Recent Standard Model Higgs Results from DØ

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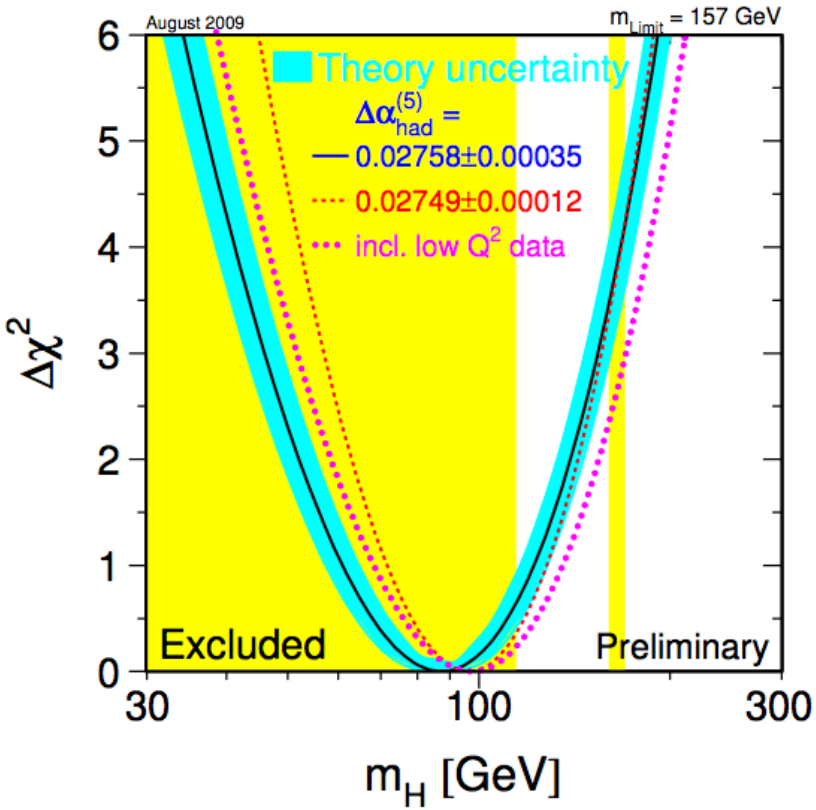
for the DØ Collaboration

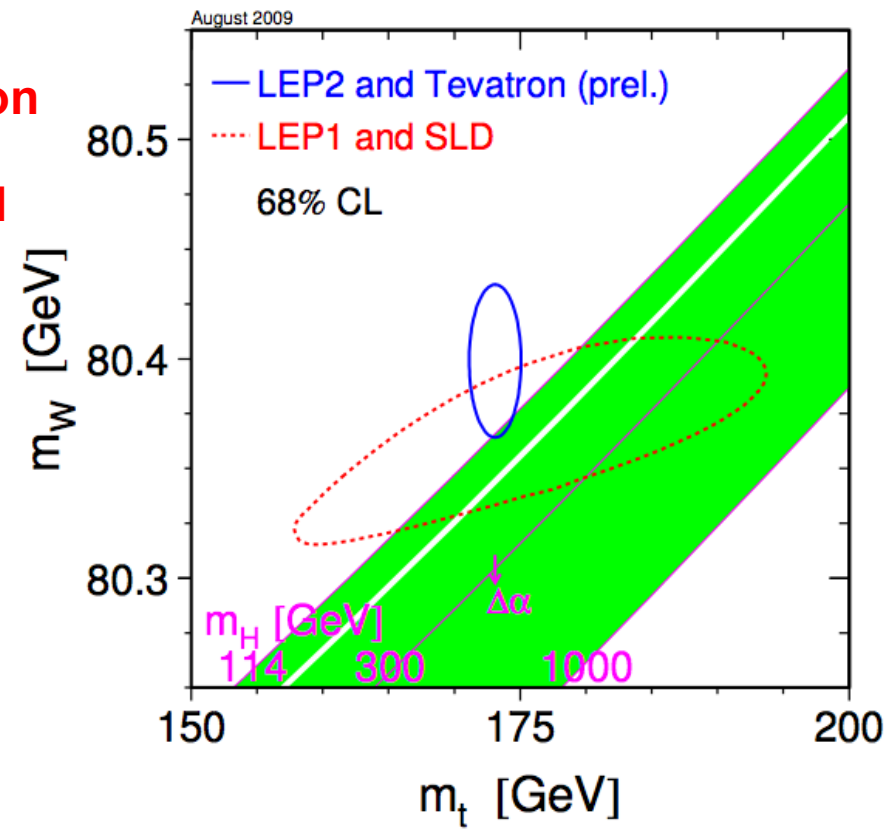
Outline

- Introduction
- Updated ZH→$\nu\nu bb$ (5.2 fb^{-1})
- Updated H→WW (dilepton plus MET) (5.4 fb^{-1})
- Combined DØ limit

The Standard Model Higgs Boson



The Higgs boson is the only standard model particle not yet observed!



