Searching for the Higgs Boson at the Tevatron

Séminaire Centre de Physique des Particules de Marseille

5th May 2008

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Outline

- Introduction
- Tevatron
- Standard model Higgs at low mass: WH & ZH searches
- Intermezzo: H $\rightarrow \tau\tau$
- Standard model Higgs at high mass: H $\rightarrow$ WW searches
- Tevatron combination
- Conclusion & Outlook

Introduction

– Standard model: very successful !

– Higgs mechanism to break electroweak symmetry

$\Rightarrow$ Massive EW bosons

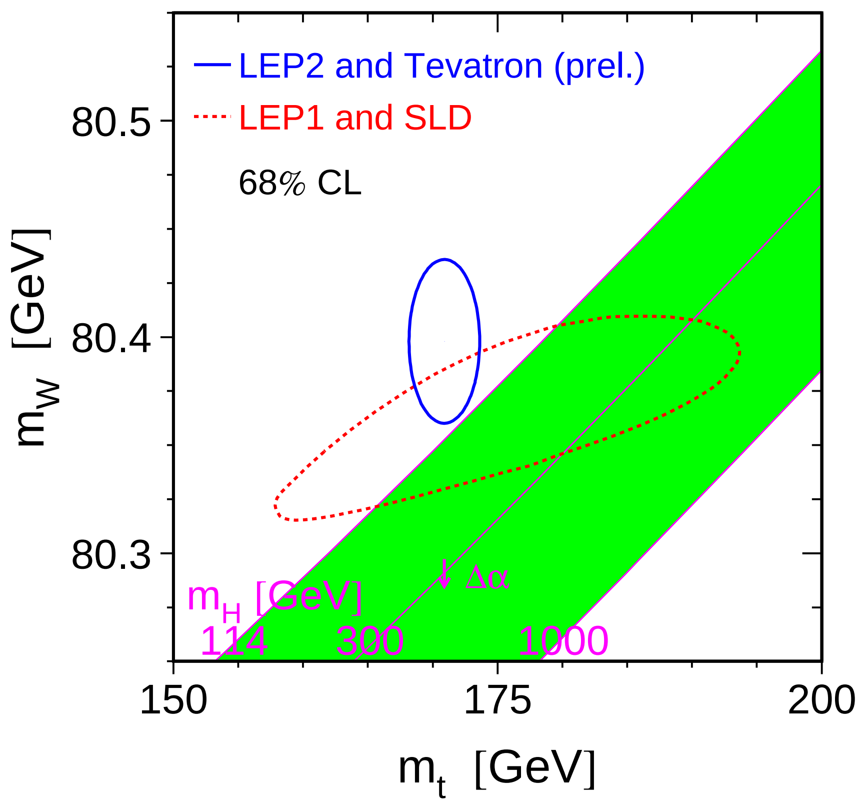
$\Rightarrow$ Massive quarks and leptons

$\Rightarrow$ Higgs boson

– Where is the Higgs ?

What Do We Know?

Precision EW measurements at Tevatron, LEP and SLD



$m_{\mathrm{H}} = 76^{+33}_{-24}$ GeV

$m_{\mathrm{H}} < 144$ GeV at 95% CL

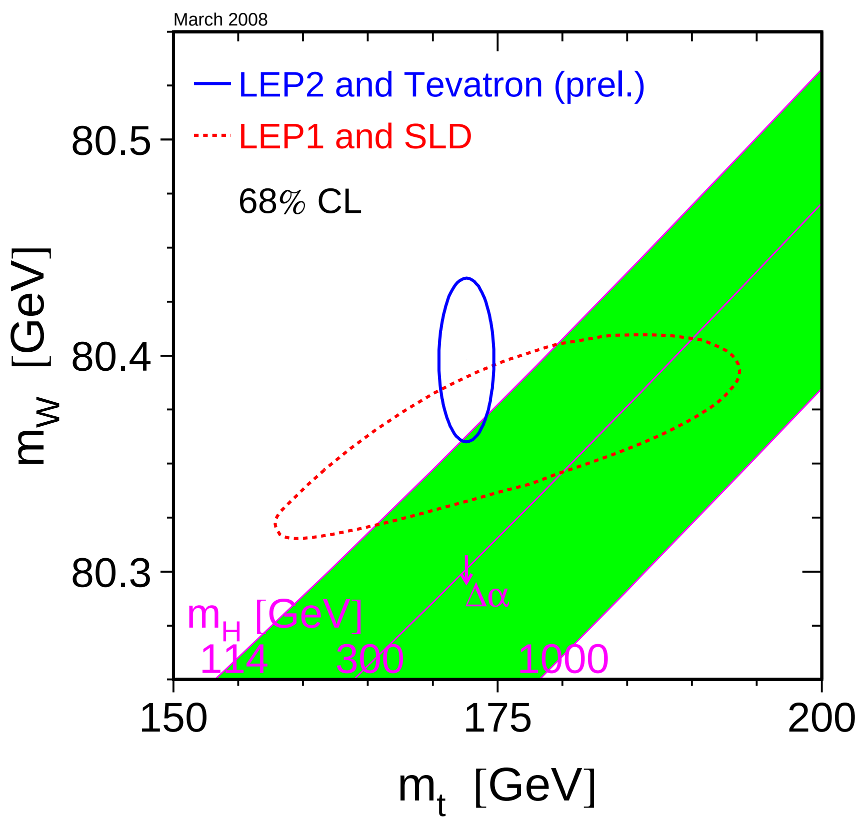
$(m_{\mathrm{t}} = 170.9 \pm 1.8$ GeV)

LEP2 direct search: $m_{\mathrm{H}} > 114$ GeV ($m_{\mathrm{H}} < 182$ GeV)

$\Rightarrow$ Within reach of the Tevatron!

What Do We Know?

Precision EW measurements at Tevatron, LEP and SLD



$m_{\mathrm{H}} = 87^{+36}_{-27}$ GeV

$m_{\mathrm{H}} < 160$ GeV at 95% CL

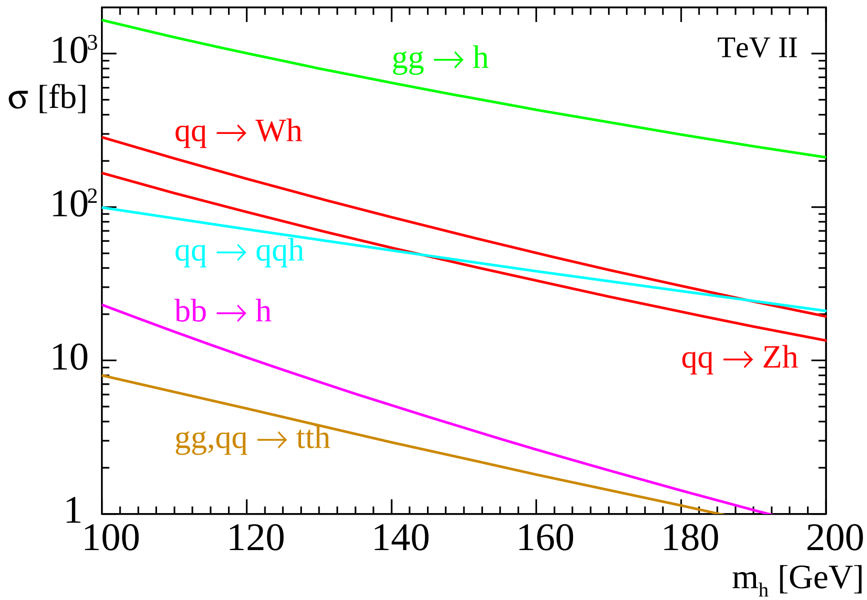
$(m_{\mathrm{t}} = 172.6 \pm 1.4$ GeV$)$

LEP2 direct search: $m_{\mathrm{H}} > 114$ GeV ($m_{\mathrm{H}} < 190$ GeV)

$\Rightarrow$ Within reach of the Tevatron!

