

Status of Higgs Searches at DØ and CDF

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For the DØ and CDF Collaborations

Outline

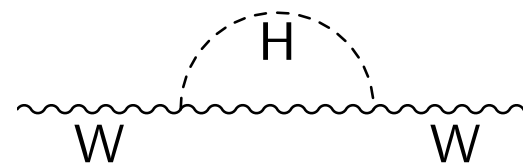
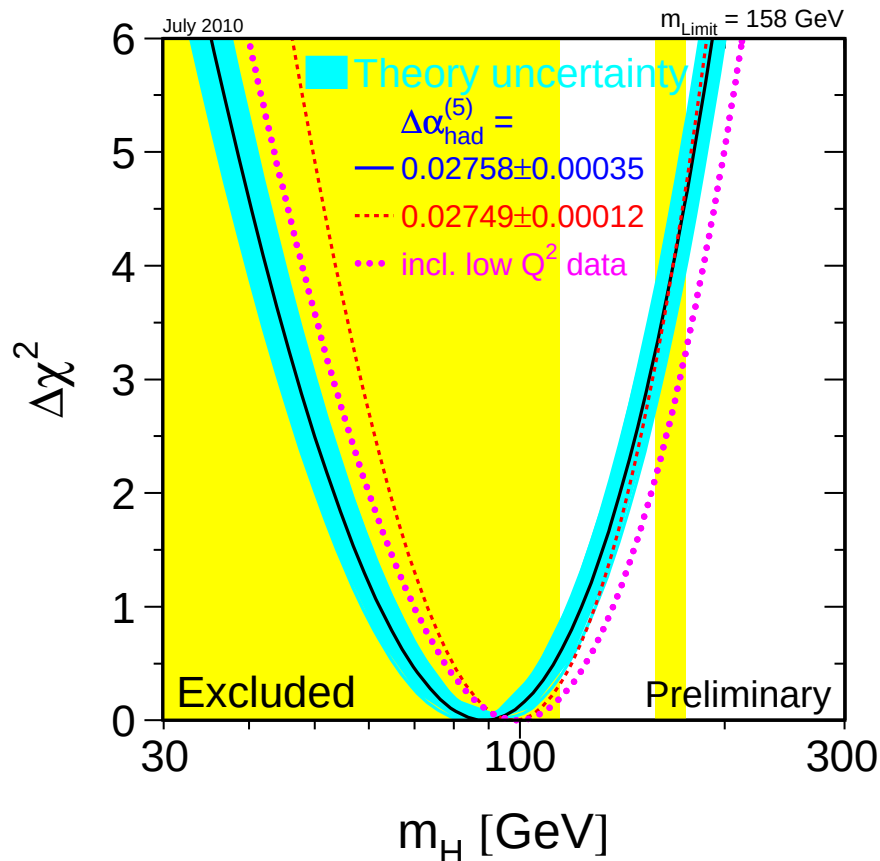
- What is the Higgs boson ?
- Higgs @ Tevatron $\rightarrow$ DØ & CDF
- High mass Higgs searches
- Low mass Higgs searches
- Conclusion

Introduction

- Standard model: very successful !
 - Higgs mechanism to break electroweak symmetry
 - * Massive W and Z bosons, massless photon
 - * Massive quarks and leptons
 - * New massive particle: Higgs boson
- ⇒ Where is the Higgs boson ?

What Do We Know?

Precision EW measurements at Tevatron, LEP and SLD



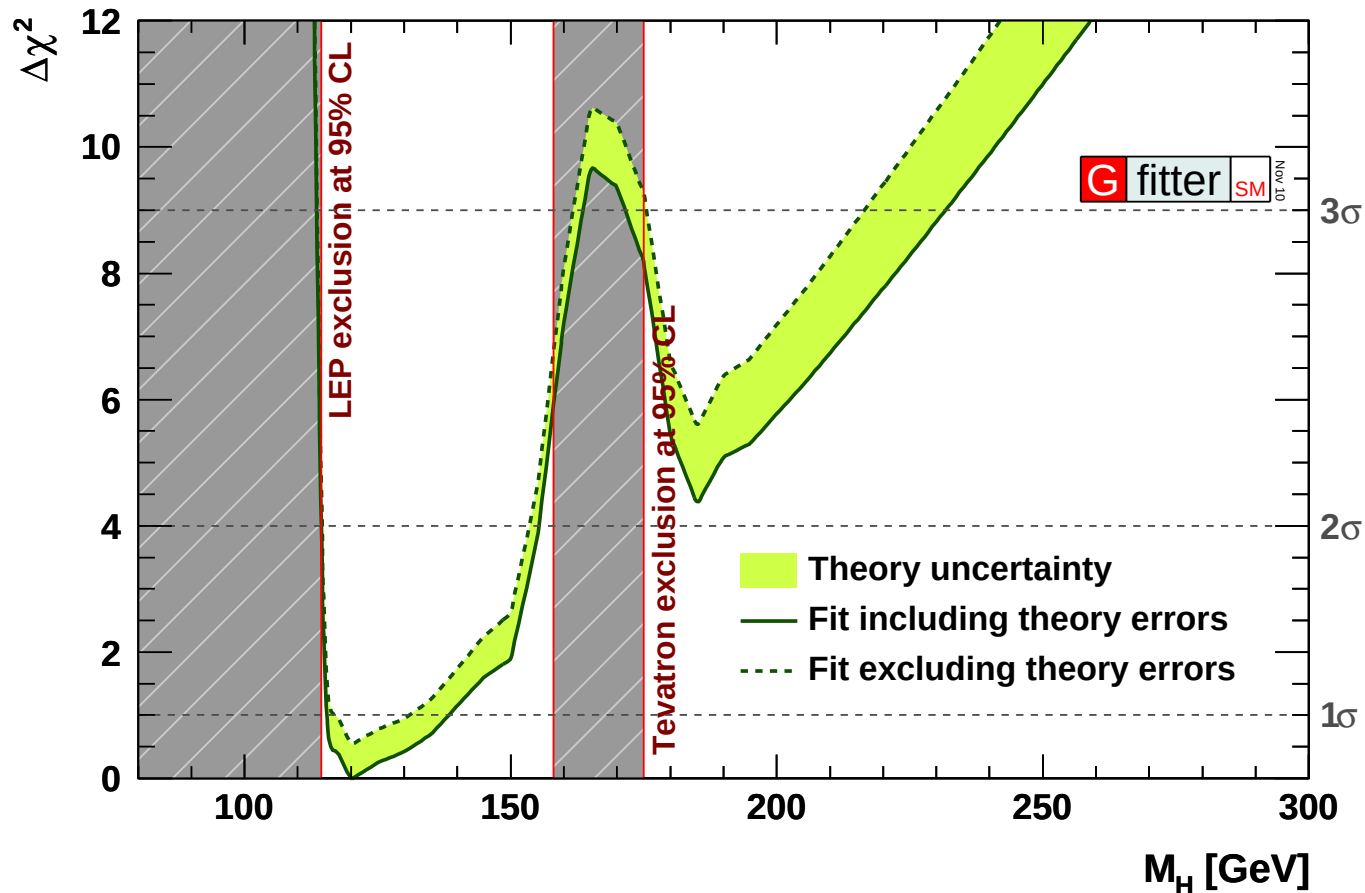
$$m_H = 89^{+35}_{-26} \text{ GeV}$$

$$m_H < 158 \text{ GeV at 95\% CL}$$

LEP2 direct search: $m_H > 114 \text{ GeV}$ ($m_H < 185 \text{ GeV}$)

What Do We Know?

Include direct Higgs search results from LEP and Tevatron

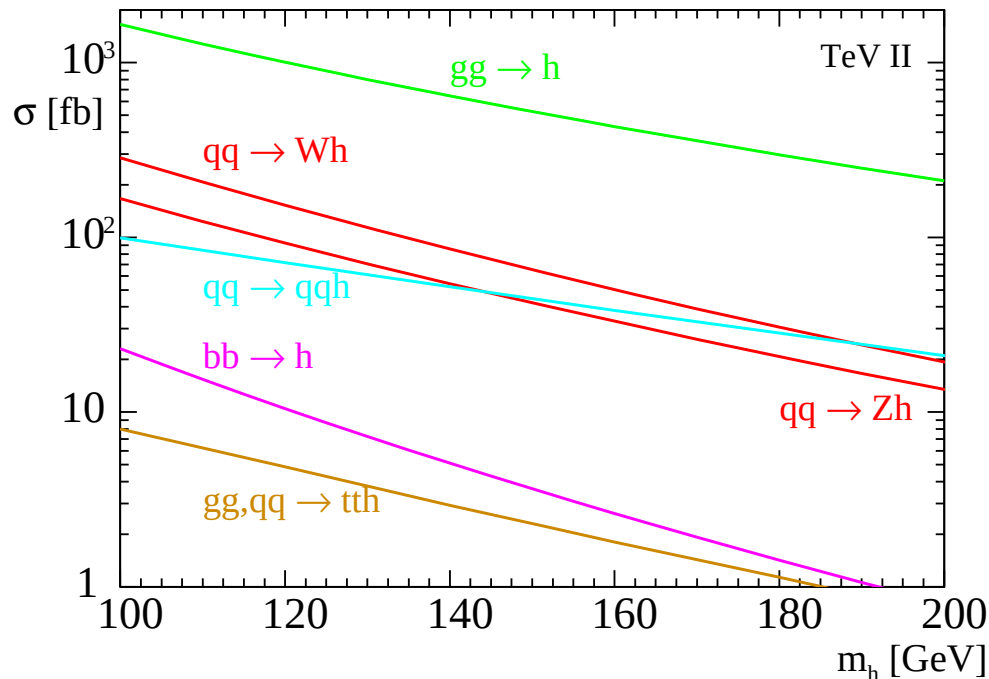


$$m_H = 120.6^{+17.9}_{-5.2} \text{ GeV}$$

Higgs @ Tevatron

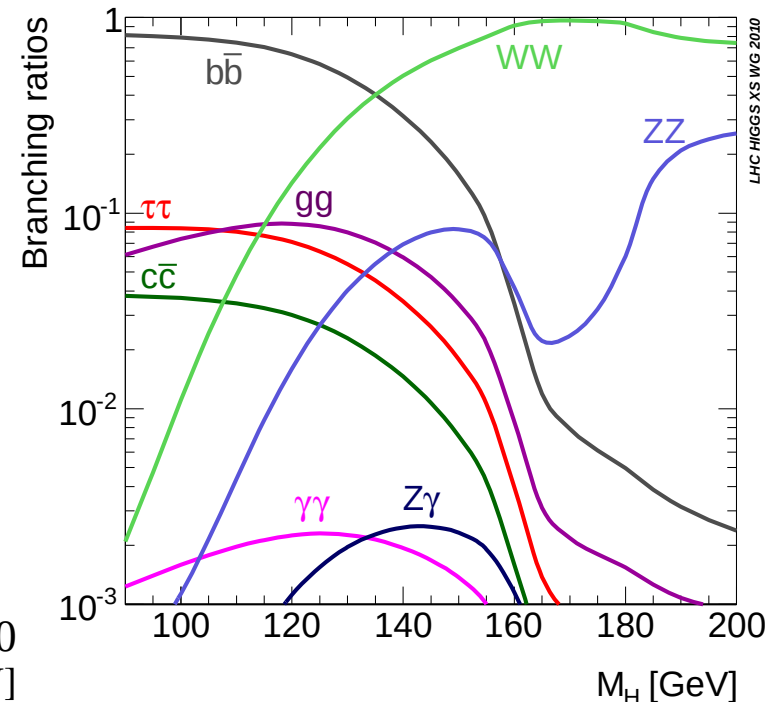
Tevatron: $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

Higgs production



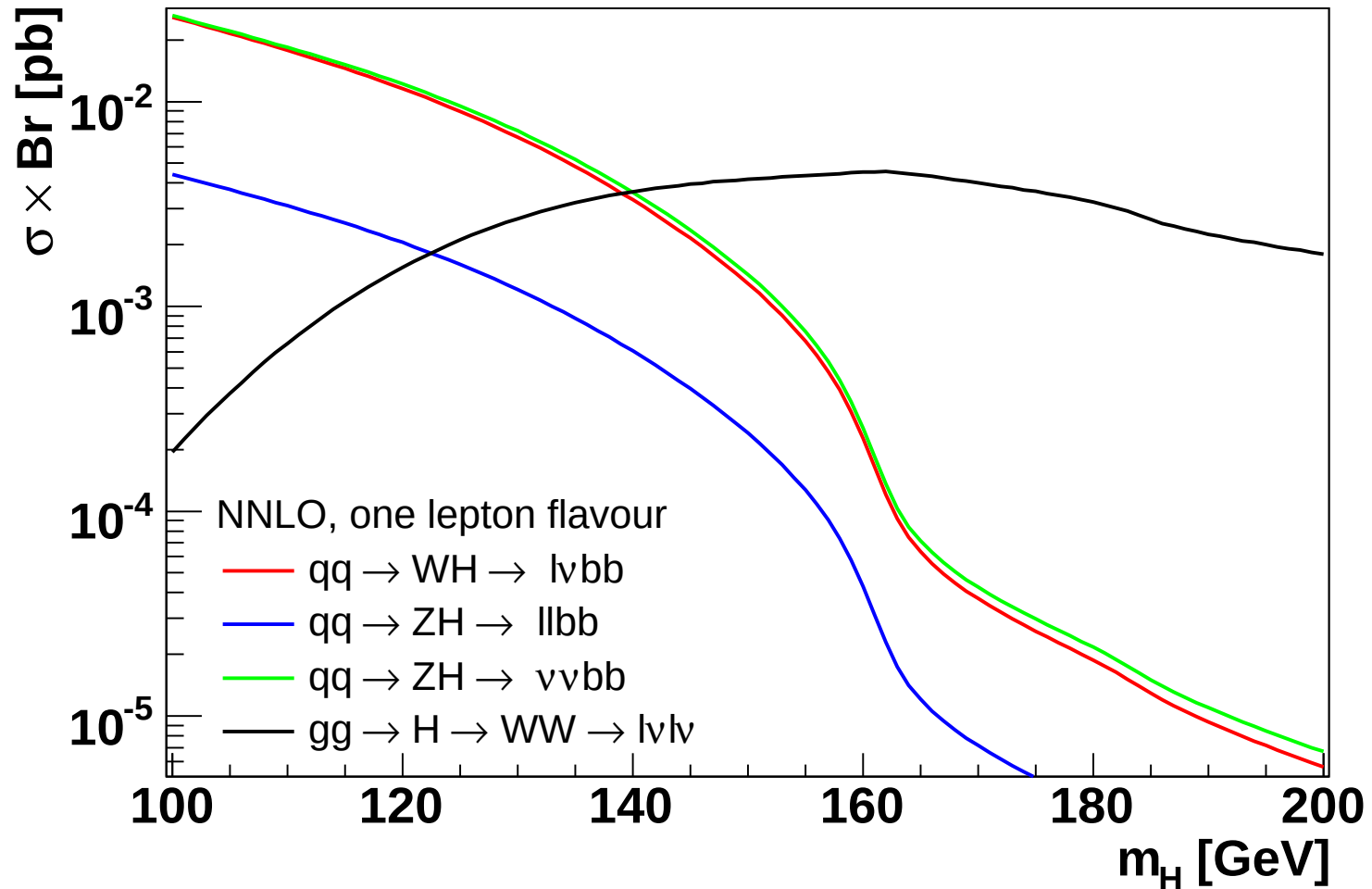
- Gluon fusion
- Associated production

Higgs decay



- $b\bar{b}$ at low m_H
- WW at high m_H

Higgs @ Tevatron



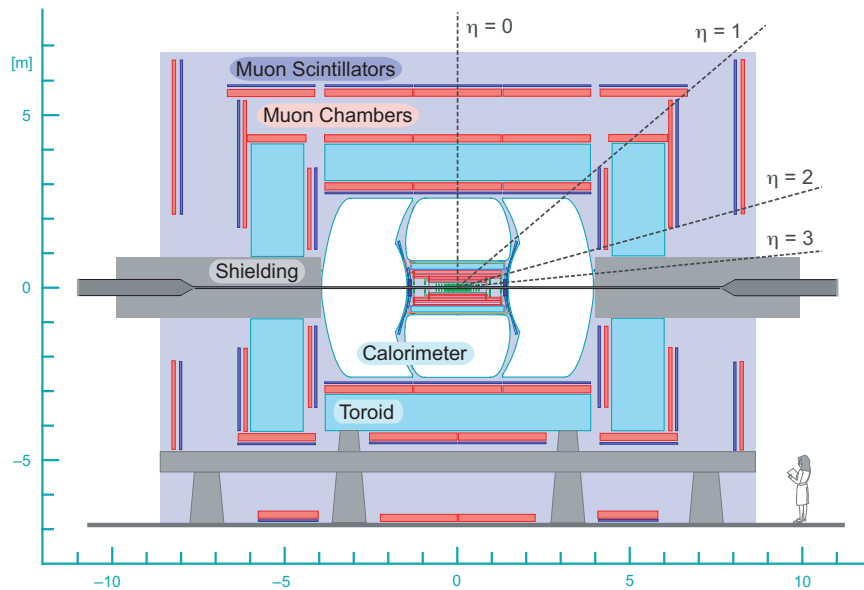
WH, ZH with $H \rightarrow b\bar{b}$ at low m_H

