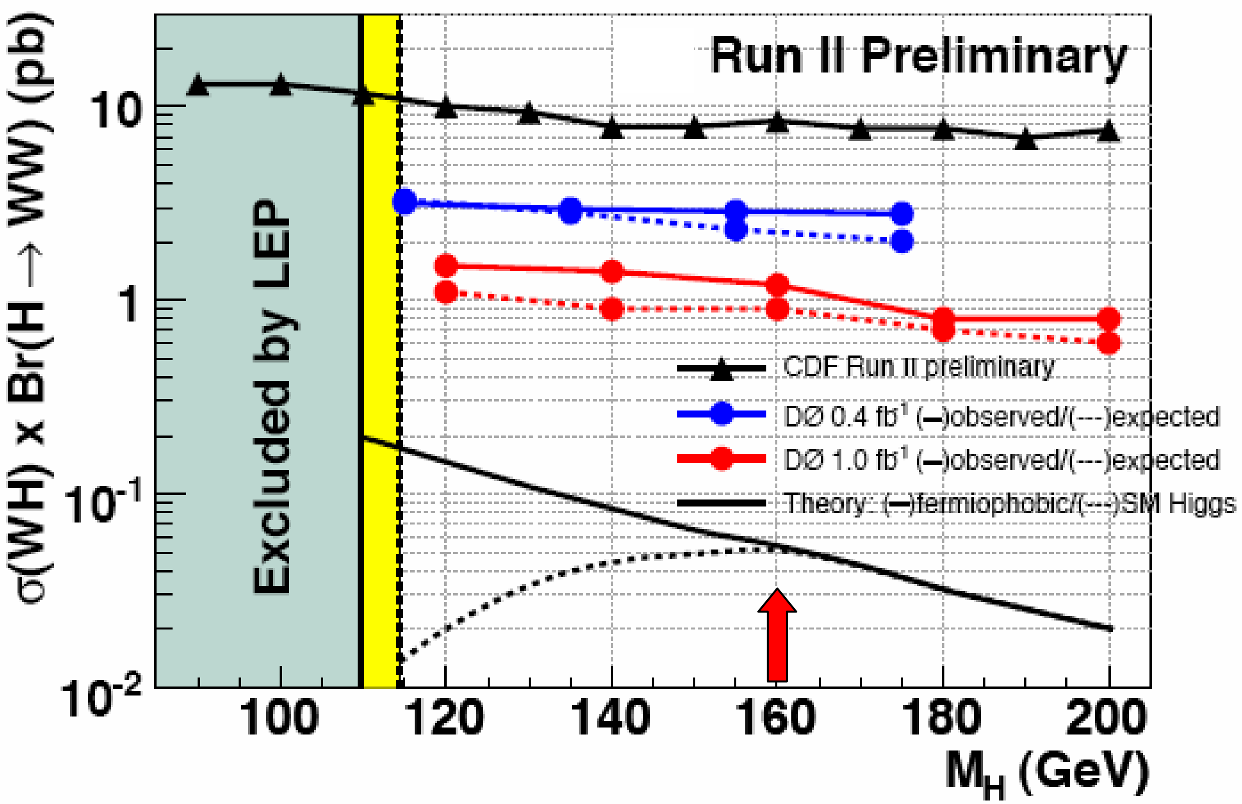
μ: solenoid vs toroid

e: solenoid vs Δφ(track,calorimeter)

WH → WWW* → lν lν X @ Dzero

L = 1 fb^{-1}

	ee	eμ	μμ
expected background	20.6	18.0	5.0
data	19	15	5
WH(160)	0.1	0.2	0.1



σ_{95}/σ_{SM} ~ 18 for M_H = 160 GeV

WW → tau_mu tau_h

Selection criteria	$m_H = 120$	$m_H = 140$	$m_H = 160$	$m_H = 180$
Cut 1 Preselection	leptons from primary vertex large tau NN at least one SMT hit for the muon μ and τ not matched with $\Delta R(\eta, \phi) > 0.15$			
Cut 2 Missing Transverse Energy $\not{E}_T$	> 20	> 20	> 20	> 20
Cut 3 $\not{E}_T^{Scaled}$	> 7	> 7	> 7	> 7
Cut 4 M^T_{min} $(l, \not{E}_T)$	> 35	> 40	> 45	> 45
Cut 5 Sum of $p_T^l + p_T^{l'} + \not{E}_T$	50-140	60-150	70-160	80-180
Cut 6 Invariant mass $M_{\mu\tau}$	< 50	< 60	< 60	< 80
Cut 7 H_T	< 70	< 70	< 70	< 70
Cut 8 $\Delta\phi(\mu, \tau)$	< 2	< 2	< 2	< 2

