Searching for the Higgs Boson at the Tevatron

GdR SUSY, Strasbourg

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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

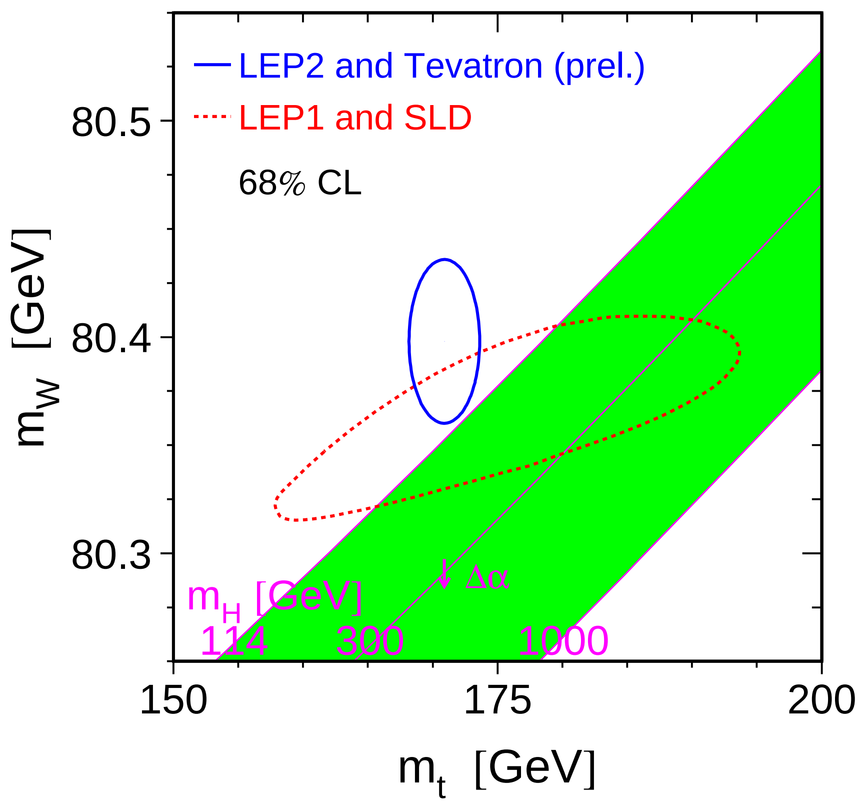
$\Rightarrow$ Massive quarks and leptons

$\Rightarrow$ 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

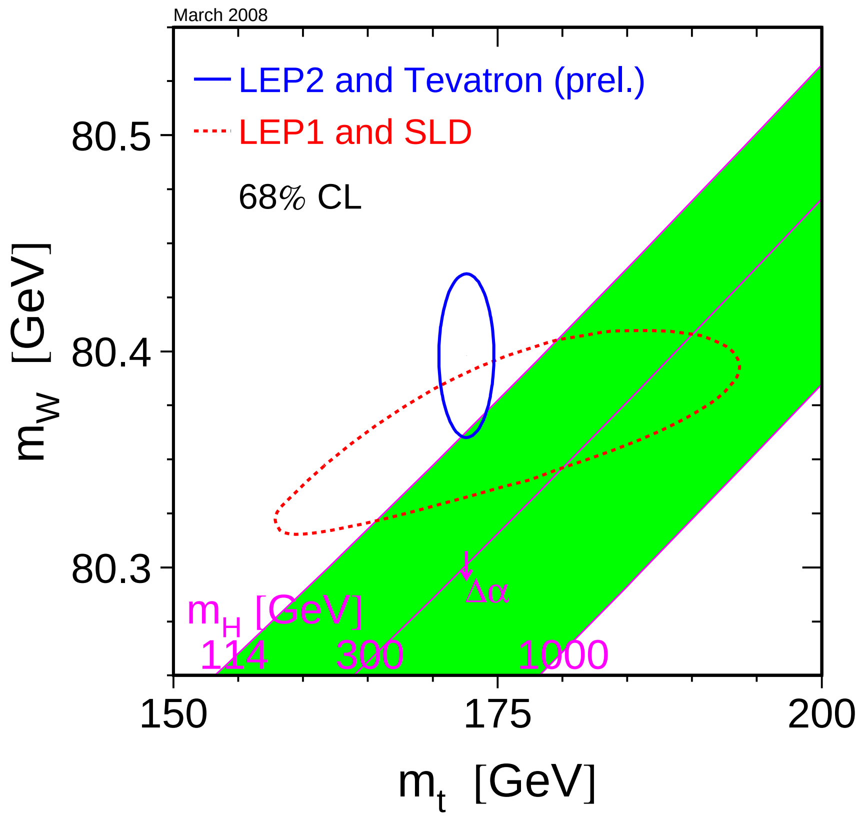
($m_{\mathrm{t}} = 170.9 \pm 1.8$ GeV)

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

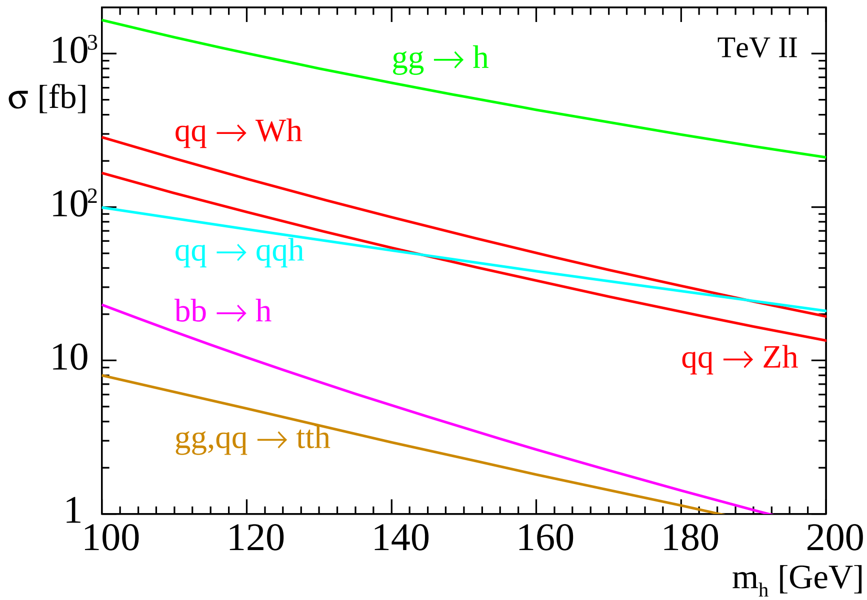
$(m_{\mathrm{t}} = 172.6 \pm 1.4$ GeV)

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

$\Rightarrow$ Within reach of the Tevatron!