$gg \rightarrow H$ with $H \rightarrow WW$ at high m_H

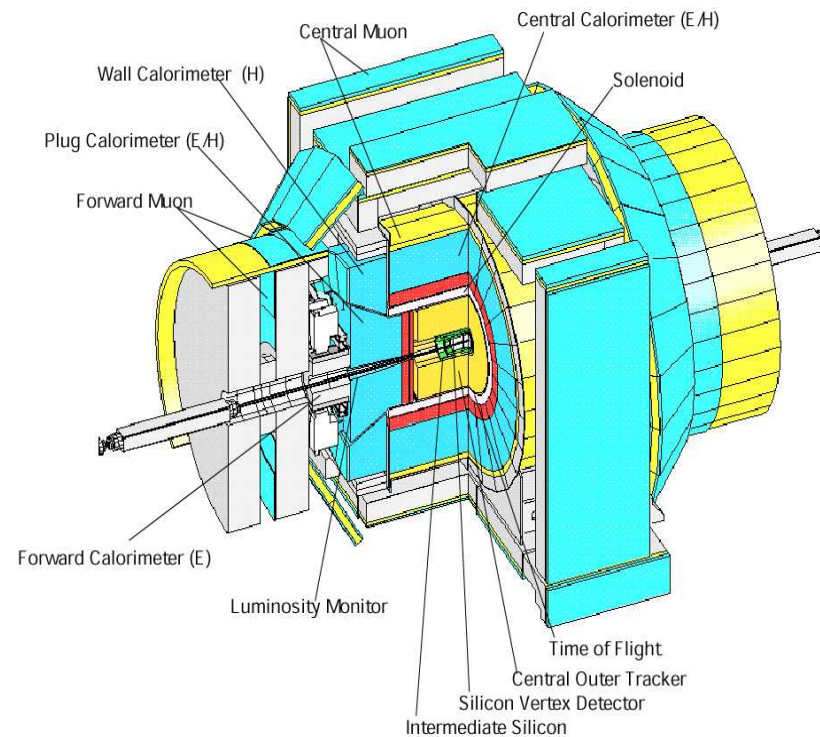
Tevatron

- $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV
- Up to now: $\int \mathcal{L} dt > 10 \text{ fb}^{-1}$ recorded / experiment
- Higgs searches: up to 8.2 fb^{-1}

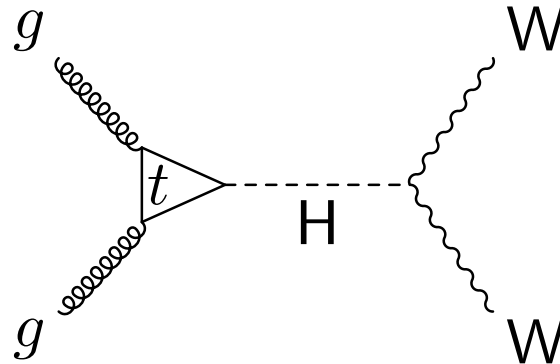
DØ



CDF

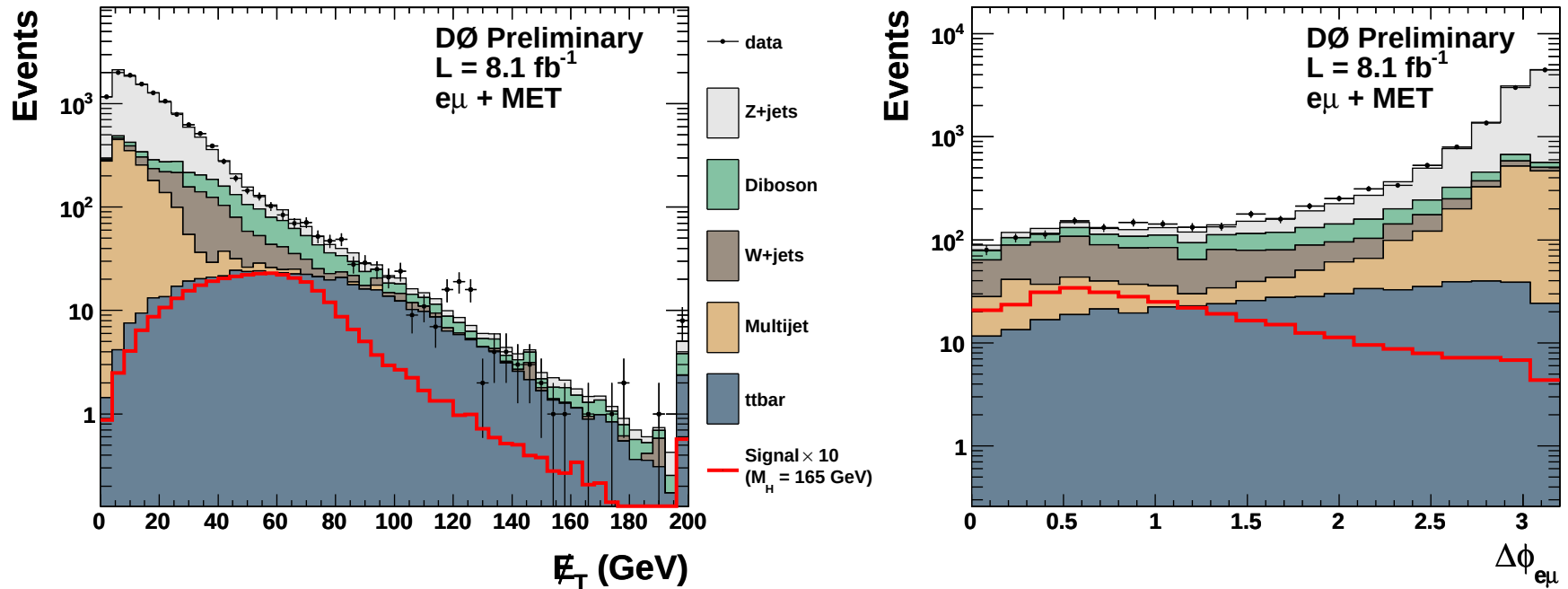


Higgs at High Mass: $H \rightarrow WW$



- $H \rightarrow WW \rightarrow \ell\nu\ell\nu$
- Gluon fusion, WBF, . . .
- Final states with e^+e^- , $\mu^+\mu^-$ or $e^\pm\mu^\mp$ and large $\cancel{E}_T$
- Background sources:
 - * Di-boson (WW, WZ, ZZ) $\rightarrow$ MC
 - * $t\bar{t}$, DY di-lepton production $\rightarrow$ MC
 - * W + mis-identified jet/ γ $\rightarrow$ MC/data

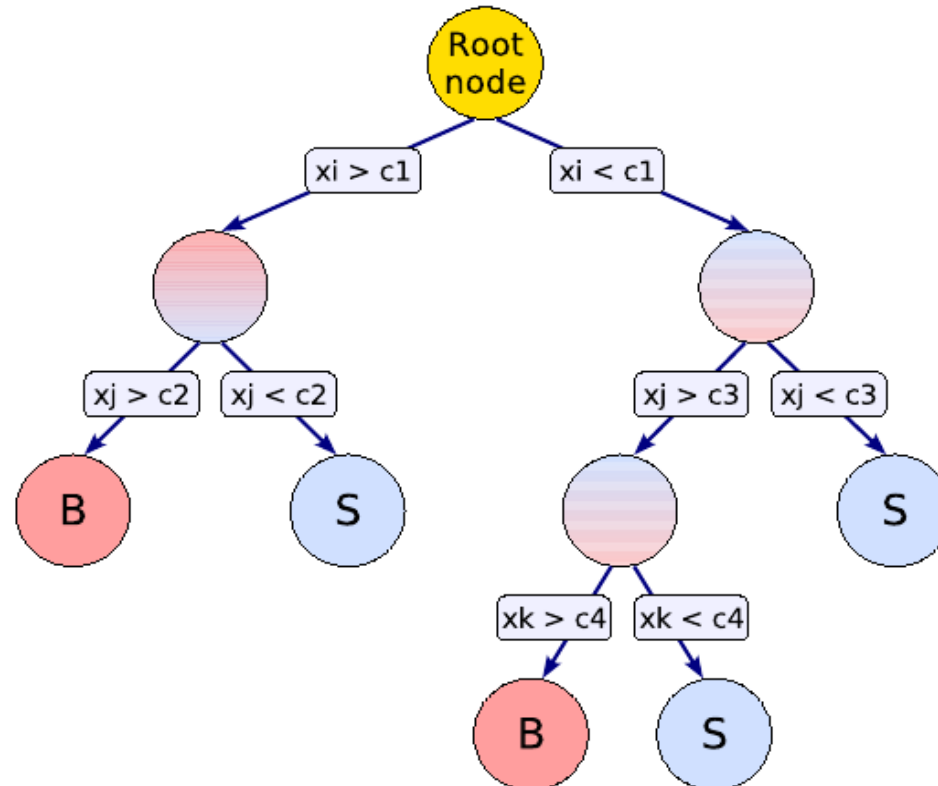
Higgs at High Mass: $H \rightarrow WW$ (DØ)



- Inclusive triggering
- $p_T(\ell_1) > 15$ GeV, $p_T(\ell_2) > 10$ GeV; no E_T cut (ee, $\mu\mu$)
- W + jets/ γ corrected using number of hits in Layer 0
- Use multi-staged “random forests”

Advanced Technique: Random Forest

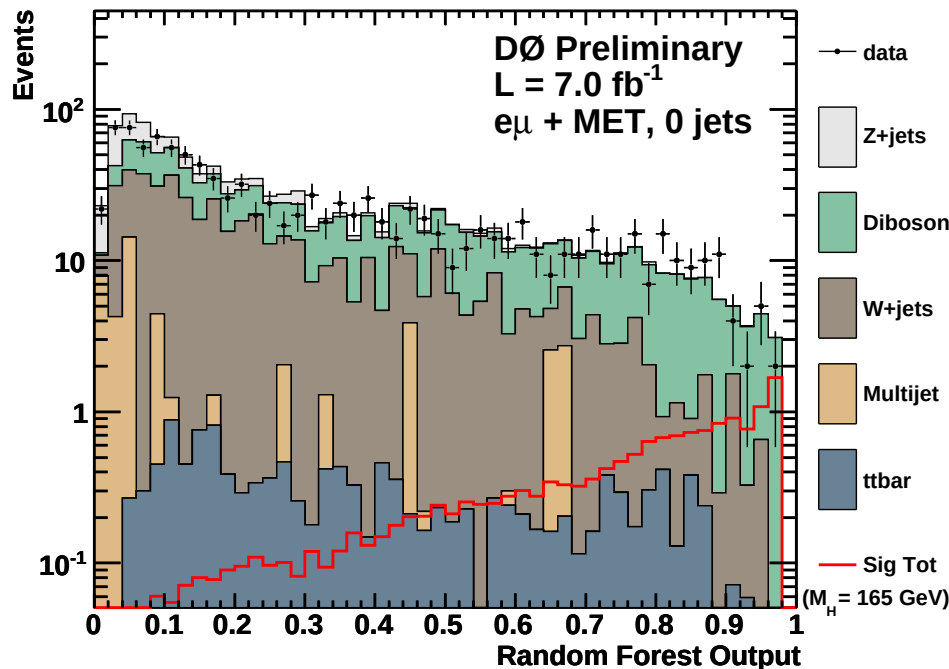
- Decision tree: recursively cut on kinematic variables
- Random forest: trees with random subsets of variables



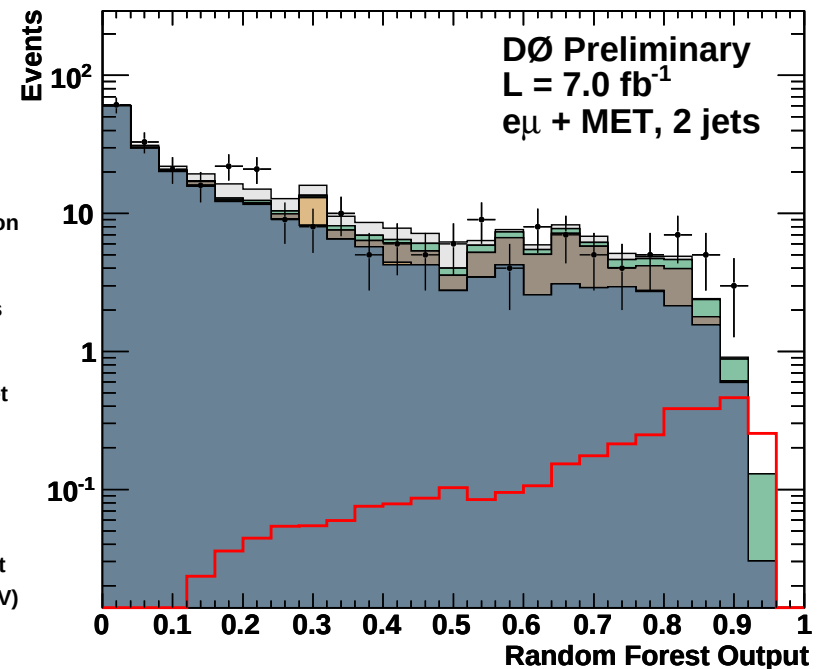
Higgs at High Mass: $H \rightarrow WW$ (DØ)