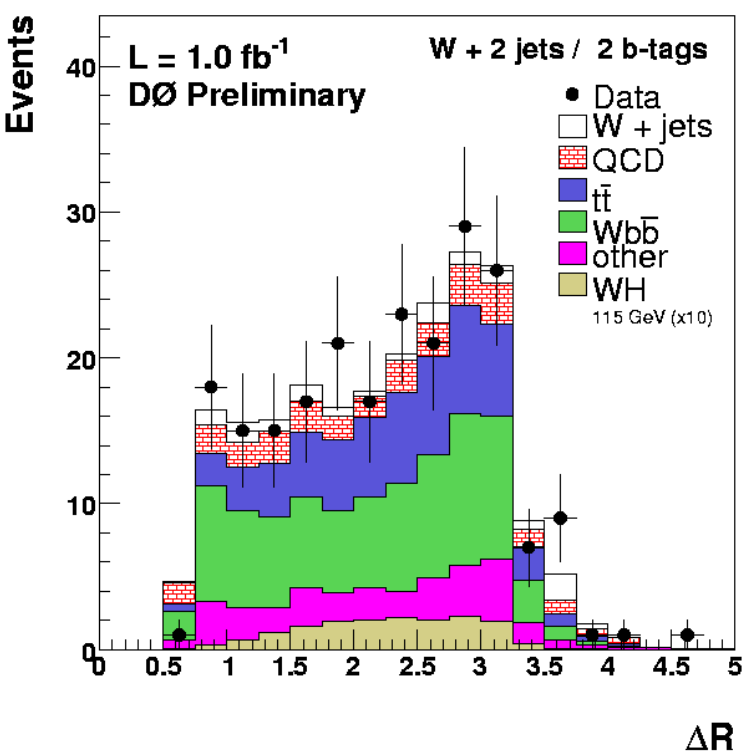
TABLE IV: Number of candidate events observed and background events expected at different stages of the selection for τ type I, $m_H = 160$ GeV and $m_H = 180$ GeV. Errors are statistical only

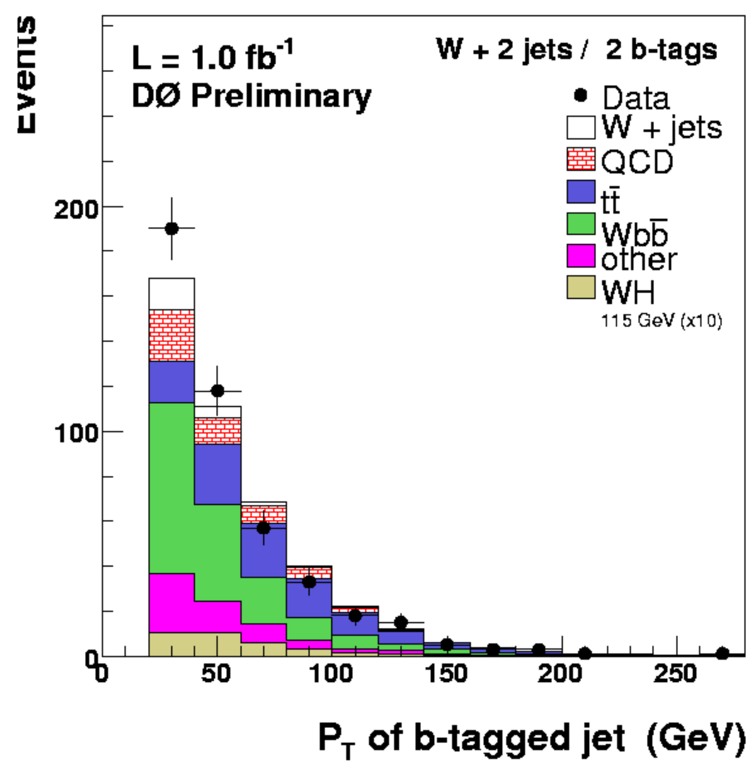
Cut	$m_H = 160$ GeV			$m_H = 180$ GeV		
	Data	Tot. Exp. Bkgd	$H \to WW$	Data	Tot. Exp. Bkgd	$H \to WW$
Preselection	1749.00 ± 41.82	1719.19 ± 33.58	0.20	1749.00 ± 41.82	1719.19 ± 33.58	0.15
$\Delta\phi(\mu, \tau)$	30.00 ± 5.48	21.66 ± 2.74	0.11	31.00 ± 5.57	24.26 ± 2.87	0.07
Final Sel. incl.	2.00 ± 1.41	4.63 ± 1.22	0.05	1.00 ± 1.00	1.25 ± 0.60	0.01
Final Sel. excl.	3.00 ± 1.73	1.78 ± 0.68	0.01	3.00 ± 1.73	5.79 ± 1.27	0.03