Higgs @ Tevatron

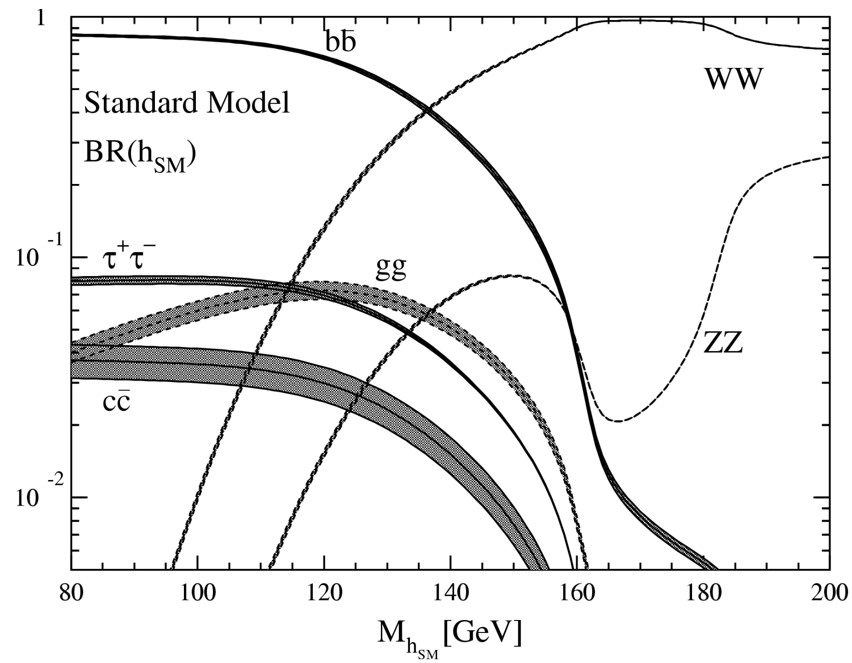
Production



– Gluon fusion

– Associated production

Decay

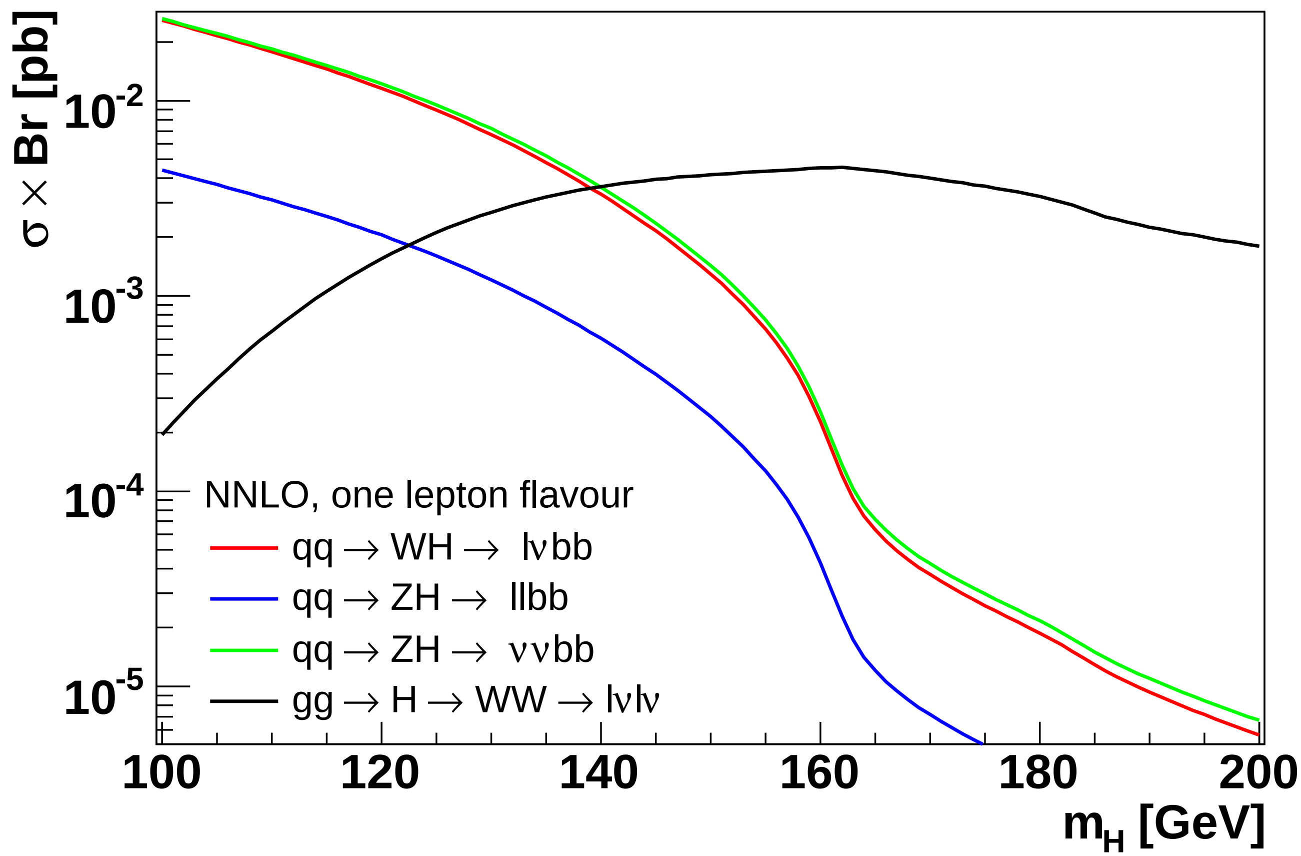


– $b\bar{b}$ at low m_{H}

– WW at high m_{H}

Higgs @ Tevatron

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



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

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

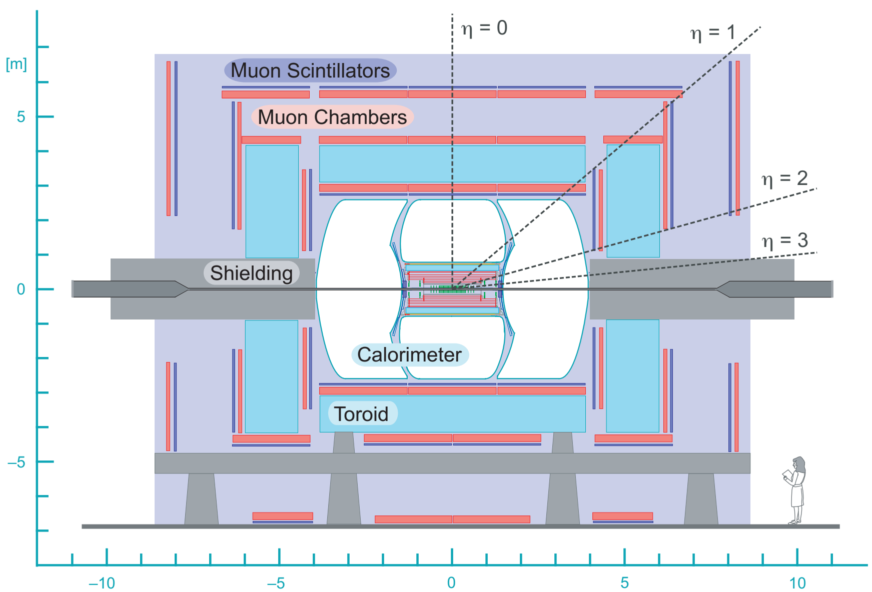
Tevatron

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

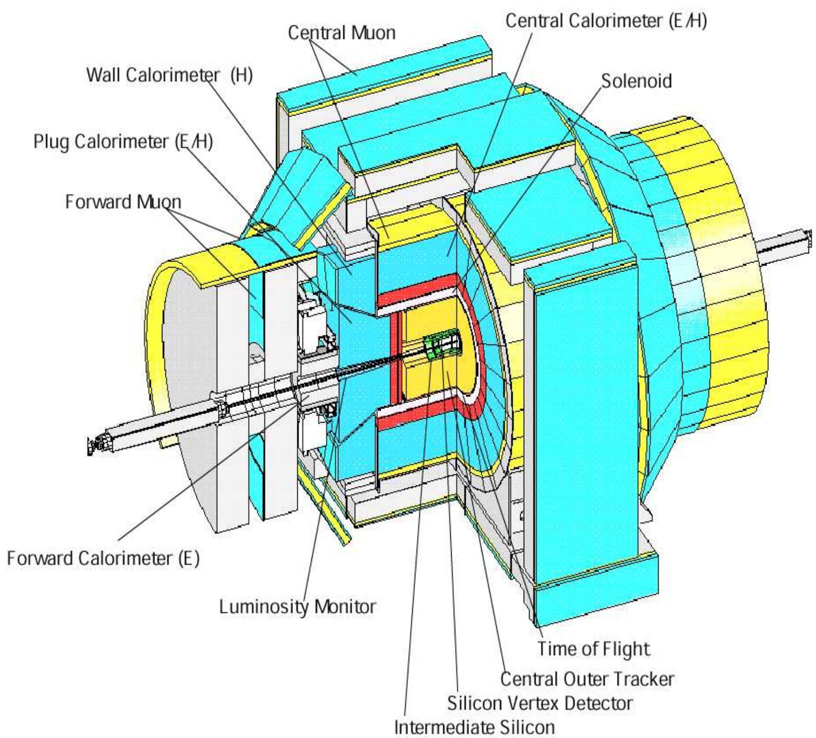
– Up to now: $\int \mathcal{L}dt \simeq 4.0\ \text{fb}^{-1}$ delivered / experiment

– 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:

