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 !

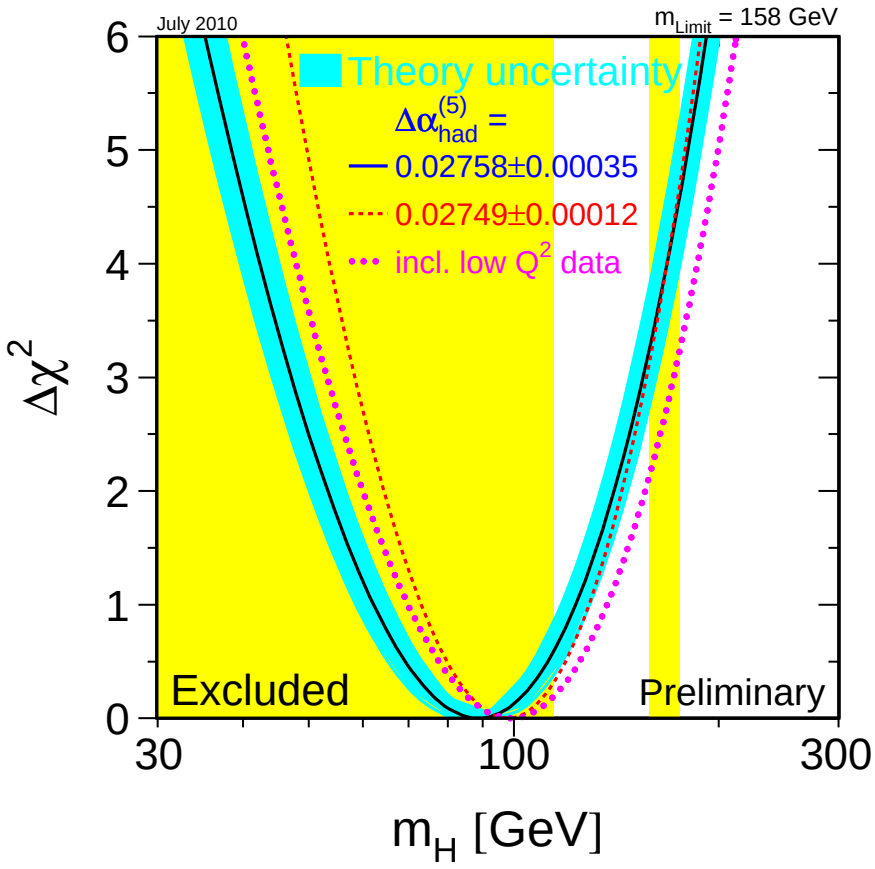
– Higgs mechanism to break electroweak symmetry

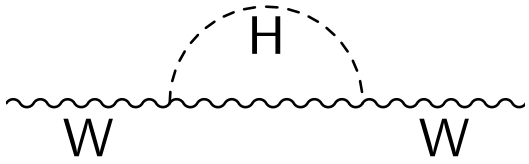
  * Massive W and Z bosons, massless photon
  * Massive quarks and leptons
  * New massive particle: Higgs boson

$\Rightarrow$ Where is the Higgs boson ?

What Do We Know?

Precision EW measurements at Tevatron, LEP and SLD





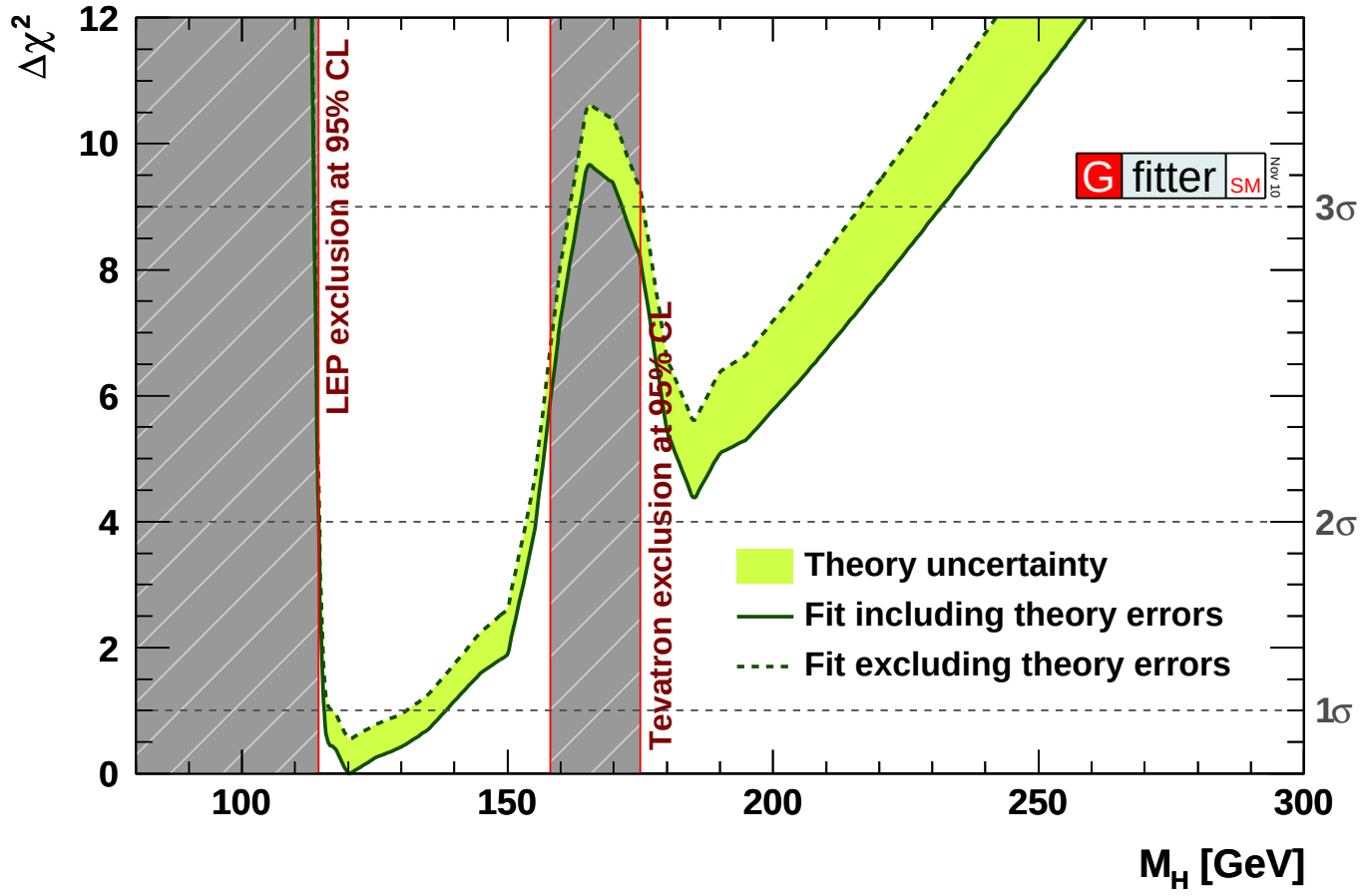
$m_{\mathrm{H}} = 89^{+35}_{-26}$ GeV

$m_{\mathrm{H}} < 158$ GeV at 95% CL

LEP2 direct search: $m_{\mathrm{H}} > 114$ GeV ($m_{\mathrm{H}} < 185$ GeV)

What Do We Know?

Include direct Higgs search results from LEP and Tevatron

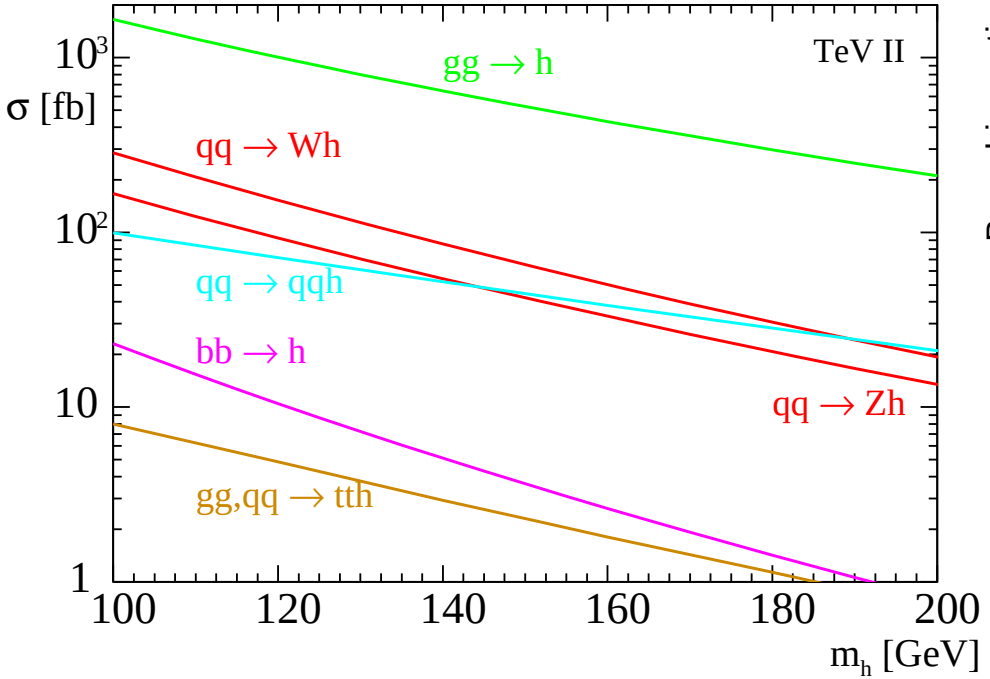


$$m_{\mathrm{H}} = 120.6^{+17.9}_{-5.2}\ \mathrm{GeV}$$

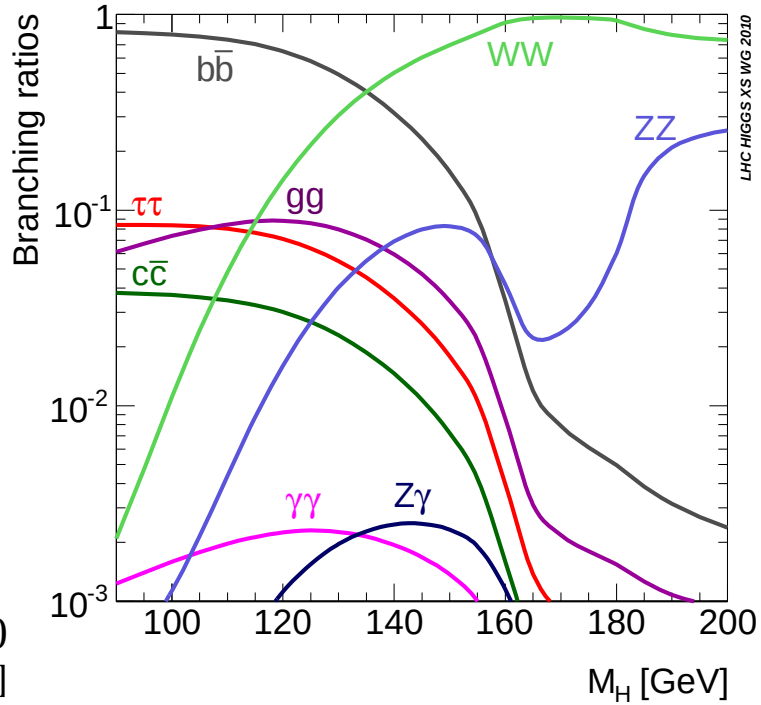
Higgs @ Tevatron

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

Higgs production

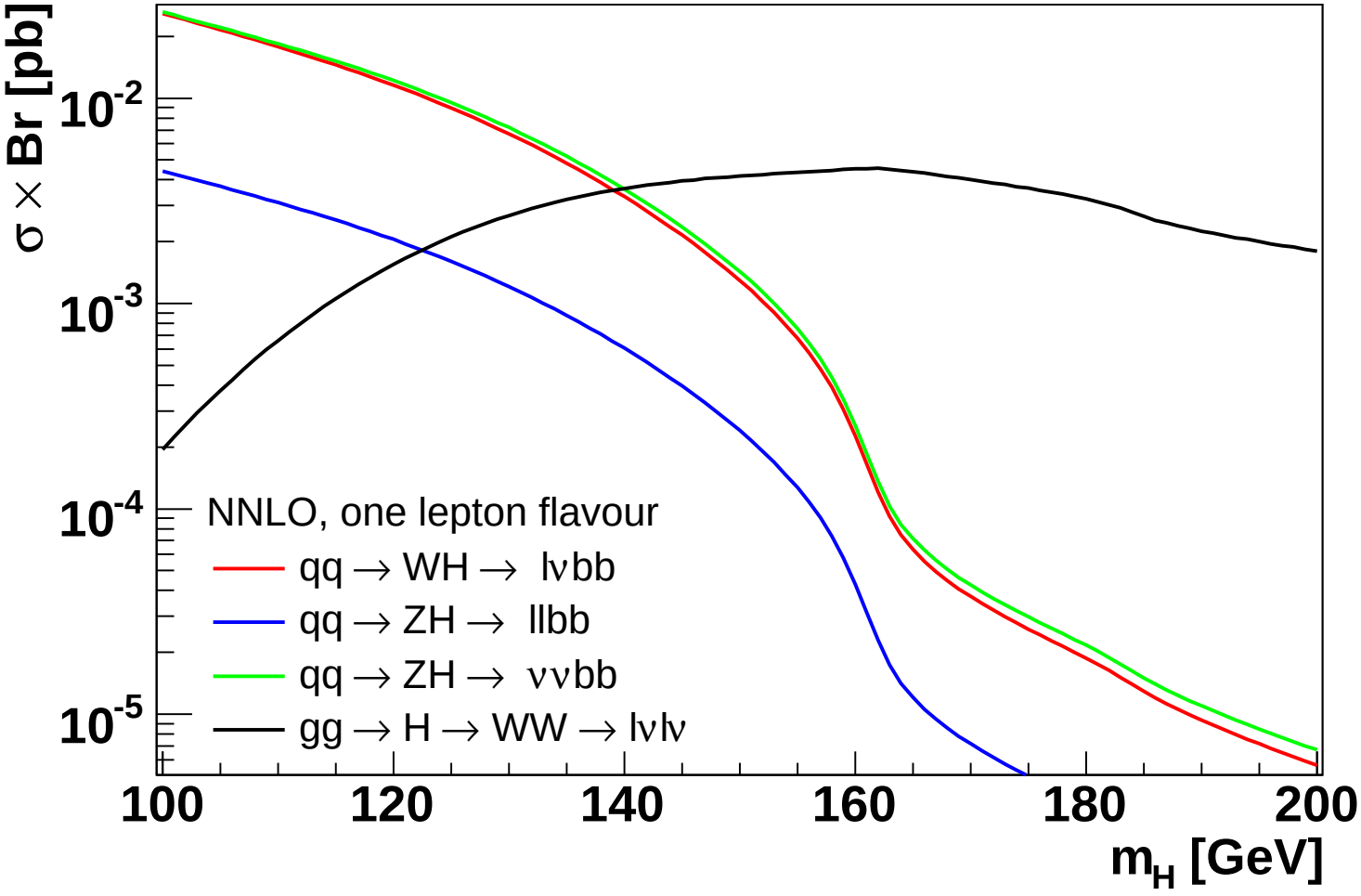


Higgs decay



- Gluon fusion
- Associated production
- $b\bar{b}$ at low m_H
- WW at high m_H

Higgs @ Tevatron



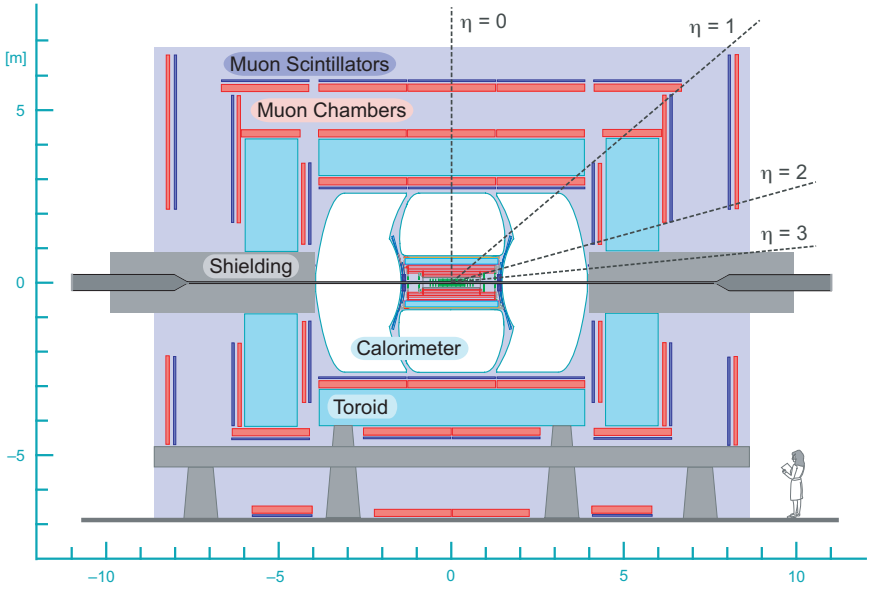
WH, ZH with H $\to$ b$\bar{\text{b}}$ at low m_{H}