Tagging b-Jets

- Update b-Tagging optimization (as compared to Single-Top result)
  - Use asymmetric *TIGHT* + *LOOSE* b-Tagging thresholds for double-tagged jet sample (*gain ~40% in sensitivity*)
  - For WH→lνbb, separate orthogonal 2 b-tag and 1 b-tag samples to salvage lost efficiency (*gain ~15% in sensitivity*)

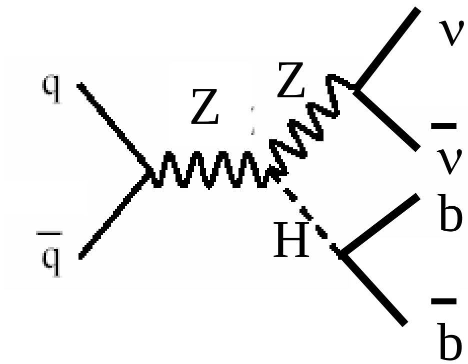
W+ 2 b-Tag control plots

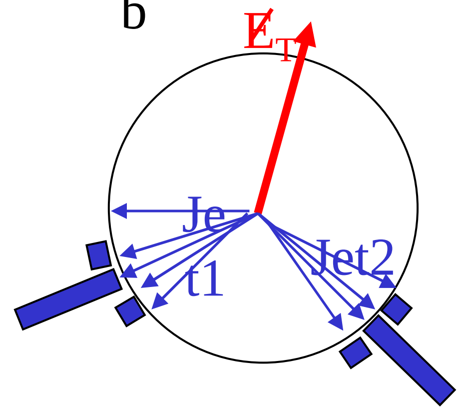




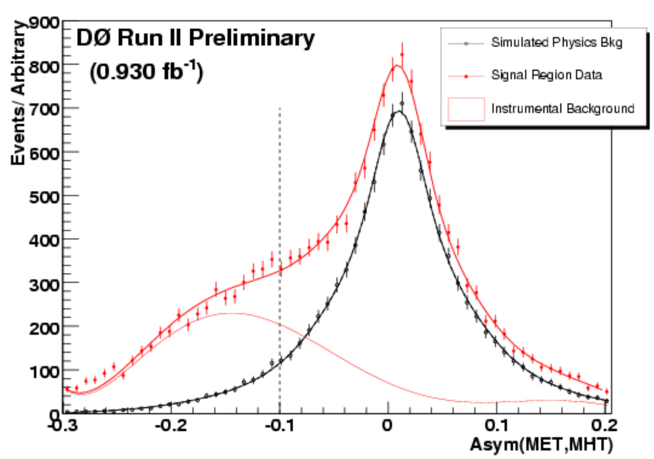
ZH→ννbb (WH → $\not\ell$νbb) searches

- **Missing E_T from Z→νν and 2 b jets from H→bb**
  - Large missing E_T > 50GeV
  - 2 acoplanar b-jets with E_T > 20 GeV, $|\eta|$ < 2.5
- **Backgrounds**
  - "physics"
    - W+jets, Z+jets, top, ZZ and WZ
  - "instrumental"
    - QCD multijet events with mismeasured jets
      - Large cross section & small acceptance
- **Strategy**
  - Trigger on events with large missing H_T (vector sum of jets' E_T)
  - Estimate "instrumental" background from data, physics bkd from simulation
  - Search for an event excess in di-jet mass distribution