Higgs @ Tevatron

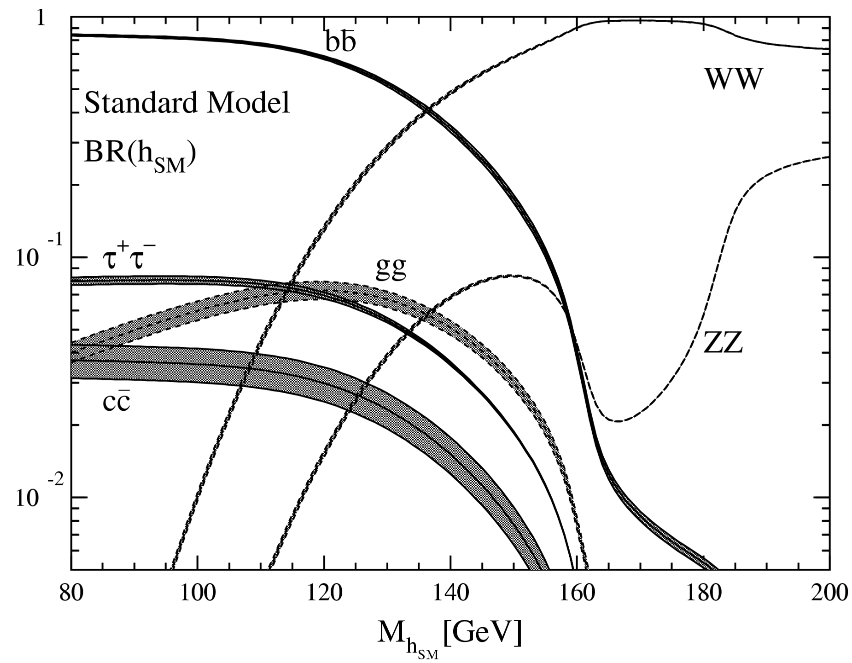
Production



– Gluon fusion

– Associated production

Decay

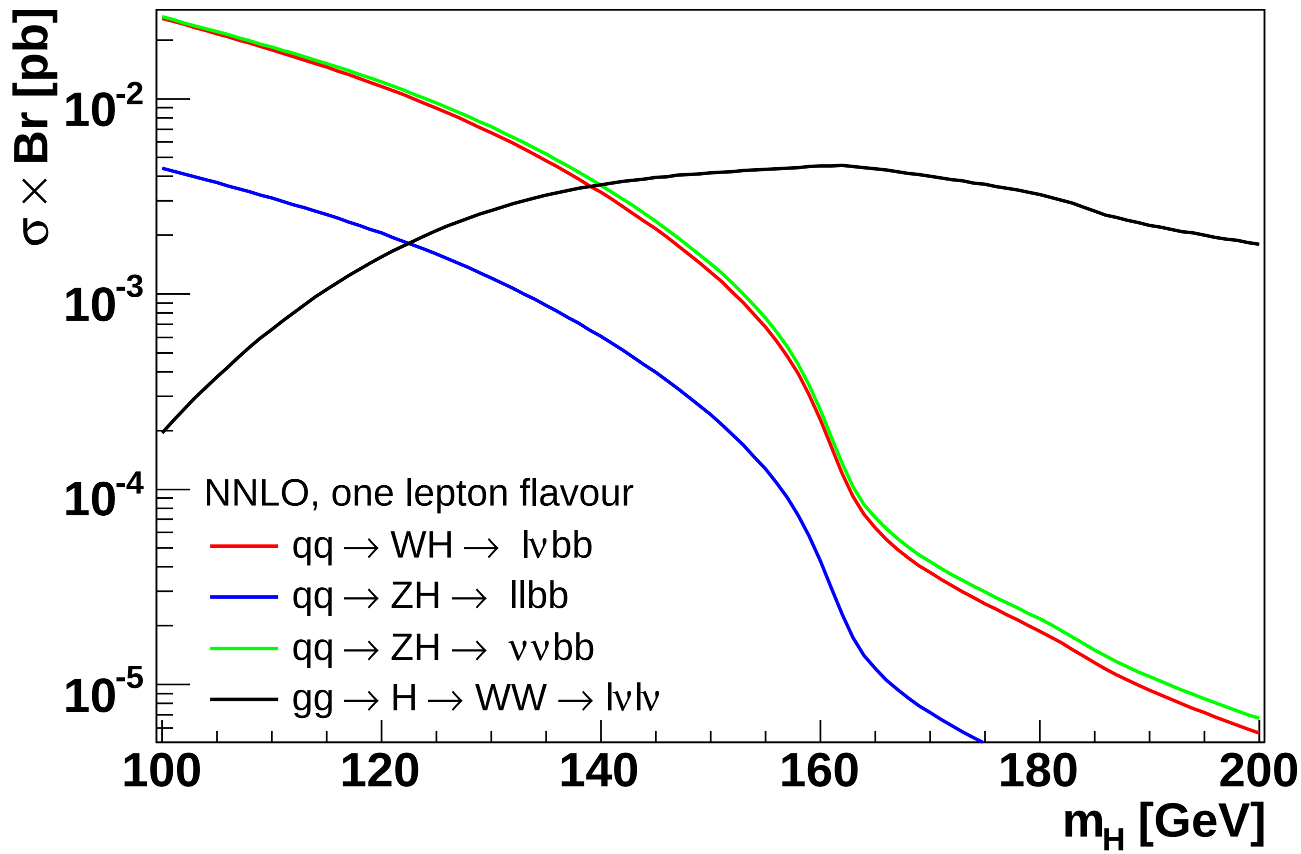


– $b\bar{b}$ at low m_H

– WW at high m_H

Higgs @ Tevatron

$\sigma \times$Br for experimentally most accessible final states



WH, ZH with H $\rightarrow$ b$\bar{\text{b}}$ at low m_{H}

$gg \rightarrow$ H with H $\rightarrow$ WW at high m_{H}

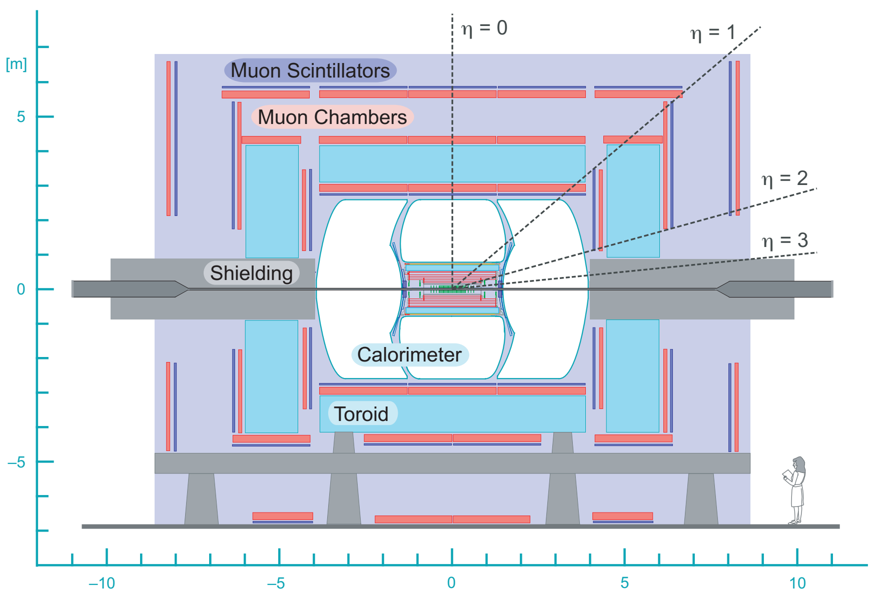
Tevatron

– $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

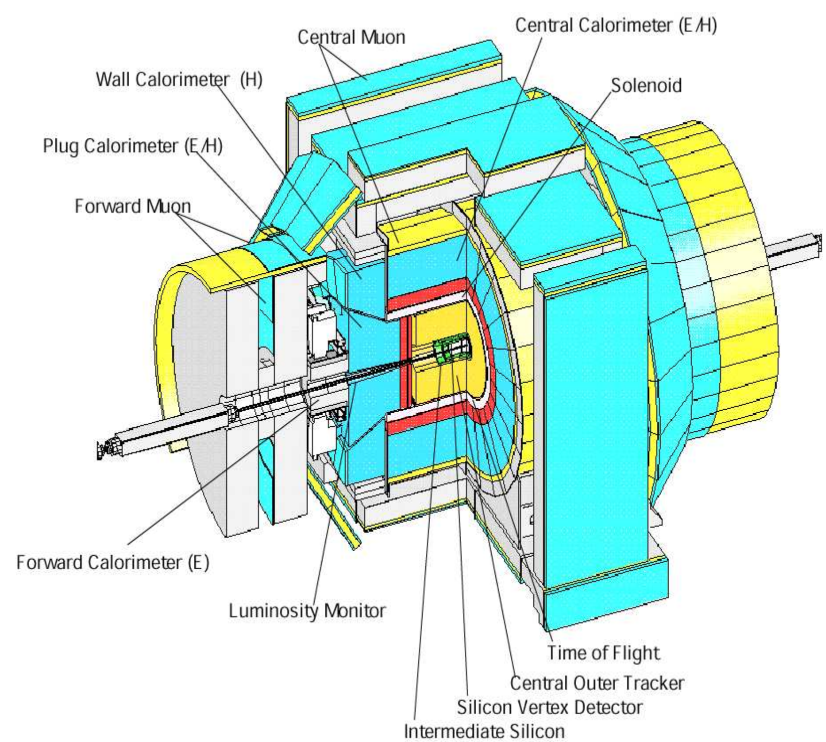
– Up to now: $\int \mathcal{L}dt \simeq 4.0$ fb^{-1} delivered / experiment

– Results shown in this talk: up to 2.3 fb^{-1} (Run IIa & Run IIb)

DØ



CDF



Higgs at Low Mass: WH & ZH Searches

– Decays of W and Z: high p_T leptons and/or $\not\!\!E_\mathrm{T}$

– H$\rightarrow$b$\bar{\mathrm{b}}$: at least two jets

– Background sources:

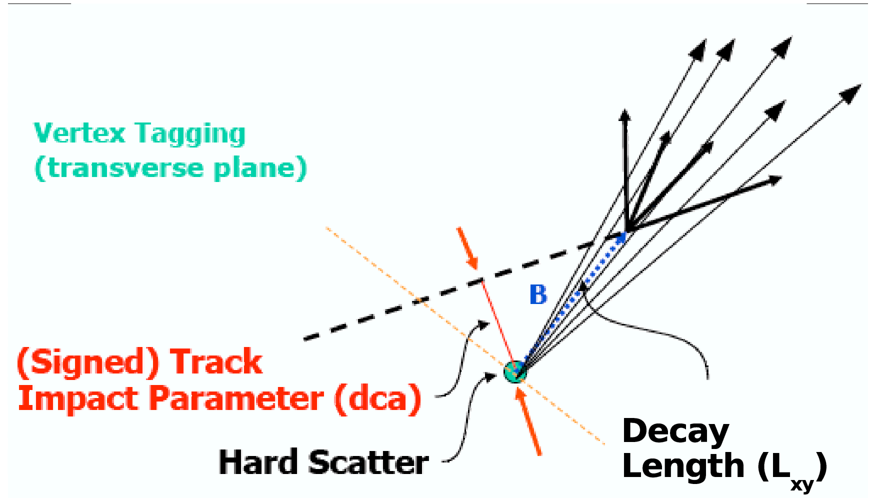
  * W/Z with additional jets (including Wb$\bar{\mathrm{b}}$, Zb$\bar{\mathrm{b}}$)
  * t$\bar{\mathrm{t}}$, single top
  * Multi-jet production with mis-ID of lepton or $\not\!\!E_\mathrm{T}$
  * Di-boson (WW, WZ, ZZ)

$\Rightarrow$ Need to precisely model these !

  * Multi-jet directly from data
  * Others from simulation (ALPGEN, PYTHIA, HERWIG)

b-Tagging

Exploit b-lifetime:



– Combine lifetime variables in, e.g. a neural network:

  ∗ Vertex mass, decay length, impact parameters, . . .

⇒ High b-tagging efficiency:

  ∗ "Tight": 50% at 0.5% fake rate (DØ neural net tagger)
  ∗ "Loose": 74% at 5.0% fake rate (DØ neural net tagger)

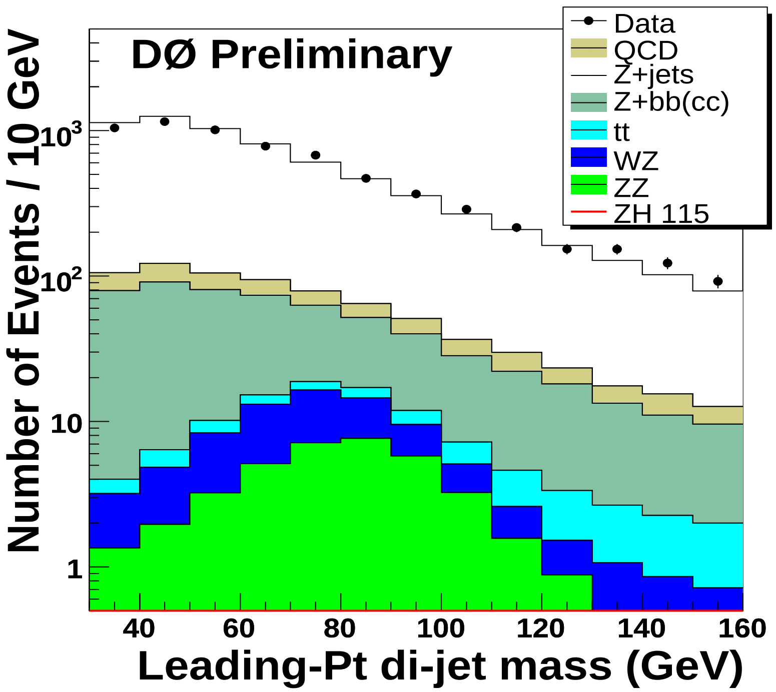
– Typical analysis: two "Loose" tags or one "Tight" tag

Two Charged Leptons: ZH $\rightarrow \ell\ell b\bar{b}$

– Clean signature: two isolated leptons, $m_{\mathrm{inv}} \simeq m_{\mathrm{Z}}$; no $\not{E}_{\mathrm{T}}$

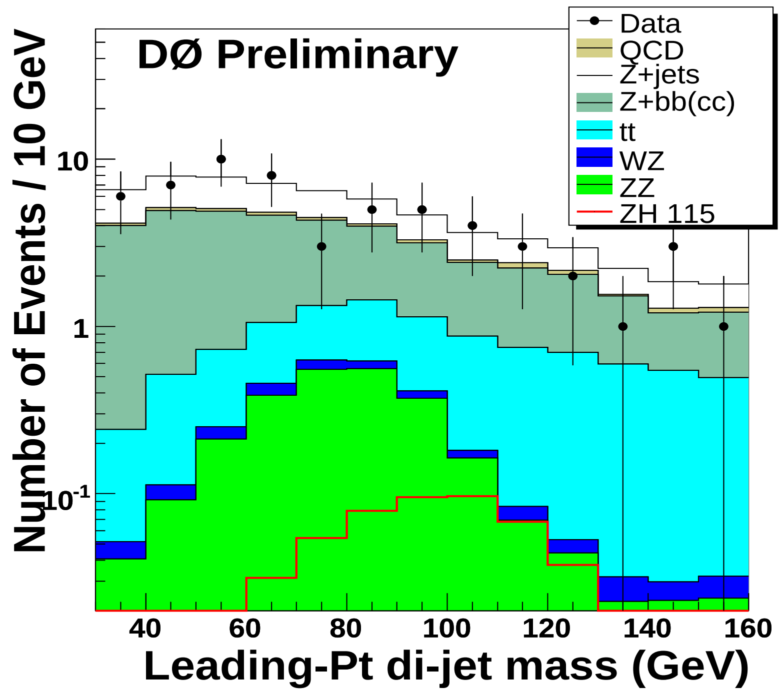
– Exclusive samples with one "Tight" or two "Loose" b-tags