- Background and signal vary with number of jets

⇒ Analyze in jet-multiplicity bins



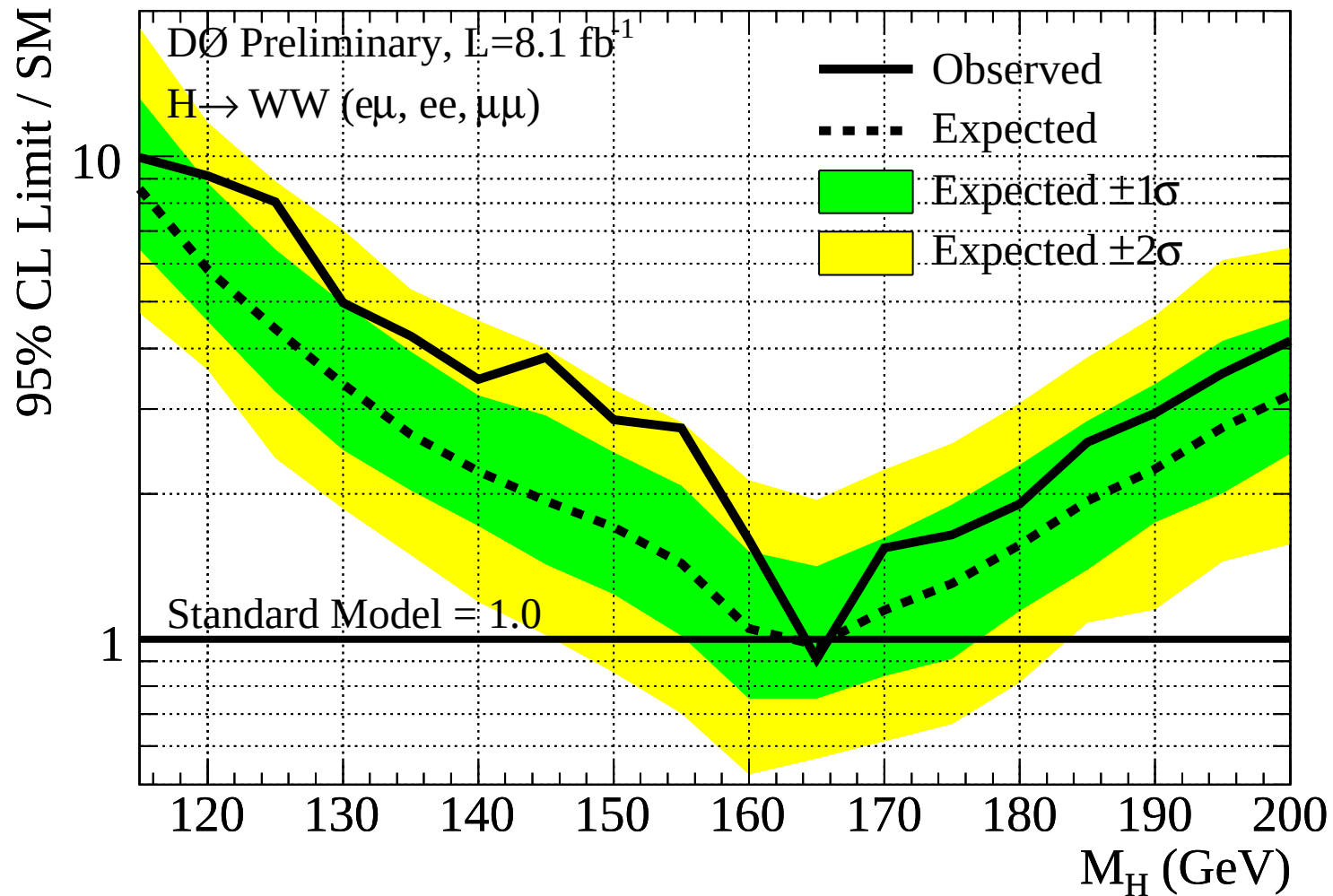
Data: 1074, Bg: 1163.5
Higgs: 16.0 events



Data: 280, Bg: 285.7
Higgs: 3.2 events

$H \rightarrow WW$ Results (DØ)

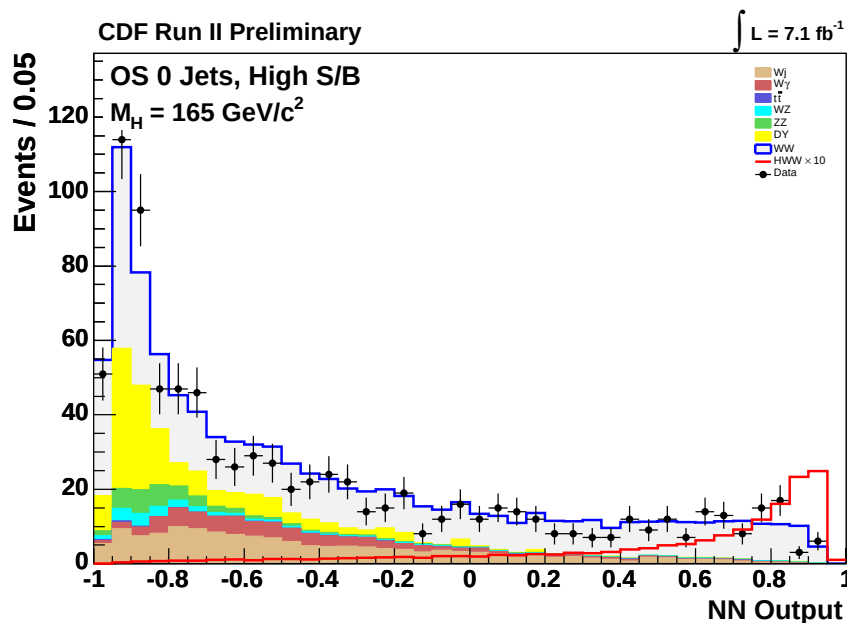
Include di-leptonic WH/ZH events



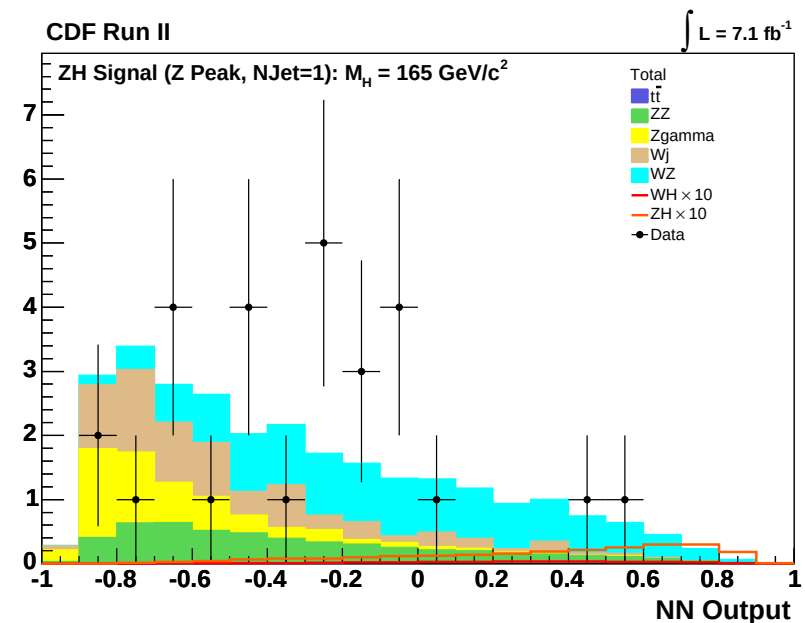
$\Rightarrow$ Exclude $m_H = 165 \text{ GeV}$

Higgs at High Mass: $H \rightarrow WW$ (CDF)

- Use neural networks
- Split analysis in many sub-channels
 - * Opposite-sign, same-sign di-lepton
 - * Low $m_{\ell\ell}$, tri-lepton
 - * Zero, one, $>$ two jets



OS, zero-jet

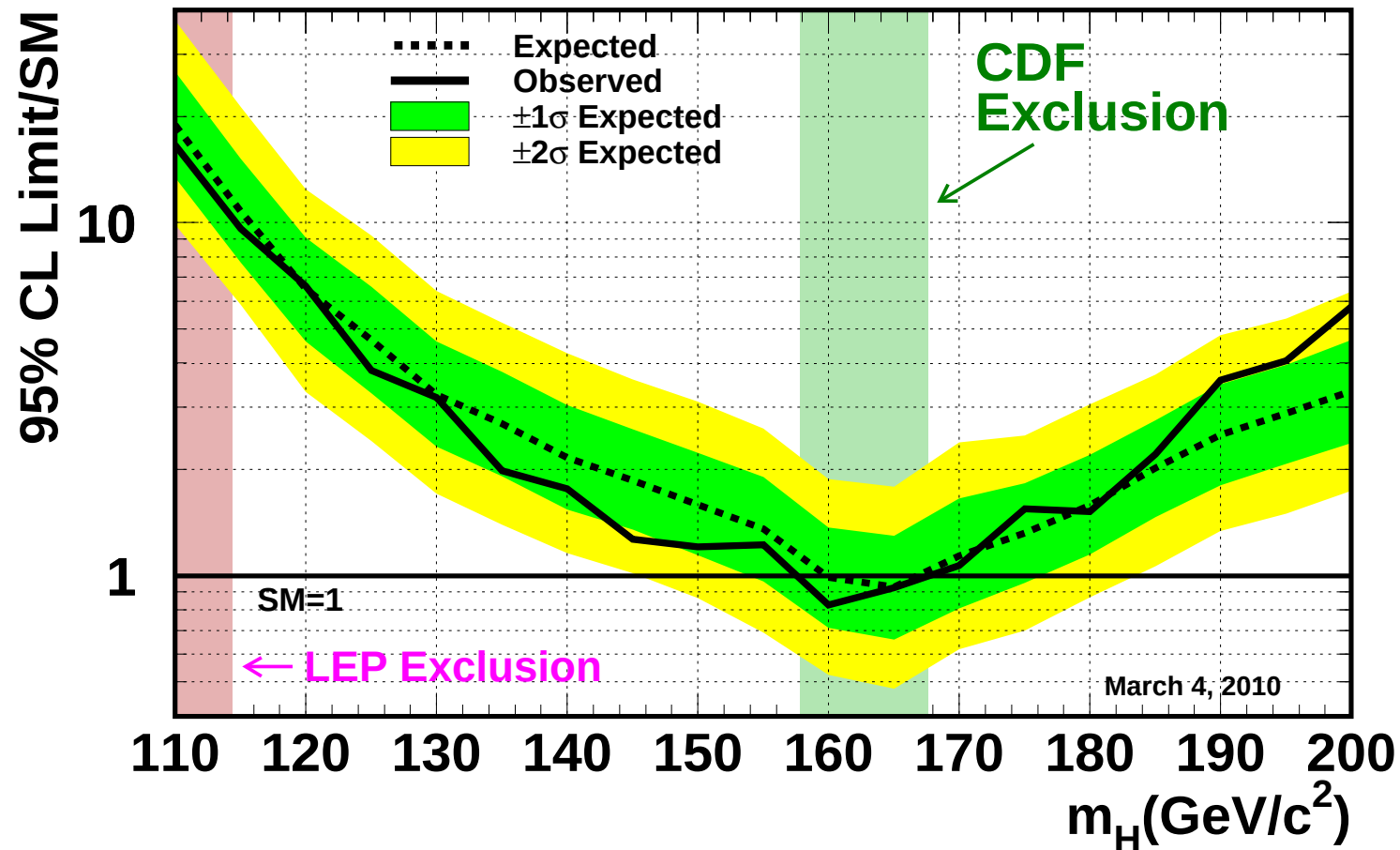


Tri-lepton, one-jet

$H \rightarrow WW$ Results (CDF)

Combine 12 channels (including τ_{had})

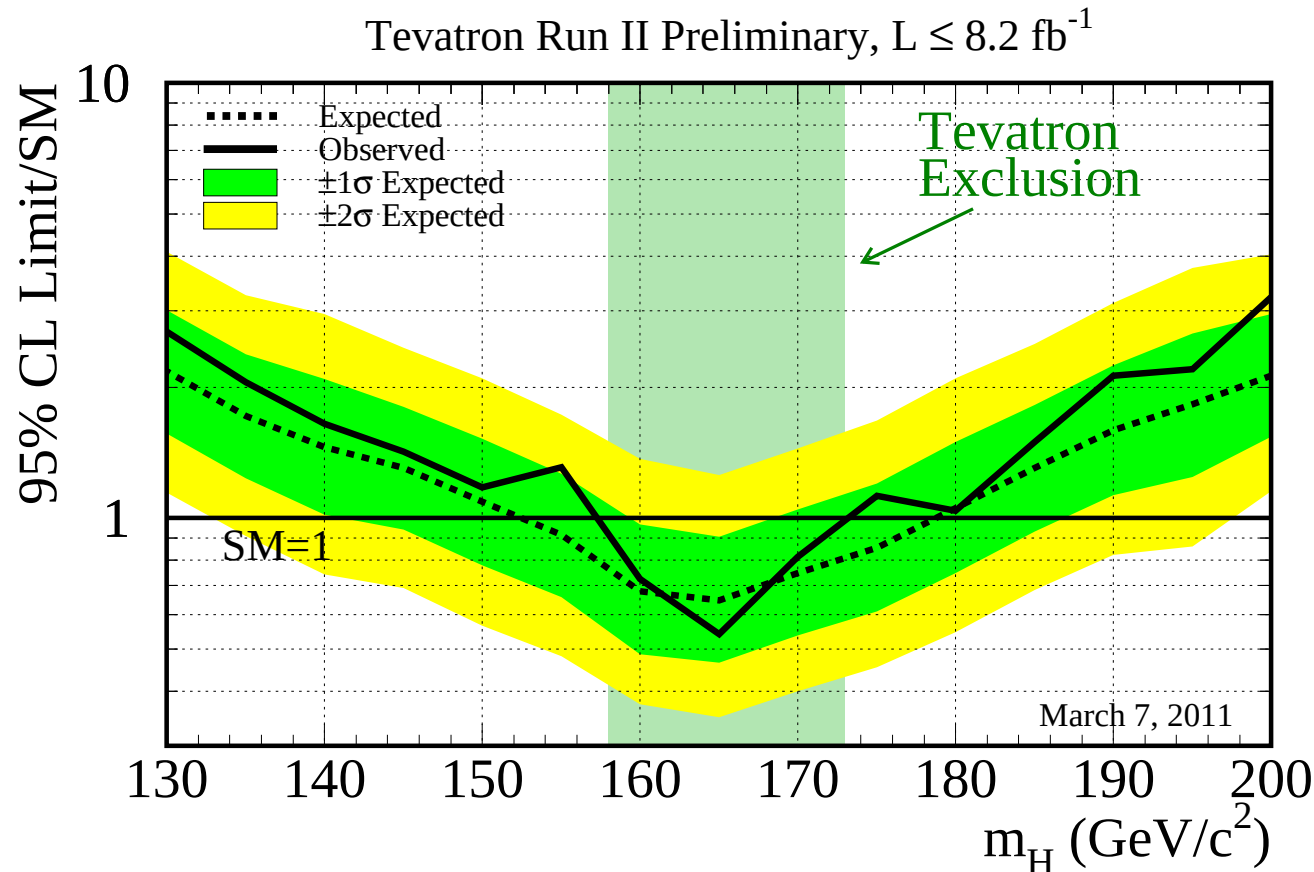
CDF Run II Preliminary $H \rightarrow W^+W^-$ Search, $L = 7.1 \text{ fb}^{-1}$



$\Rightarrow$ Exclude $158 < m_H < 168 \text{ GeV}$

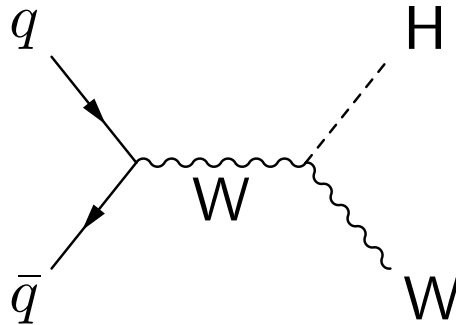
Higgs at High Mass: Combined Tevatron Limit

- $H \rightarrow WW, \tau\tau, \gamma\gamma$, latest $\sigma(gg \rightarrow H)$
- Correlated and uncorrelated systematics