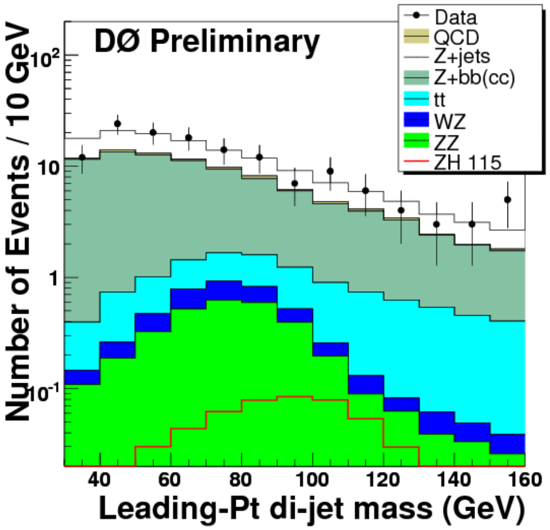
- **Reduce "instrumental" background**
  - Jet acoplanarity $\Delta\phi$(dijet) < 165°
  - define missing energy/momentum variables
    - $\not{E}_T$ calculated using calorimeter cells
    - $\not{H}_T = -|\Sigma p_T(\text{jet})|$ … jets
  - And select on their asymmetry
    - $\text{Asym}(\not{E}_T, \not{H}_T) = (\not{E}_T - \not{H}_T)/(\not{E}_T + \not{H}_T)$



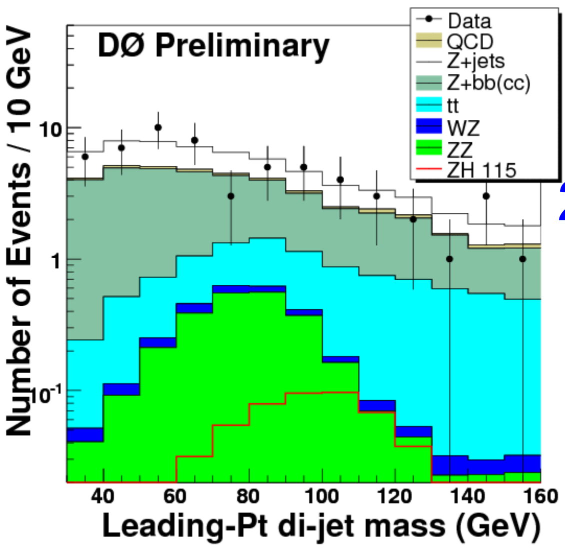
ZH → l l bb / NN @ D0

$L = 1.1\ \mathrm{fb}^{-1}$

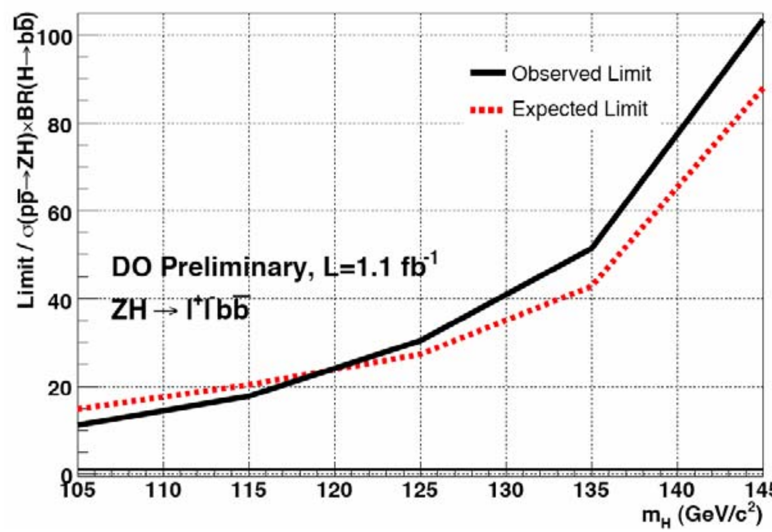
- NN trained based on kinematics
- ZZ is irreducible background