$$\int \mathcal{L}dt \simeq 1\ \mathrm{fb}^{-1}$$



Before b-tag: 1.45 ZH

7.6k background events



Double b-tag: 0.53 ZH

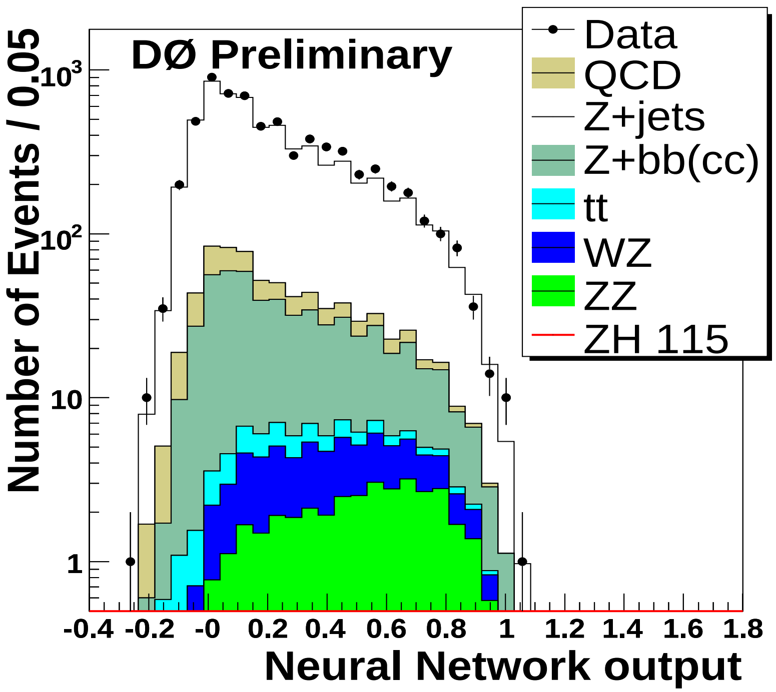
73.6 background events

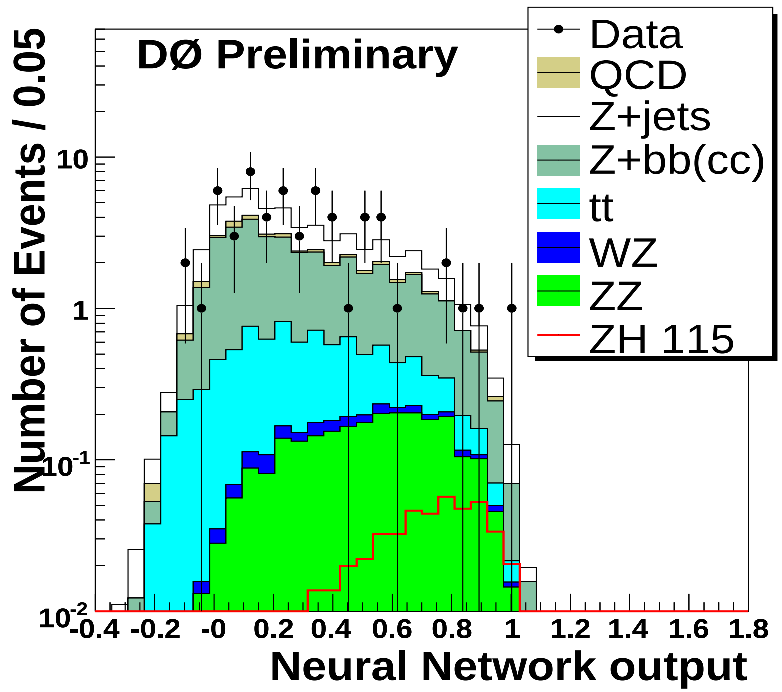
Two Charged Leptons: ZH $\rightarrow \ell\ell b\bar{b}$

– Improve sensitivity by using more information

$\Rightarrow$ Neural network, using event kinematics as input

$$\int \mathcal{L}dt \simeq 1 \text{ fb}^{-1}$$

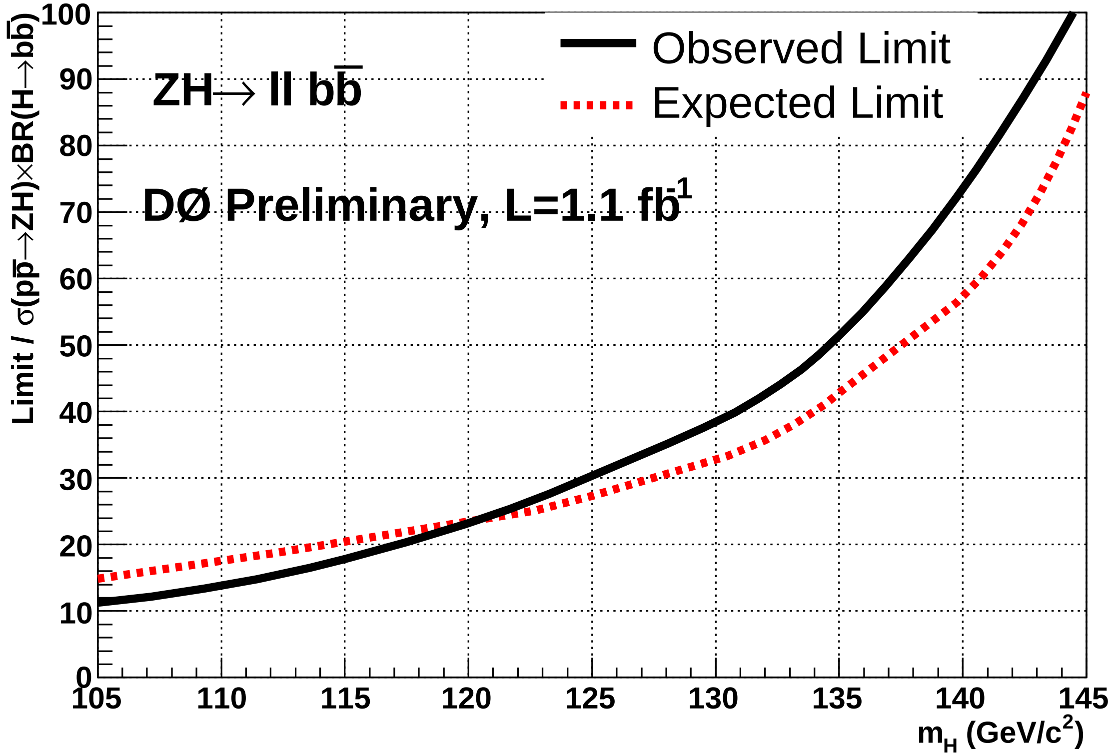




ZH $\longrightarrow \ell\ell b\bar{b}$ Results

– No excess, data agree with background model

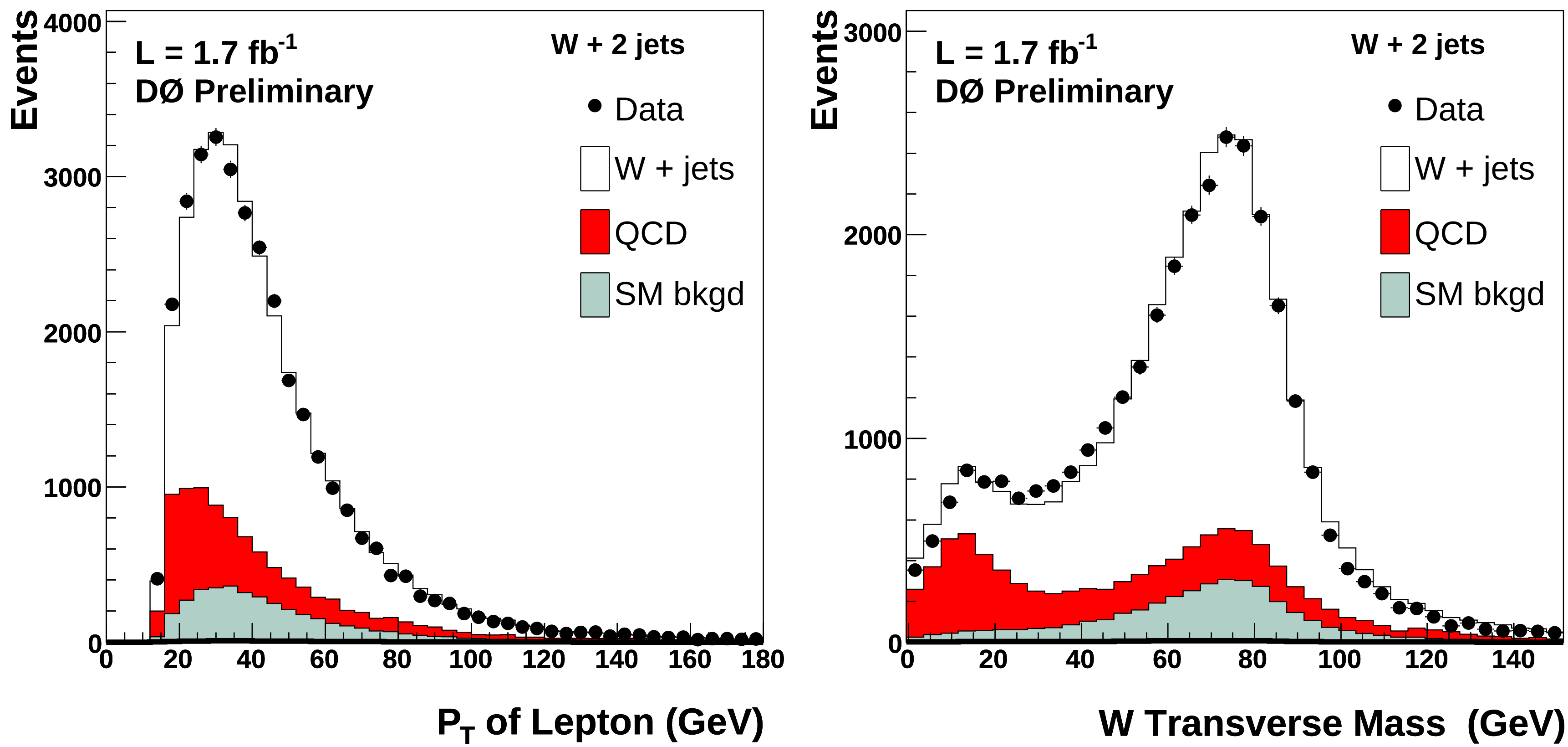
– Use neural network output to derive limits



At $m_{\mathrm{H}} = 115$ GeV: limit/SM 18 (20 expected)

One Charged Lepton: WH $\rightarrow \ell\nu b\bar{b}$

- Signature: one isolated lepton, large $\not\!\!E_T$
- Events with exactly two jets, b-tagged

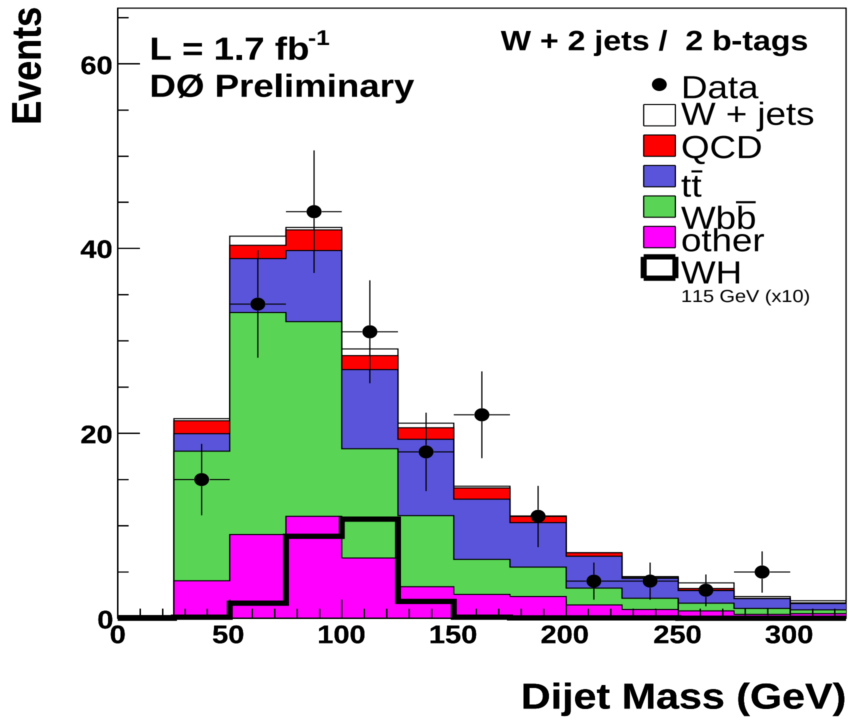


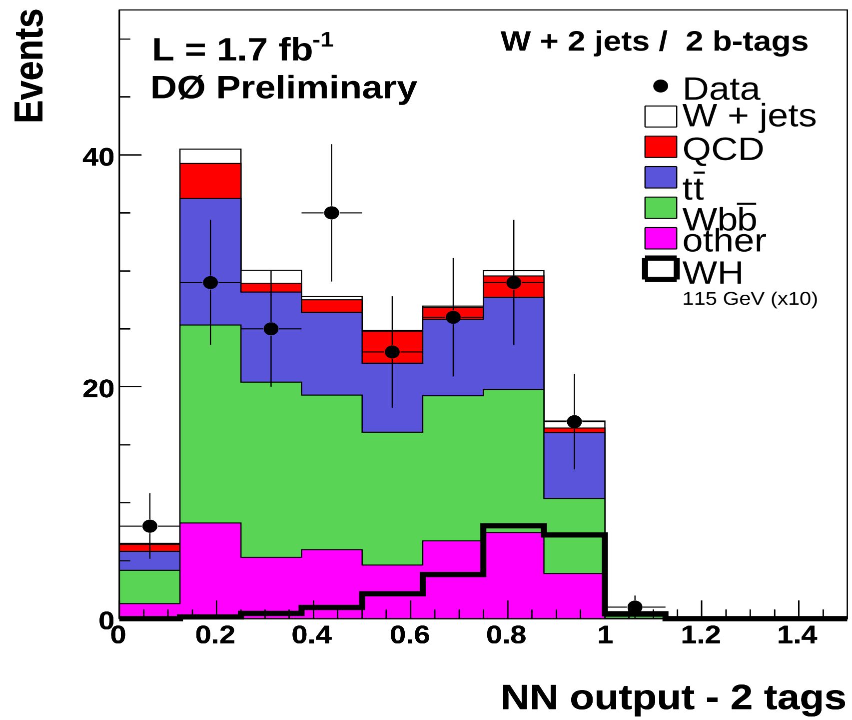
Before b-tag: 9.9 WH, 33.5k background events