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

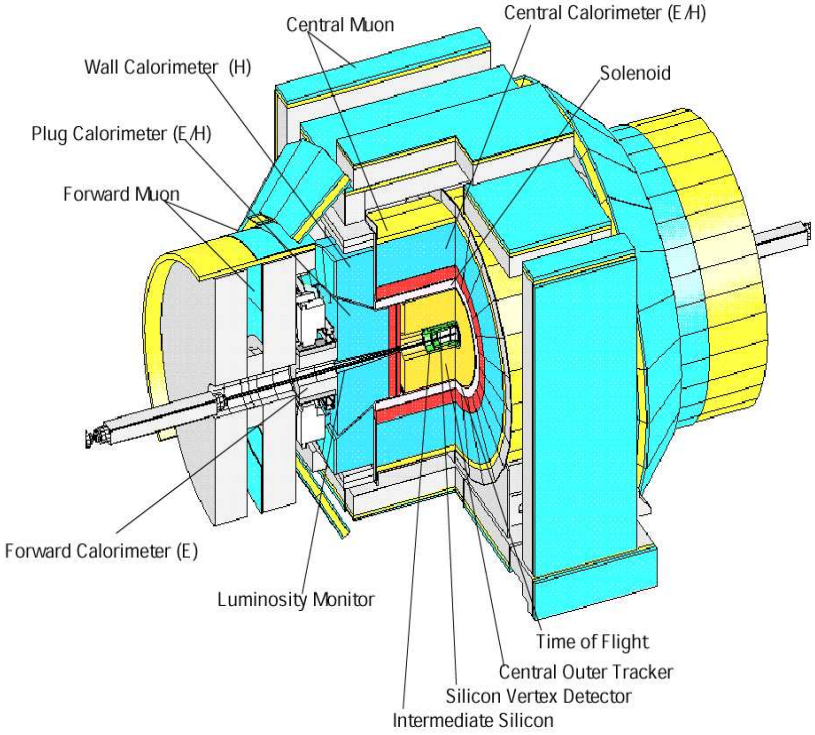
Tevatron

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

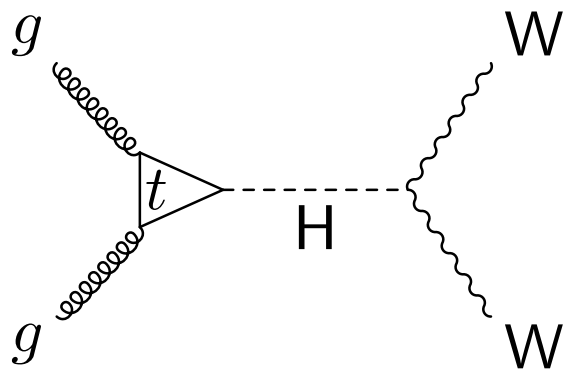
DØ



CDF

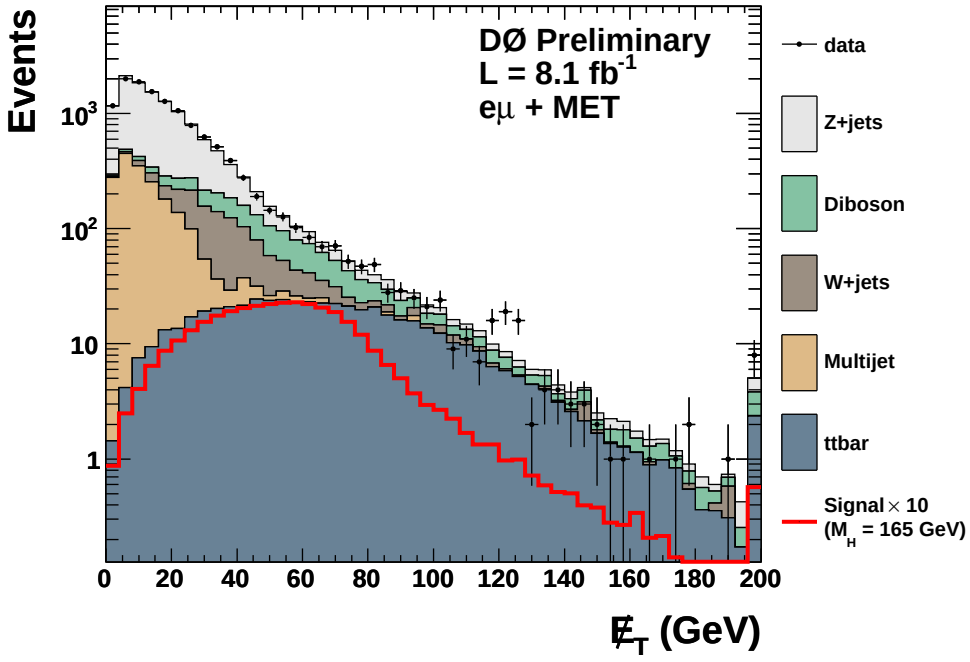


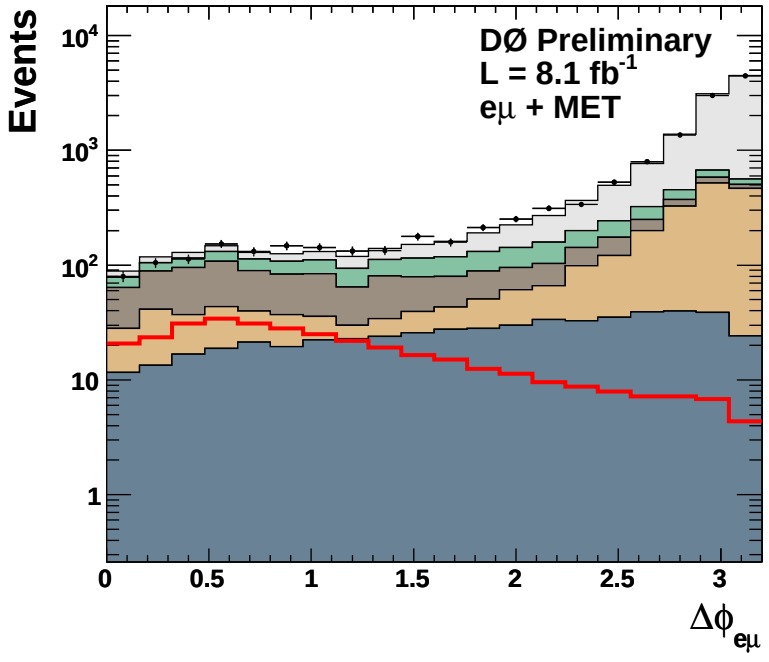
Higgs at High Mass: H $\rightarrow$ WW



- 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 $\not{E}_T$
- 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 → WW (DØ)



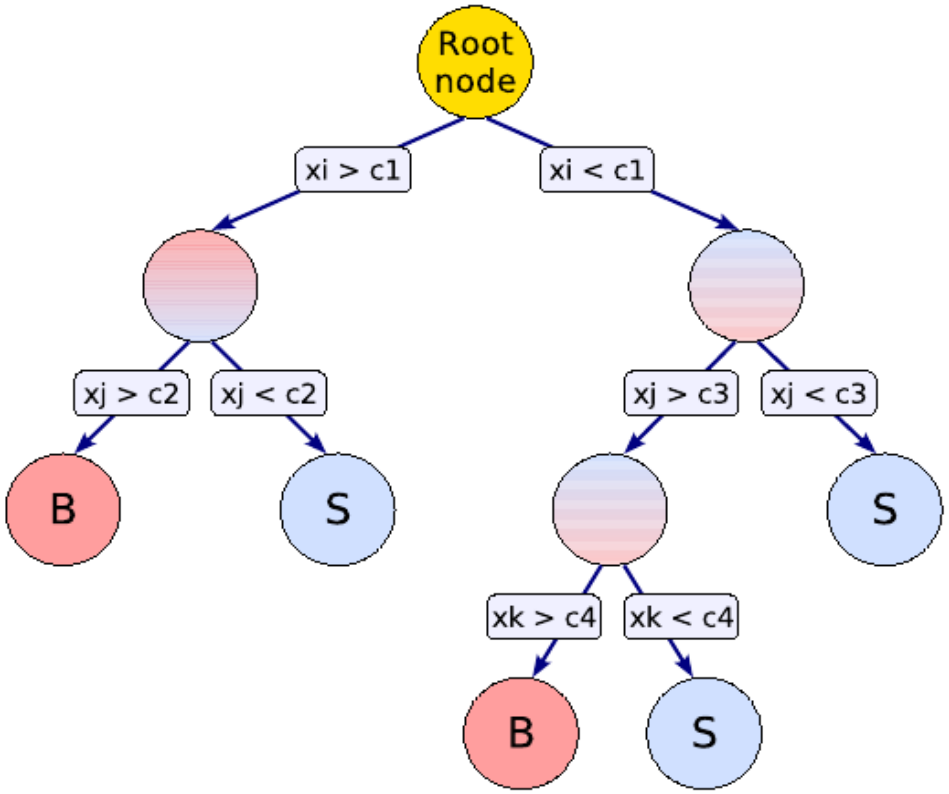


- Inclusive triggering
- $p_{\mathrm{T}}(\ell_1) > 15$ GeV, $p_{\mathrm{T}}(\ell_2) > 10$ GeV; no $\not\!\!E_{\mathrm{T}}$ cut (ee, $\mu\mu$)
- W + jets/γ corrected using number of hits in Layer 0
- Use multi-staged "random forests"

Advanced Technique: Random Forest

– Decision tree: recursively cut on kinematic variables

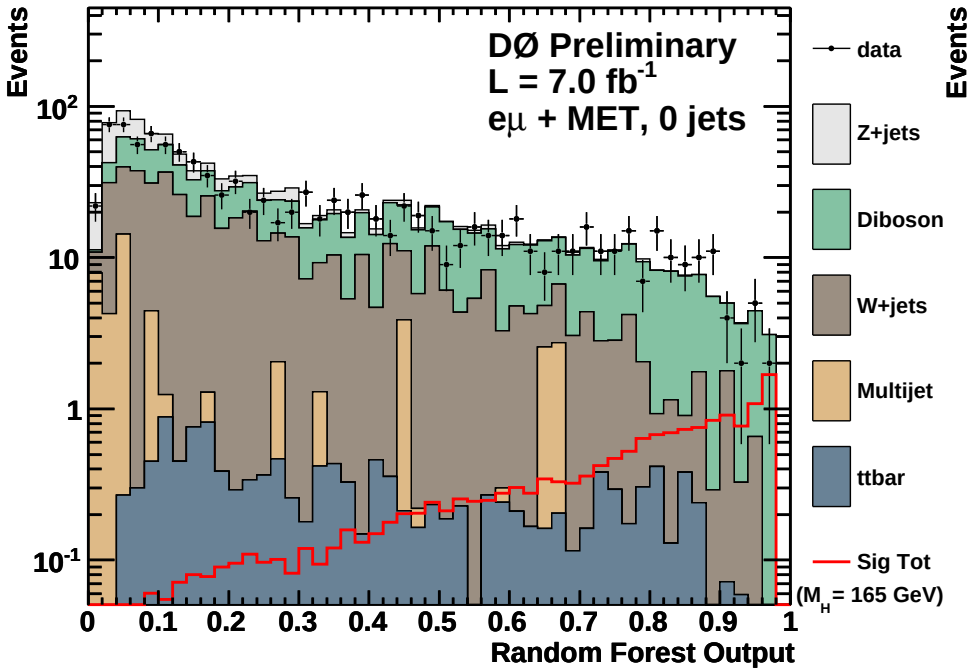
– Random forest: trees with random subsets of variables



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

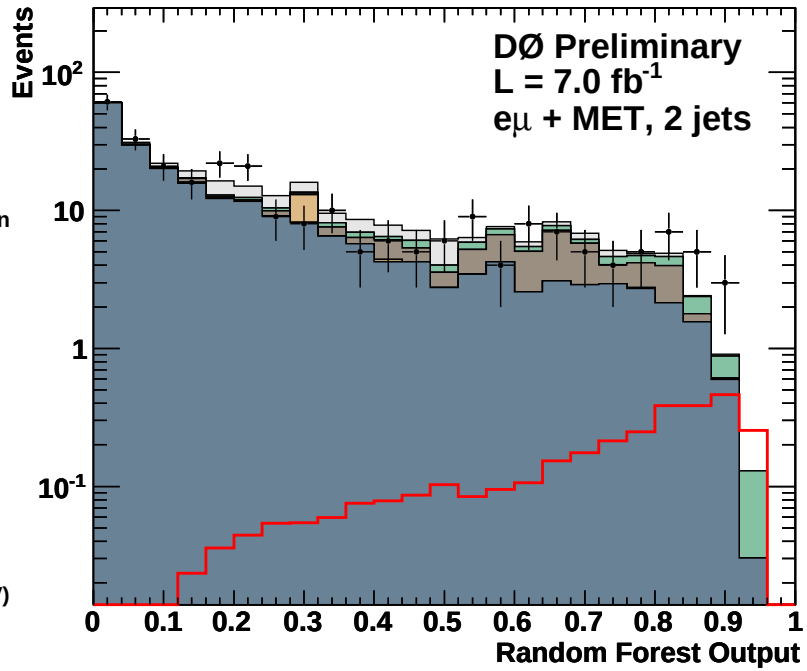
– Background and signal vary with number of jets