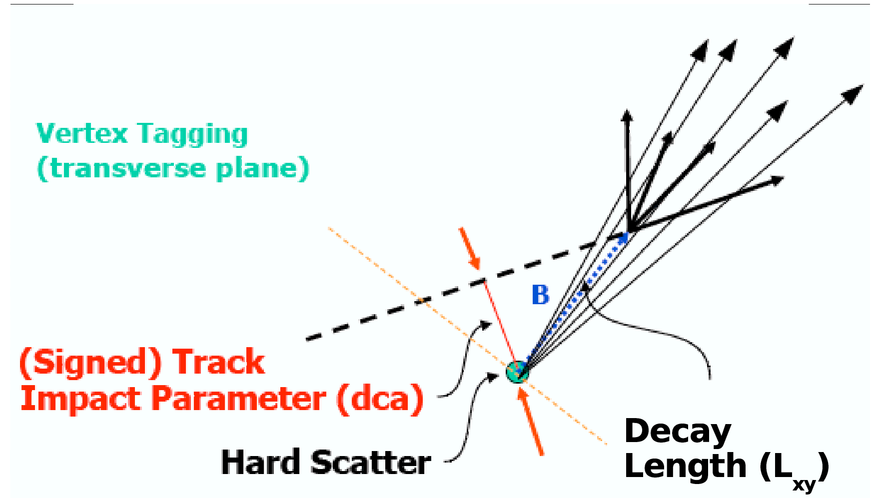
  * W/Z with additional jets (including Wb$\bar{\mathrm{b}}$, Zb$\bar{\mathrm{b}}$)
  * t$\bar{\mathrm{t}}$, single top
  * Multi-jet production with mis-ID of lepton or $\not\!\!E_{\mathrm{T}}$
  * Di-boson (WW, WZ, ZZ)

$\Rightarrow$ 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:

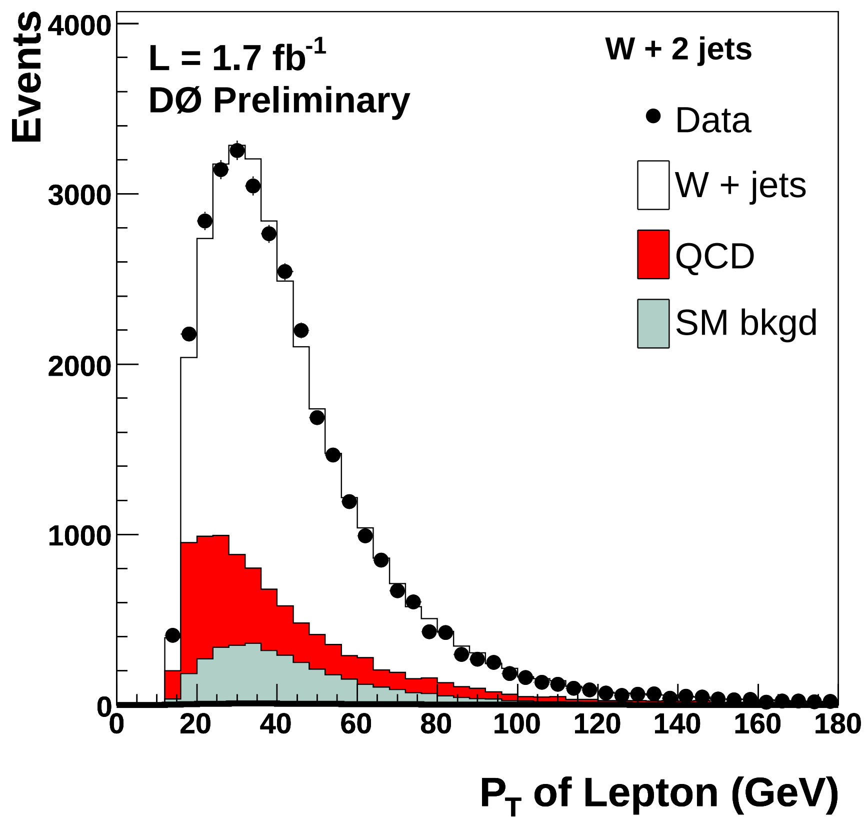
  ∗ "Tight": 50% at 0.5% fake rate (DØ neural net tagger)
  ∗ "Loose": 74% at 5.0% fake rate (DØ neural net tagger)

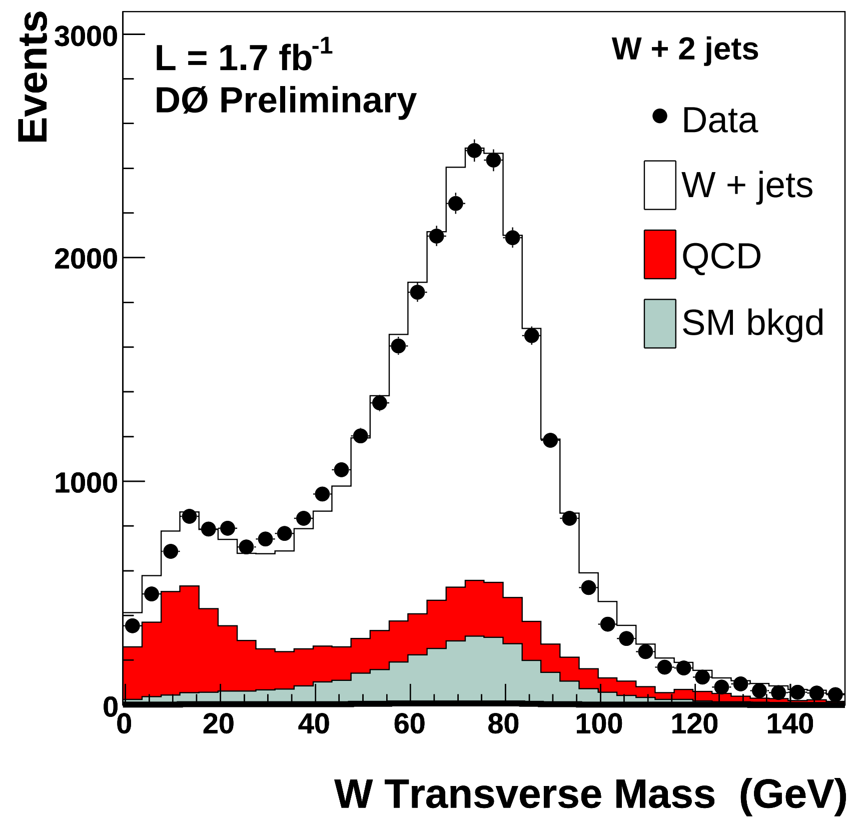
– Typical analysis: two "Loose" tags or one "Tight" tag