$\Rightarrow$ Exclude $158 < m_H < 173 \text{ GeV}$

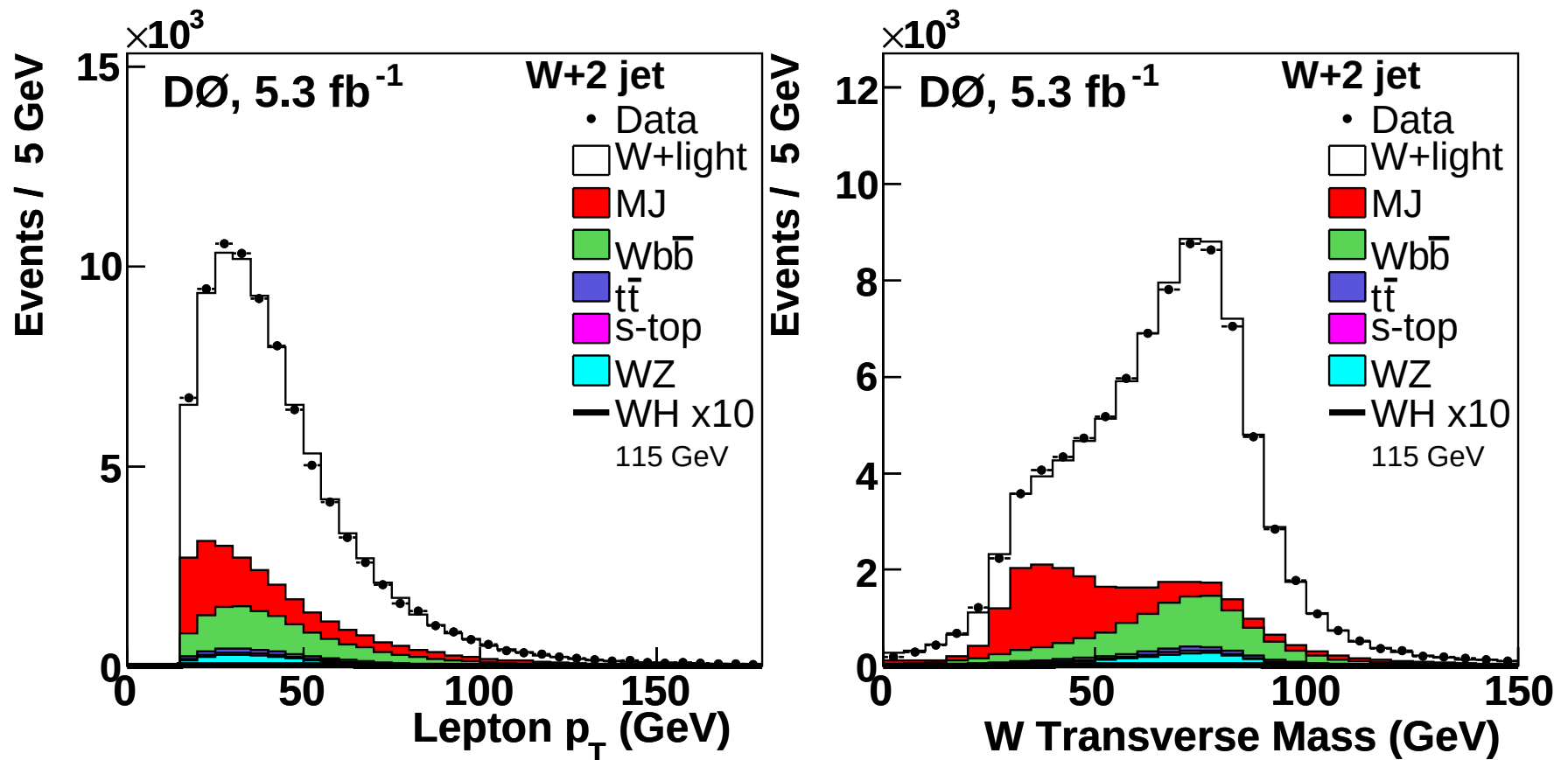
Higgs at Low Mass: $WH \rightarrow \ell \nu b \bar{b}$



- Decays of W : high p_T lepton and $\cancel{E}_T$
- $H \rightarrow b\bar{b}$: at least two jets
- Background sources:
 - * W with additional jets (including $Wb\bar{b}$) $\rightarrow$ MC/data
 - * $t\bar{t}$, single top $\rightarrow$ MC
 - * Multi-jet production with mis-ID of lepton and $\cancel{E}_T \rightarrow$ data
 - * Di-boson (WW , WZ , ZZ) $\rightarrow$ MC

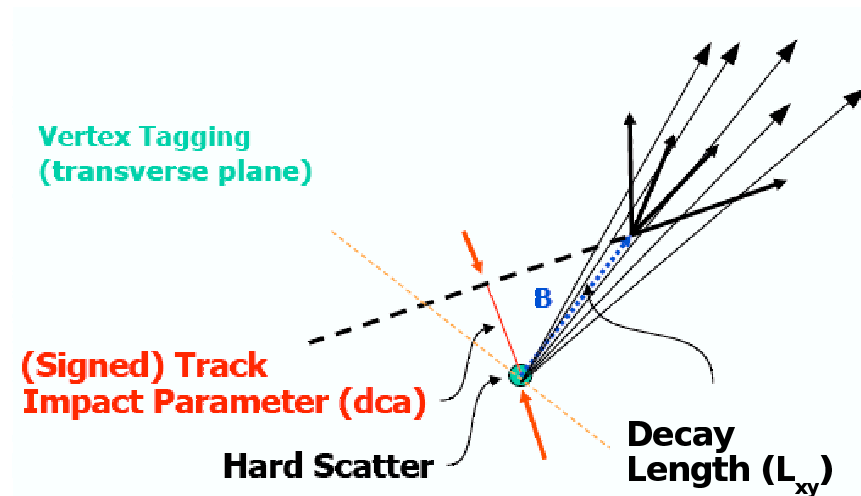
Higgs at Low Mass: $WH \rightarrow \ell \nu b \bar{b}$ (DØ)

- Signature: one isolated lepton, large $\cancel{E}_T$
- Consistent with W decay



b-Tagging

Exploit b-lifetime:



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

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

⇒ High b-tagging efficiency ($p_T = 50$ GeV):

* “Tight”: 53% at 0.9% fake rate (DØ neural net tagger)

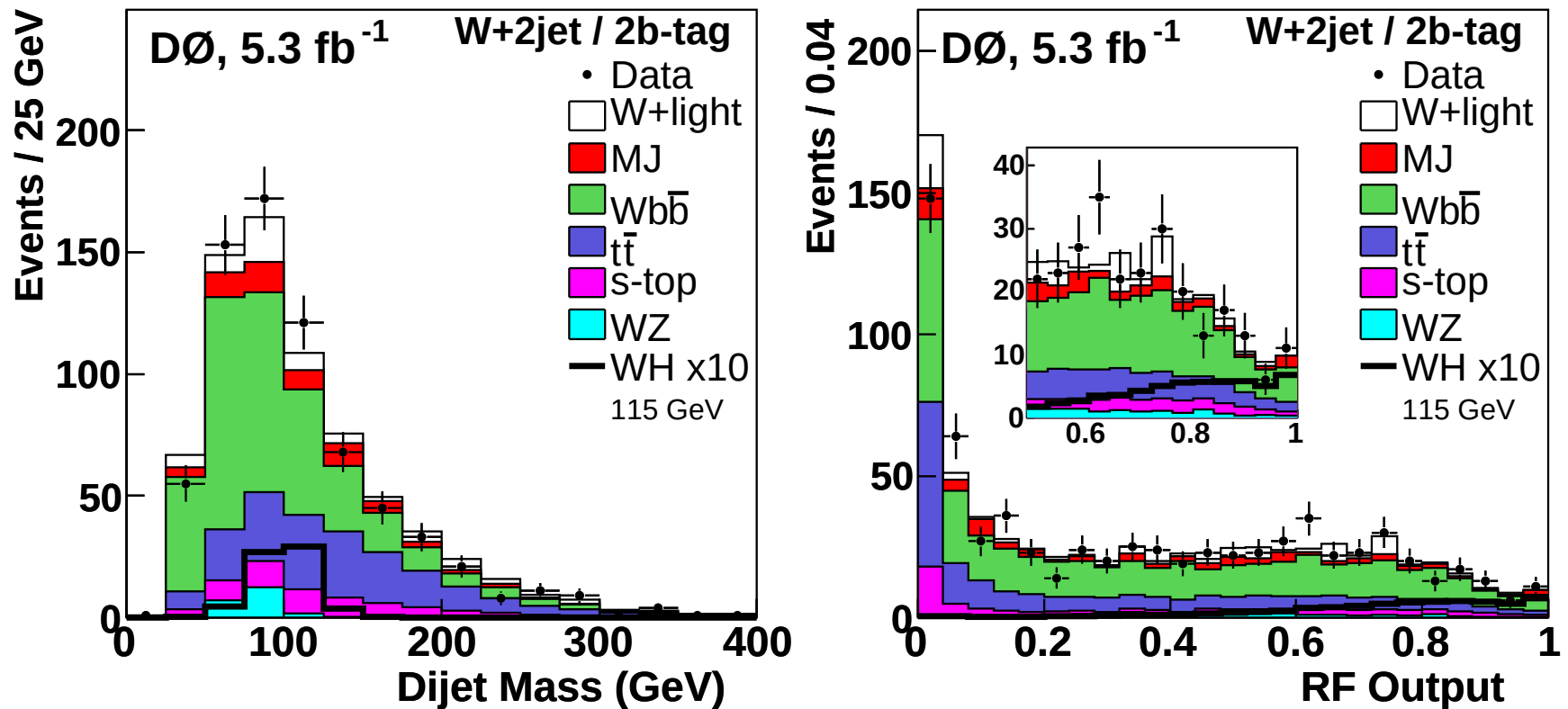
* “Loose”: 63% at 2.7% fake rate (DØ neural net tagger)

– Used also as anti-top tagger

Higgs at Low Mass: $WH \rightarrow \ell \nu b \bar{b}$ (DØ)

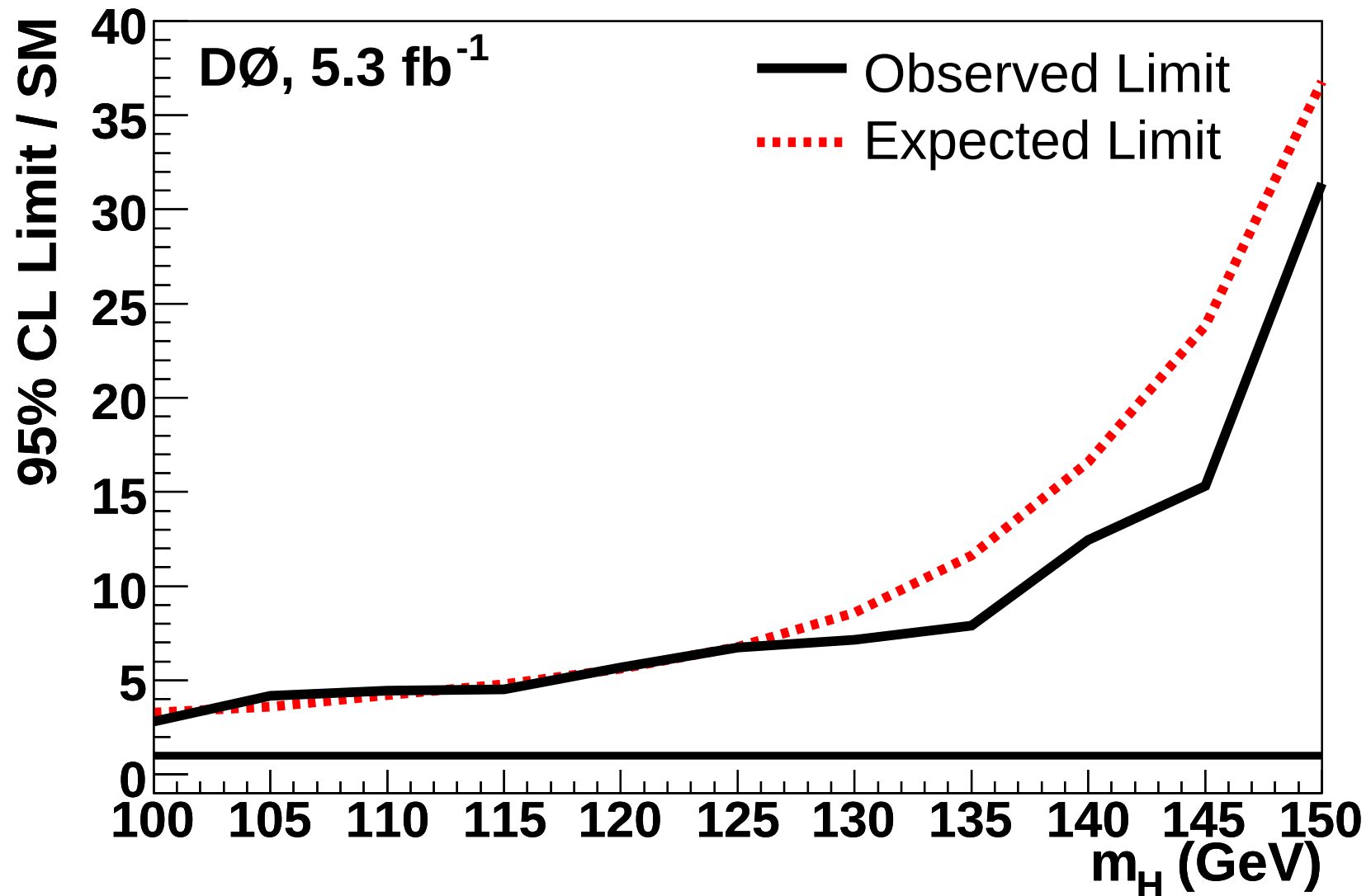
– Use “random forests” against background

⇒ Gain 20% in sensitivity



Data: 709, Bg: 718, WH ($m_H = 115$ GeV): 6.5 events

$WH \rightarrow \ell \nu b \bar{b}$ Results (DØ)



At $m_H = 115$ GeV: limit/SM 4.5 (4.8 expected)

Advanced Technique: Matrix Element

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

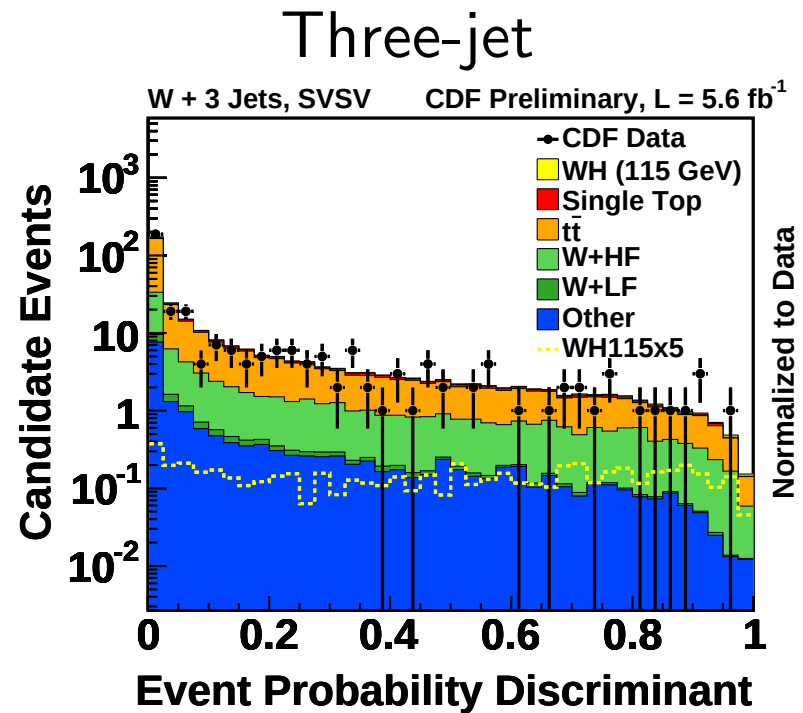
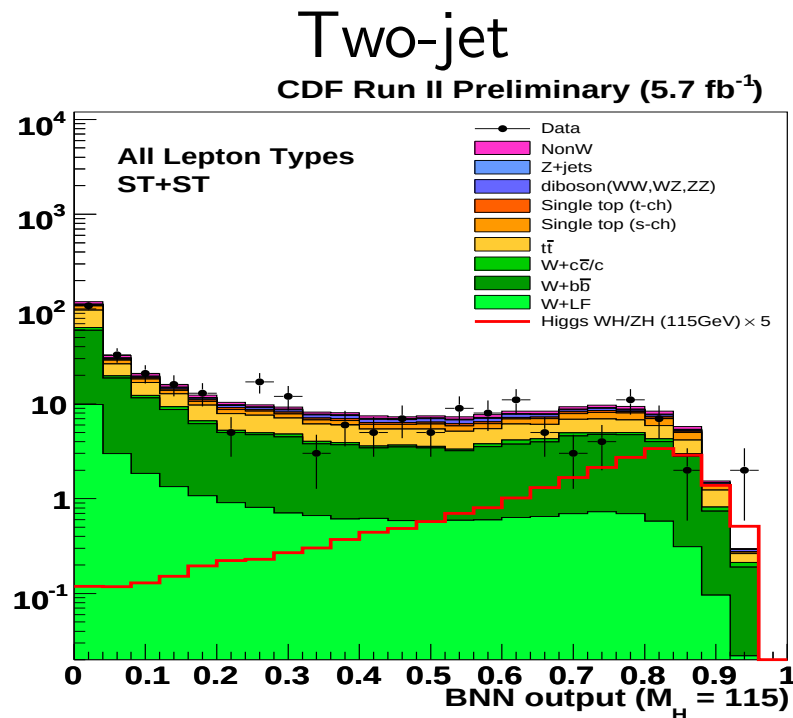
$$P(\vec{x}_{\text{obs}}) = \frac{1}{\sigma} \int \frac{d\sigma_{\text{theory}}}{d\vec{y}} \epsilon(\vec{y}) G(\vec{x}_{\text{obs}}, \vec{y}) d\vec{y}$$