$\Rightarrow$ Analyze in jet-multiplicity bins



Data: 1074, Bg: 1163.5

Higgs: 16.0 events

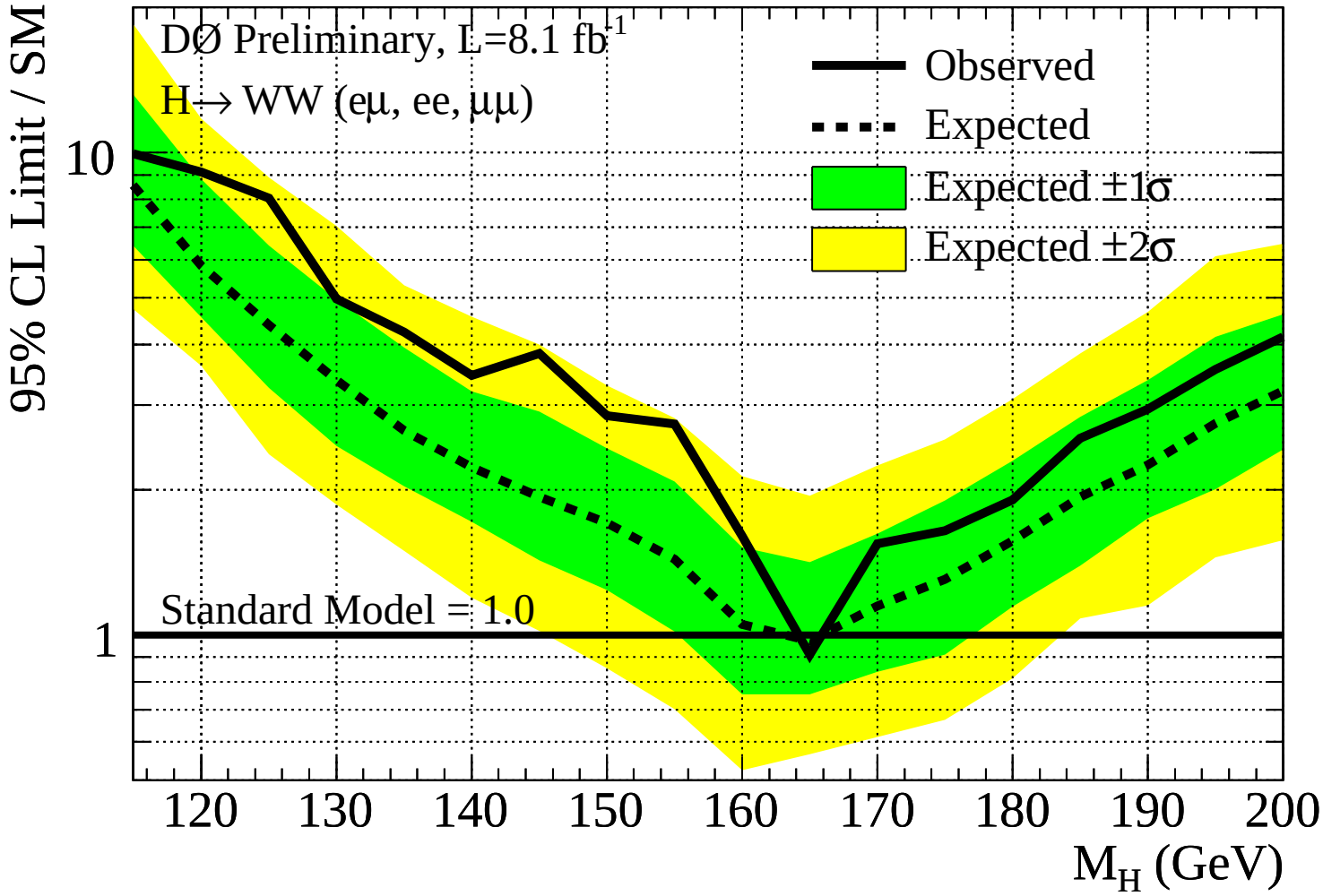


Data: 280, Bg: 285.7

Higgs: 3.2 events

$H \rightarrow WW$ Results (DØ)

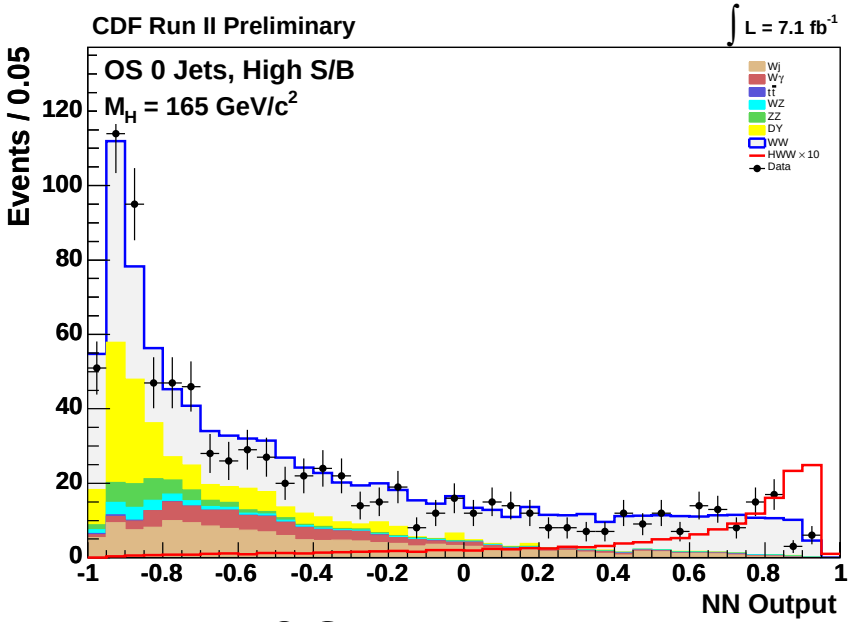
Include di-leptonic WH/ZH events



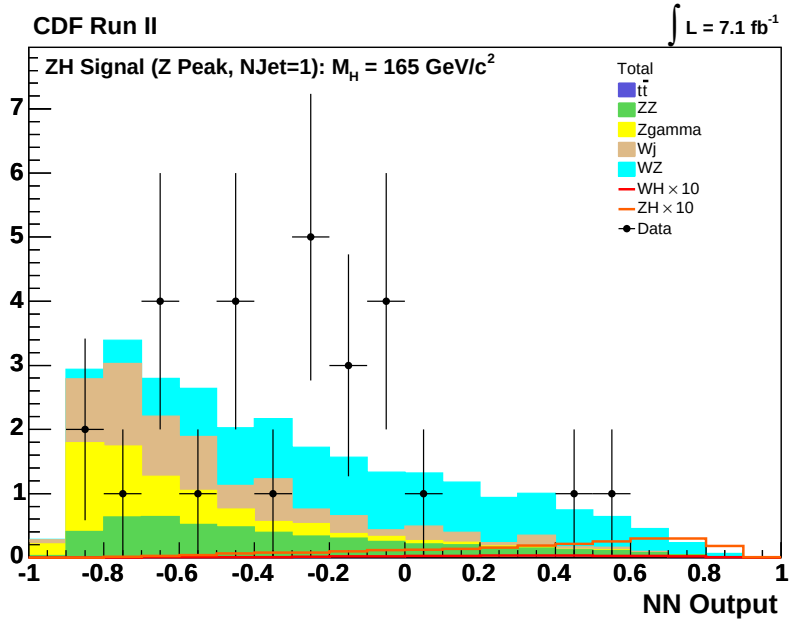
$\Rightarrow$ Exclude $m_H = 165$ GeV

Higgs at High Mass: $H \to WW$ (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



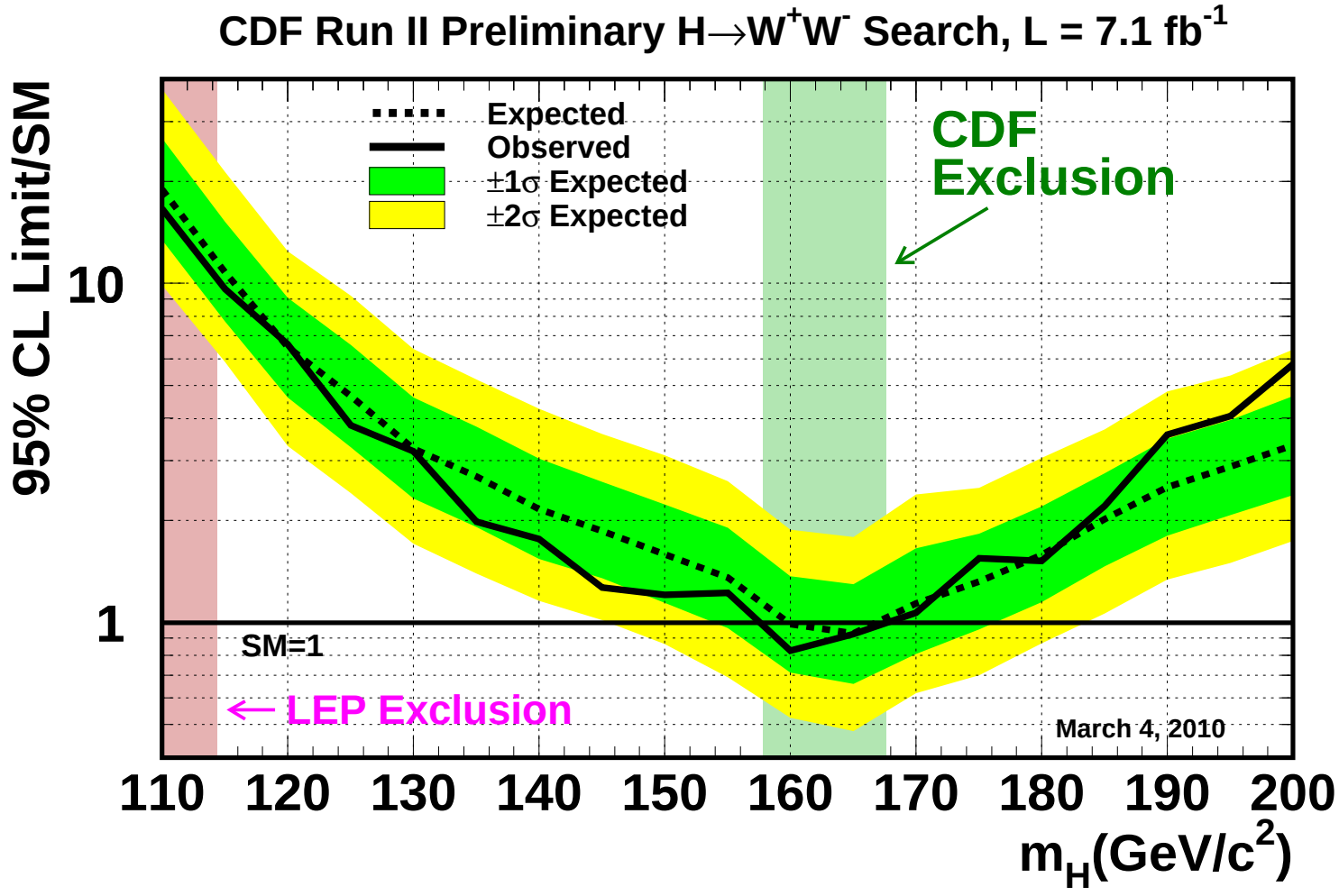
OS, zero-jet



Tri-lepton, one-jet

$H \to WW$ Results (CDF)

Combine 12 channels (including τ_{had})

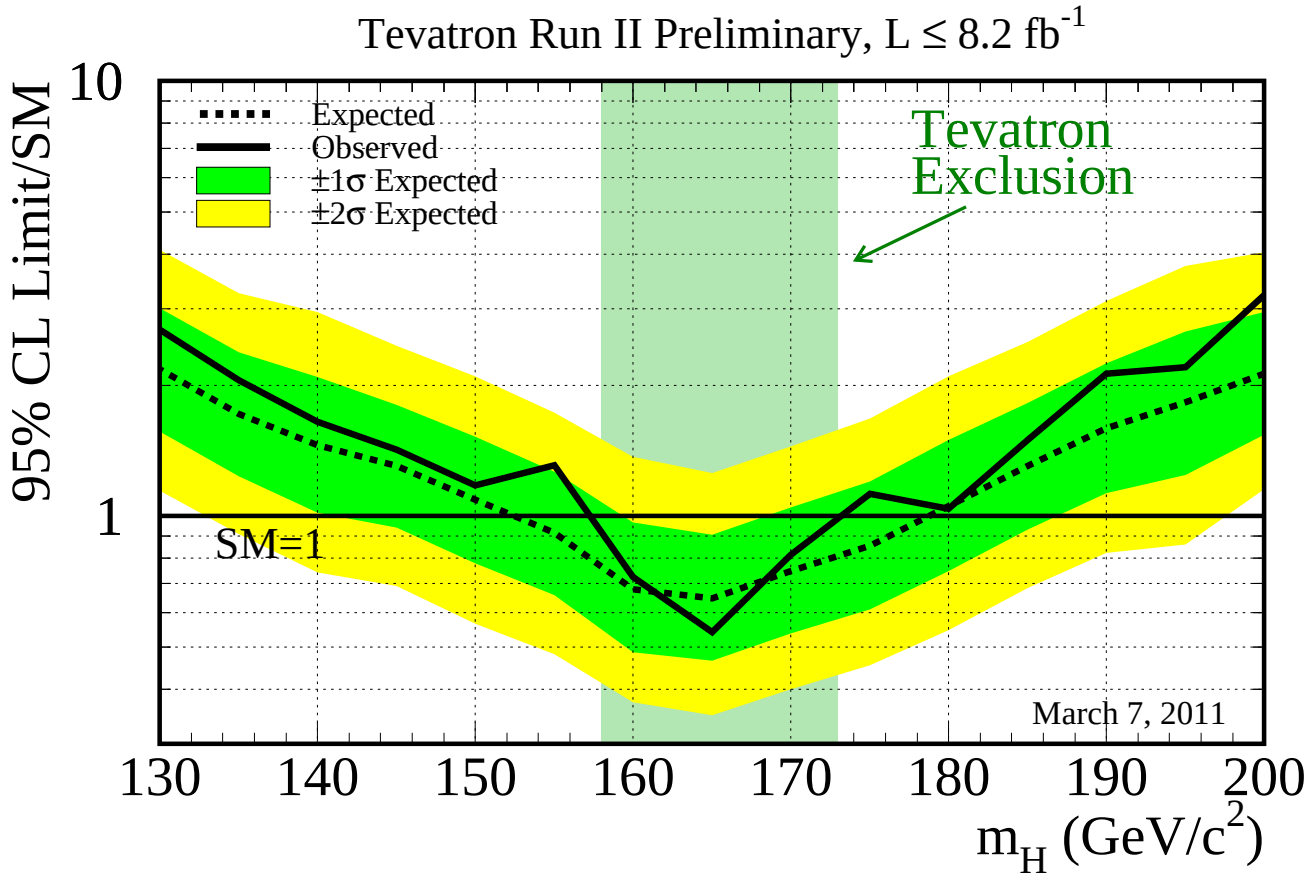


$\Rightarrow$ Exclude $158 < m_H < 168$ GeV

Higgs at High Mass: Combined Tevatron Limit

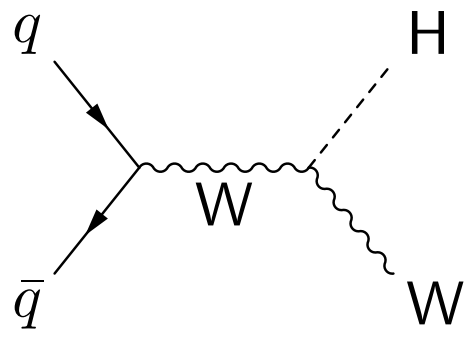
– H $\rightarrow$ WW, $\tau\tau$, $\gamma\gamma$, latest $\sigma(gg \rightarrow \mathrm{H})$