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

– Signature: one isolated lepton, large $\not{E}_T$

– Events with exactly two jets, b-tagged



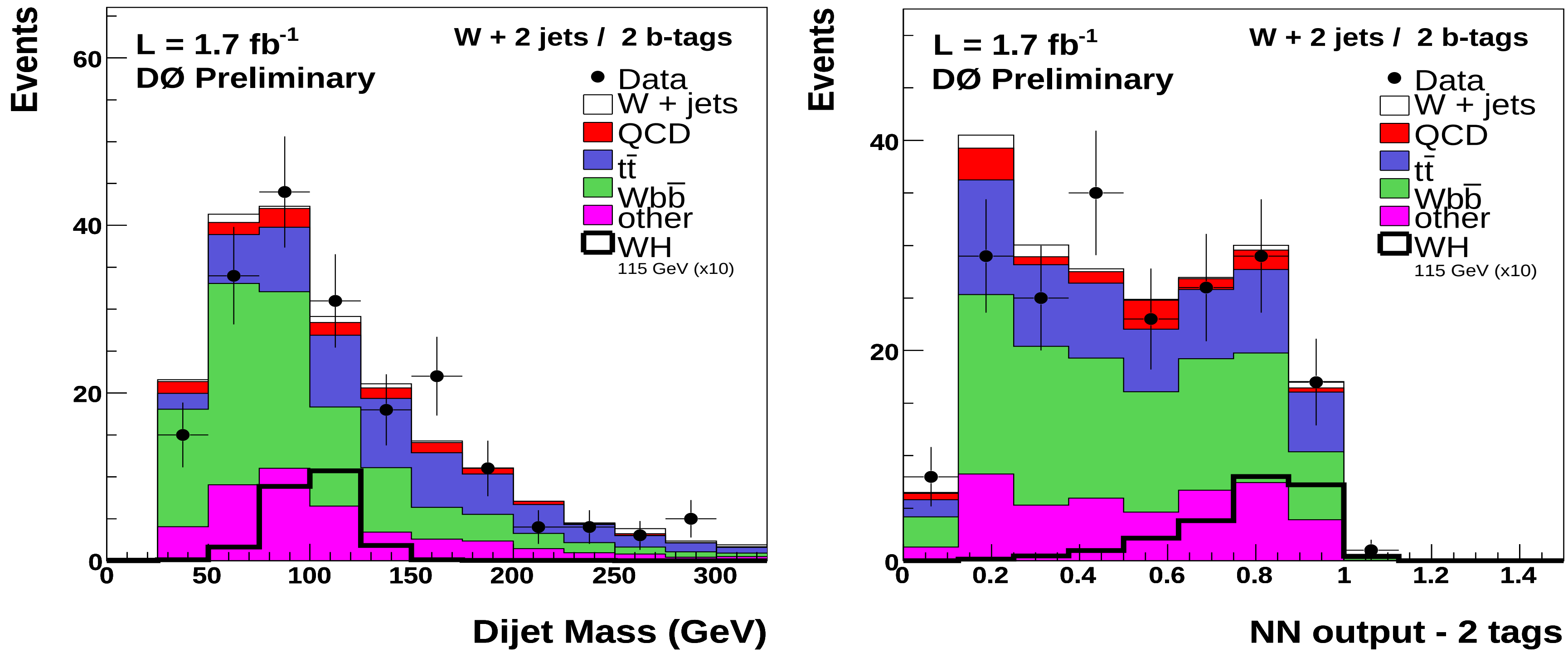


Before b-tag: 9.9 WH, 33.5k background events

Double b-tag: 2.3 WH 204.1 background events

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

– 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), $p_{\mathrm{T}}(\mu\text{-}\not{E}_{\mathrm{T}}$ system), $m_{jj} \Rightarrow \simeq 15\%$ improvement in limit



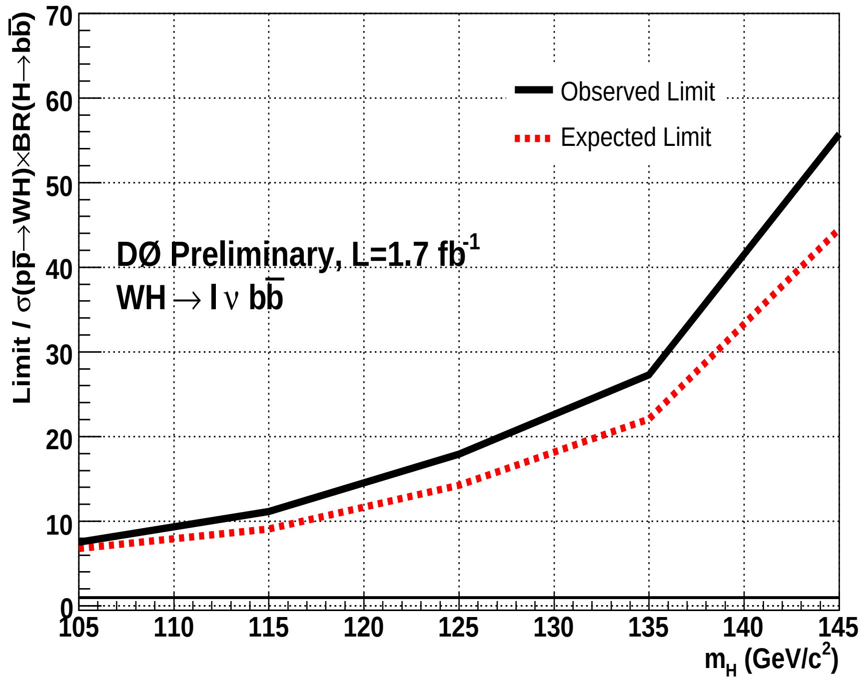
Near future:

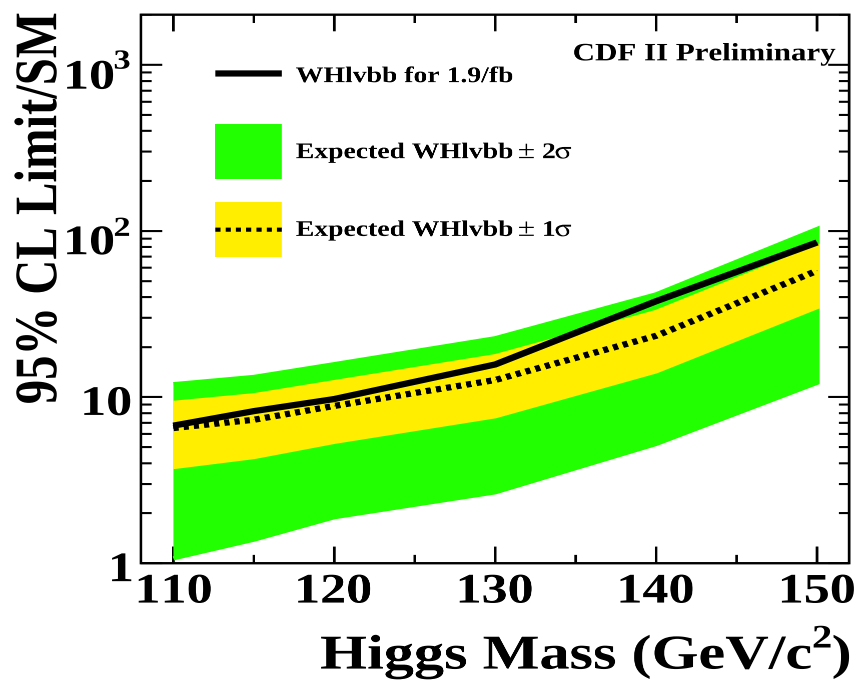
Forward electrons, 3 jet channel, improved neural network

WH $\to \ell\nu b\bar{b}$ 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)

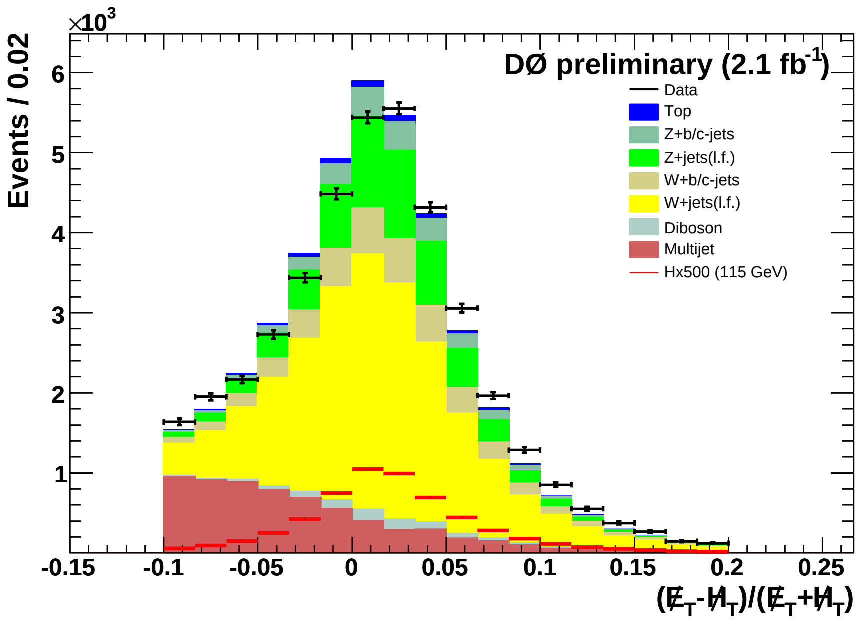
CDF at $m_{\mathrm{H}} = 115$ GeV
limit/SM 8.2 (7.3 expected)