Double b-tag: 2.3 WH 204.1 background events

One Charged Lepton: WH $\to \ell\nu b\bar{b}$

– Train a neural network against $Wb\bar{b}$, kinematics as input:
ΔR(jets), p_{T}(di-jet system), $\Delta\phi$(jets), p_{T}((sub-)leading jet), p_{T}(μ-$\not{E}_{\mathrm{T}}$ system), m_{jj} $\Rightarrow$ $\simeq$ 15% improvement in limit





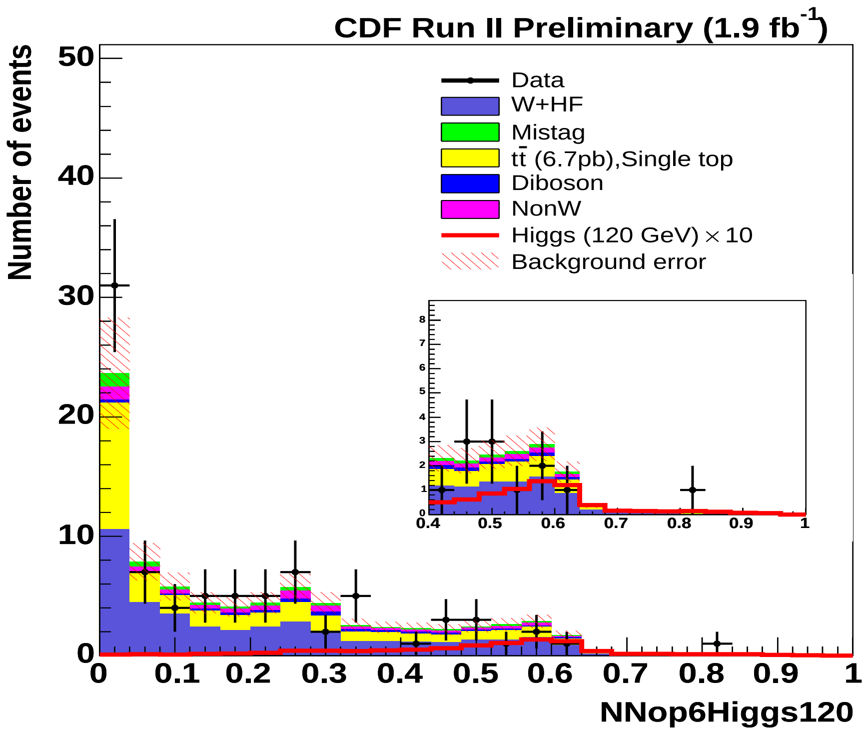
Near future:

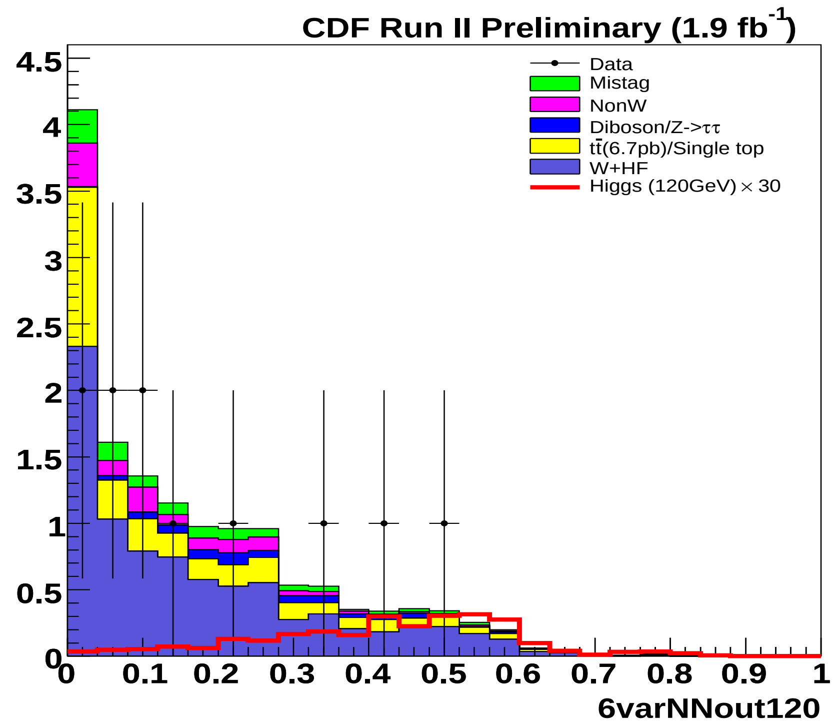
Forward electrons, 3 jet channel, improved neural network

One Charged Lepton: WH $\rightarrow \ell\nu b\bar{b}$

– CDF, $\int \mathcal{L}dt \simeq 1.9$ fb^{-1}

  * Two double b-tag, one single b-tag categories
  * Forward electrons included



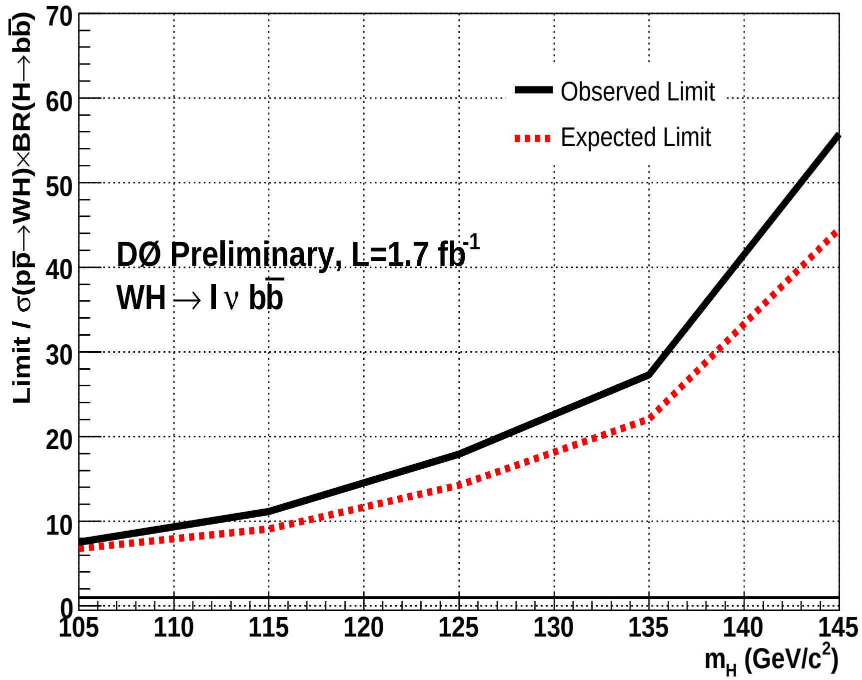


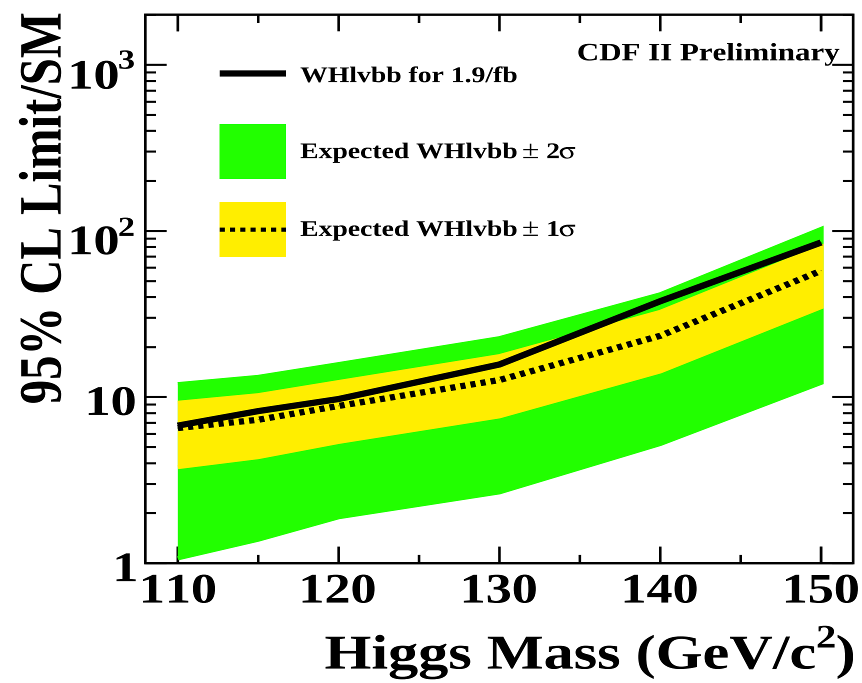
Central e $+ \mu$ 0.94 WH
80.62 background events

Forward e 0.09 WH
14.18 background events

WH $\rightarrow \ell\nu b\bar{b}$ Results

- No excess, data agree with background model
- Use neural network output to derive limits



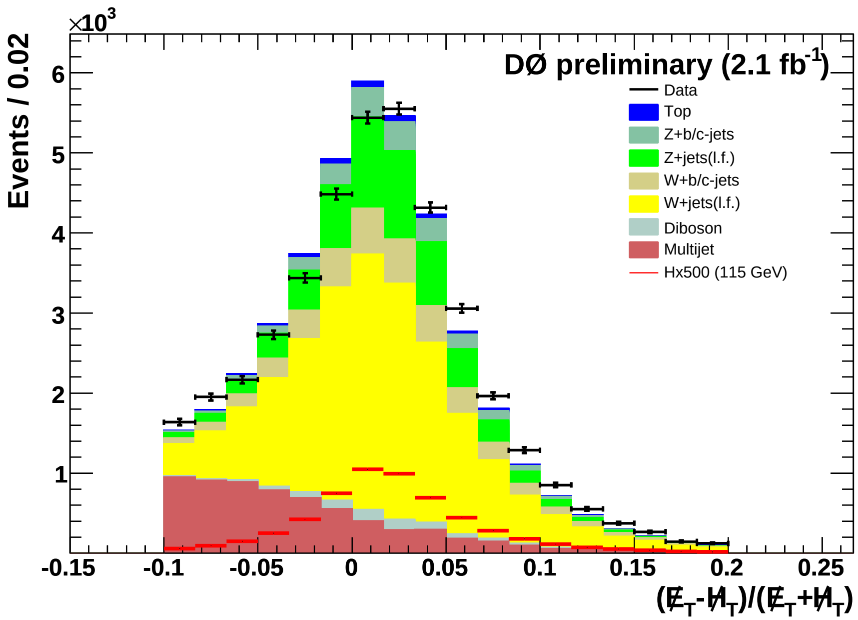


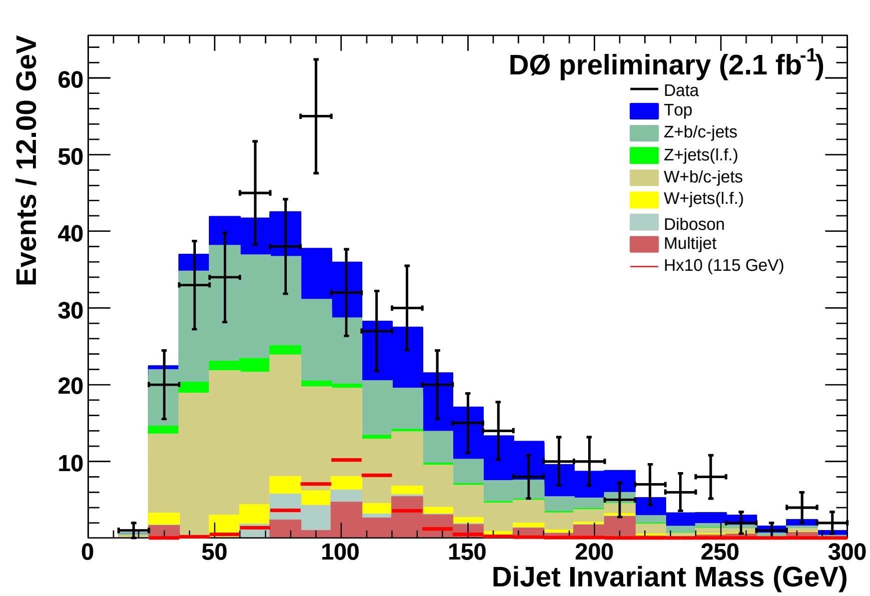
DØ at $m_{\mathrm{H}} = 115$ GeV
limit/SM 11.1 (9.1 expected)

CDF at $m_{\mathrm{H}} = 115$ GeV
limit/SM 8.2 (7.3 expected)