– Correlated and uncorrelated systematics



$\Rightarrow$ Exclude $158 < m_{\mathrm{H}} < 173$ GeV

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

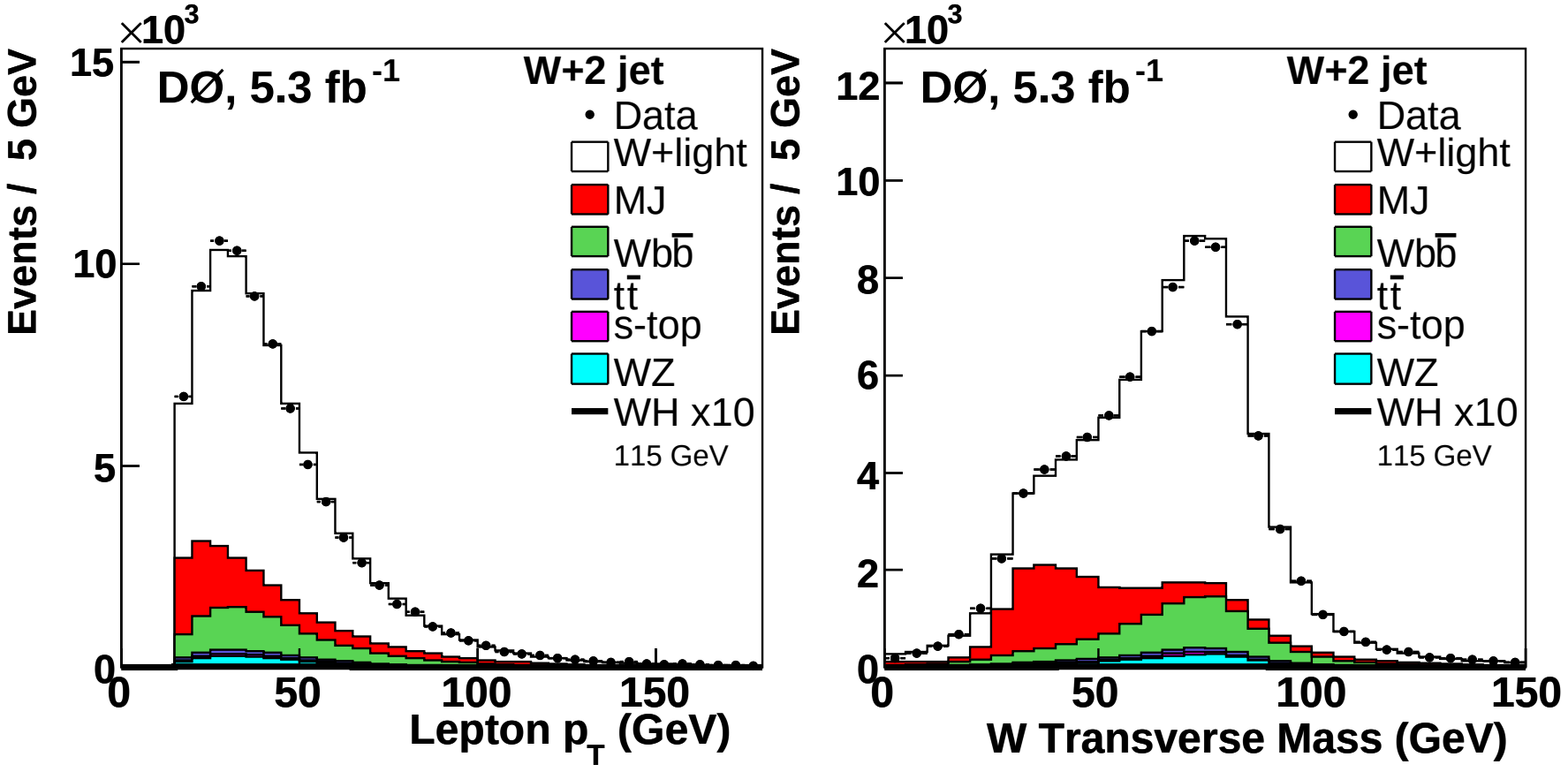


- Decays of W: high p_T lepton and $\not\!\!E_T$
- H $\rightarrow$ b$\bar{\text{b}}$: at least two jets
- Background sources:
  - W with additional jets (including Wb$\bar{\text{b}}$) $\rightarrow$ MC/data
  - t$\bar{\text{t}}$, single top $\rightarrow$ MC
  - Multi-jet production with mis-ID of lepton and $\not\!\!E_T$ $\rightarrow$ data
  - Di-boson (WW, WZ, ZZ) $\rightarrow$ MC

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

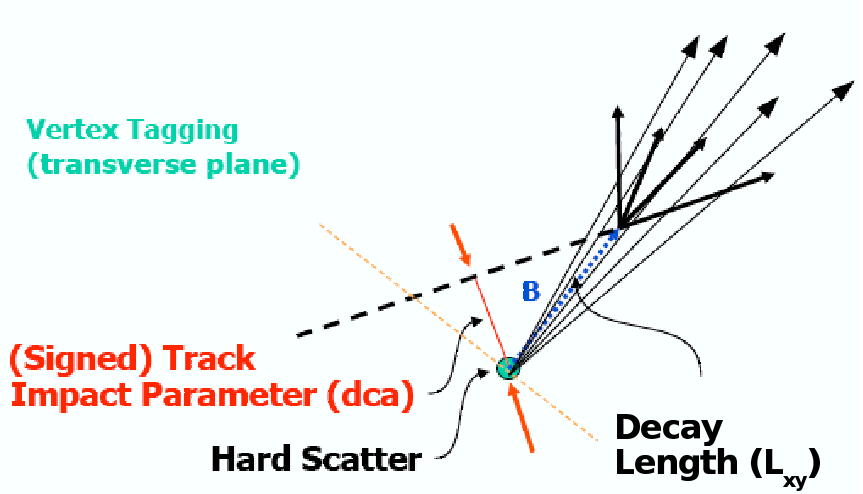
– Signature: one isolated lepton, large $\not\!\!E_T$

– Consistent with W decay



b-Tagging

Exploit b-lifetime:



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

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

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

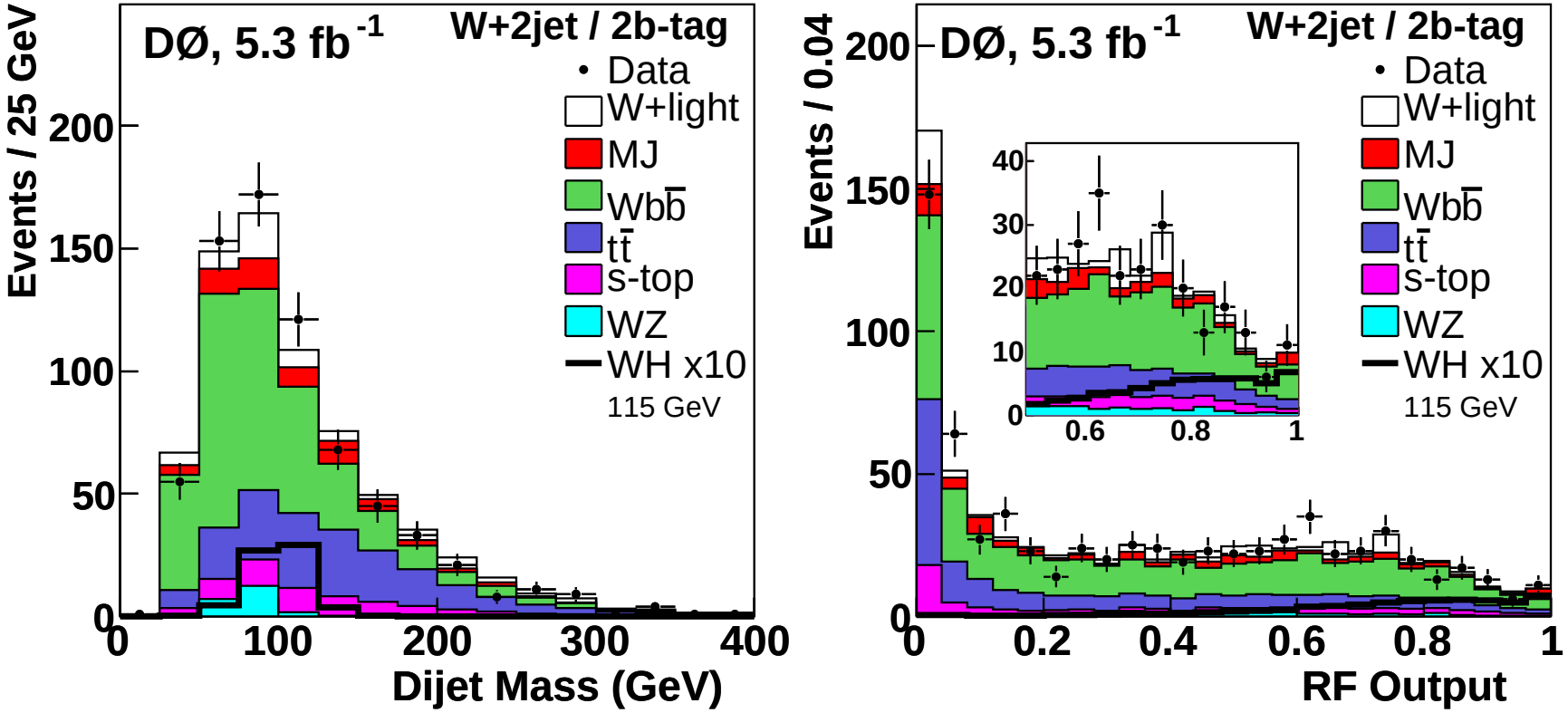
  * "Tight": 53% at 0.9% fake rate (DØ neural net tagger)
  * "Loose": 63% at 2.7% fake rate (DØ neural net tagger)

– Used also as anti-top tagger

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

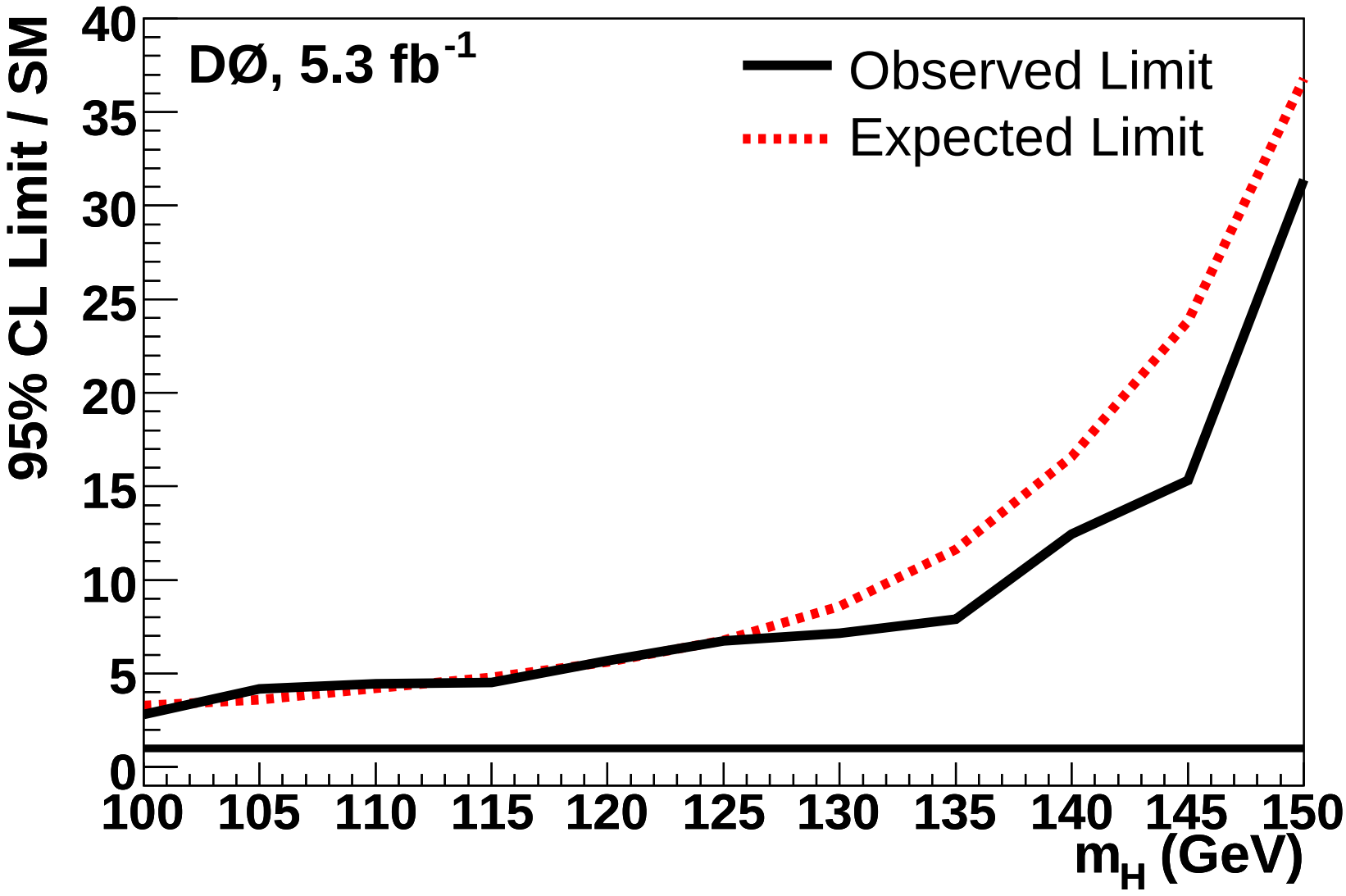
– Use "random forests" against background

$\Rightarrow$ Gain 20% in sensitivity



Data: 709, Bg: 718, WH ($m_{\mathrm{H}} = 115$ GeV): 6.5 events

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



At $m_{\mathrm{H}} = 115$ GeV: limit/SM 4.5 (4.8 expected)