1 'tight' b tag



2 'loose' b tags



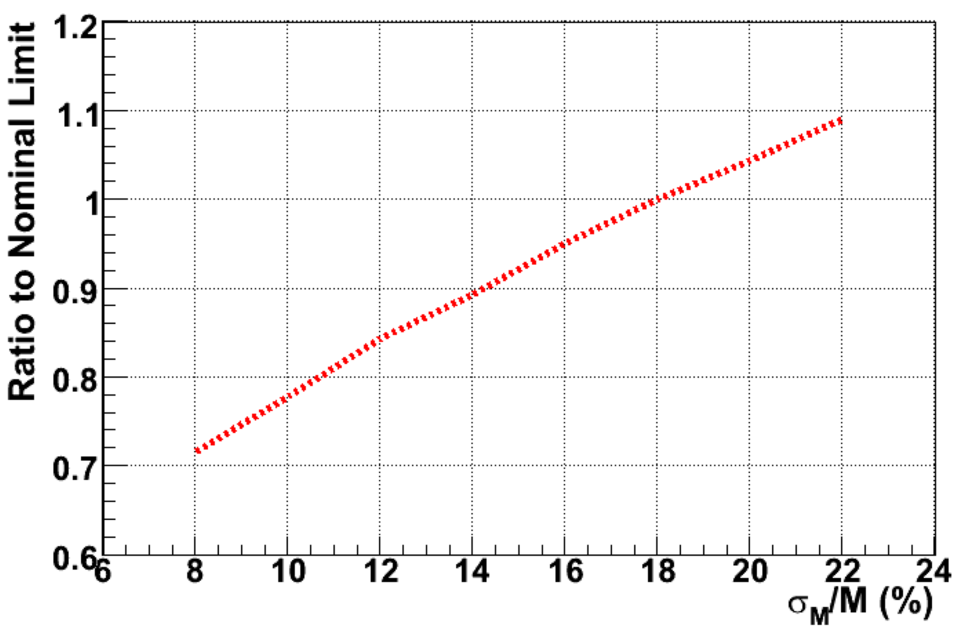
- M=115 GeV:
  σ_{95}/SM=20 (exp), 18 (obs)

- all channels important for final sensitivity

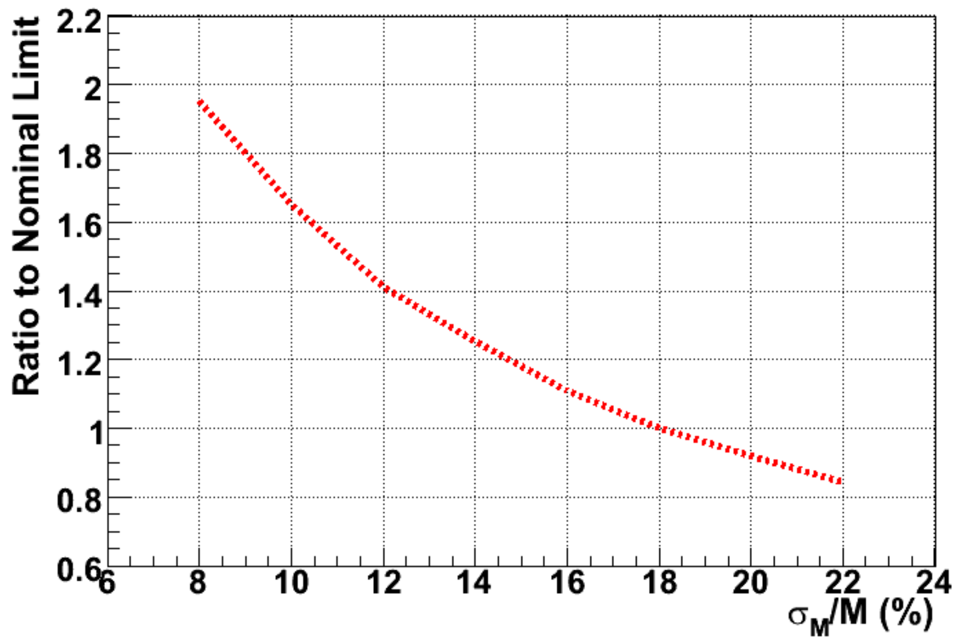
Di-Jet Mass Resolution

- ✗ **SHWG/HSG quoted at 10% dijet mass resolution**
  - ✗ **Bad news: We're currently at 17-18%**
  - ✗ **Good news: Don't need 10% to get expected factor in lumi**
- ✗ **Several techniques available: energy-flow algorithms, constrained fitting of jets+MET system, ISR/FSR jet recovery**

Change in Limit



Effective Lumi



Combining Higgs boson Searches

CDF uses a Bayesian approach

- Use Bayesian posterior probability
- Assume flat prior density for the number of Higgs events

- Combined Binned Poisson Likelihood:

$$\mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) = \prod_{i=1}^{N_C} \prod_{j=1}^{Nbins} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}} / n_{ij}!$$

- Combined Posterior Density Function:

$$p(R|\vec{n}) = \int d\vec{s} \int d\vec{b} \mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) \times s_{tot} / \int dR \int d\vec{s} \int d\vec{b} \mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) \times s_{tot}$$