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

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

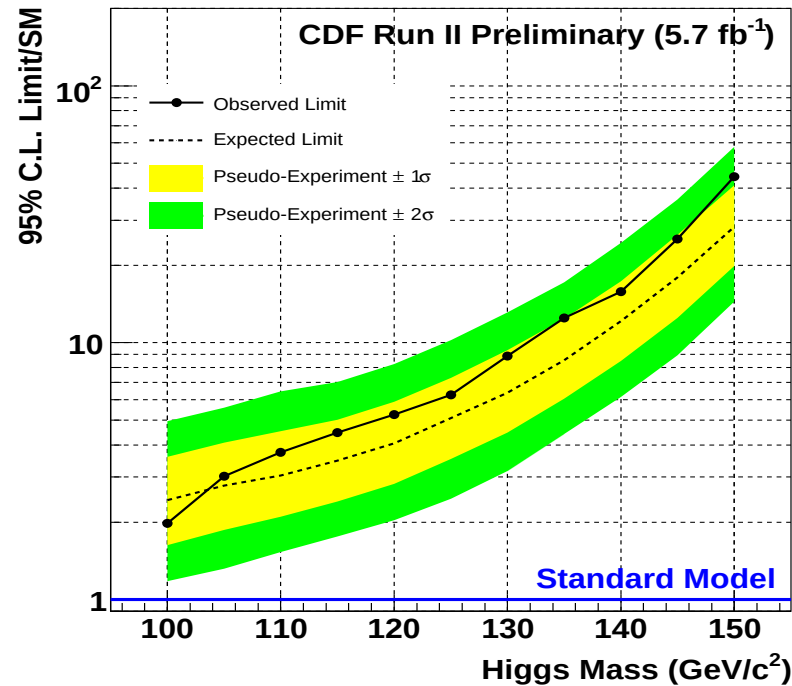
Higgs at Low Mass: $WH \rightarrow \ell\nu b\bar{b}$ (CDF)

- Include “isolated track” as lepton candidate
- Multiple exclusive b-tagging categories
- Neural net to improve b-jet energy resolution
- Matrix element techniques in three-jet channel



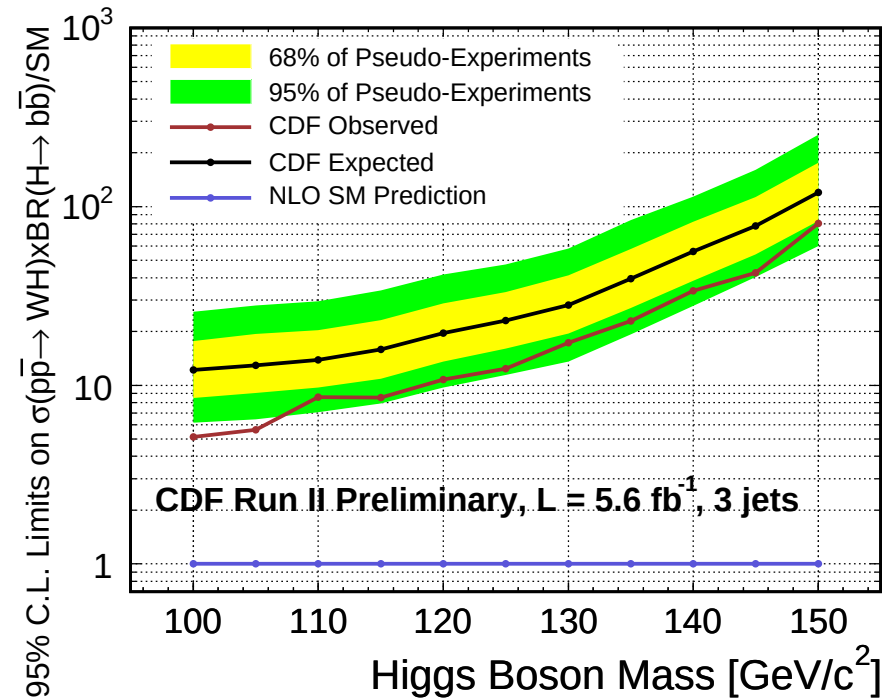
$WH \rightarrow \ell \nu b \bar{b}$ Results (CDF)

Two-jet



At $m_H = 115$ GeV:
limit/SM 4.5 (3.5 exp.)

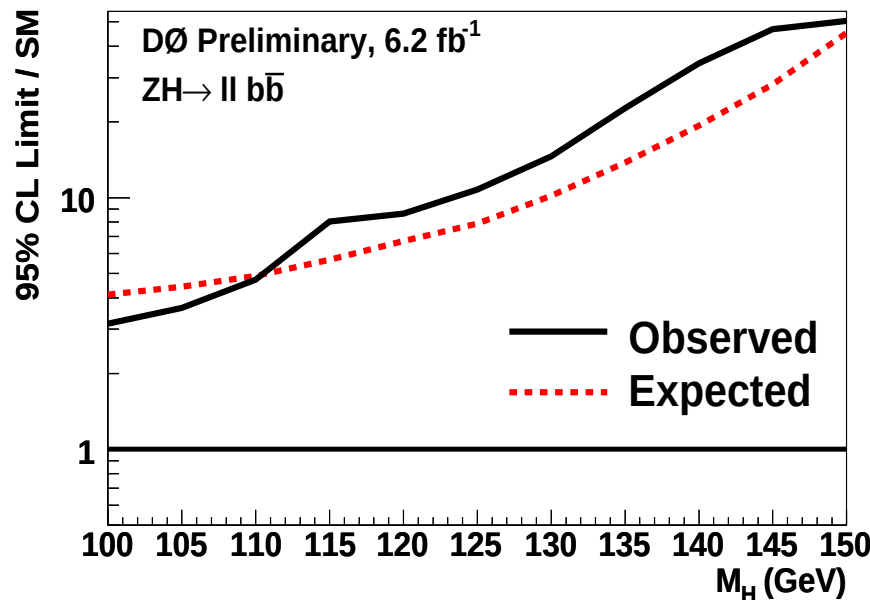
Three-jet



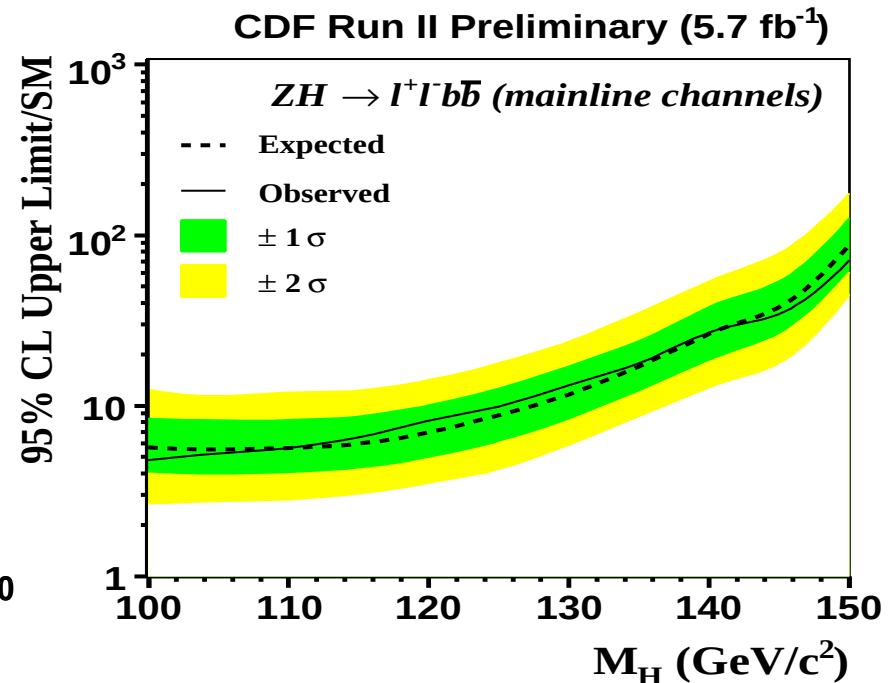
At $m_H = 115$ GeV:
limit/SM 8.5 (15.8 exp.)

Higgs at Low Mass: $ZH \rightarrow \ell\ell b\bar{b}$

Two leptons, at least two jets, b-tags



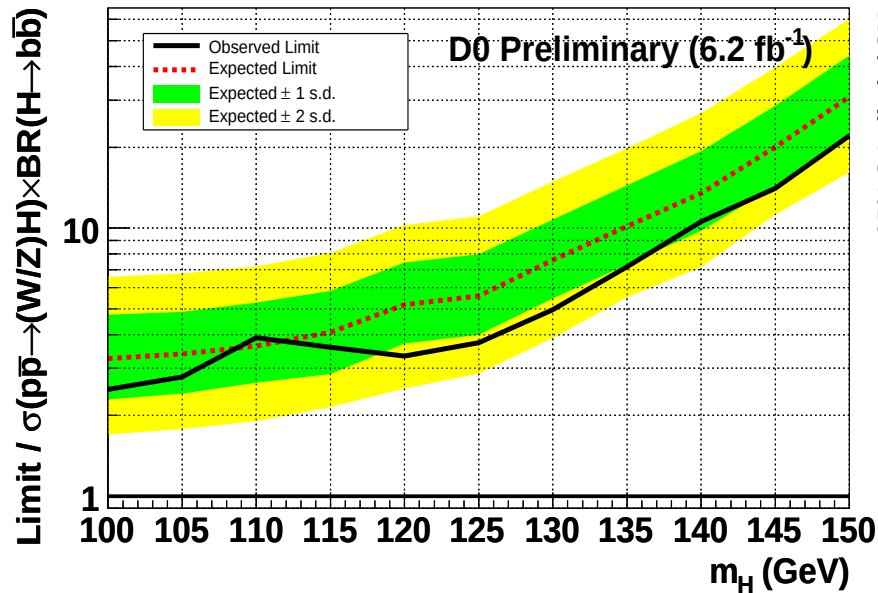
DØ at $m_H = 115$ GeV:
limit/SM 8.0 (5.7 exp.)



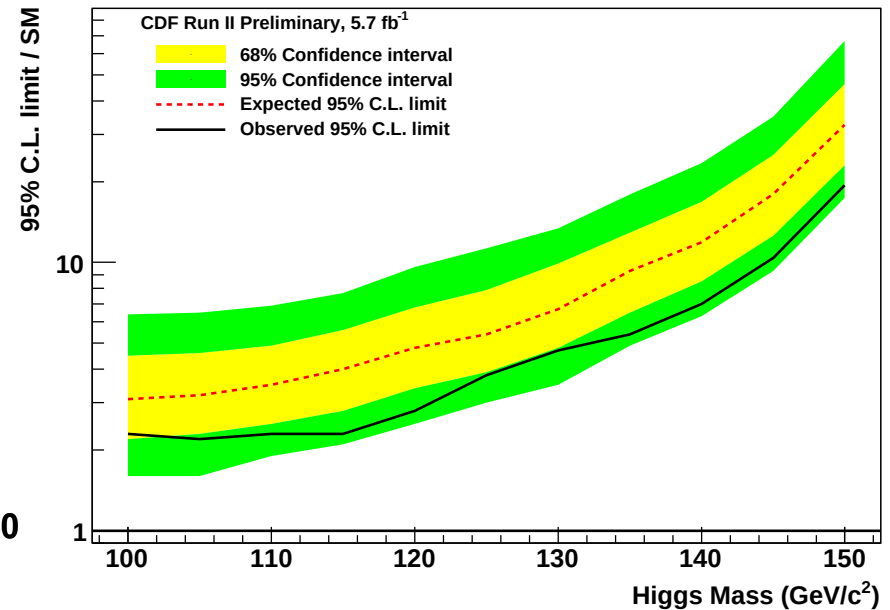
CDF at $m_H = 115$ GeV:
limit/SM 6.5 (6.0 exp.)

Higgs at Low Mass: $ZH \rightarrow \nu\bar{\nu}b\bar{b}$

No leptons, large $\cancel{E}_T$, at least two jets, b-tags

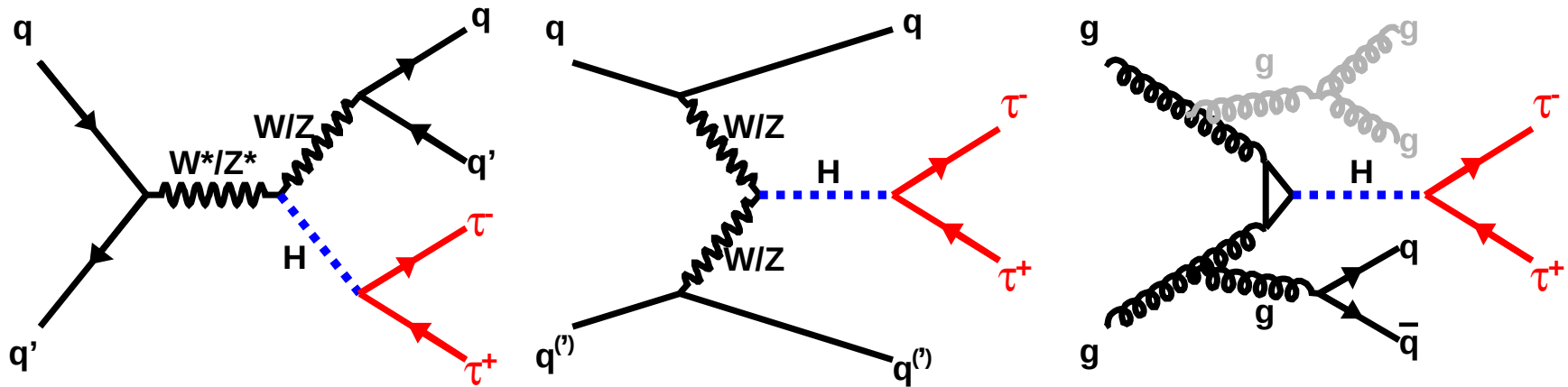


DØ at $m_H = 115$ GeV:
limit/SM 3.4 (4.0 exp.)



CDF at $m_H = 115$ GeV:
limit/SM 2.3 (4.0 exp.)