Advanced Technique: Matrix Element

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

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

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

– $\vec{x}, \vec{y}$: event kinematics

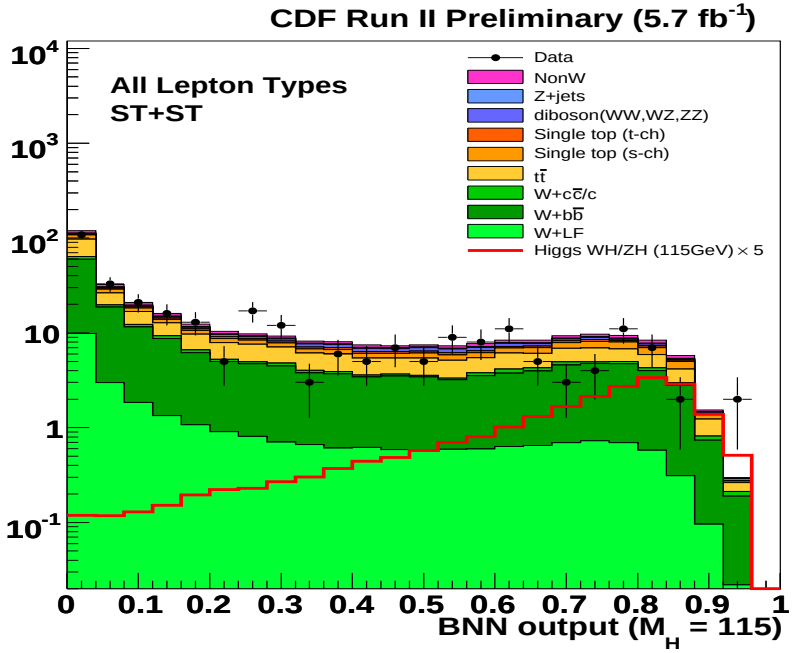
ϵ: acceptance×efficiency

G: resolution function

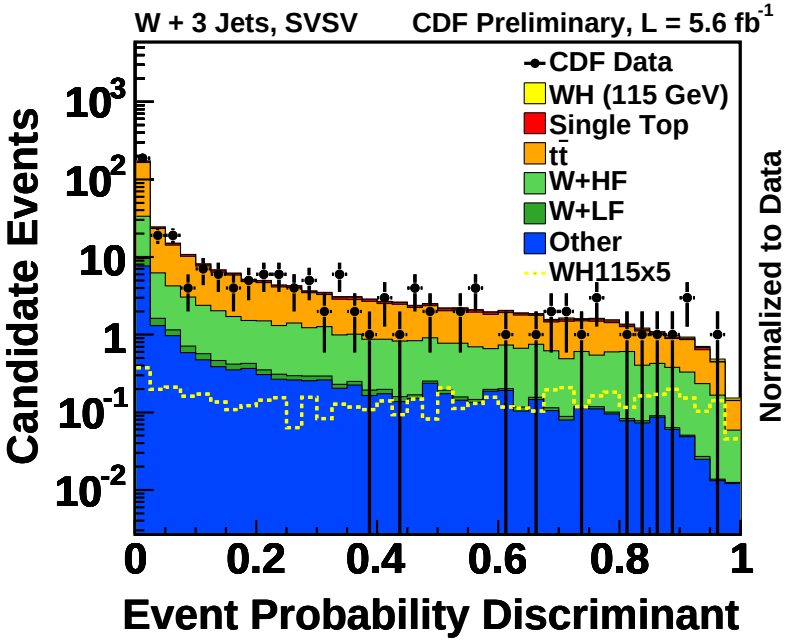
Higgs at Low Mass: WH $\rightarrow \ell\nu b\bar{b}$ (CDF)

- 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

Two-jet

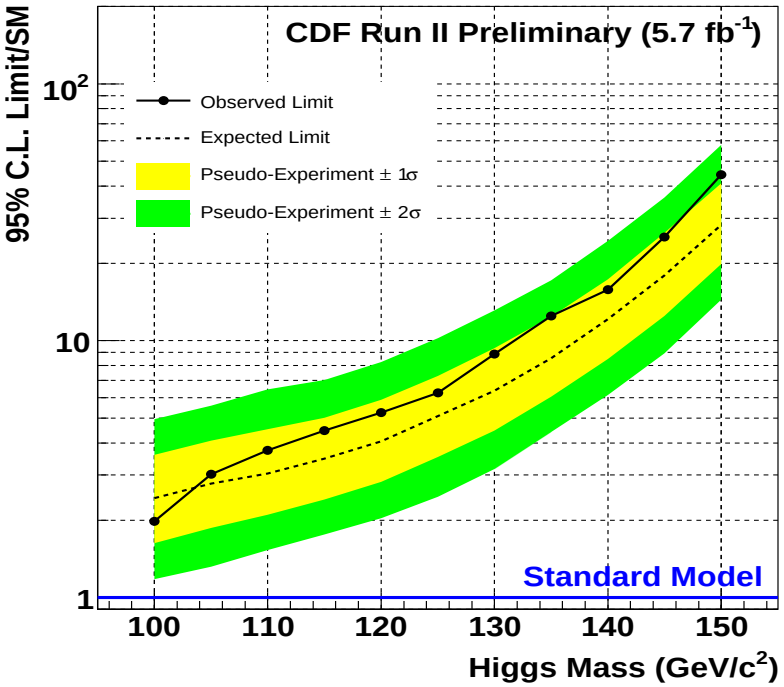


Three-jet



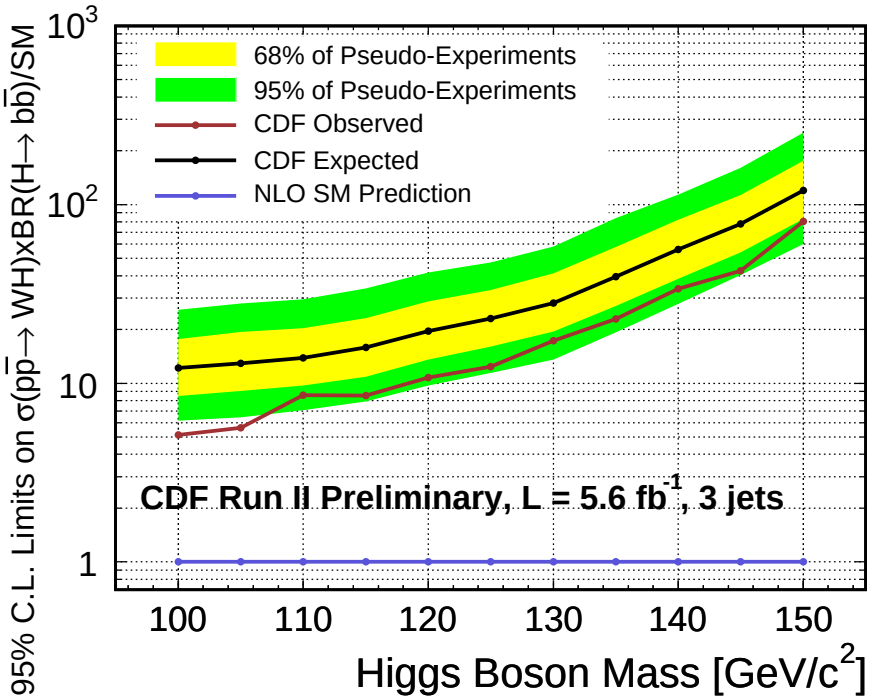
$WH \to \ell\nu b\bar{b}$ Results (CDF)

Two-jet



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

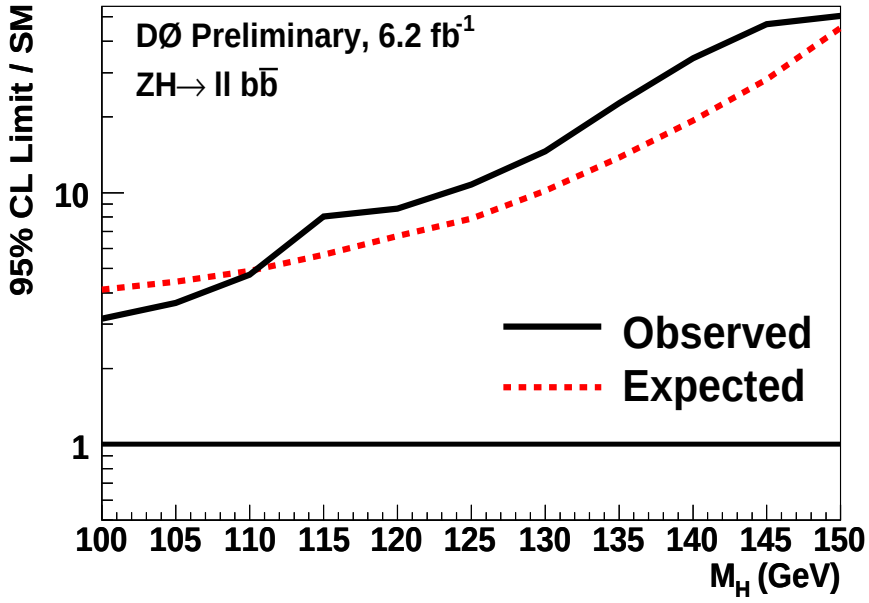
Three-jet

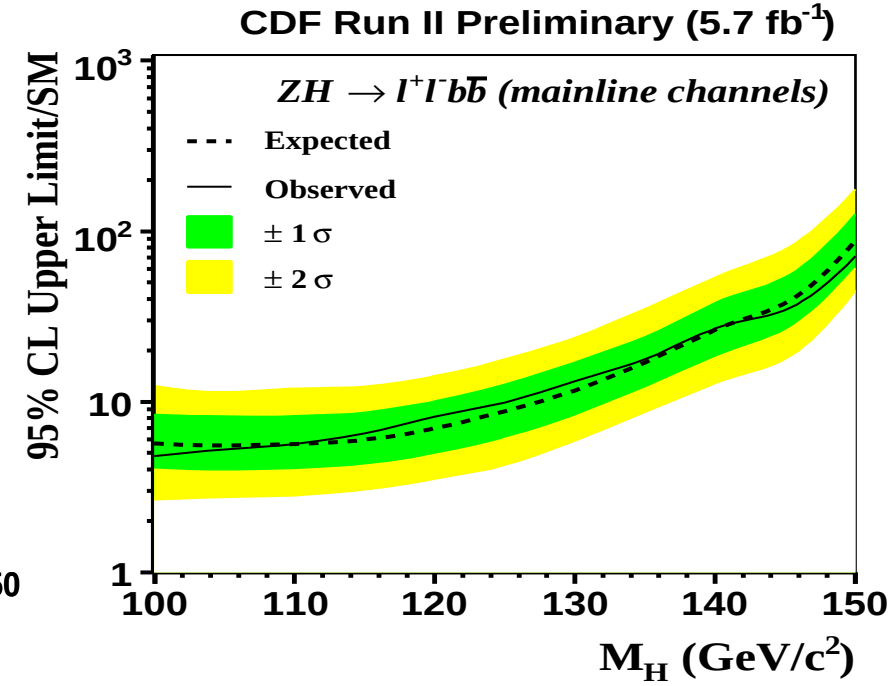


At $m_H = 115$ GeV:
limit/SM 8.5 (15.8 exp.)

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

Two leptons, at least two jets, b-tags



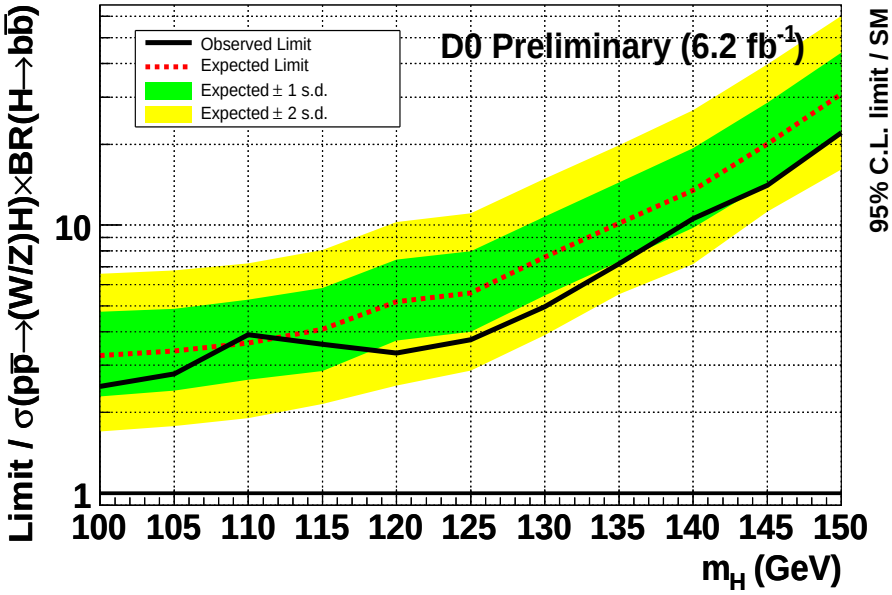


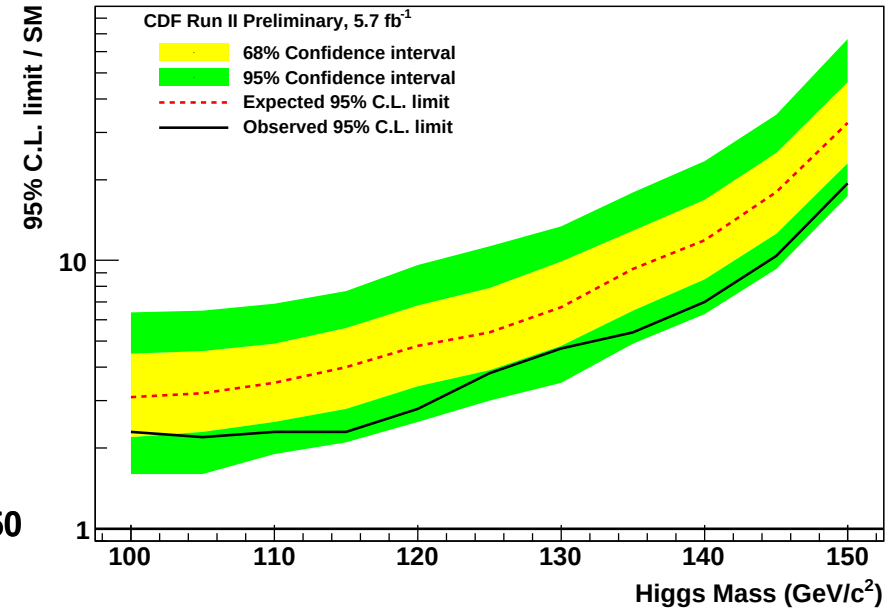
DØ at $m_{\mathrm{H}} = 115$ GeV:
limit/SM 8.0 (5.7 exp.)

CDF at $m_{\mathrm{H}} = 115$ GeV:
limit/SM 6.5 (6.0 exp.)

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

No leptons, large $\not\!\!E_T$, at least two jets, b-tags

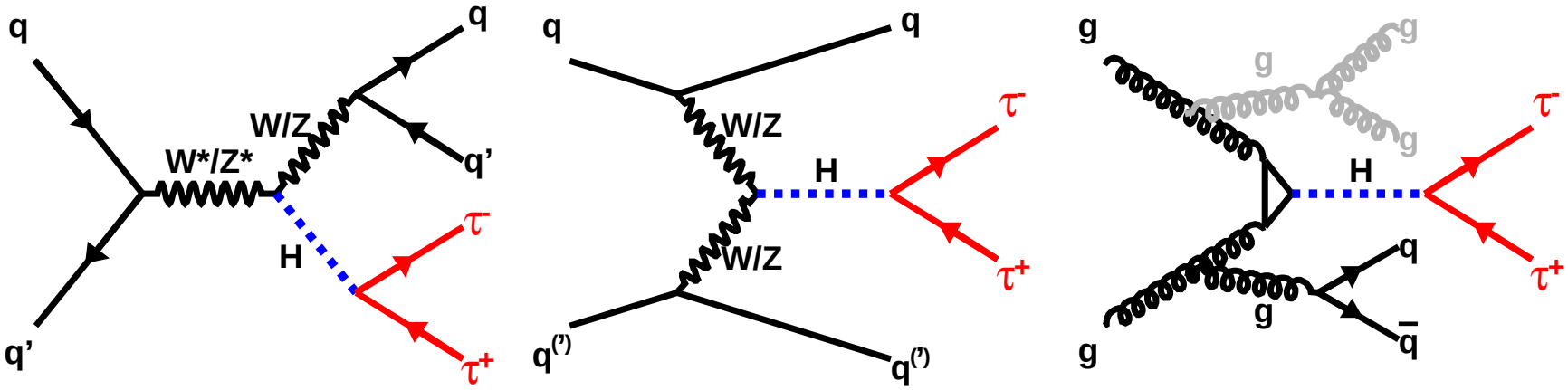




DØ at $m_H = 115$ GeV:
limit/SM 3.4 (4.0 exp.)