No Charged Lepton: ZH $\rightarrow \nu\nu b\bar{b}$

- Signature: two jets and large $\not\!\!E_T$
- Instrumental background from mismeasured $\not\!\!E_T$
  - ∗ Direction $\not\!\!E_T \neq$ direction jet
  - ∗ $\not\!\!E_T$ vs $\not\!\!H_T$ asymmetry
  - ∗ Use calorimeter-based $\not\!\!E_T$ and tracks



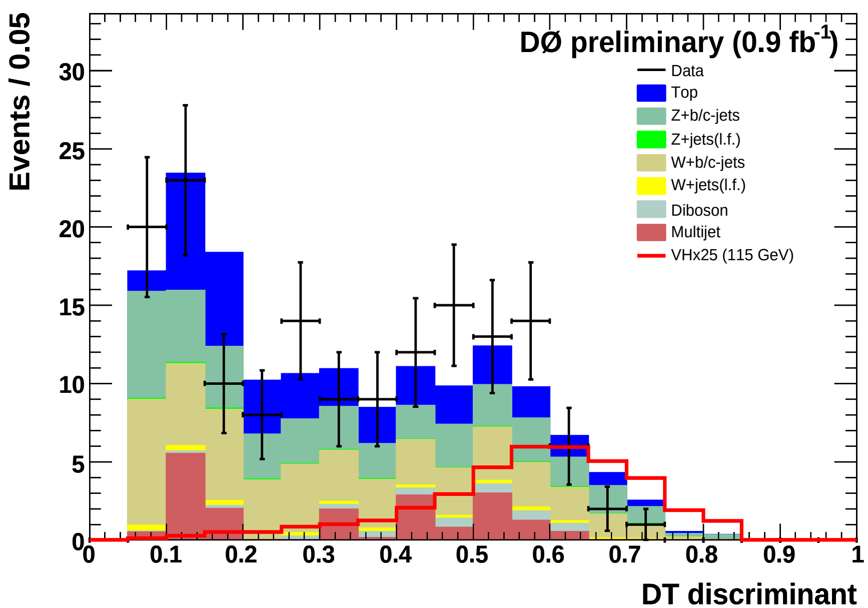


No Charged Lepton: ZH $\rightarrow \nu\nu b\bar{b}$

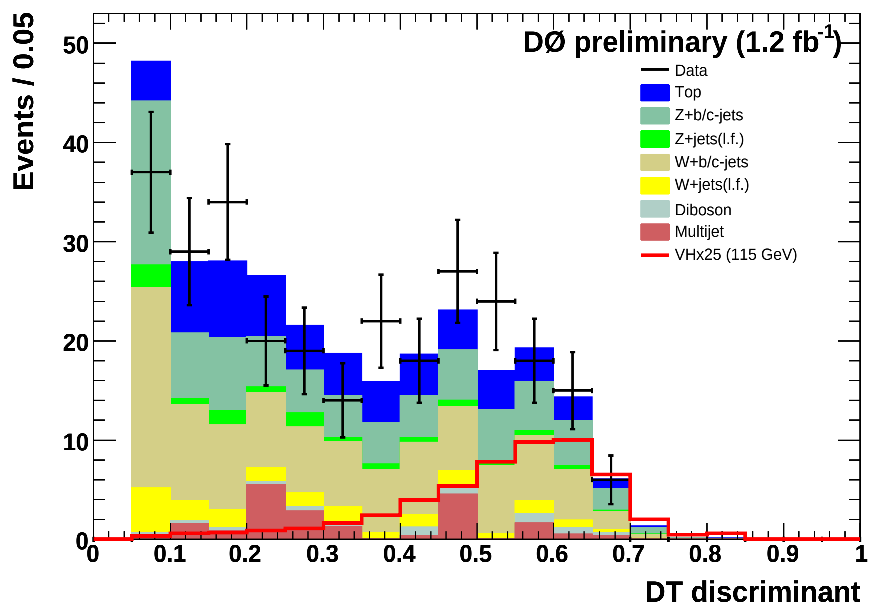
– Decision trees to improve sensitivity

  * Recursively cut on kinematic variables
  * More discriminating than m_{jj}

Run IIa



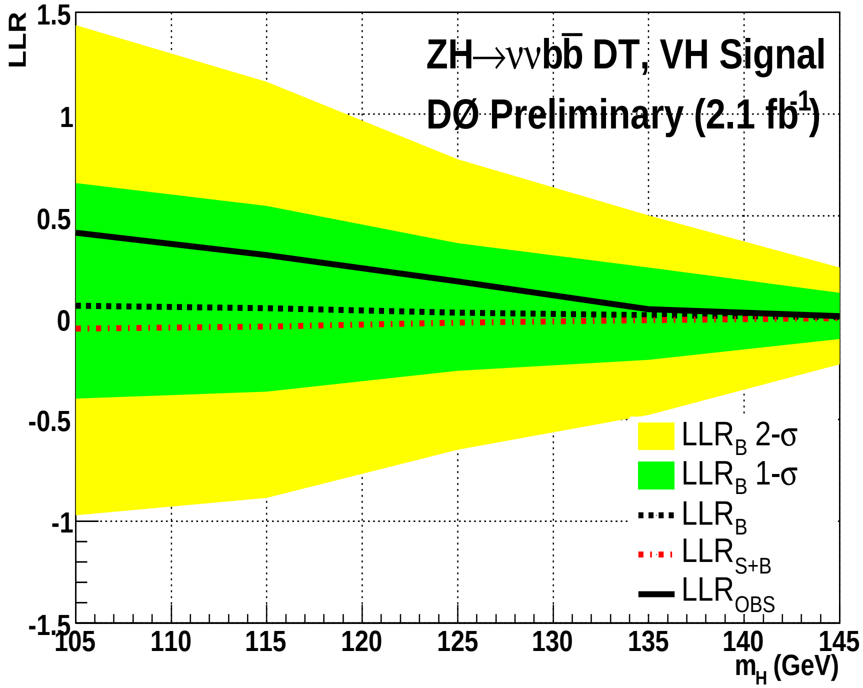
Run IIb

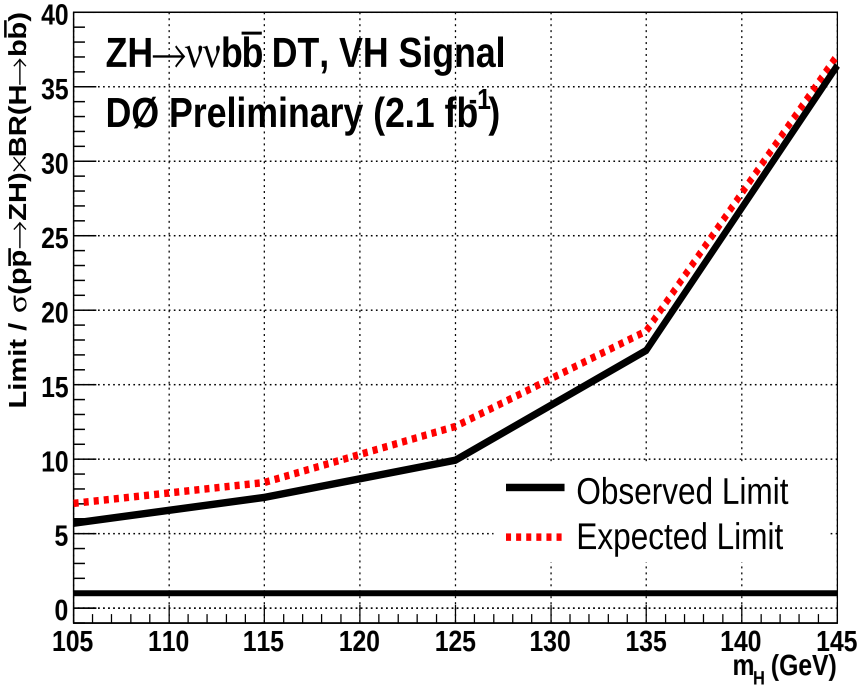


ZH $\rightarrow \nu\nu b\bar{b}$ Results

– No excess, data agree with background model

– Use decision tree output to derive limits

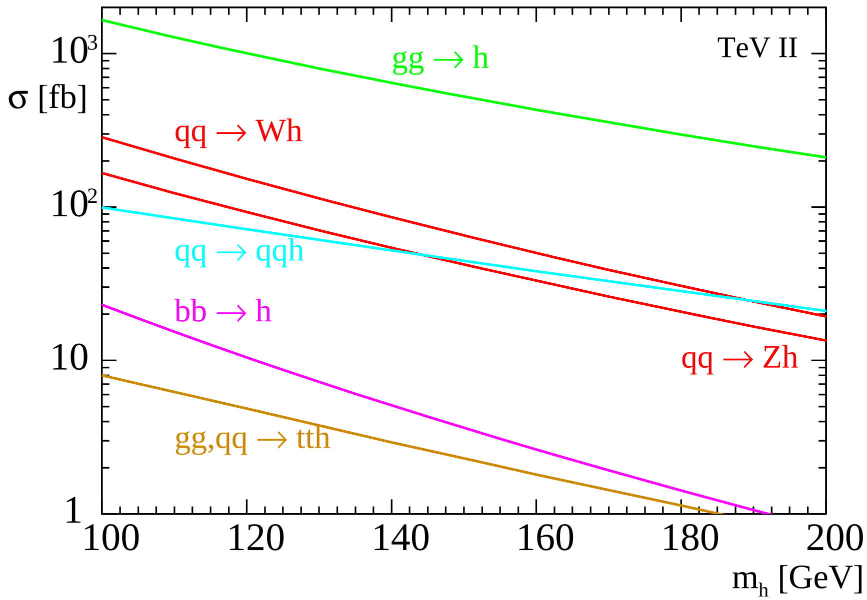




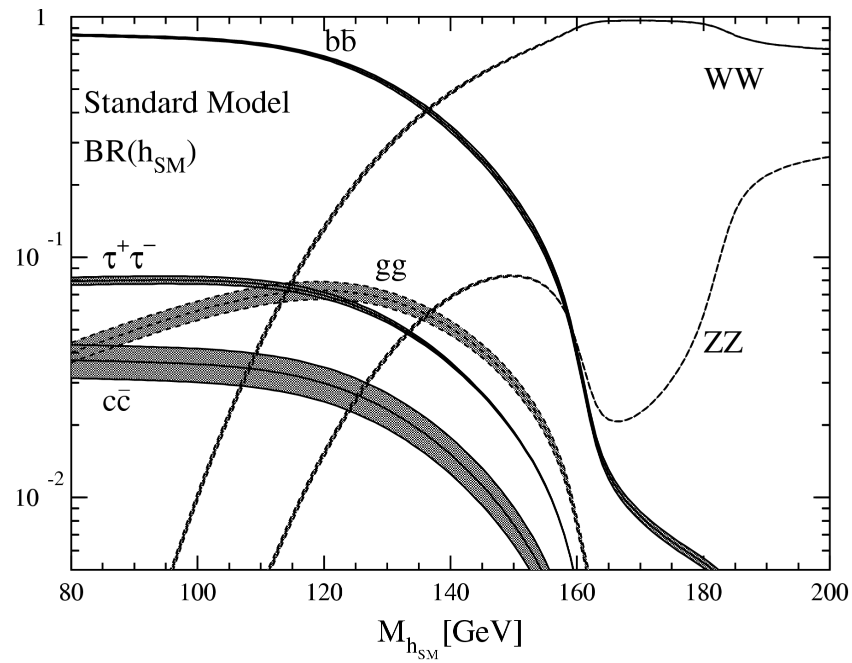
At $m_{\mathrm{H}} = 115$ GeV: limit/SM 7.5 (8.4 expected)

Higgs $\rightarrow \tau\tau$

Production



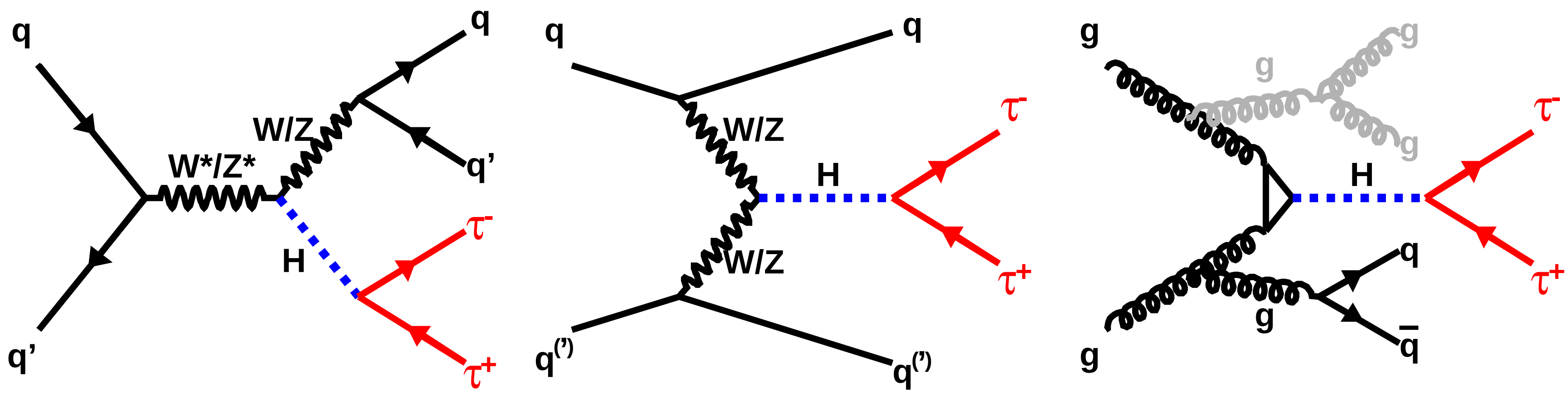
Decay



$H \rightarrow \tau\tau \simeq 10\%$ of $H \rightarrow b\bar{b}$

VBF $H \rightarrow \tau\tau$ important at LHC !