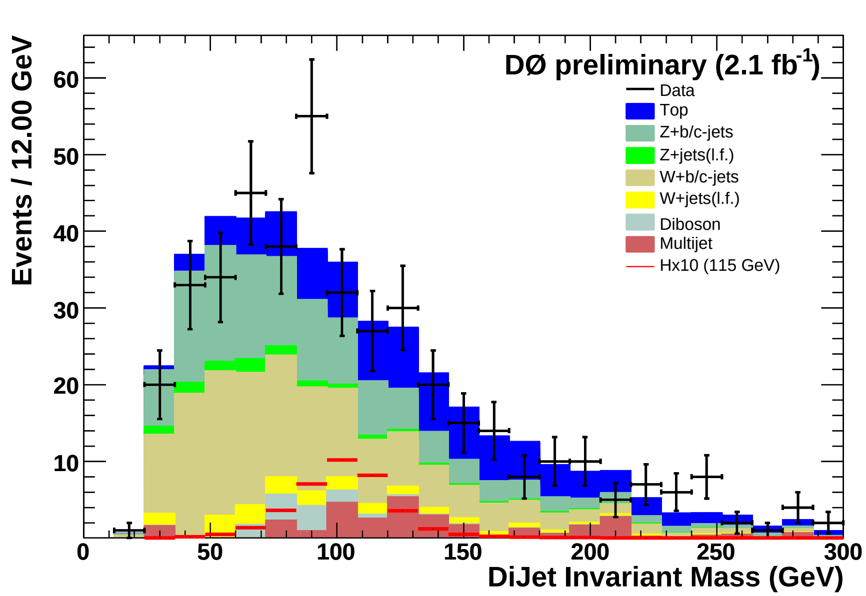
No Charged Lepton: ZH $\rightarrow \nu\nu b\bar{b}$ (DØ)

– 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





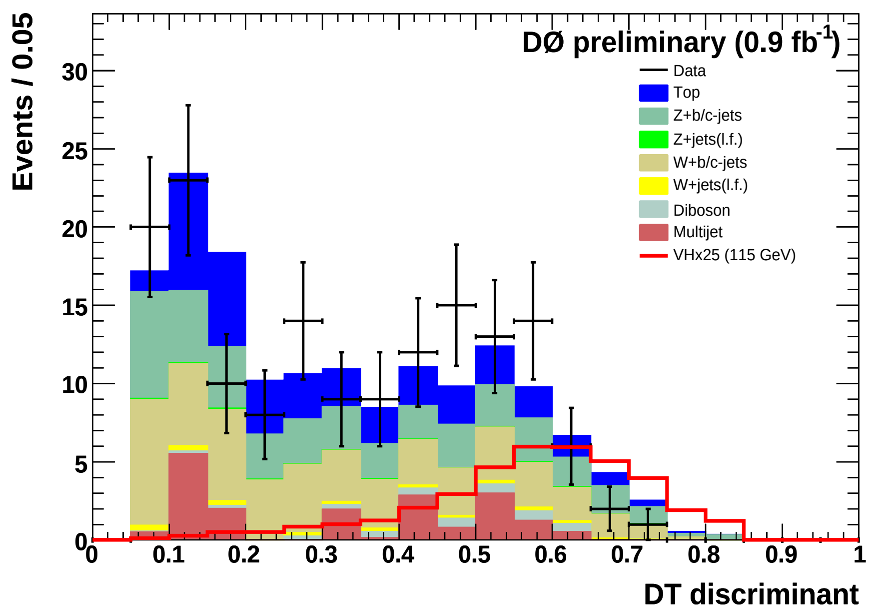
No Charged Lepton: ZH $\rightarrow \nu\nu b\bar{b}$ (DØ)

– Decision trees to improve sensitivity

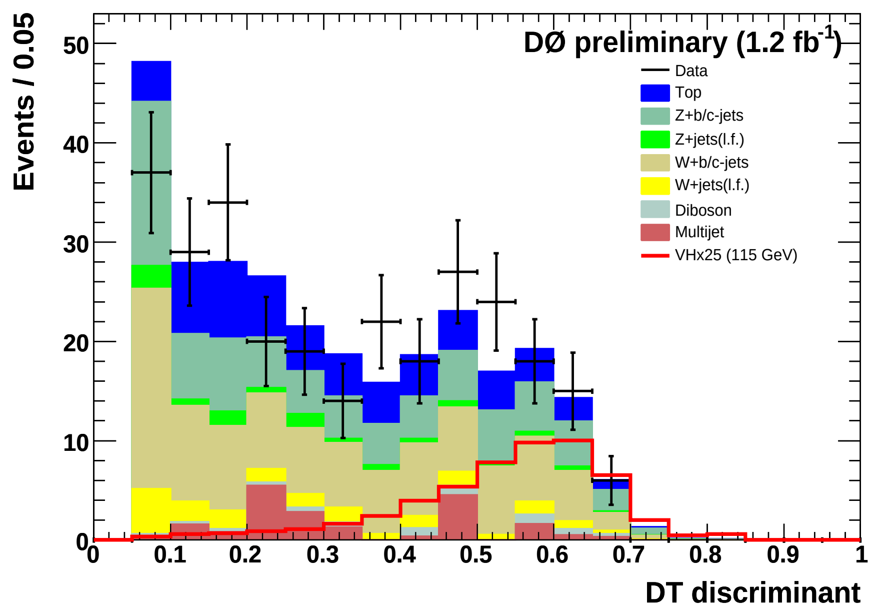
  $*$ Recursively cut on kinematic variables

  $*$ More discriminating than m_{jj}

Run IIa



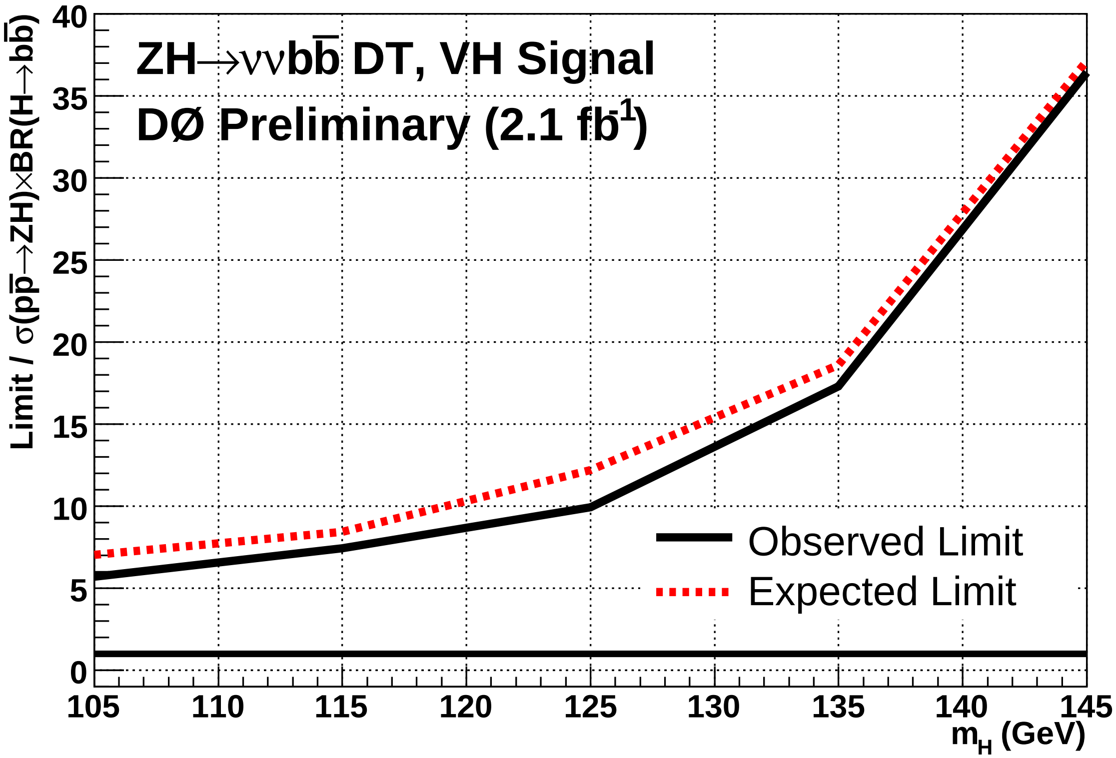
Run IIb



ZH $\to \nu\nu b\bar{b}$ Results (DØ)