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

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



– Br(H $\to \tau\tau$) $\simeq 10\%$ of Br(H $\to b\bar{b}$)

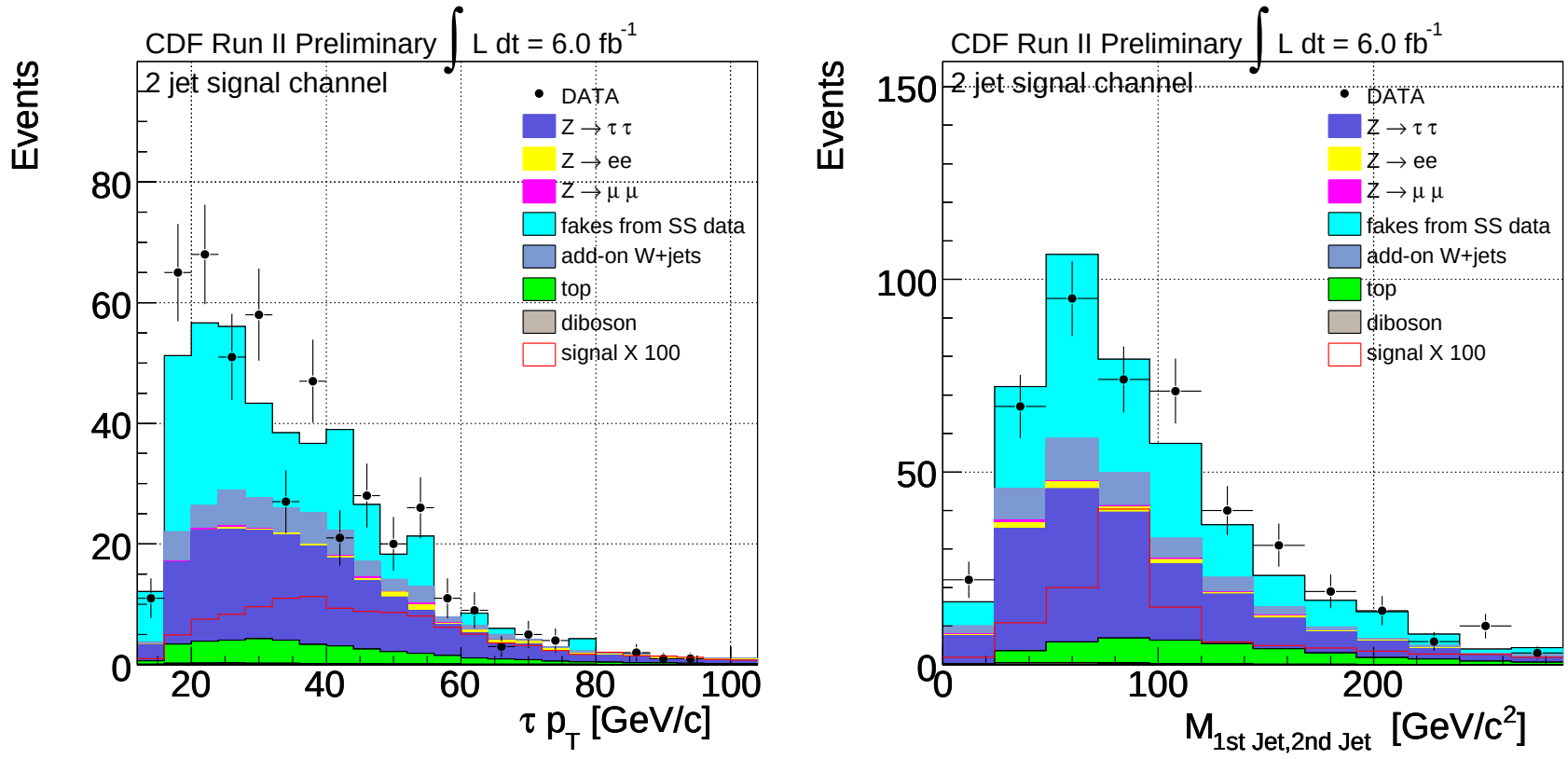
– Final state: $\tau(\to \ell X)\,\tau(\to$ hadrons$) +$ one or $\geq$ two jets

– Background sources:

  * Multi-jet, γ+jet, W+jet $\to$ data
  * $Z/\gamma^*, t\bar{t} \to$ MC

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

– Identify $\tau \to$ hadrons using decision trees



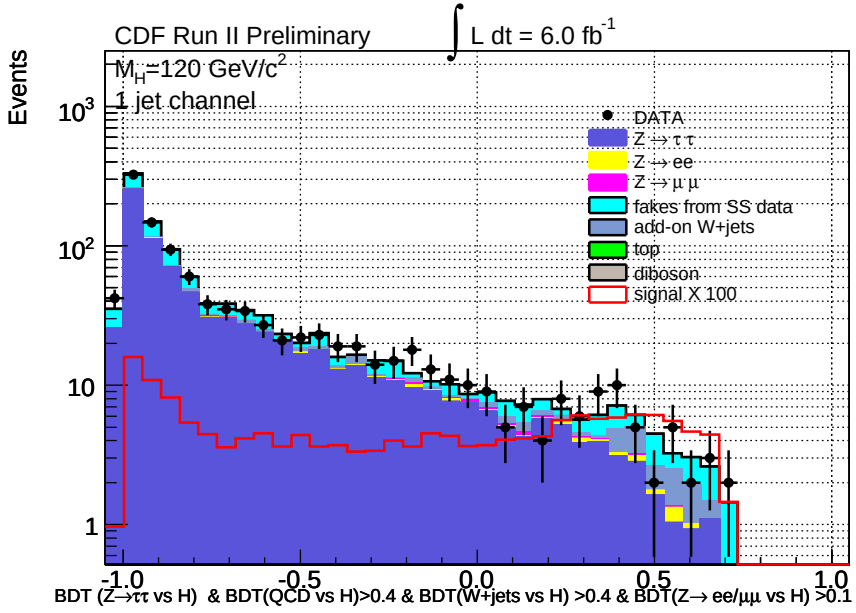
Data: 462, Bg: 427.9

Higgs ($m_{\mathrm{H}} = 120$ GeV): 1.23 events

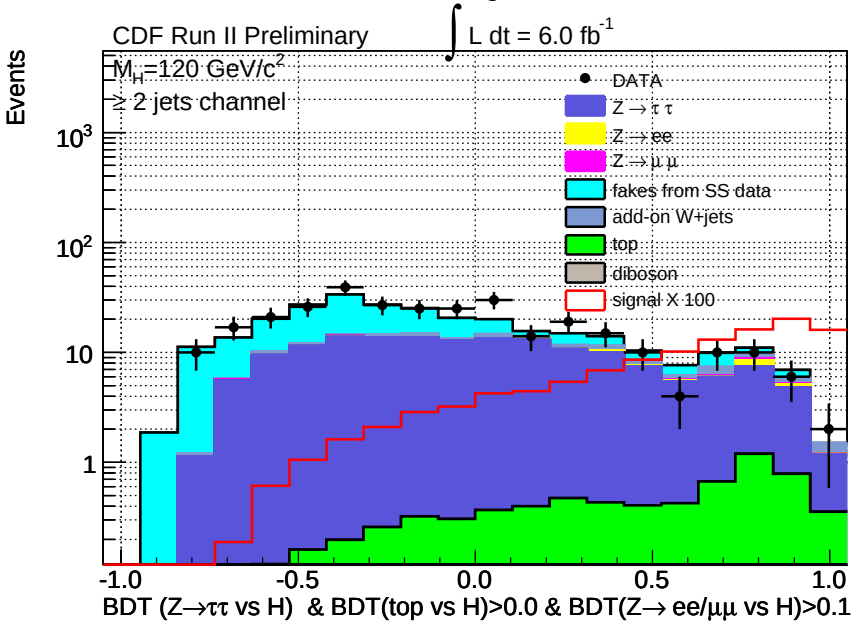
Higgs at Low Mass: $H \to \tau\tau$ (CDF)

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

One-jet



$\geq$ Two-jet

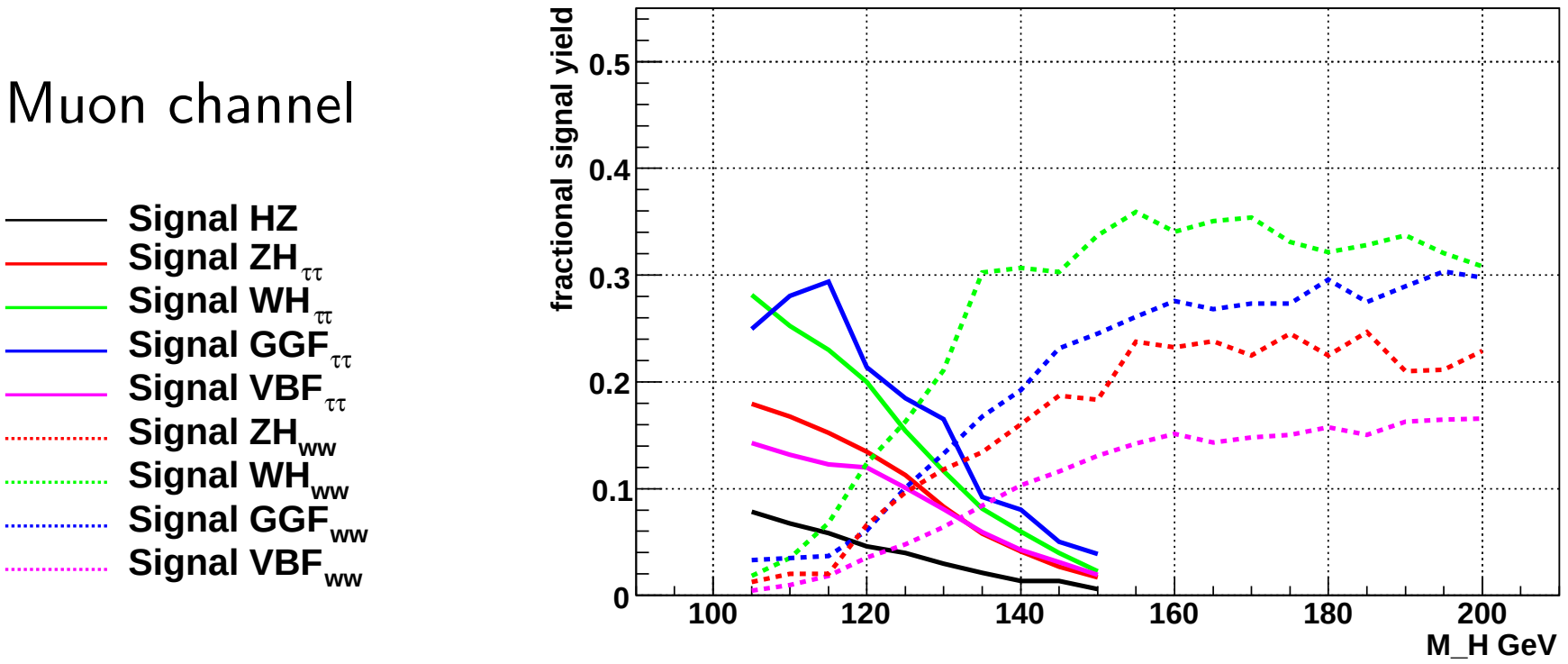


Higgs at Low Mass: H $\to \tau\tau$ (DØ)

– Final state: $e/\mu + \tau_{had} + \geq$ two jets

  * WH, ZH, WBF, gluon fusion
  * H $\to \tau\tau$, H $\to$ WW
  * ZH $\to \tau\tau b\bar{b}$

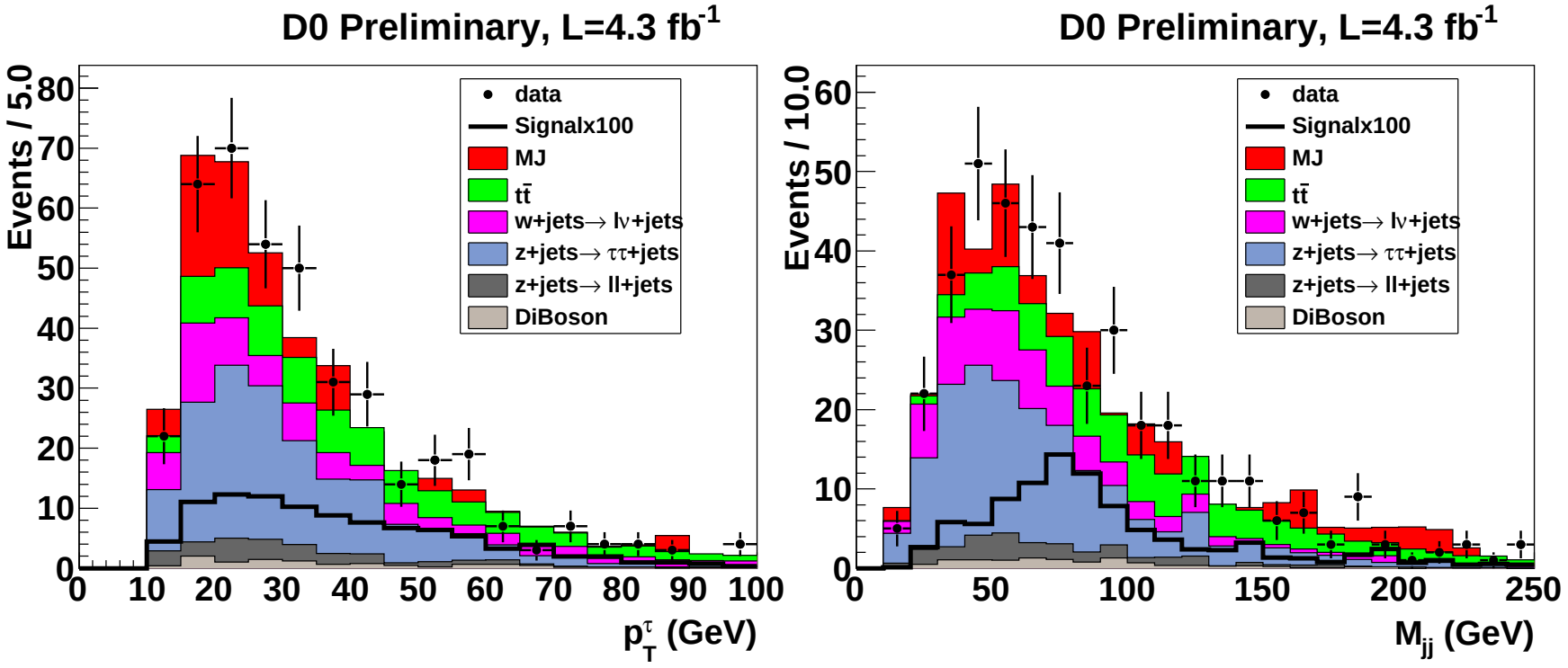
Muon channel



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

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

Muon channel



Data: 414, Bg: 404.9

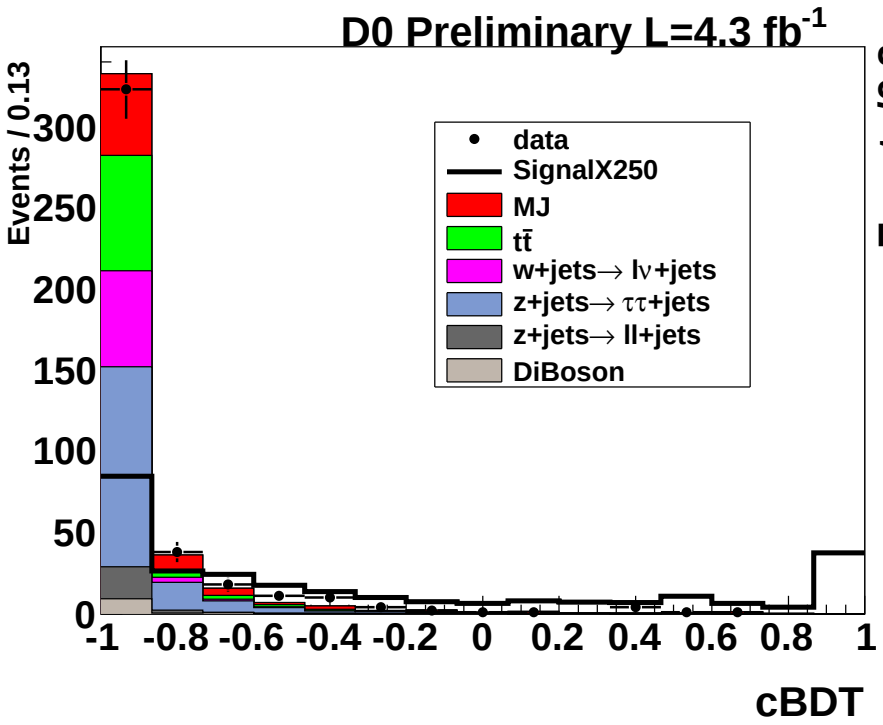
Higgs ($m_{\mathrm{H}} = 115$ GeV): 1.1 events