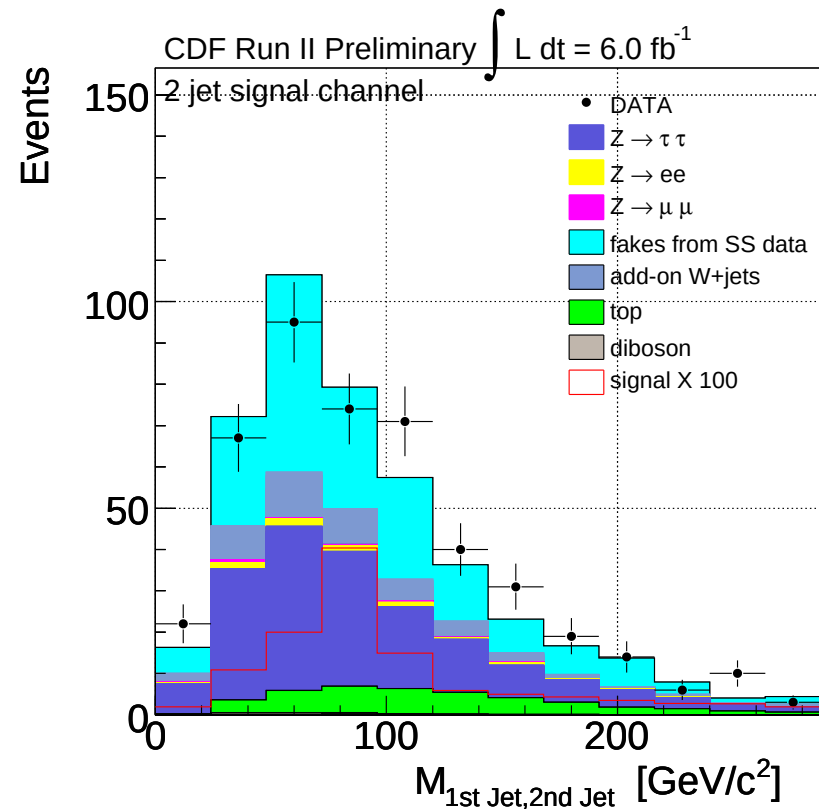
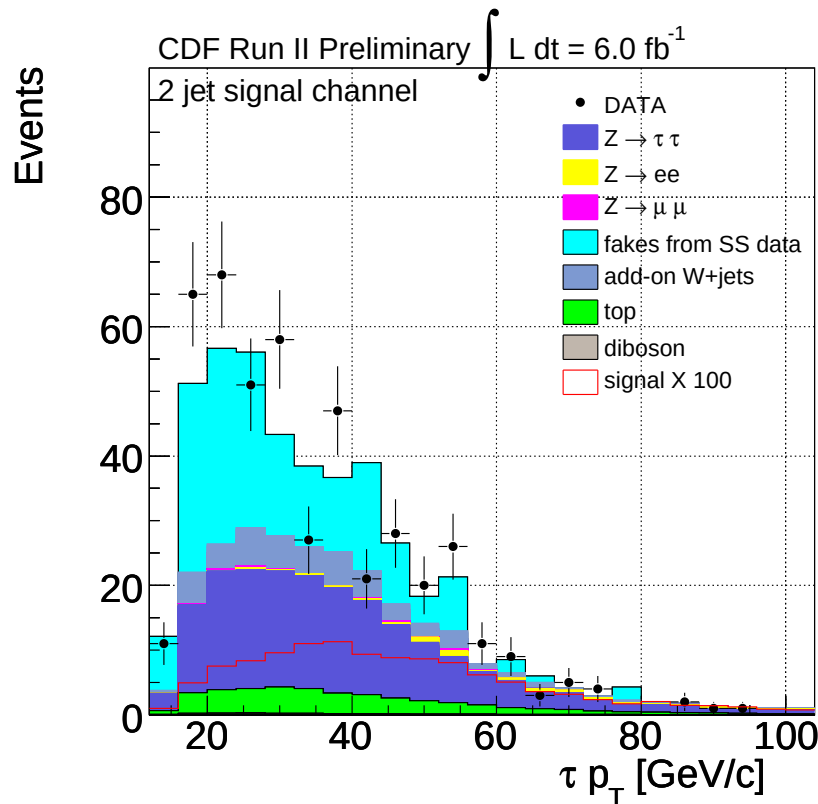
Higgs at Low Mass: $H \rightarrow \tau\tau$ (CDF)



- $\text{Br}(H \rightarrow \tau\tau) \simeq 10\%$ of $\text{Br}(H \rightarrow b\bar{b})$
- Final state: $\tau(\rightarrow \ell X) \tau(\rightarrow \text{hadrons}) + \text{one or } \geq \text{two jets}$
- Background sources:
 - * Multi-jet, γ +jet, W +jet $\rightarrow$ data
 - * $Z/\gamma^*, t\bar{t} \rightarrow$ MC

Higgs at Low Mass: $H \rightarrow \tau\tau$ (CDF)

- Identify $\tau \rightarrow$ hadrons using decision trees

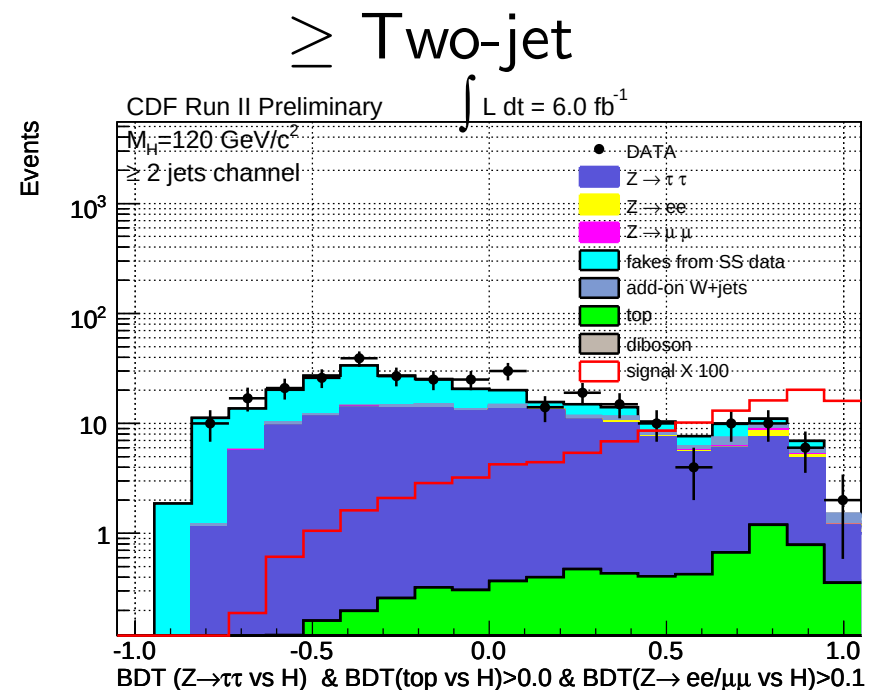
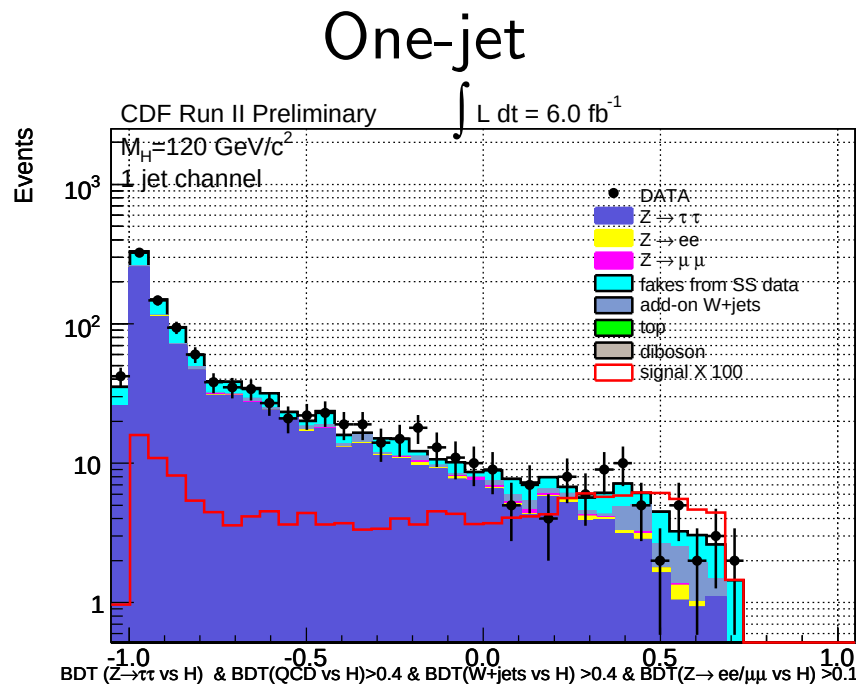


Data: 462, Bg: 427.9

Higgs ($m_H = 120 \text{ GeV}$): 1.23 events

Higgs at Low Mass: $H \rightarrow \tau\tau$ (CDF)

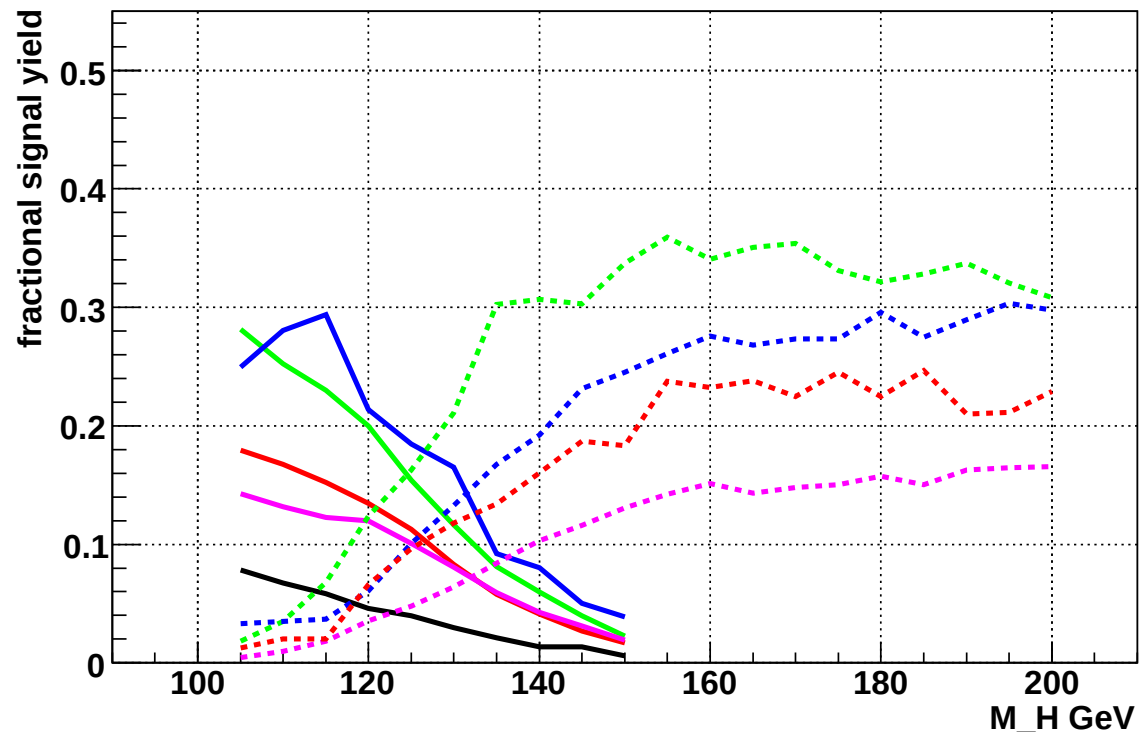
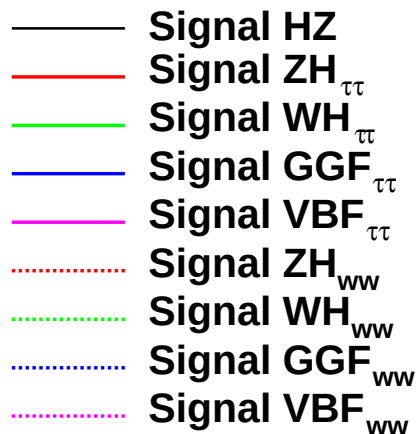
- Multiple decision trees:
 - * In one jet and $\geq$ two jet channels
 - * Against different background sources
- Cut on output; apply $Z \rightarrow \tau\tau$ tree to remaining events



Higgs at Low Mass: $H \rightarrow \tau\tau$ (DØ)

- Final state: $e/\mu + \tau_{\text{had}} + \geq \text{two jets}$
 - * WH, ZH, WBF, gluon fusion
 - * $H \rightarrow \tau\tau$, $H \rightarrow WW$
 - * $ZH \rightarrow \tau\tau b\bar{b}$

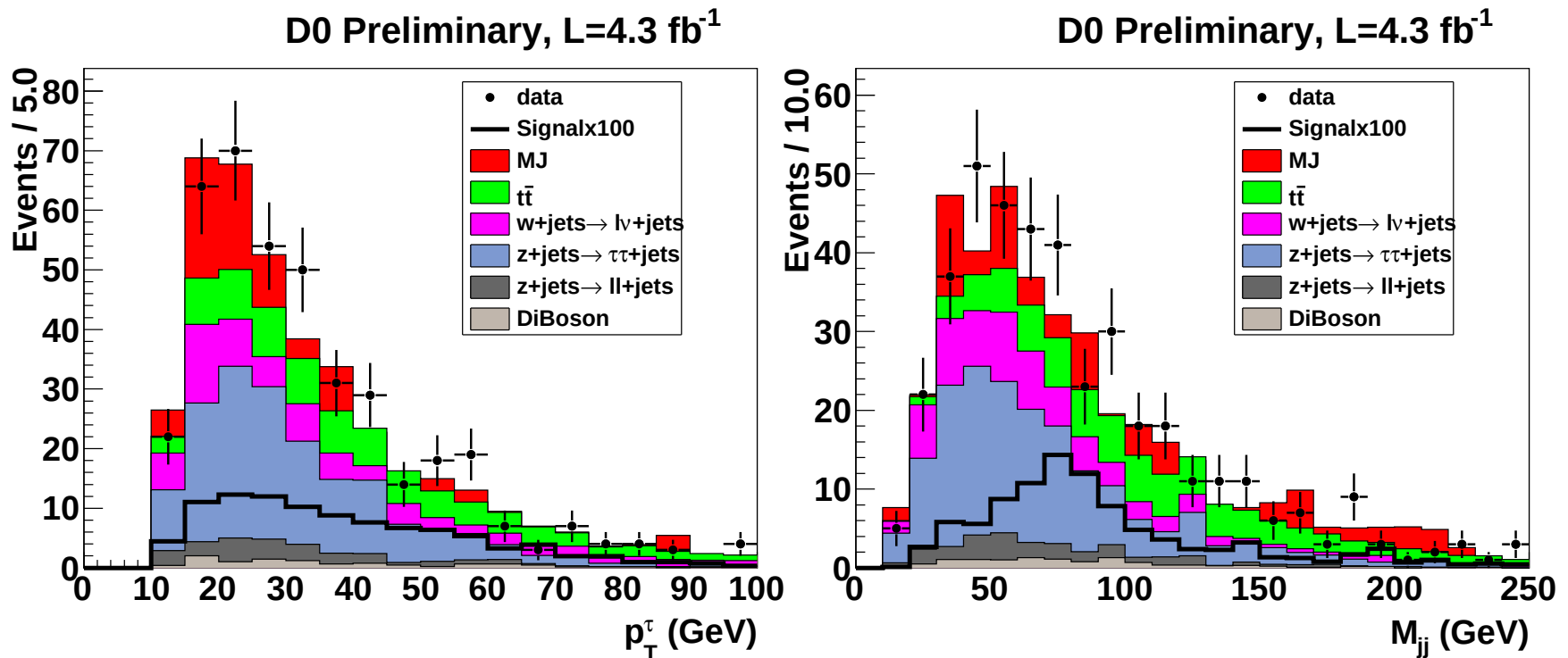
Muon channel



Higgs at Low Mass: $H \rightarrow \tau\tau$ (DØ)