– No excess, data agree with background model

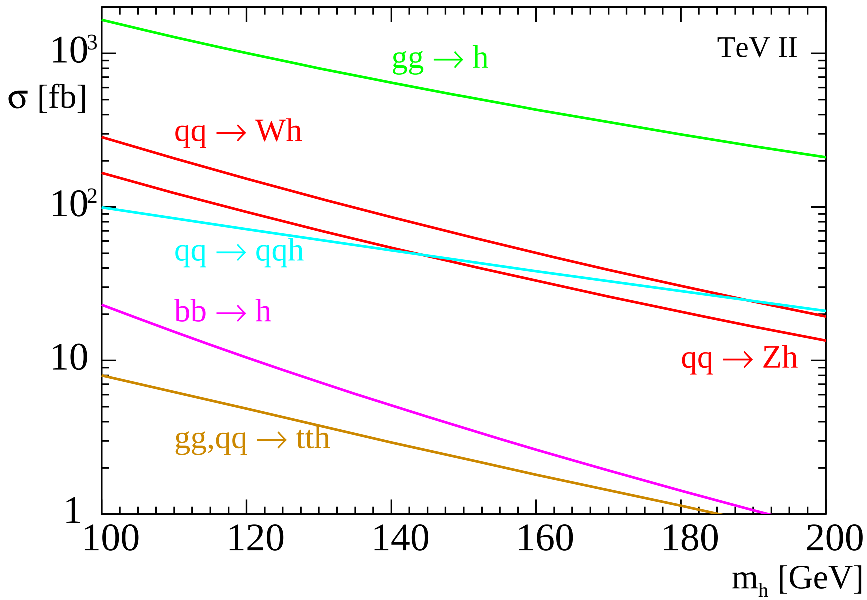
– Use decision tree output to derive limits



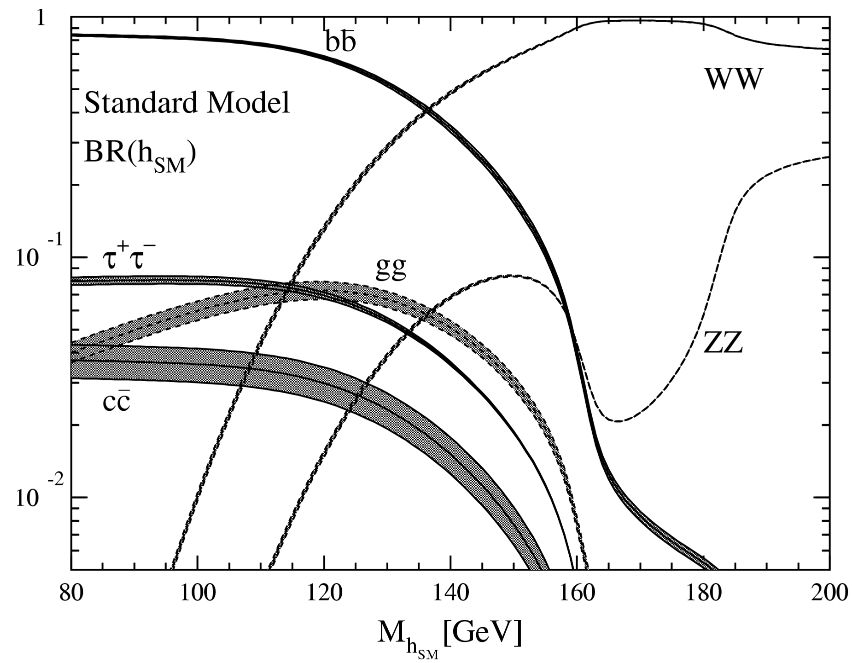
At $m_{\mathrm{H}} = 115$ GeV: limit/SM 7.5 (8.4 expected)

Higgs $\rightarrow \tau\tau$

Production



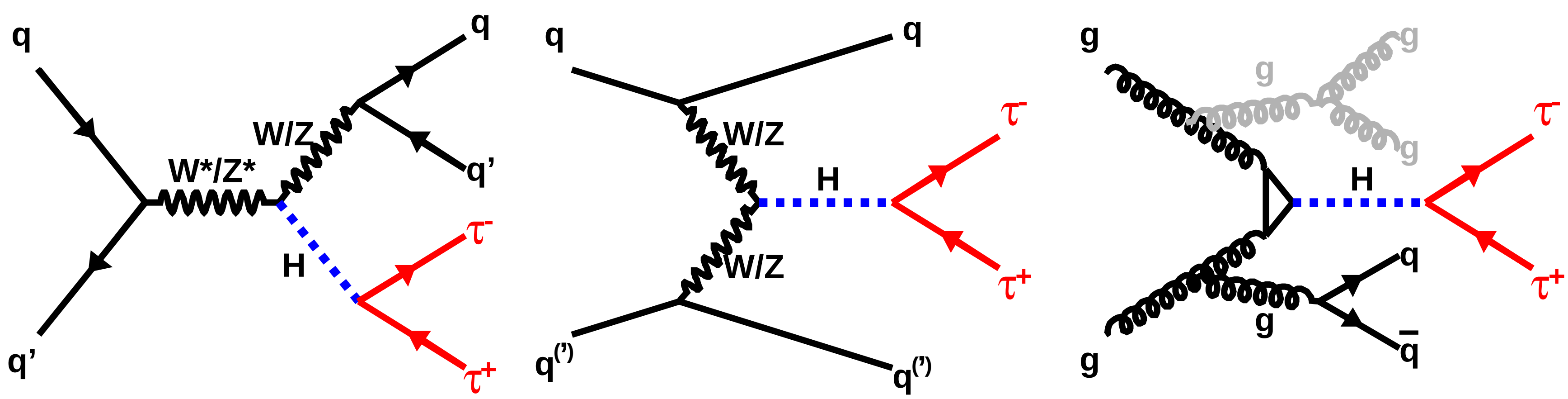
Decay



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

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

Higgs $\to \tau\tau$

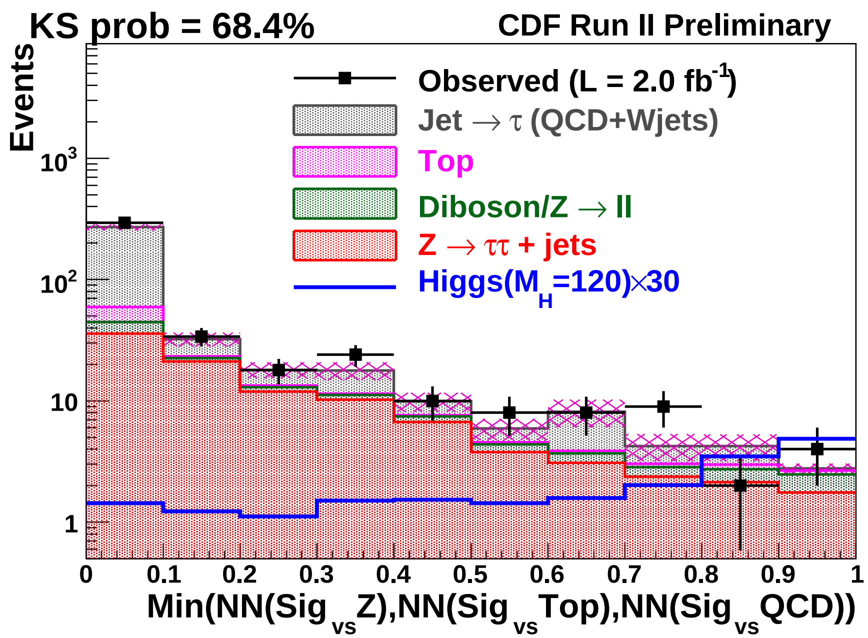


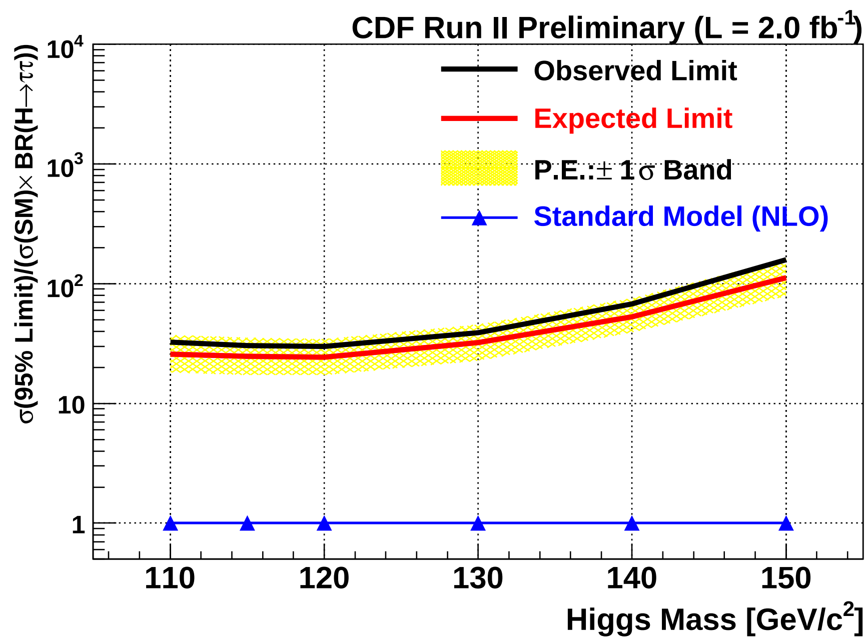
- CDF, $\int \mathcal{L}\mathrm{d}t \simeq 2$ fb^{-1}
- Final state: $\tau(\to \ell X)\,\tau(\to$ hadrons$)+2$ jets
- Sensitive to WH, ZH, VBF, gluon fusion
- Background from Z/W+jets, $t\bar{t}$, di-boson, multi-jet
- Neural networks trained against main backgrounds