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

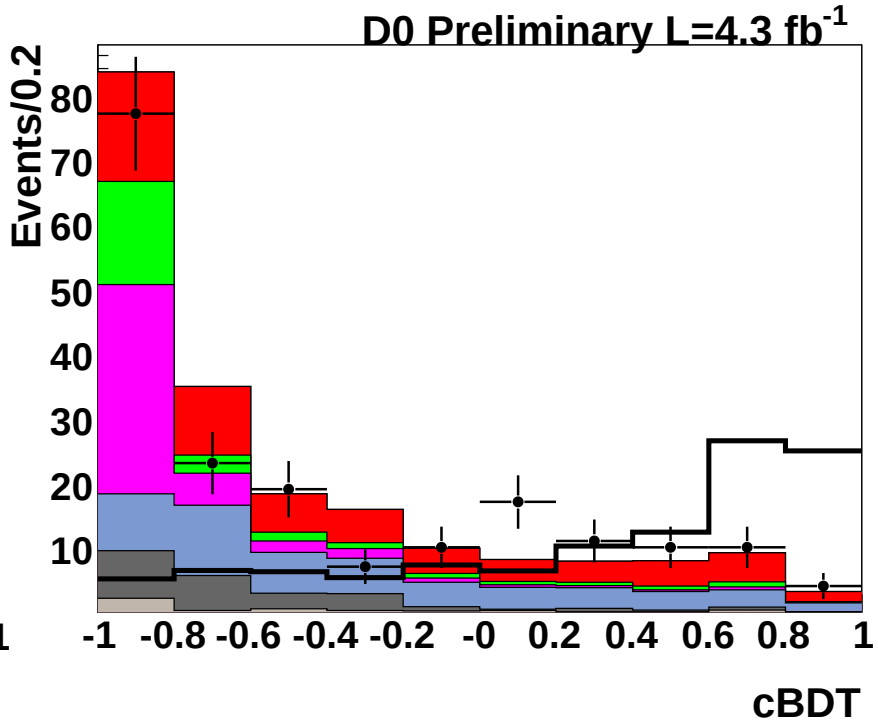
$\Rightarrow$ Train DT for various signal-background combinations

- In three m_{H} ranges
- Combine into one DT

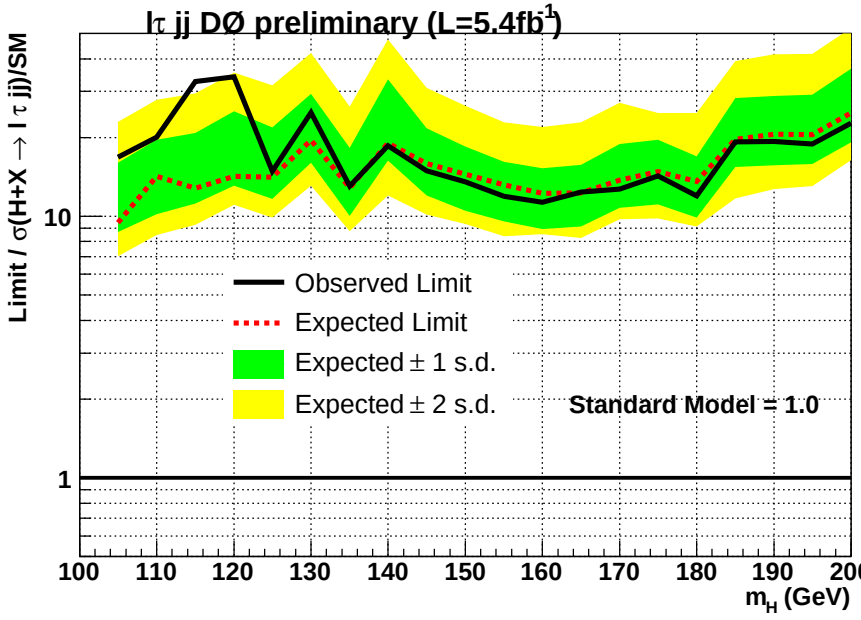
Muon channel

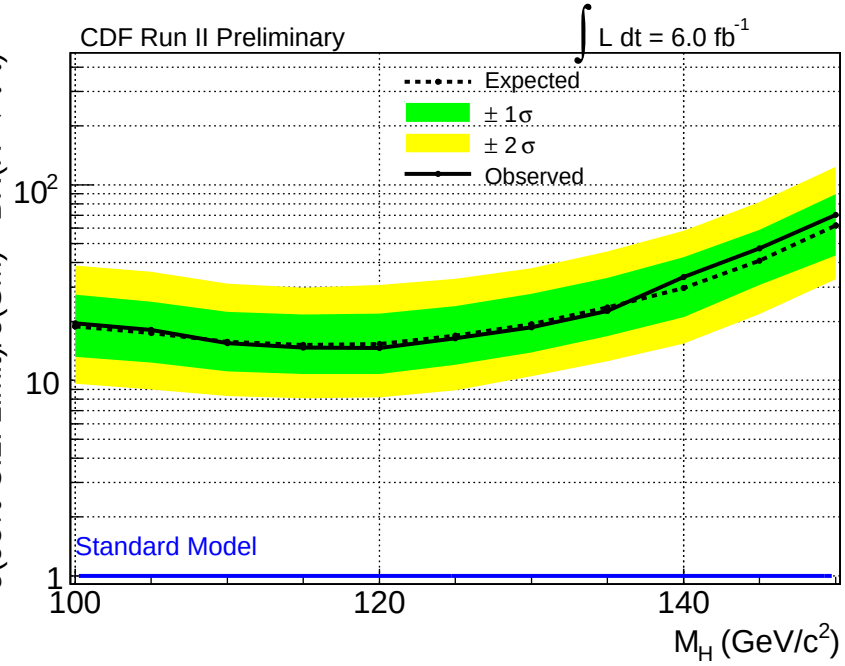


Electron channel



$H \to \tau\tau$ Results

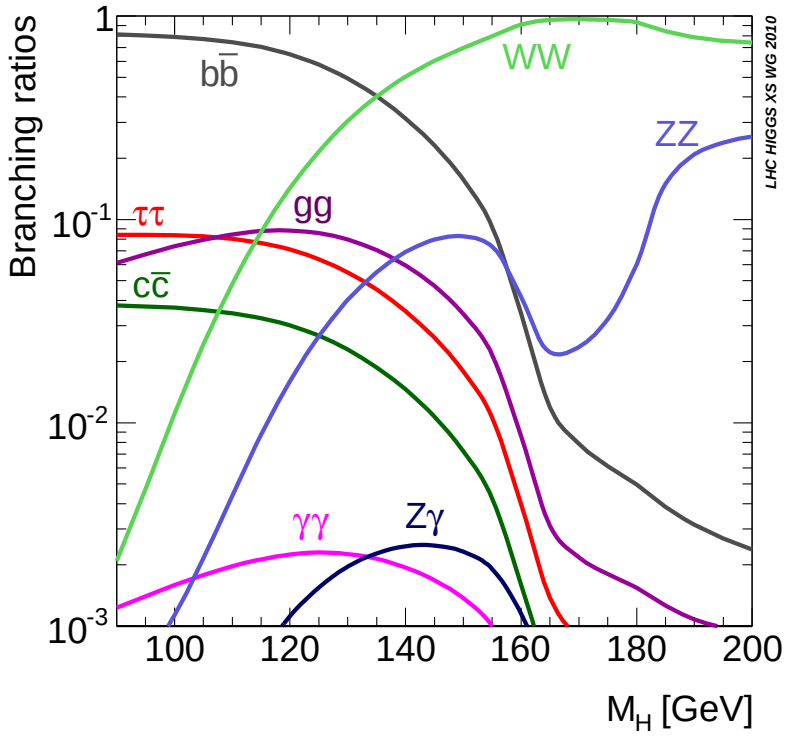




DØ at $m_{\mathrm{H}} = 115$ GeV:
limit/SM 32.8 (12.8 exp.)

CDF at $m_{\mathrm{H}} = 115$ 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

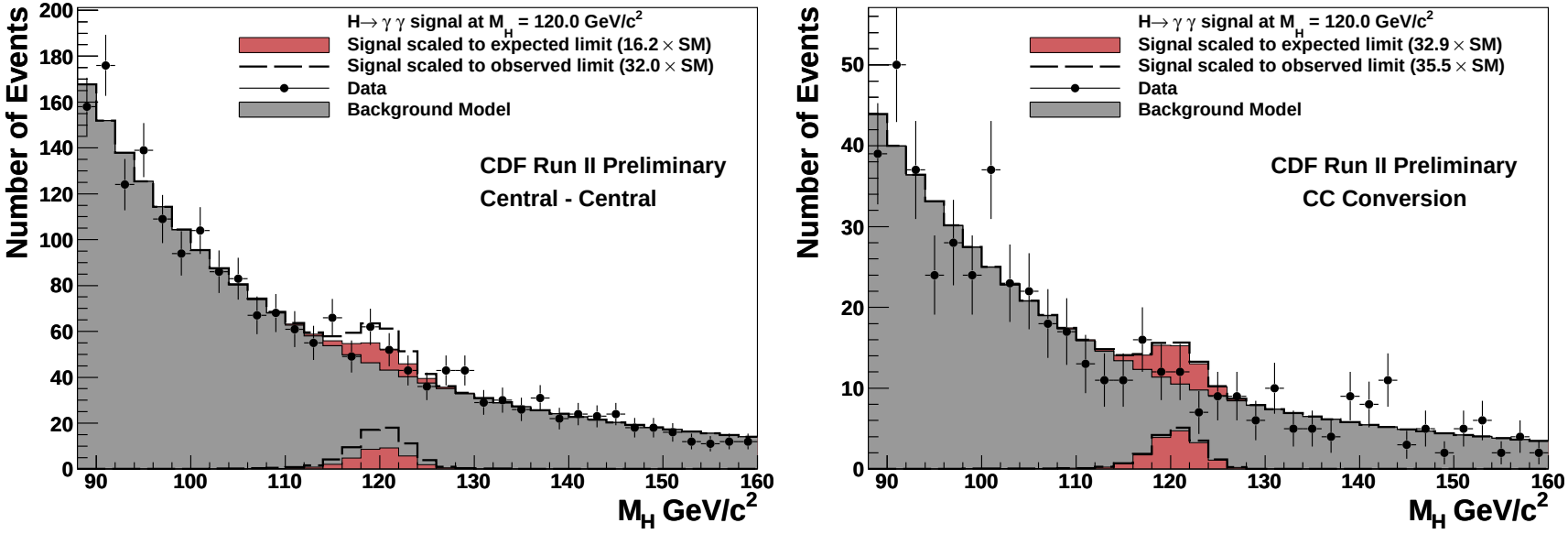
  * Neural net against jets (π^0, η) for central γ
  * Include forward γ
  * Reconstruct γ-conversions

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

– Mass resolution for $m_{\mathrm{H}} = 120$ GeV: $\simeq 3$ GeV

– Background model: smooth curve, excluding signal region

$$\int \mathcal{L} \mathrm{d}t = 7 \text{ fb}^{-1}$$

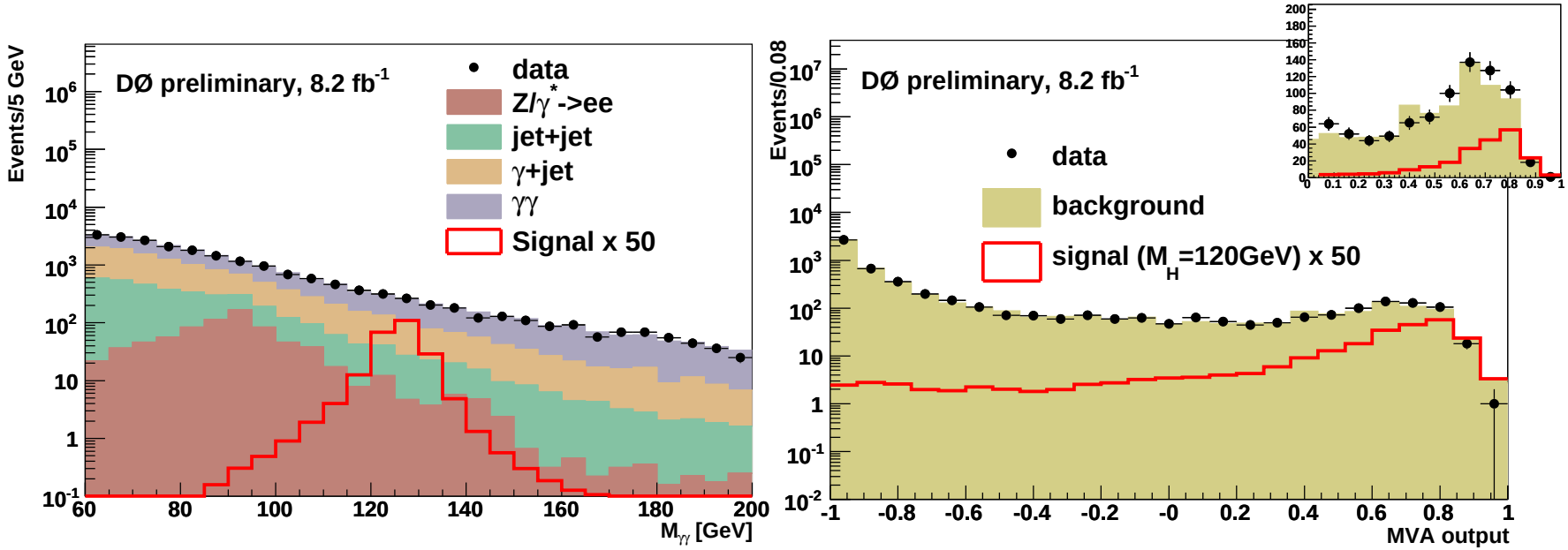


Higgs at Low Mass: H $\rightarrow \gamma\gamma$ (DØ)