Higgs $\rightarrow \tau\tau$

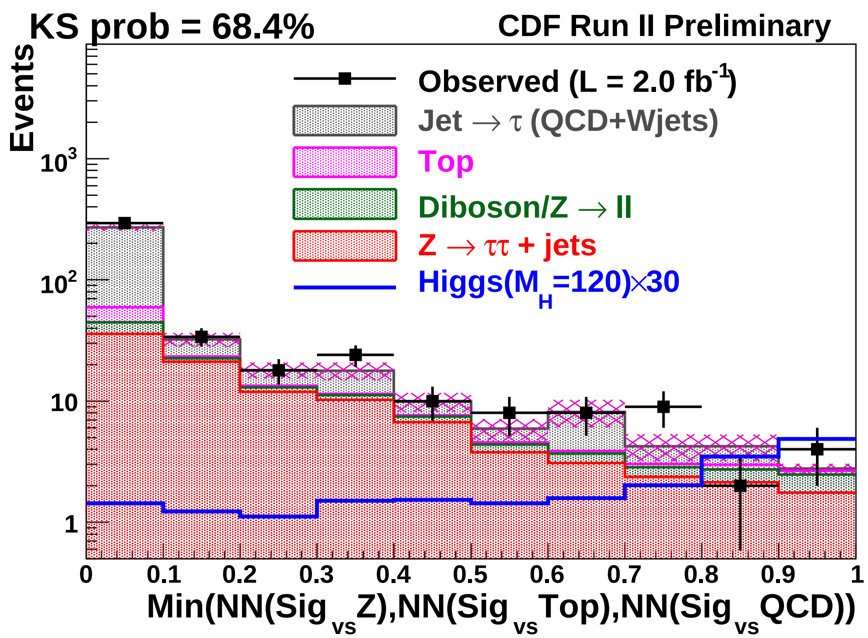


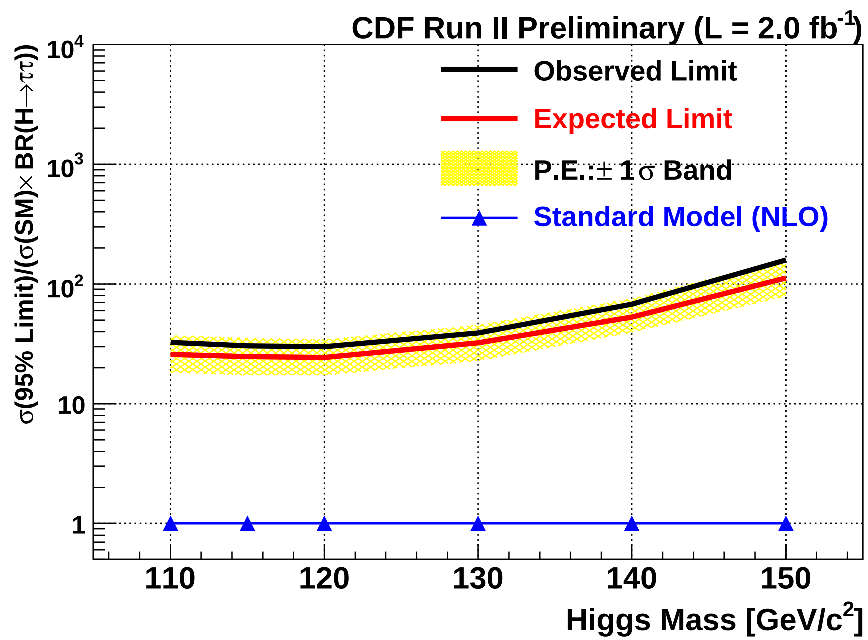
- CDF, $\int \mathcal{L}dt \simeq 2$ fb^{-1}
- Final state: $\tau(\rightarrow \ell X)\,\tau(\rightarrow$ hadrons$) + 2$ jets
- Sensitive to WH, ZH, VBF, gluon fusion
- Background from Z/W+jets, $t\bar{t}$, di-boson, multi-jet
- Neural networks trained against main backgrounds

Higgs $\rightarrow \tau\tau$

– At $m_{\mathrm{H}} = 115$ GeV: 0.76 Higgs, 373.8 background events

– No excess, data agree with background model





At $m_{\mathrm{H}} = 115$ GeV: limit/SM 30.5 (24.8 expected)

$\Rightarrow$ Another step in sensitivity!

Higgs at High Mass

– H $\rightarrow$ WW $\rightarrow \ell\nu\ell\nu$

– Final states with e^+e^-, $\mu^+\mu^-$ or $e^\pm\mu^\mp$ and large $\not\!\!E_T$

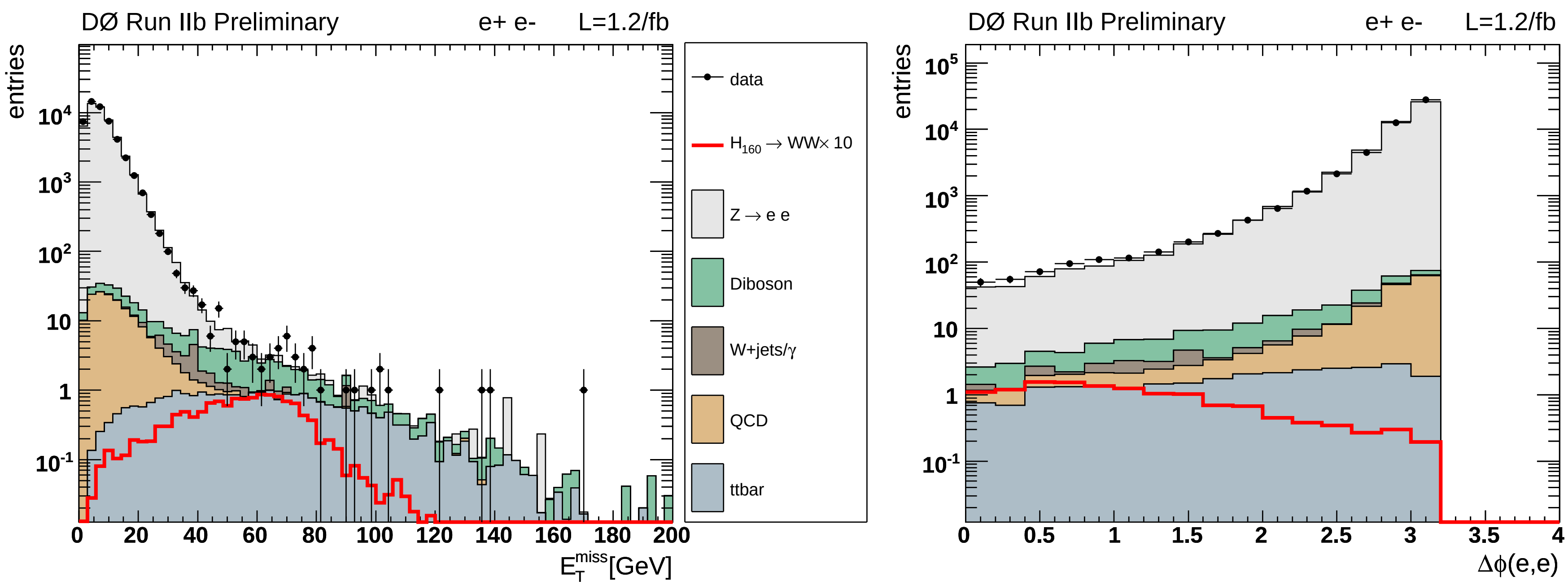
– Background sources:

  * Di-boson (WW, WZ, ZZ)
  * $t\bar{t}$, DY di-lepton production
  * W + mis-identified jet/γ

– Signal includes VBF, leptonic τ decays

Higgs at High Mass

Good agreement at preselection level



– Cannot reconstruct m_{H}, but . . .

– Spin correlations: $\Delta\phi(\ell\ell)$ small for H $\rightarrow$ WW $\rightarrow \ell\nu\ell\nu$

Advanced Technique: Matrix Element

– For each event, estimate compatibility with signal or background hypothesis

$$P(\vec{x}_{\text{obs}}) = \frac{1}{\sigma} \int \frac{\mathrm{d}\sigma_{\text{theory}}}{\mathrm{d}\vec{y}} \epsilon(\vec{y}) G(\vec{x}_{\text{obs}}, \vec{y}) \mathrm{d}\vec{y}$$

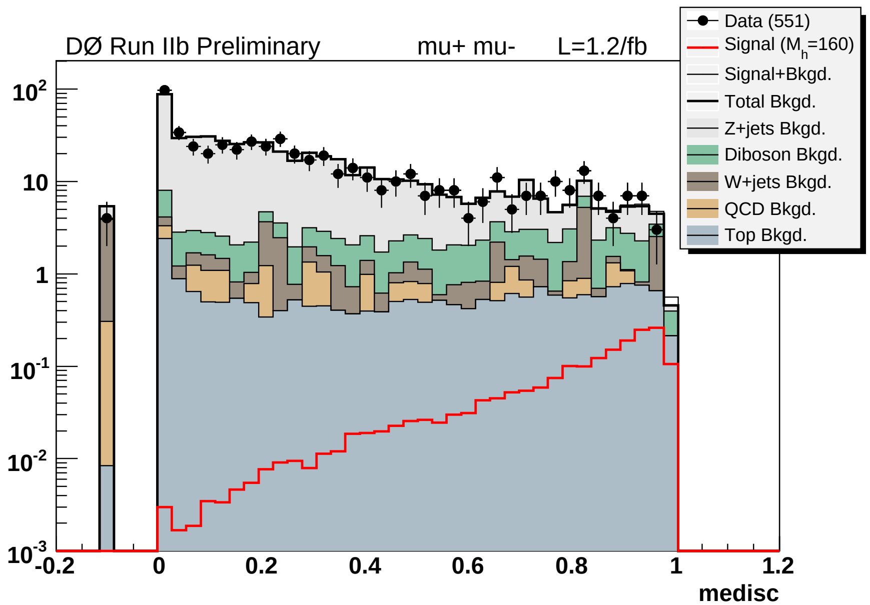
$$\text{MEdisc}(\vec{x}_{\text{obs}}) = \frac{P_{\text{signal}}}{P_{\text{signal}} + P_{\text{background}}}$$

– $\vec{x}, \vec{y}$: event kinematics ϵ: acceptance$\times$efficiency
G: resolution function

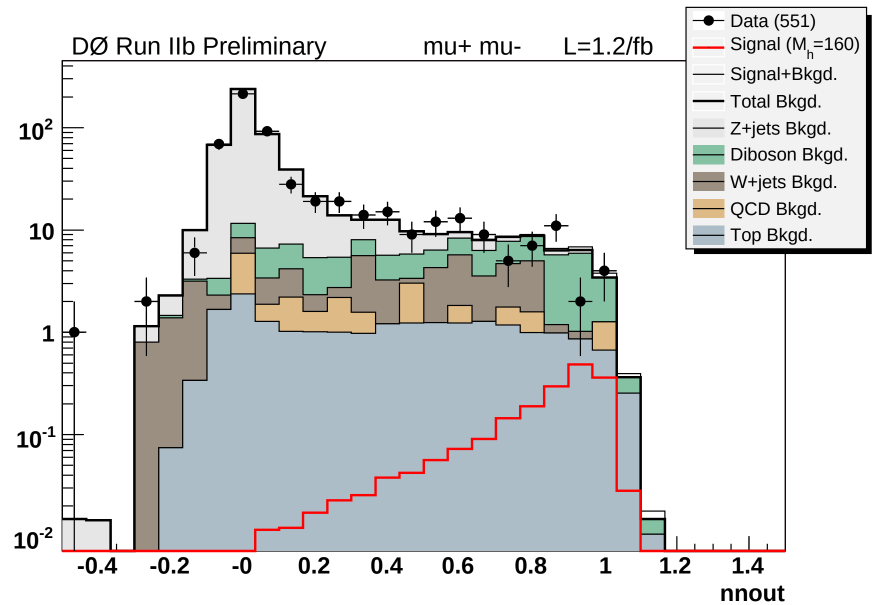
– Use discriminant as input to a neural network