- Identify $\tau \rightarrow$ hadrons using neural networks

Muon channel



Data: 414, Bg: 404.9

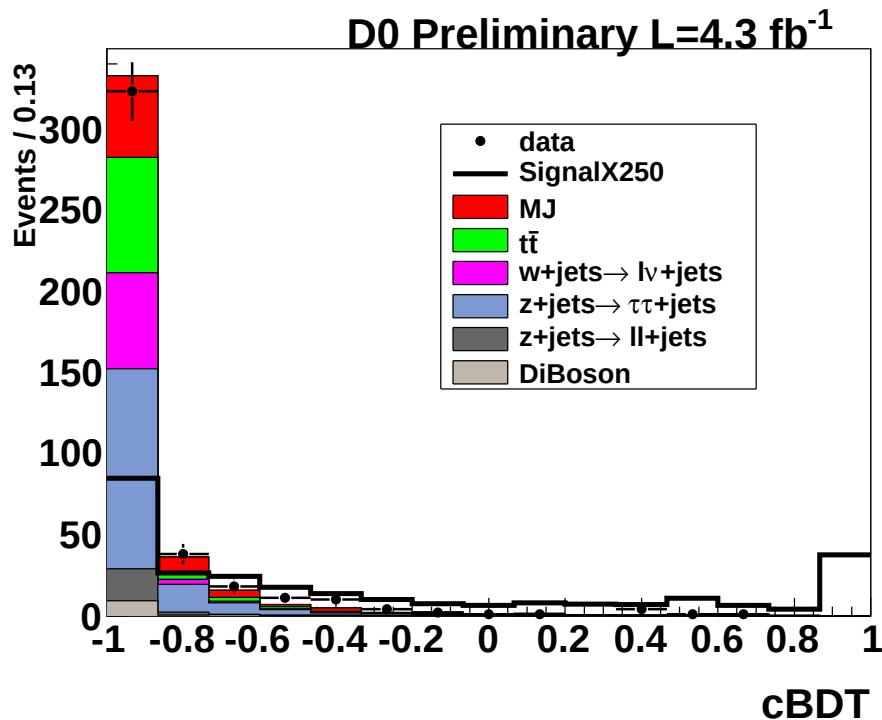
Higgs ($m_H = 115 \text{ GeV}$): 1.1 events

Higgs at Low Mass: $H \rightarrow \tau\tau$ (DØ)

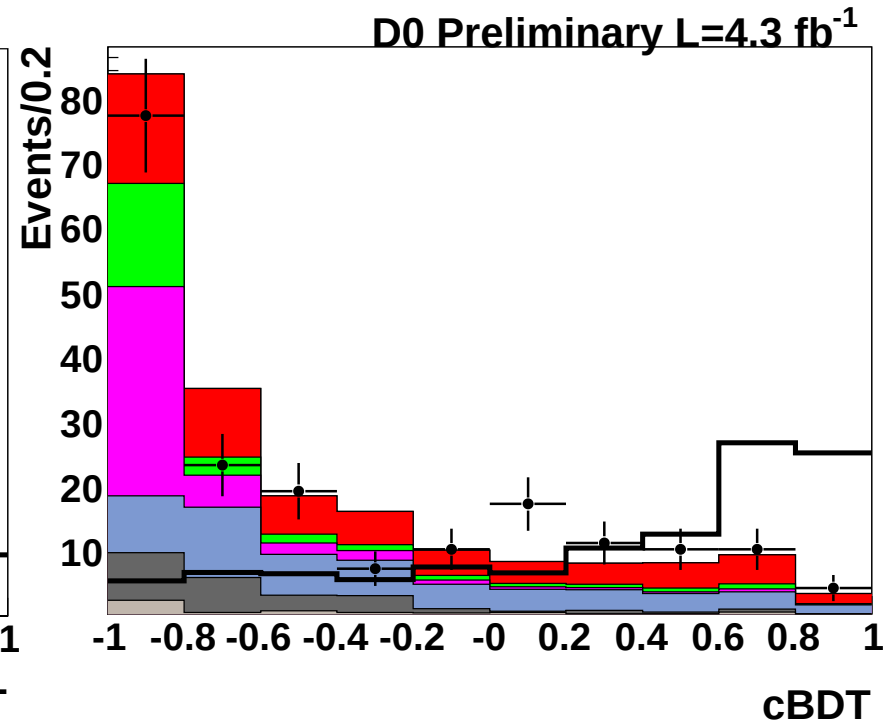
⇒ Train DT for various signal-background combinations

- In three m_H ranges
- Combine into one DT

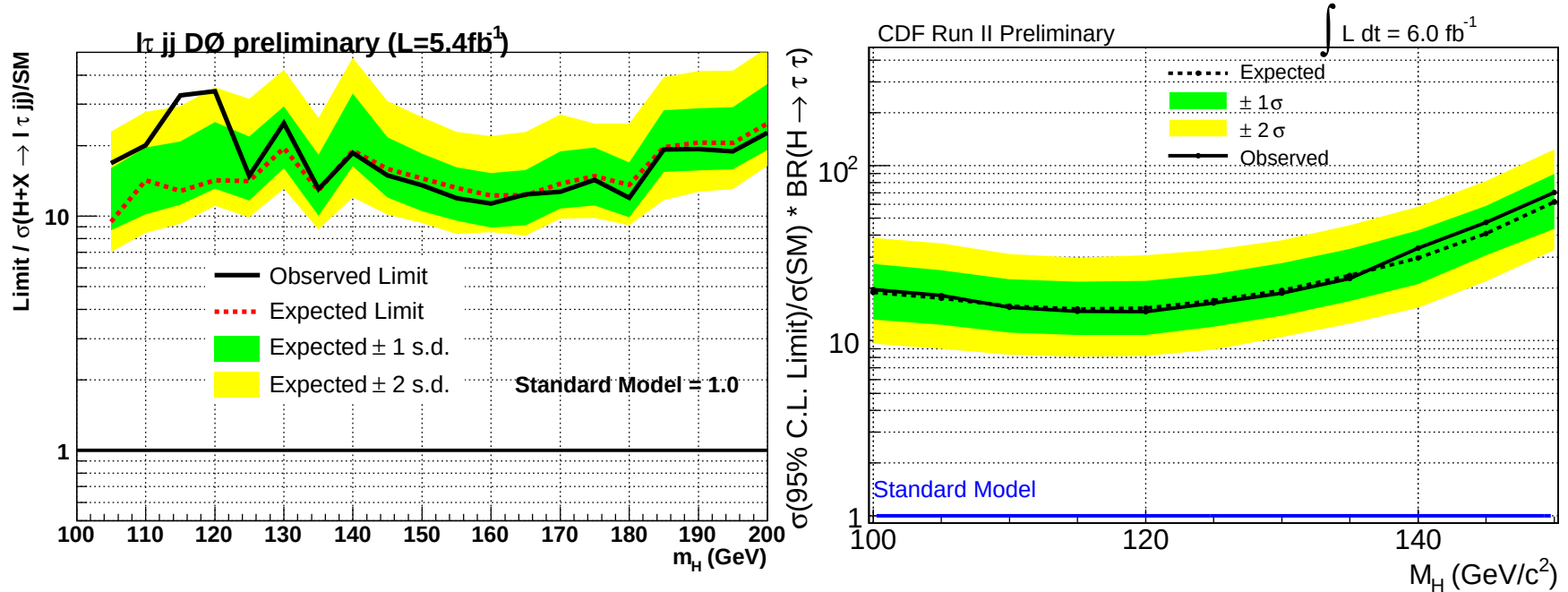
Muon channel



Electron channel



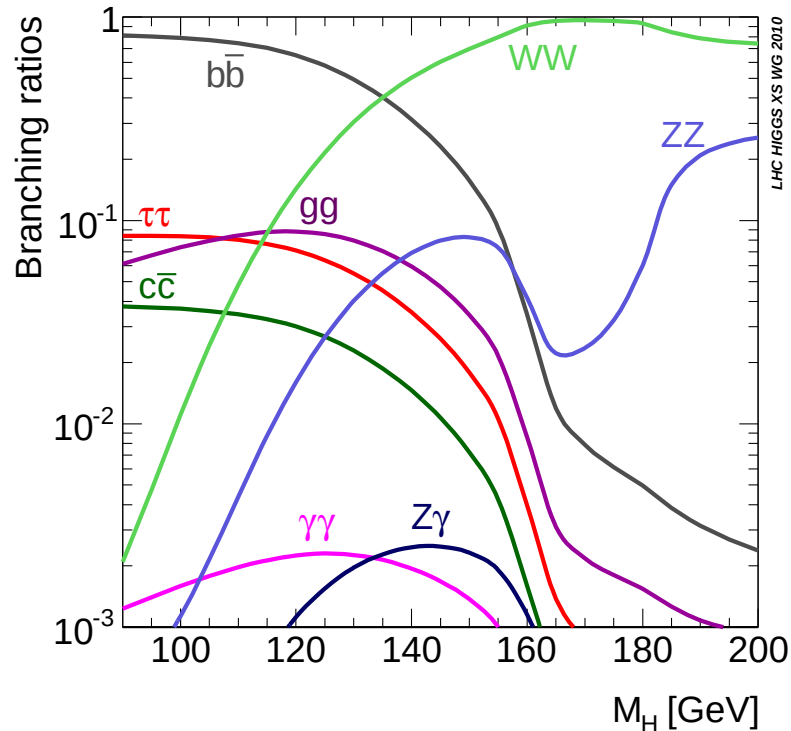
H $\rightarrow$ $\tau\tau$ Results



D0 at $m_H = 115$ GeV:
limit/SM 32.8 (12.8 exp.)

CDF at $m_H = 115$ GeV:
limit/SM 14.7 (15.2 exp.)

Higgs at Low Mass: $H \rightarrow \gamma\gamma$



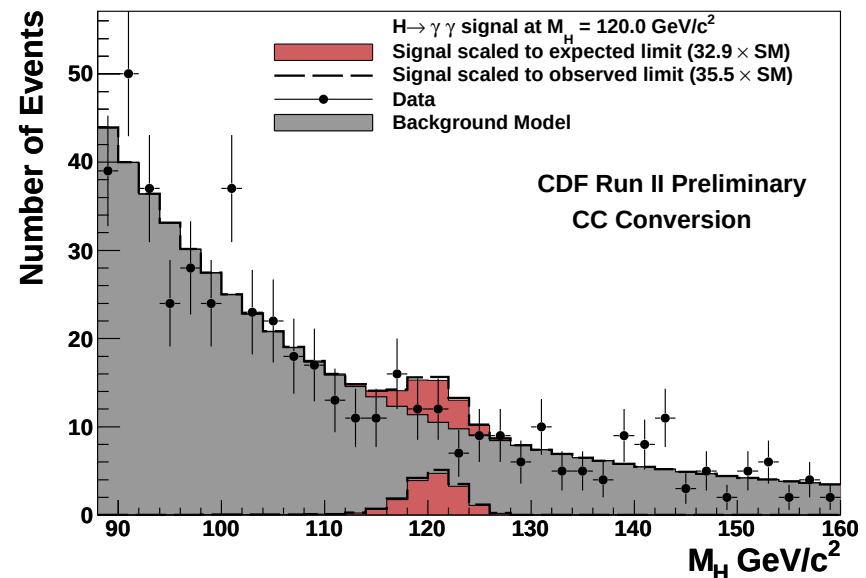
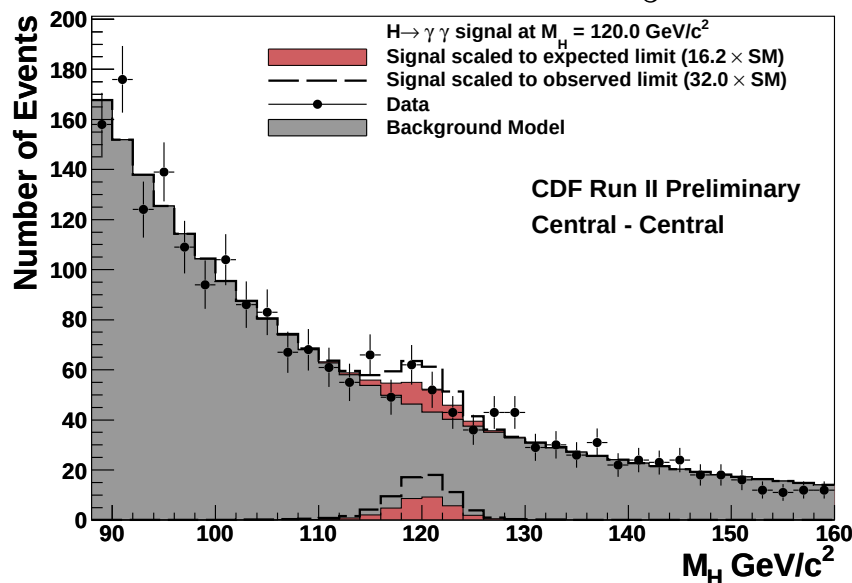
- Very small branching ratio
- Excellent mass resolution

- CDF: maximize acceptance
 - * Neural net against jets (π^0, η) for central γ
 - * Include forward γ
 - * Reconstruct γ -conversions

Higgs at Low Mass: $H \rightarrow \gamma\gamma$ (CDF)

- Mass resolution for $m_H = 120$ GeV: $\simeq 3$ GeV
- Background model: smooth curve, excluding signal region

$$\int \mathcal{L} dt = 7 \text{ fb}^{-1}$$

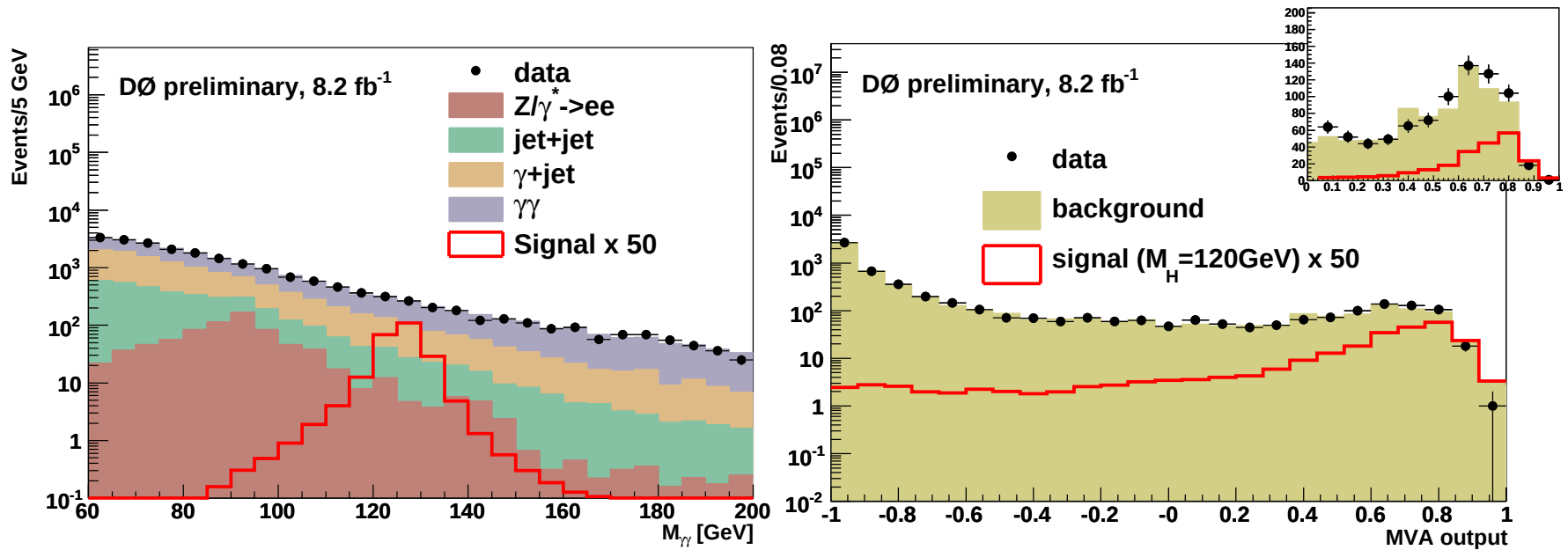


Higgs at Low Mass: $H \rightarrow \gamma\gamma$ (DØ)