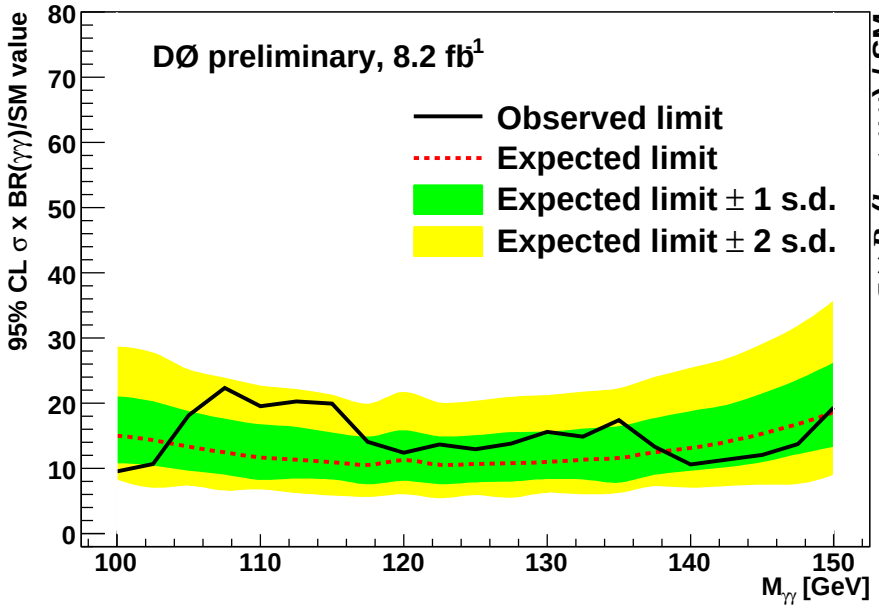
– Background sources:

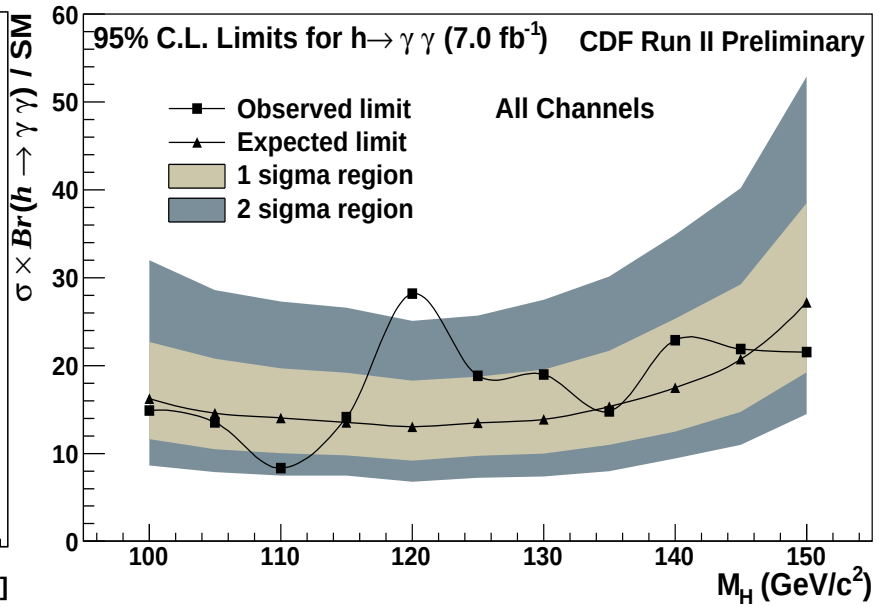
* γ+jet, di-jet $\rightarrow$ data
* Z/γ^*, $\gamma\gamma \rightarrow$ MC

$\Rightarrow$ Decision trees



$H \to \gamma\gamma$ Results





DØ at $m_{\mathrm{H}} = 115$ GeV:
limit/SM 19.9 (11.0 exp.)

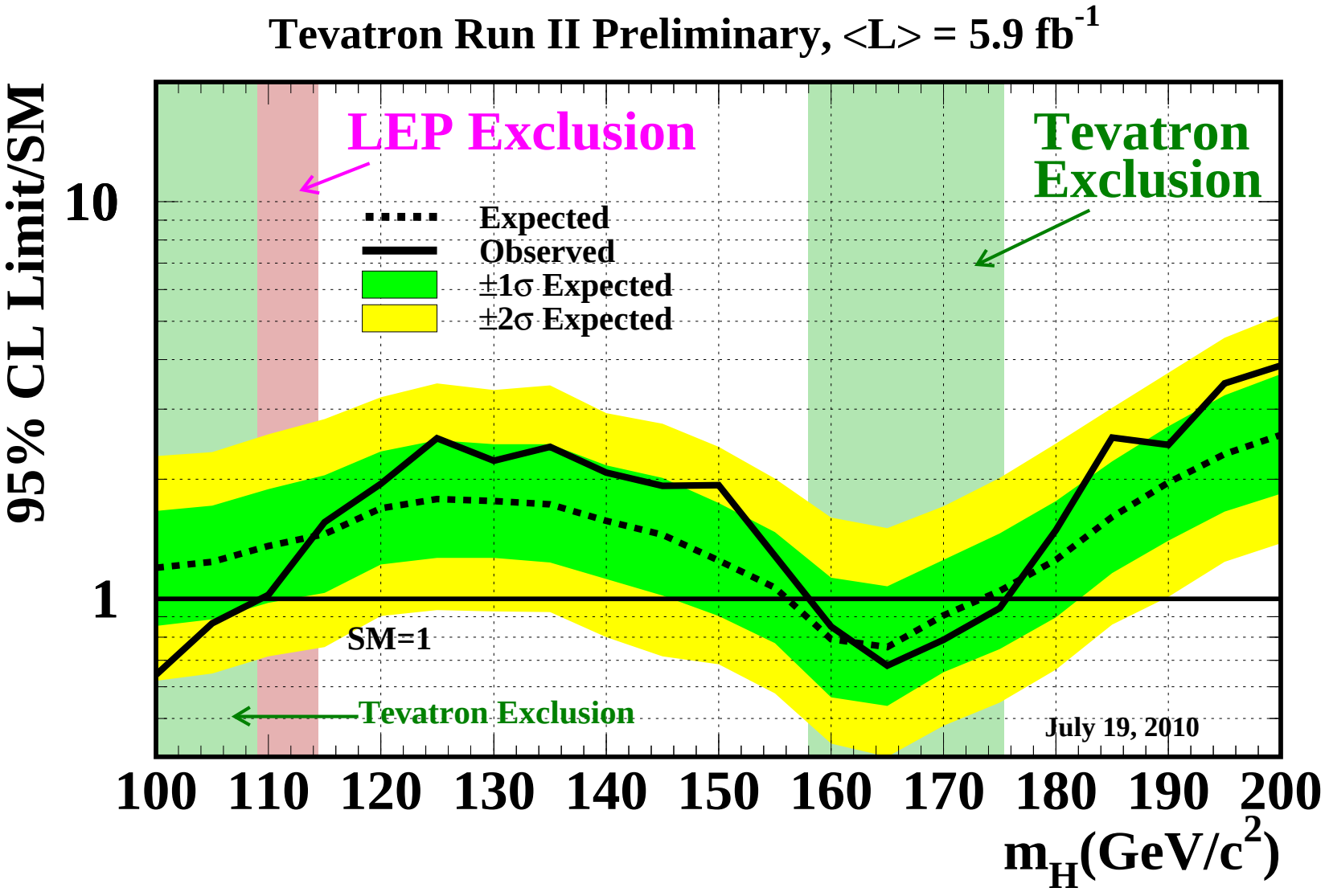
CDF at $m_{\mathrm{H}} = 115$ GeV:
limit/SM 14.1 (13.5 exp.)

Higgs at Low Mass: Summary

For $m_{\mathrm{H}} = 115$ GeV

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

(Old) Combined Tevatron Limit



At $m_{\mathrm{H}} = 115$ GeV: limit/SM 1.6 (1.5 expected)

Conclusion

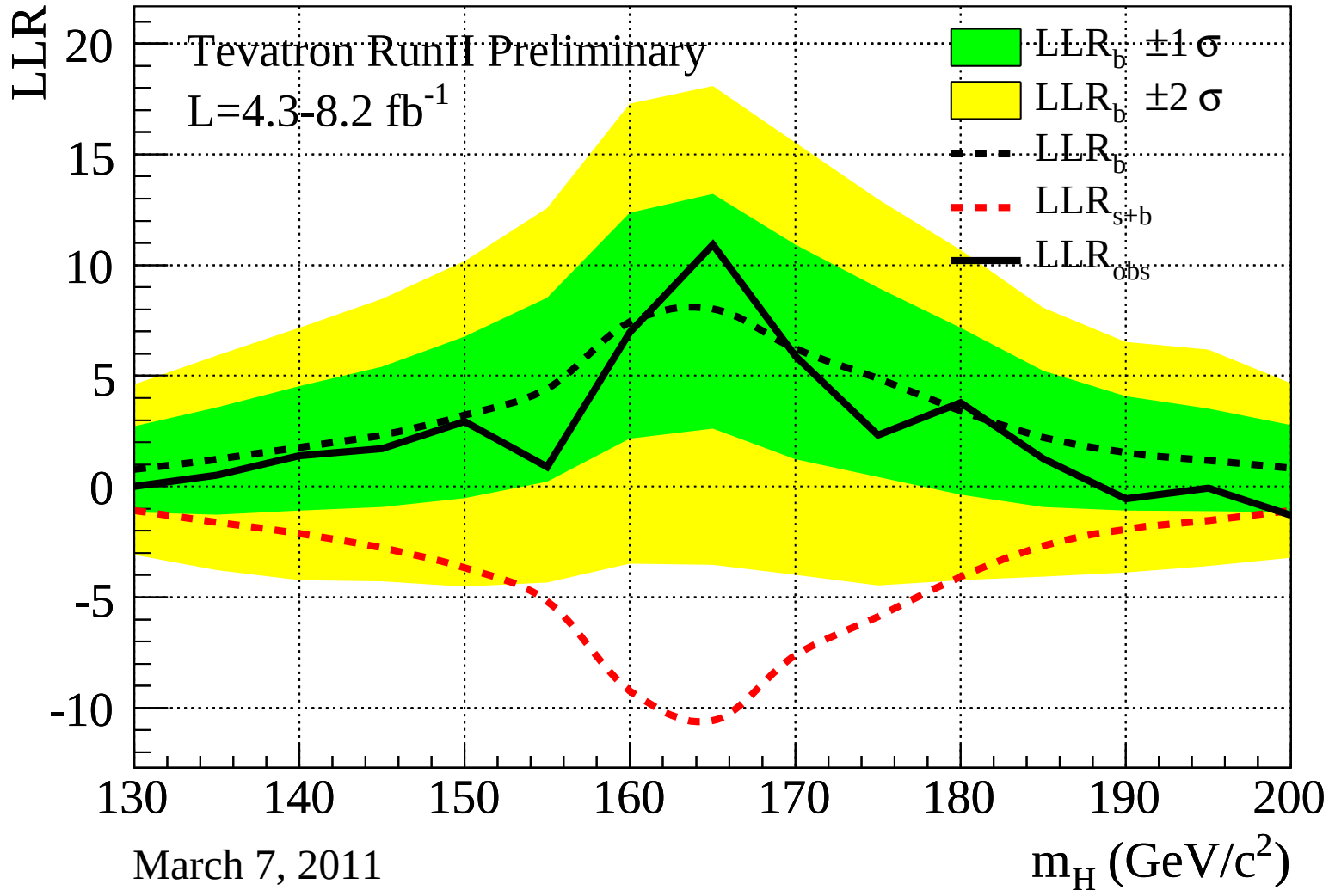
– Need a Higgs boson, or something like it

– Not found yet

– Tevatron will run a few more months

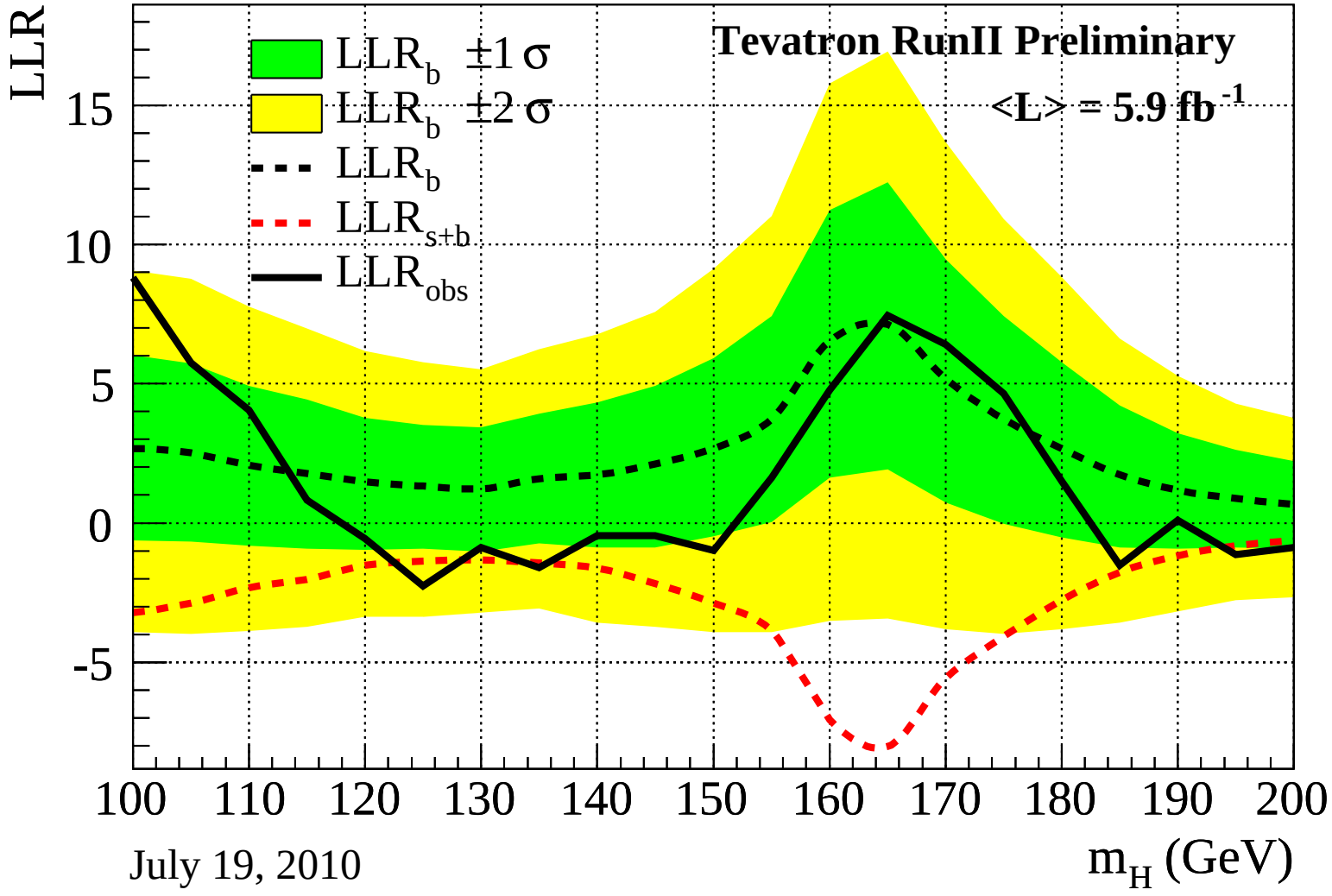
– Keep looking. . .

Combined Tevatron LLR



arXiv:1103.xxxx [hep-ex]

Combined Tevatron LLR



arXiv:1007.4587 [hep-ex]