Matrix Element & Neural Net

Matrix Element discriminant



Neural Net discriminant



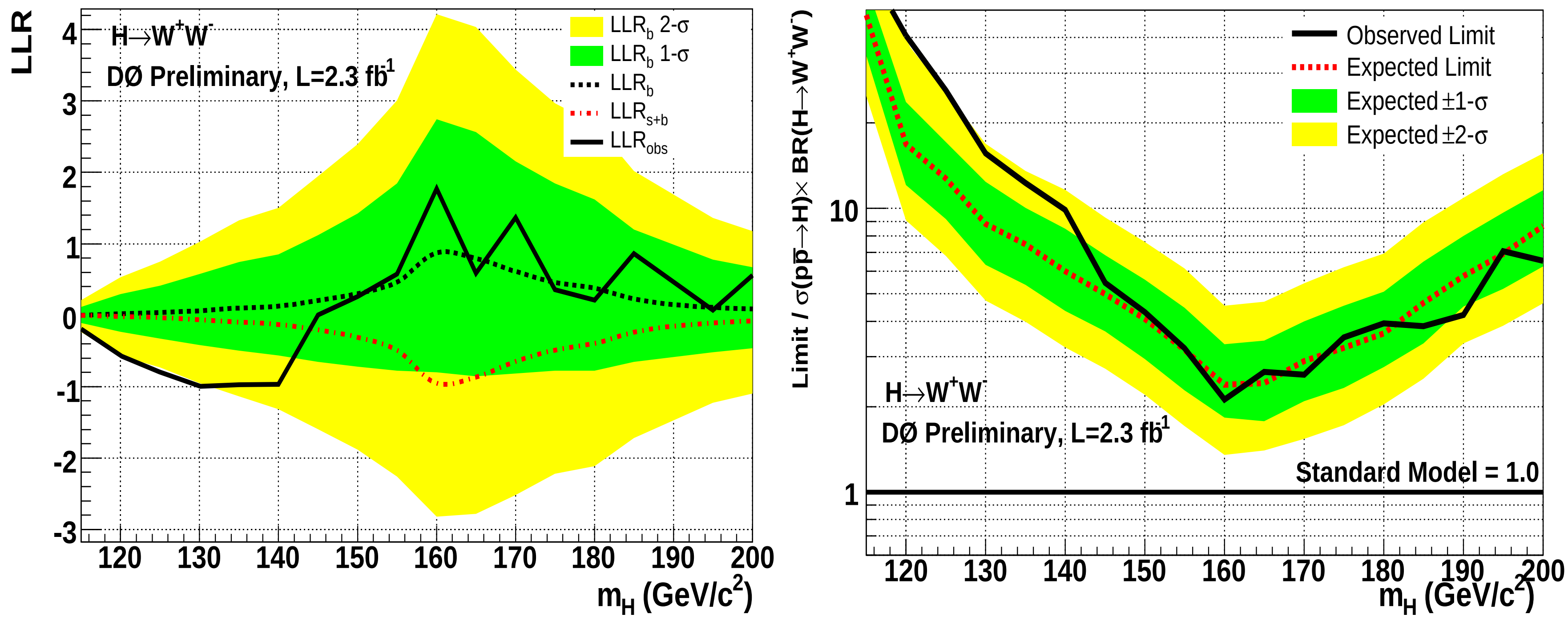
Neural Net gives even better separation then Matrix Element

(Neural Net trained against all background sources)

Higgs at High Mass

– No excess, data agree with background model

– Use neural network output to derive limits



Just DØ at $m_{\mathrm{H}} = 160$ GeV: limit/SM 2.1 (2.4 expected)

DØ Combination

– Looking for SM Higgs $\rightarrow$ assume SM branching ratios $\rightarrow$ combine search channels

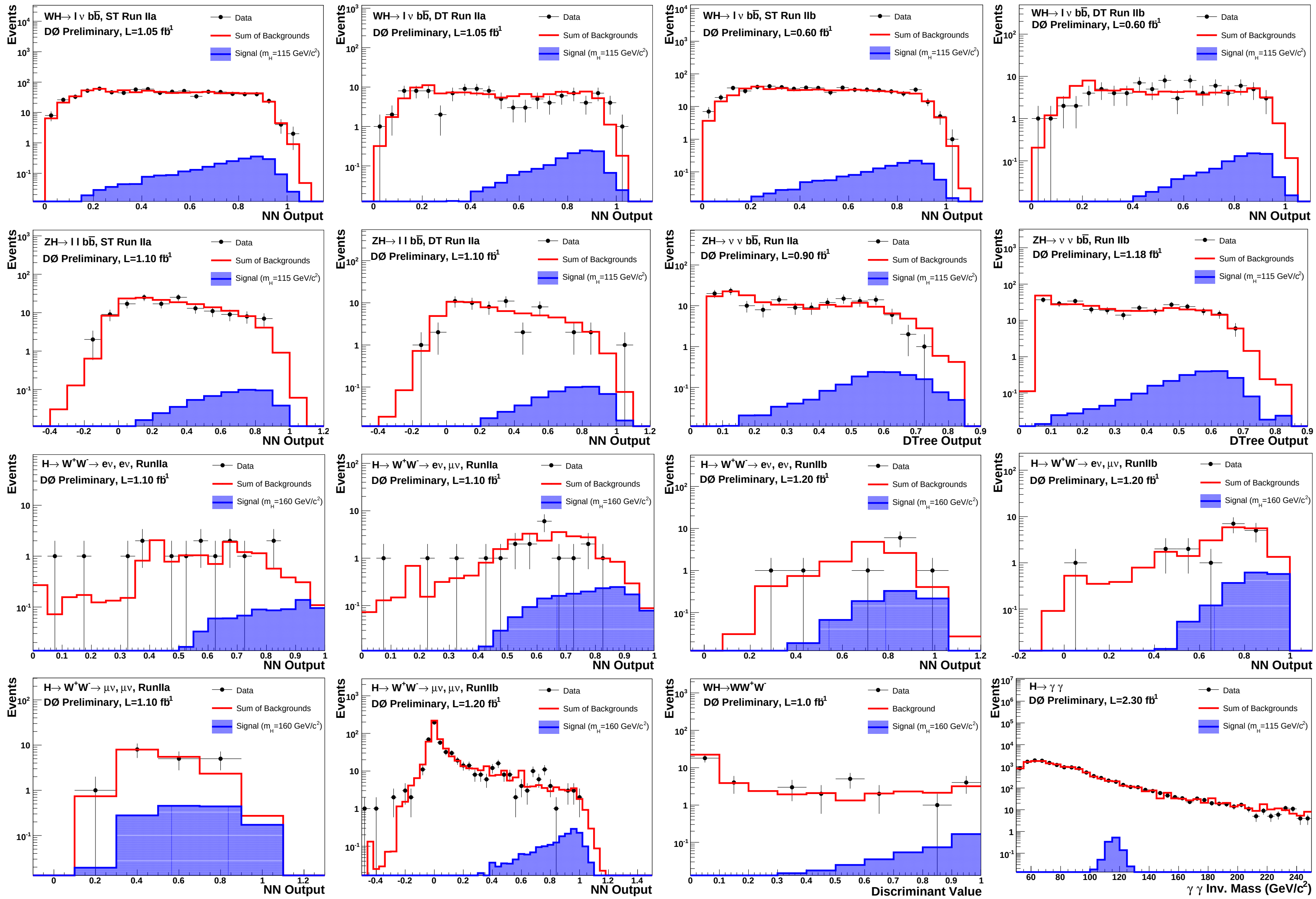
– WH $\rightarrow \ell\nu \mathrm{b\bar{b}}$, ZH $\rightarrow \ell\ell \mathrm{b\bar{b}}$, ZH $\rightarrow \nu\nu \mathrm{b\bar{b}}$, H $\rightarrow$ WW, WH $\rightarrow$ WWW, H $\rightarrow \gamma\gamma$

– Treat Run IIa and Run IIb separately

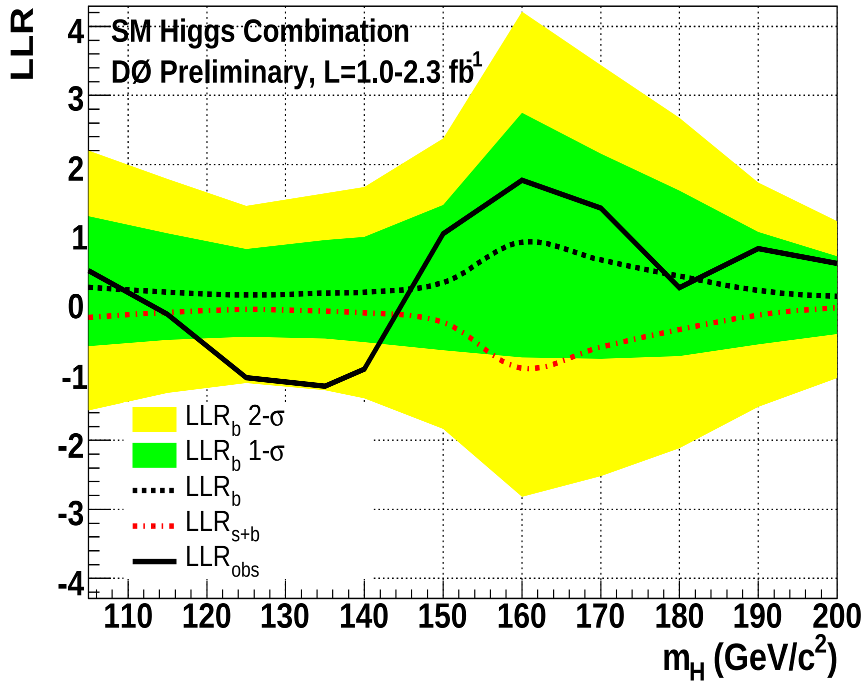
– Per channel $\int \mathcal{L} \mathrm{d}t = 1.0 \rightarrow 2.3$ fb^{-1}