Higgs $\rightarrow \tau\tau$ (CDF)

– 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: $\mathbf{H \longrightarrow WW \longrightarrow \ell\nu\ell\nu}$

– 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

– 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

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

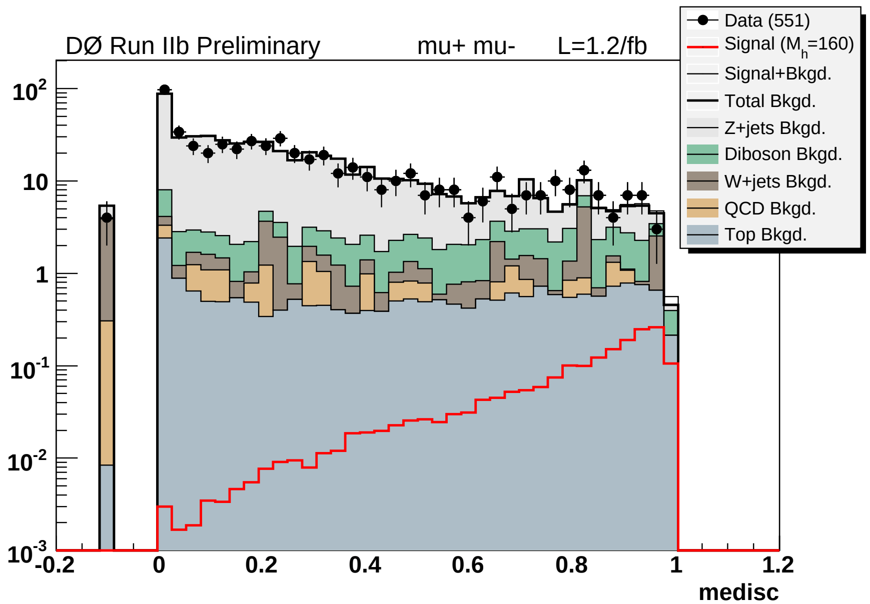
$$\text{MEdisc}(\vec{x}_{\text{obs}}) = \frac{P_{\text{signal}}}{P_{\text{signal}} + P_{\text{background}}}$$

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

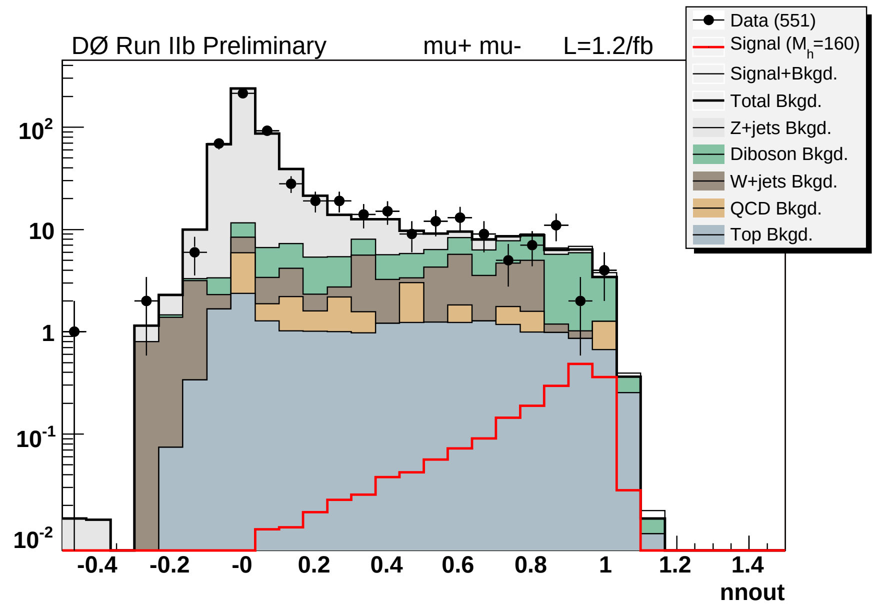
– Use discriminant as input to a neural network

Matrix Element & Neural Net (DØ)

Matrix Element discriminant



Neural Net discriminant



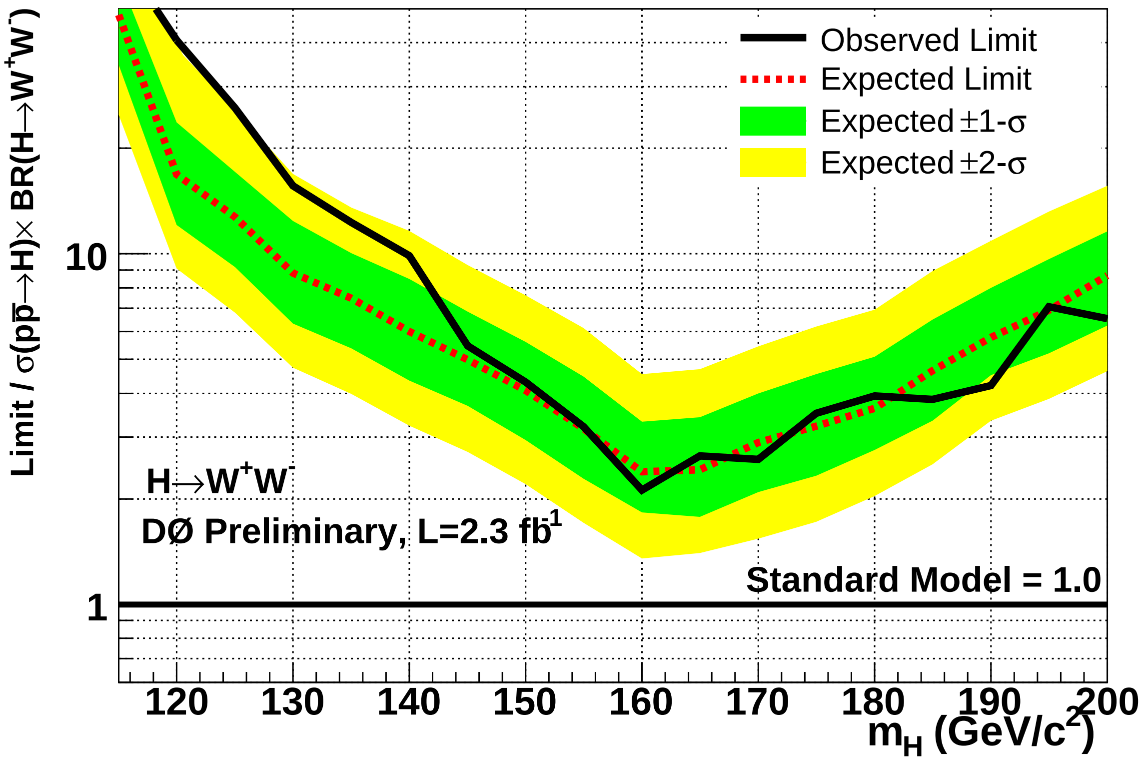
Neural Net gives even better separation then Matrix Element

(Neural Net trained against all background sources)

Higgs at High Mass (DØ)