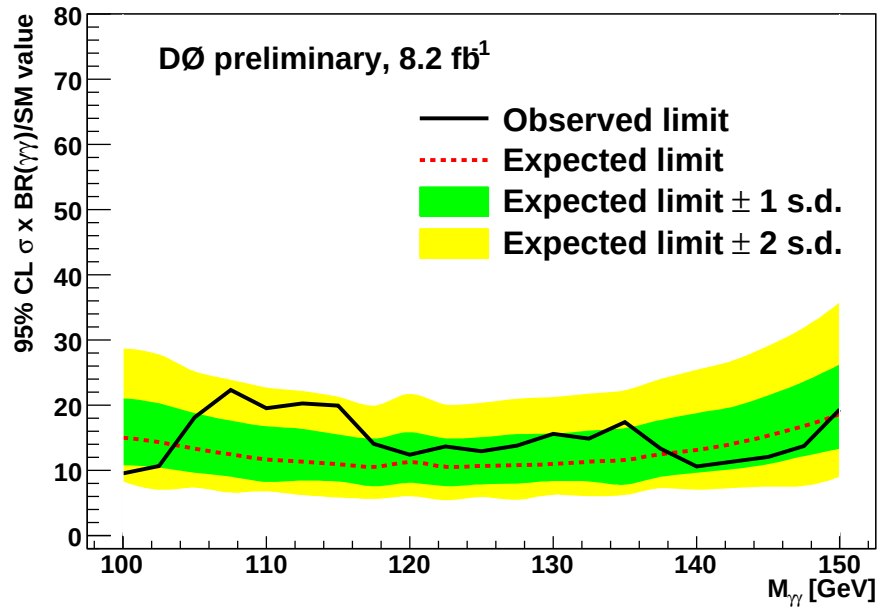
– Background sources:

- * γ +jet, di-jet $\rightarrow$ data
- * Z/γ^* , $\gamma\gamma \rightarrow$ MC

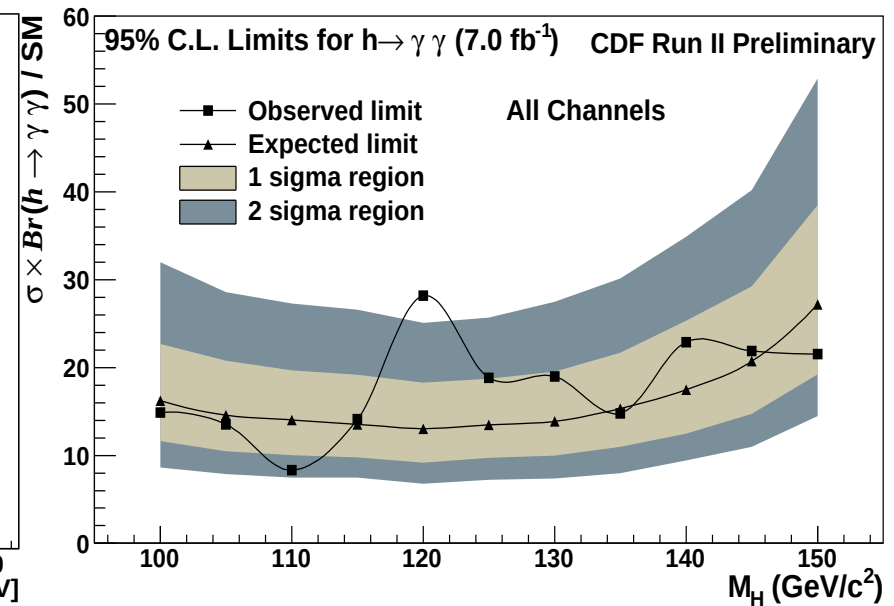
$\Rightarrow$ Decision trees



H $\rightarrow \gamma\gamma$ Results



DØ at $m_H = 115$ GeV:
 limit/SM 19.9 (11.0 exp.)



CDF at $m_H = 115$ GeV:
 limit/SM 14.1 (13.5 exp.)

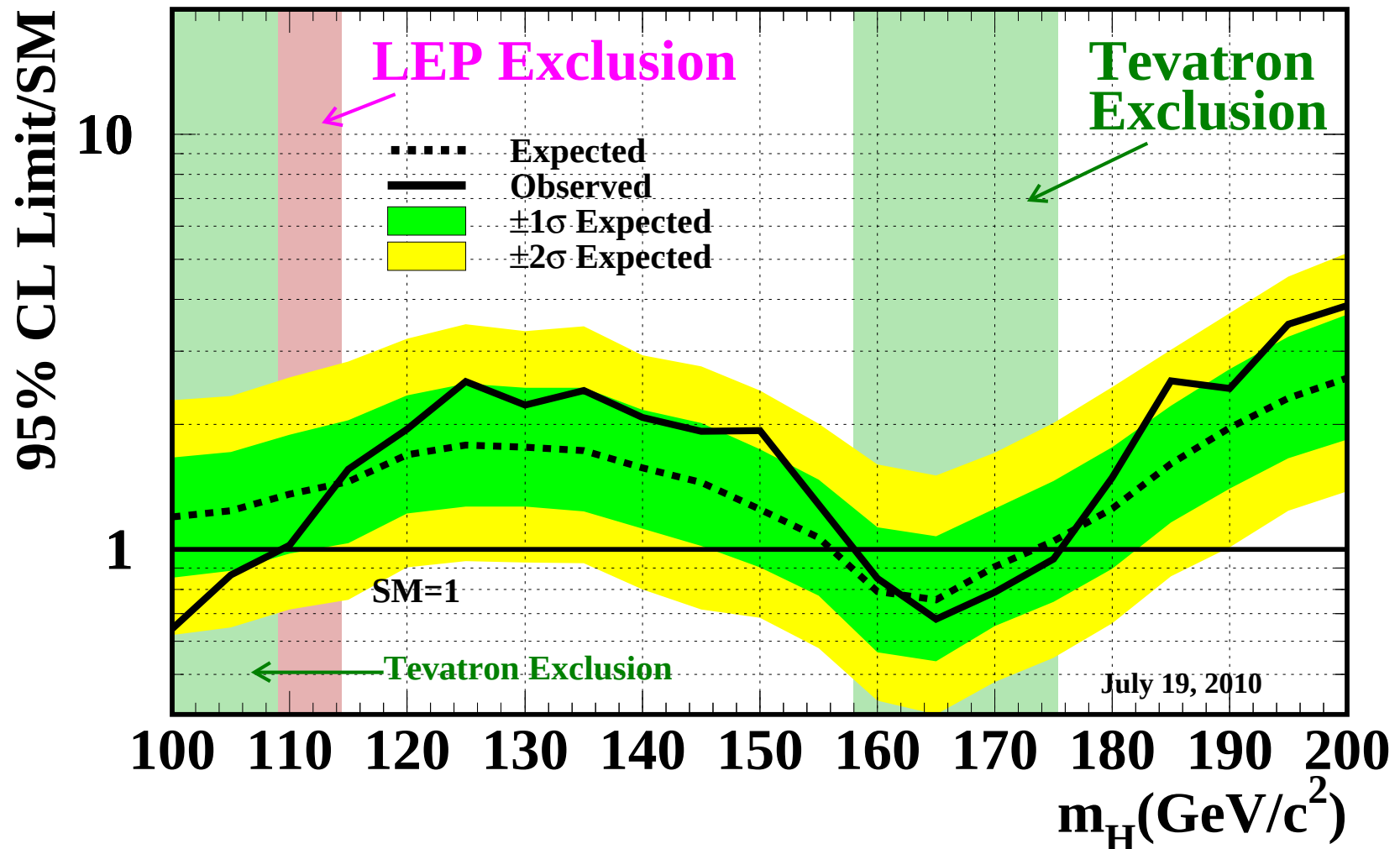
Higgs at Low Mass: Summary

For $m_H = 115$ GeV

	DØ		CDF	
	$\int \mathcal{L} dt$	limit (exp.)	$\int \mathcal{L} dt$	limit (exp.)
$WH \rightarrow \ell \nu b \bar{b}$	5.3	4.5 (4.8)	5.7	4.5 (3.5)
$ZH \rightarrow \ell \ell b \bar{b}$	6.2	8.0 (5.7)	5.7	6.5 (6.0)
$ZH \rightarrow \nu \nu b \bar{b}$	6.2	3.4 (4.0)	5.7	2.3 (4.0)
$H \rightarrow \tau \tau$	5.4	32.8 (12.8)	6.0	14.7 (15.2)
$H \rightarrow \gamma \gamma$	8.2	19.9 (11.0)	7.0	14.1 (13.5)

(Old) Combined Tevatron Limit

Tevatron Run II Preliminary, $\langle L \rangle = 5.9 \text{ fb}^{-1}$

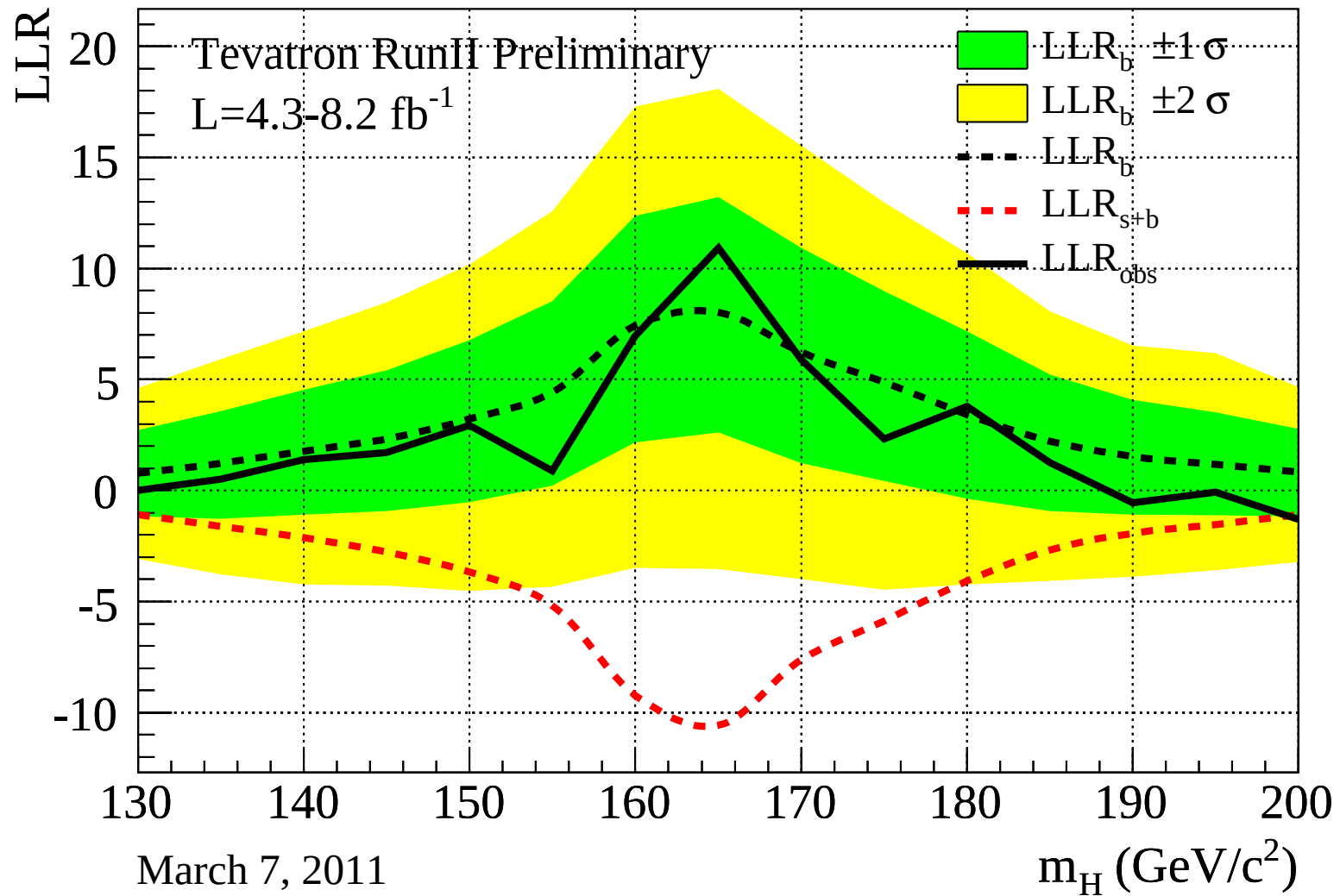


At $m_H = 115 \text{ GeV}$: limit/SM 1.6 (1.5 expected)

Conclusion

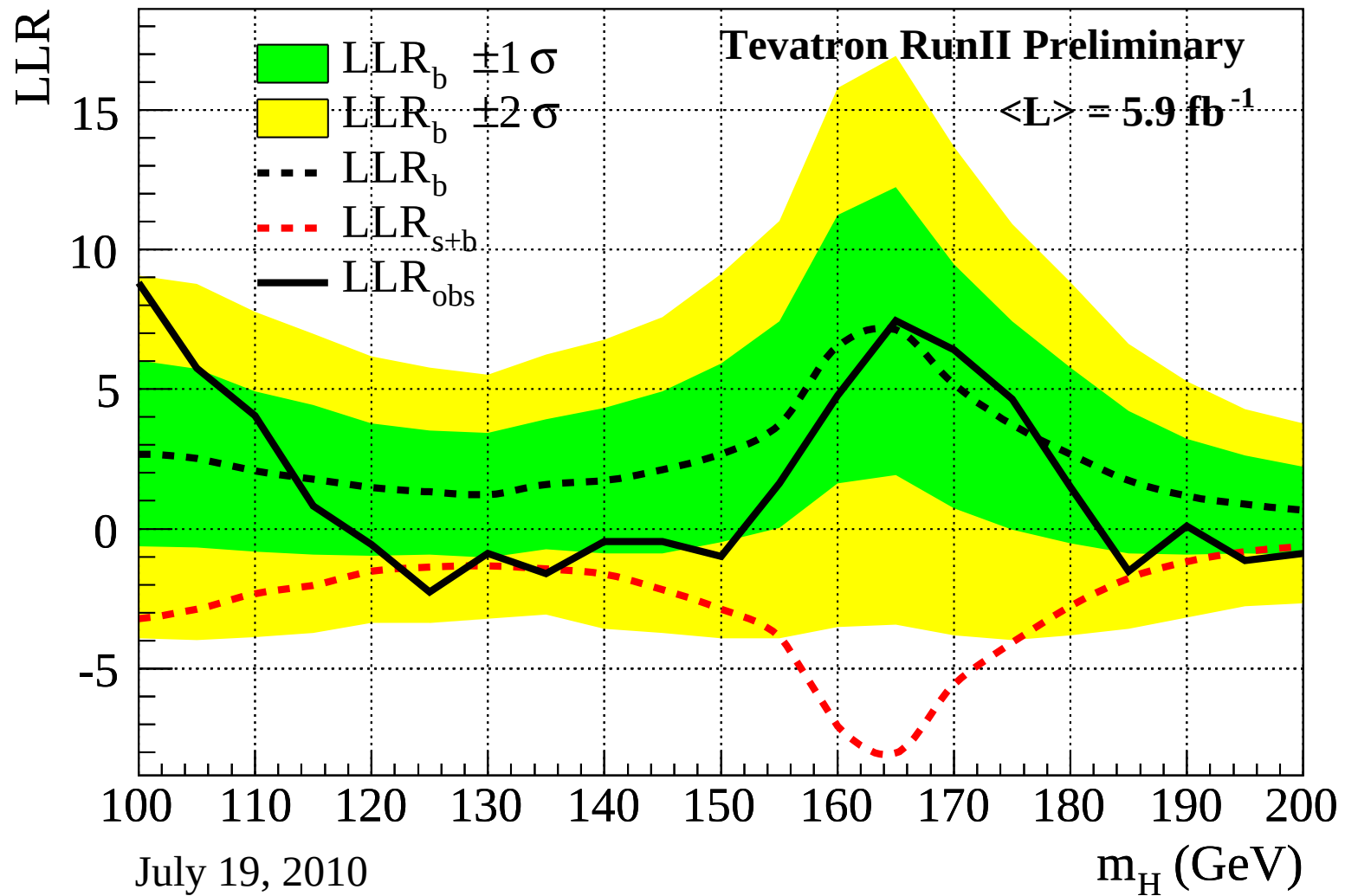
- Need a Higgs boson, or something like it
- Not found yet
- Tevatron will run a few more months
- Keep looking. . .

Combined Tevatron LLR



arXiv:1103.xxxx [hep-ex]

Combined Tevatron LLR



arXiv:1007.4587 [hep-ex]