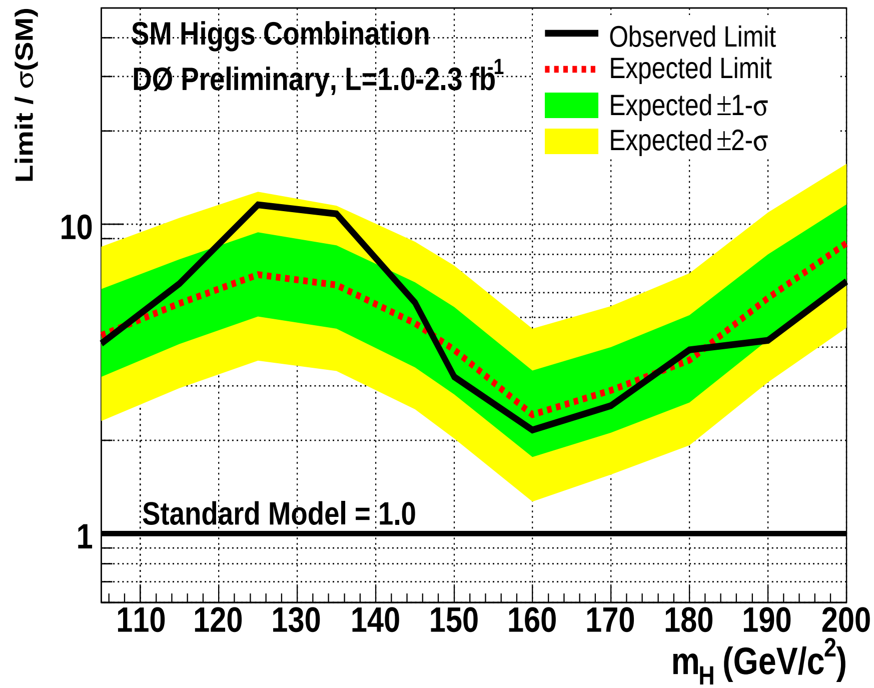
DØ Combination

> 16 Analyses



DØ Combination



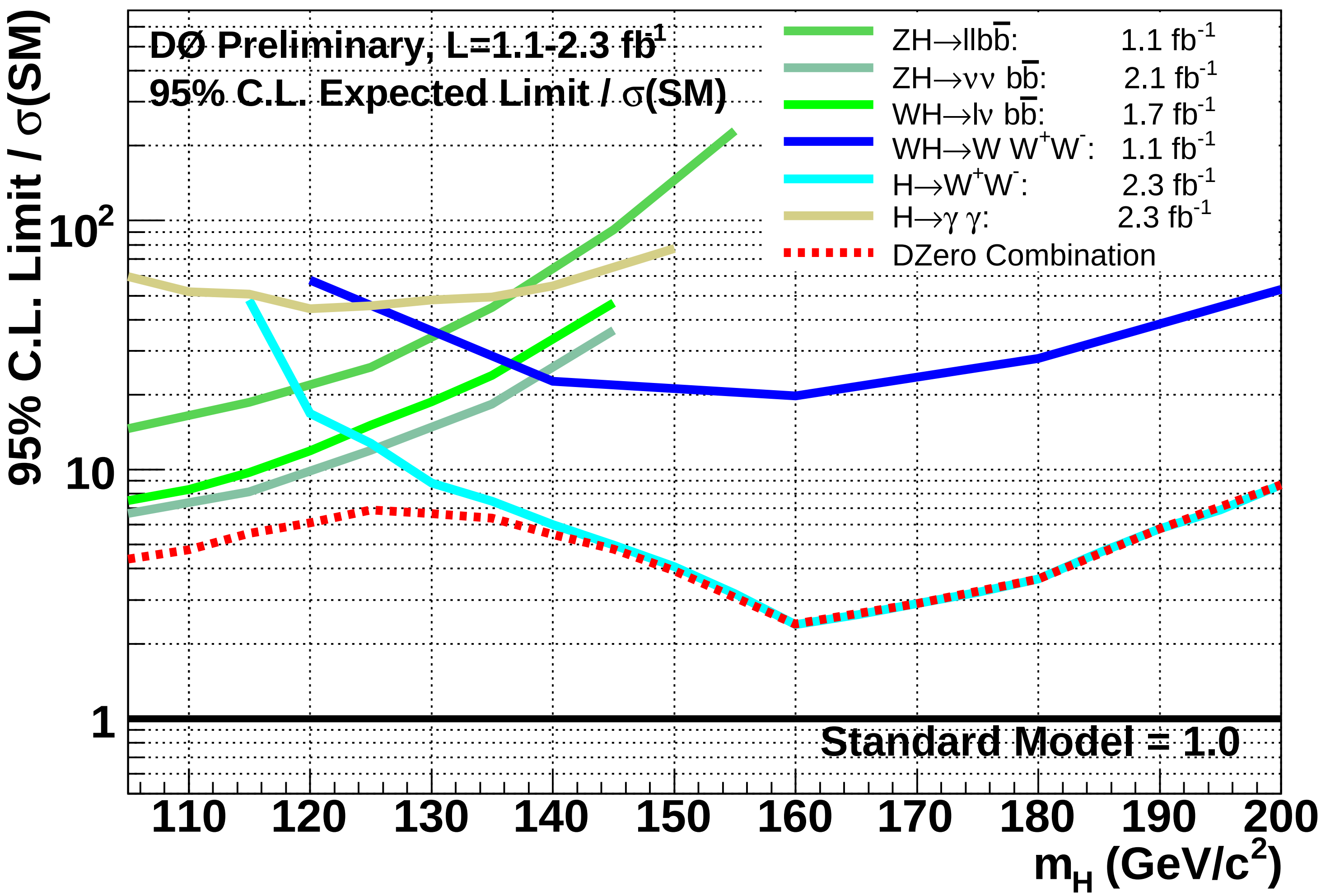


At $m_\mathrm{H} = 115$ GeV: limit/SM 6.4 (5.5 expected)

At $m_\mathrm{H} = 160$ GeV: limit/SM 2.2 (2.4 expected)

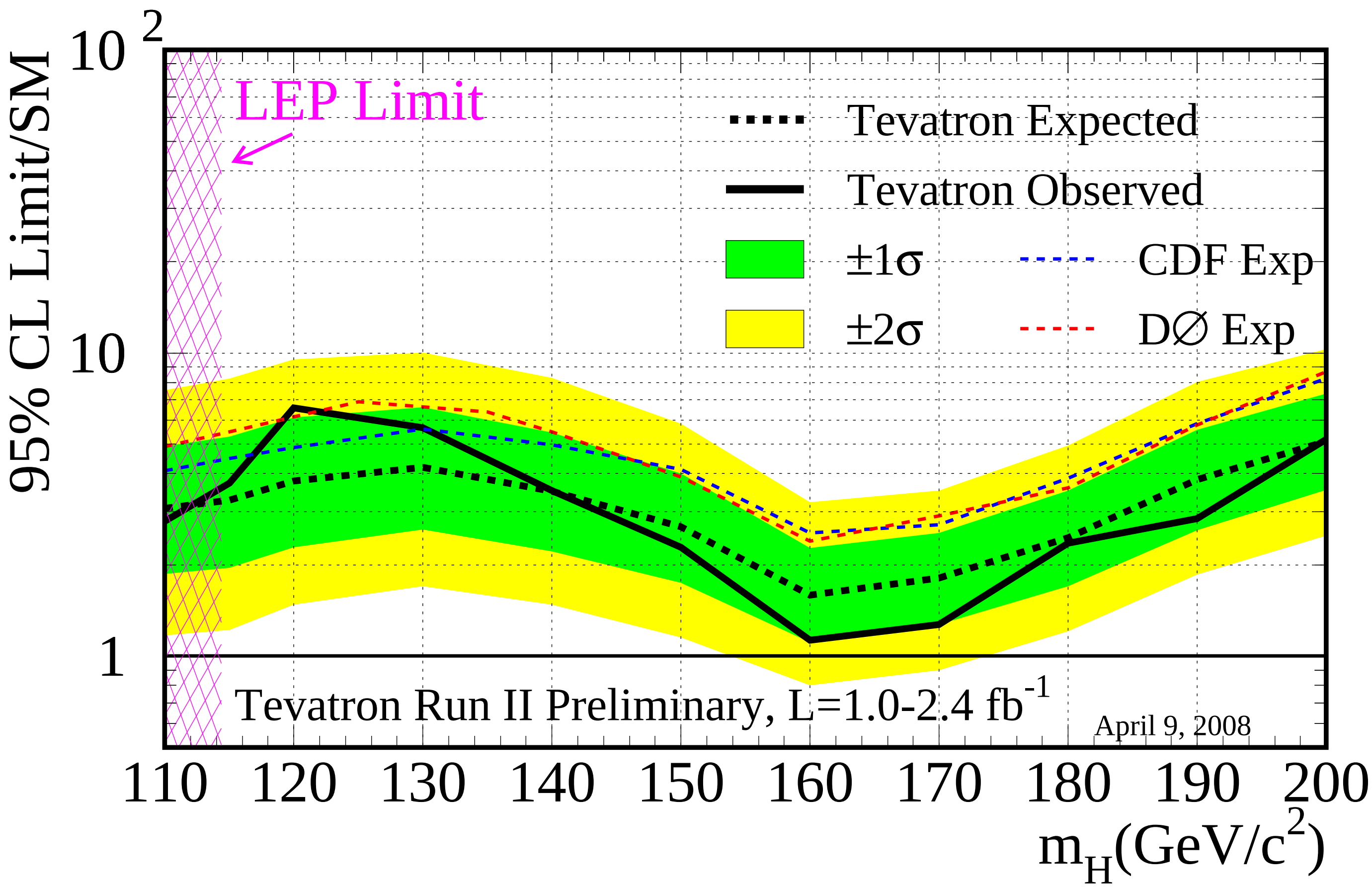
$\Rightarrow$ Getting close to the Standard Model expectation!

Contributions from Individual Channels



Tevatron Combination

WH $\rightarrow \ell\nu b\bar{b}$, ZH $\rightarrow \ell\ell/\nu\nu b\bar{b}$, H $\rightarrow$ WW, WH $\rightarrow$ WWW, H $\rightarrow \gamma\gamma$, H $\rightarrow \tau\tau$ + 2 jets



At $m_{\rm H} = 115$ GeV: limit/SM 3.7 (3.3 expected)

At $m_{\rm H} = 160$ GeV: limit/SM 1.1 (1.6 expected)

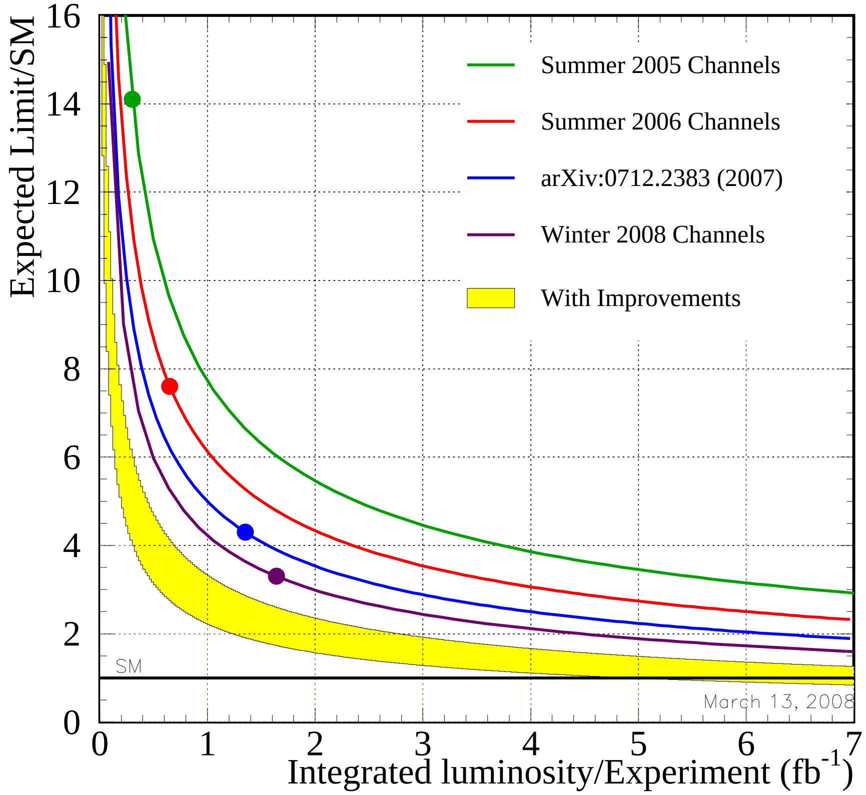
$\Rightarrow$ Getting really close to the Standard Model expectation!

Conclusion & Outlook

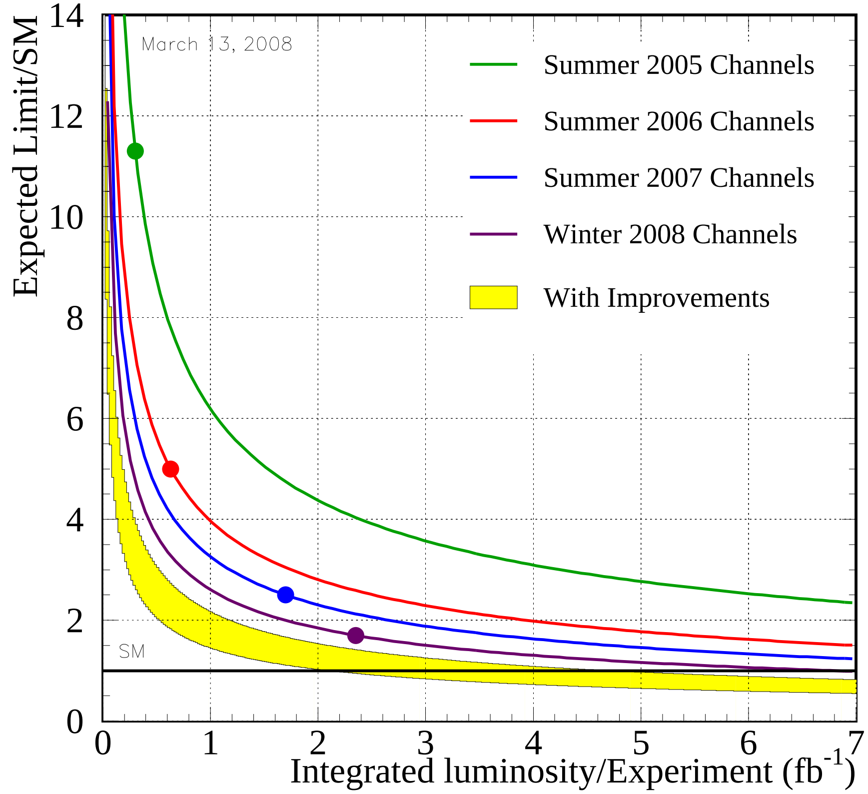
– Higgs not found yet . . .

– Improvement in sensitivity $\sim \int \mathcal{L} dt$

m_H=115 GeV



m_H=160 GeV



Conclusion & Outlook

– Many small steps to follow:

  * $\int \mathcal{L}\mathrm{d}t =$ 7 to 9 fb^{-1} by 2010
  * Improvements to b-tagging, jet energy, mass resolution
  * Improved multivariate techniques
  * Increased efficiency for leptons
  * Add more production/decay channels
  * Better understanding of systematics
  * Observe di-boson production in hadronic ($b\bar{b}$) decays

– Exclusion or observation possible soon !