– No excess, data agree with background model

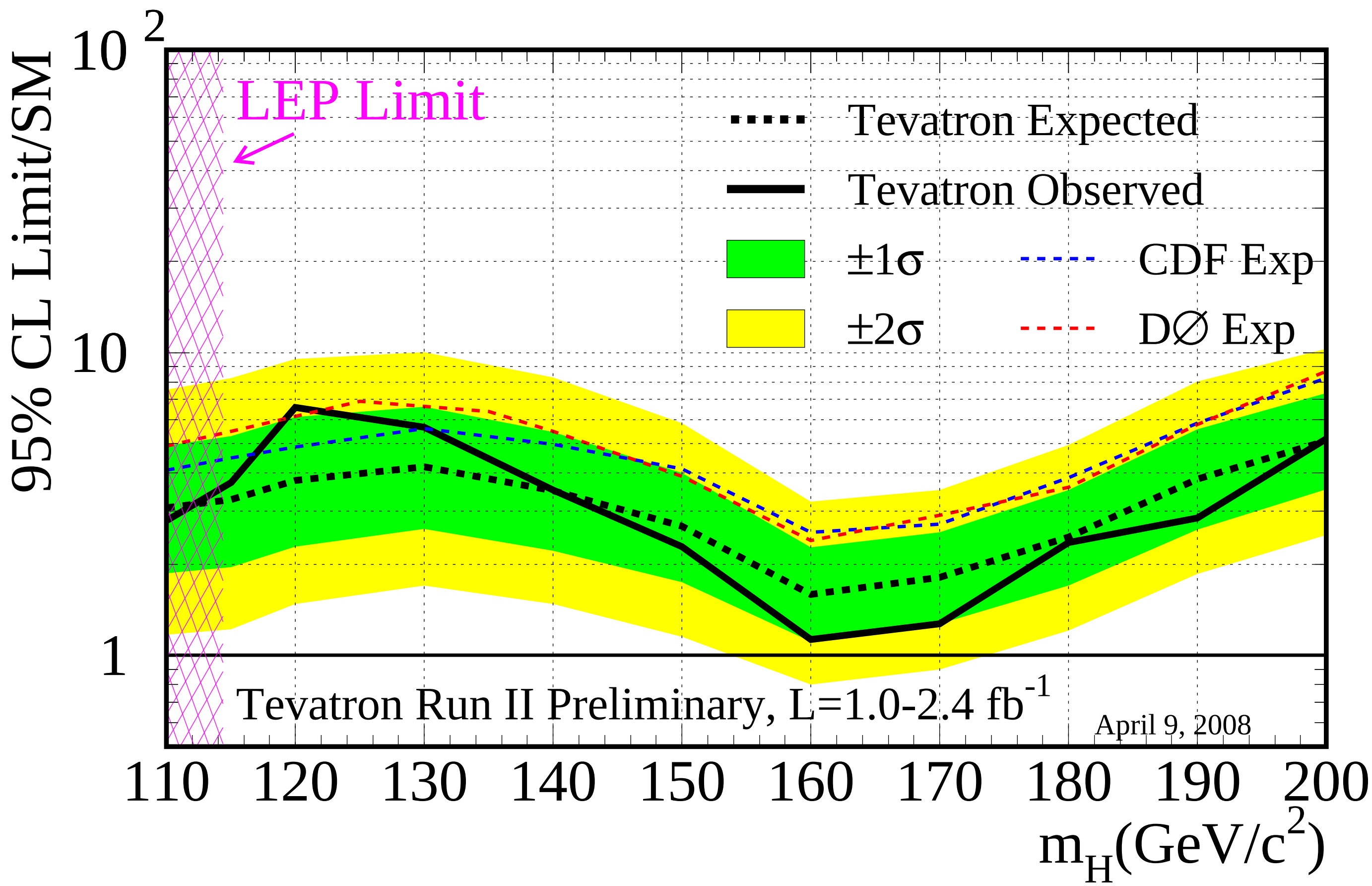
– Use neural network output to derive limits



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

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

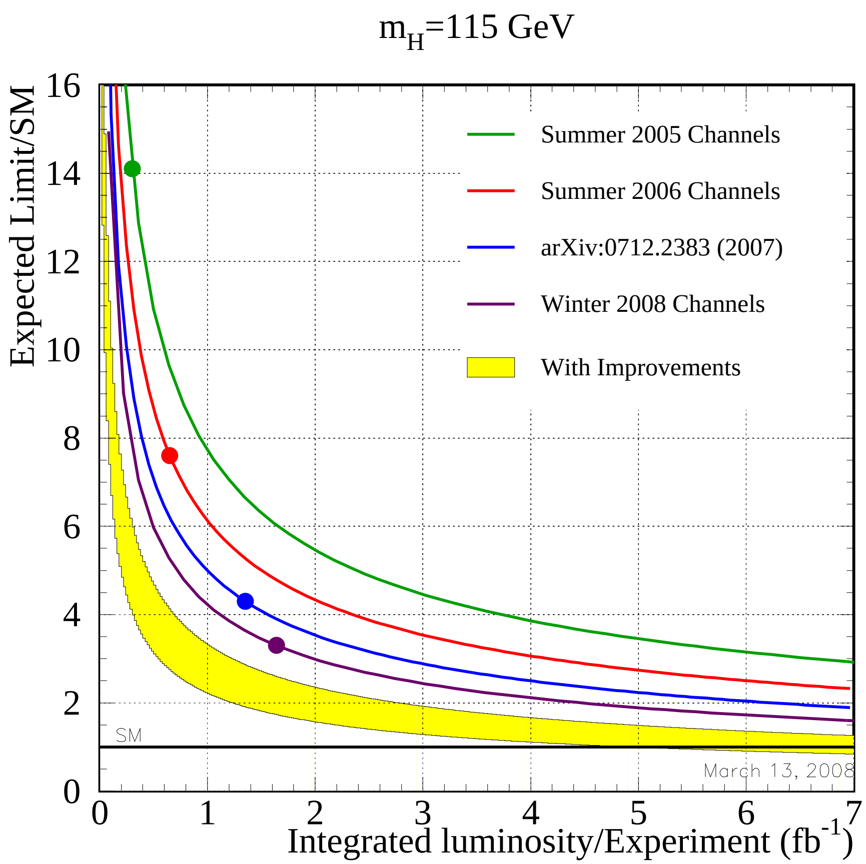
At $m_{\mathrm{H}} = 160$ GeV: limit/SM 1.1 (1.6 expected)

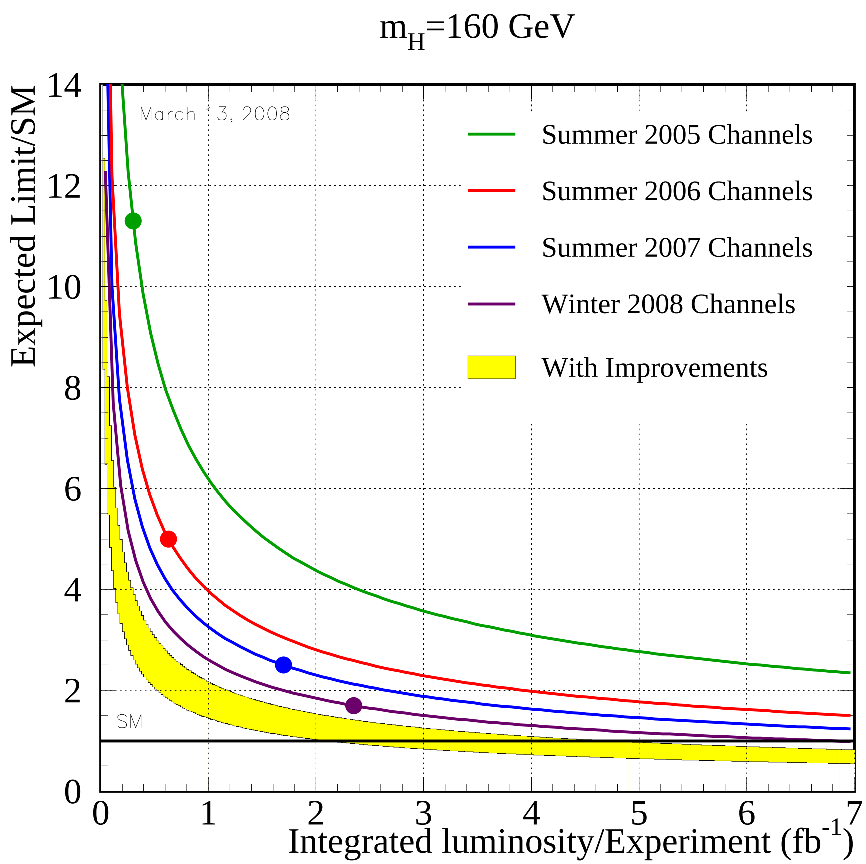
$\Rightarrow$ Getting really close to the standard model expectation!

Conclusion & Outlook

– Higgs not found yet . . .

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





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 !