DØ uses the CLs (LEP) Method

the CL_S confidence interval is a normalization of CL_{S+B}

CL_{S+B} = signal + bkgd hypothesis, CL_B = bkgd only hypothesis

$CL_S = CL_{S+B}/CL_B$: CL_{S+B} & CL_B are defined using a "test statistic"

Test statistic used is the Log-Likelihood Ratio (LLR=-2 ln Q)

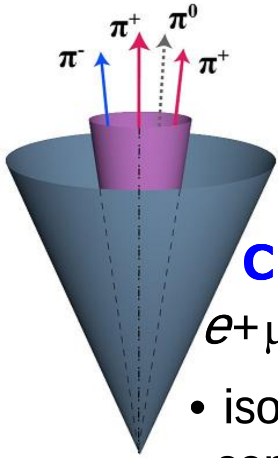
generated via Poisson statistics **($Q=e^{-(s+b)}(s+b)^d/e^{-b}b^d$) s,b,d=sig.,bkd,data)**

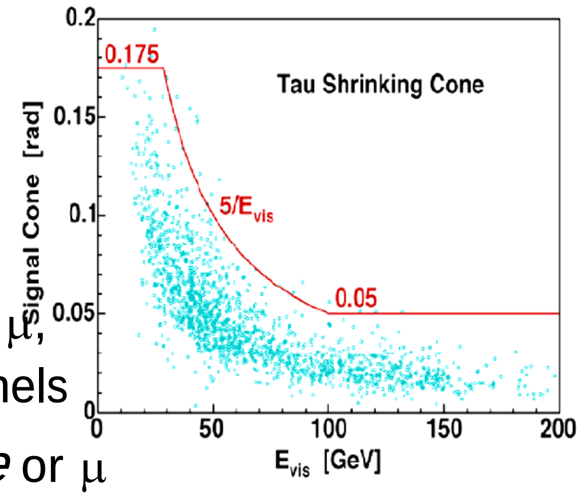
Tevatron Higgs combination is done with both methods

➔ they give results compatible within 10%.

Neutral MSSM Higgs $\rightarrow\tau\,\tau_{had\ell}$

Main backgrounds: $Z\rightarrow\tau\tau$ (irreducible), W+jets, $Z\rightarrow ee,\mu\mu$, mulijet, di-boson

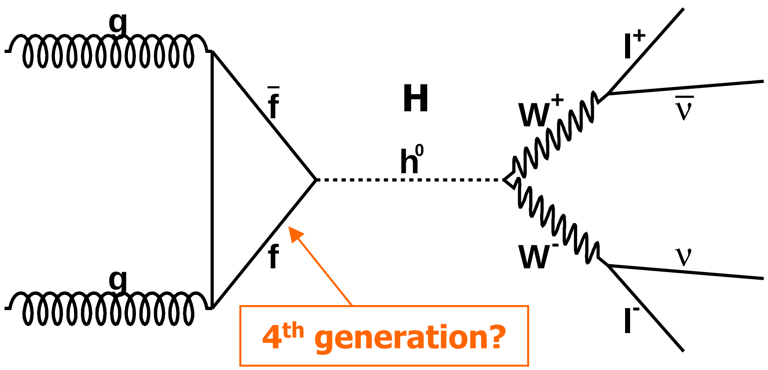




CDF: e, μ, $e+\mu$ channels

- isolated e or μ separated from opposite sign hadronic τ
- variable-size cone algorithm for τ
- $H_T = |p_T^{\ell}| + |p_T^{had}| + |\not{E}_T|$ > 55 GeV
- Ws removed by a cut on the MET projected on the bisector between τs.

SM "Heavy" Higgs: H → WW* → lνlν

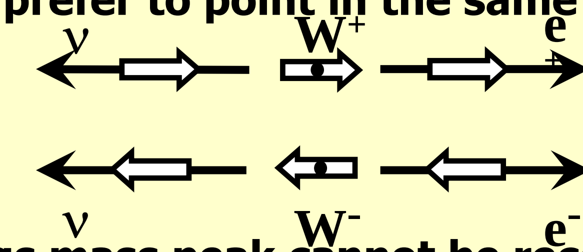


Search strategy:

→ 2 high P_t leptons and missing E_t

→ WW comes from spin 0 Higgs:

leptons prefer to point in the same direction.



But Higgs mass peak cannot be reconstructed due to the presence of 2 ν→ look for an excess

CDF and DØ already published on 0.3-0.4 fb^{-1}