Tevatron W and top mass measurements are key inputs!

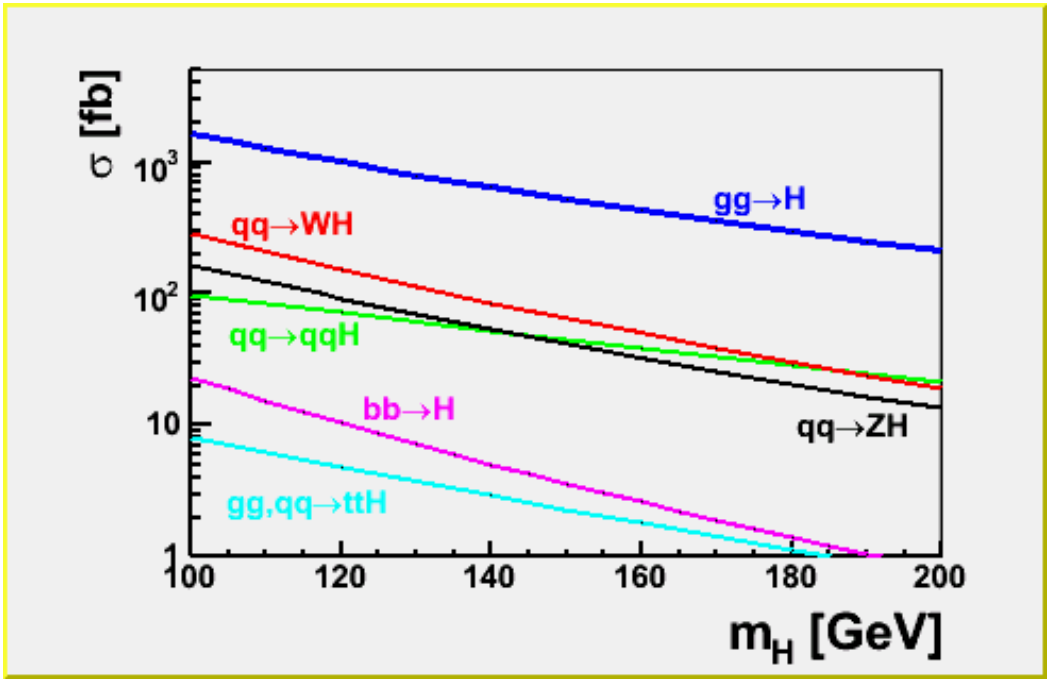
LEP exclusion is 114.4 GeV

A light Higgs boson is favored!

m_H < 157 GeV at 95% CL

m_H < 186 GeV (including LEP direct limit)

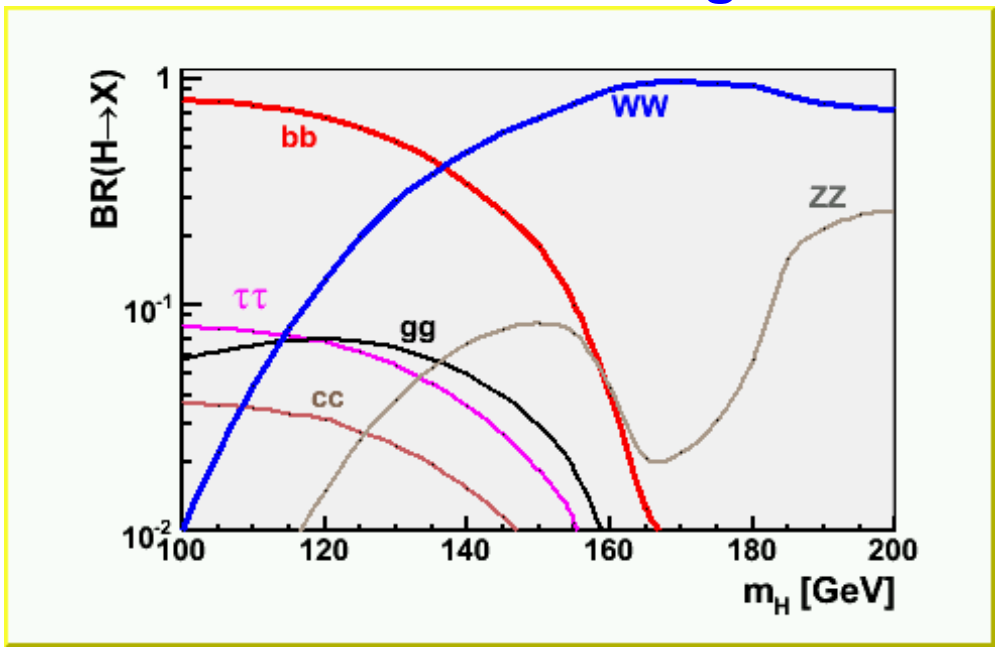
SM Higgs at the Tevatron



gg→H has largest cross section

H→bb dominates at low mass

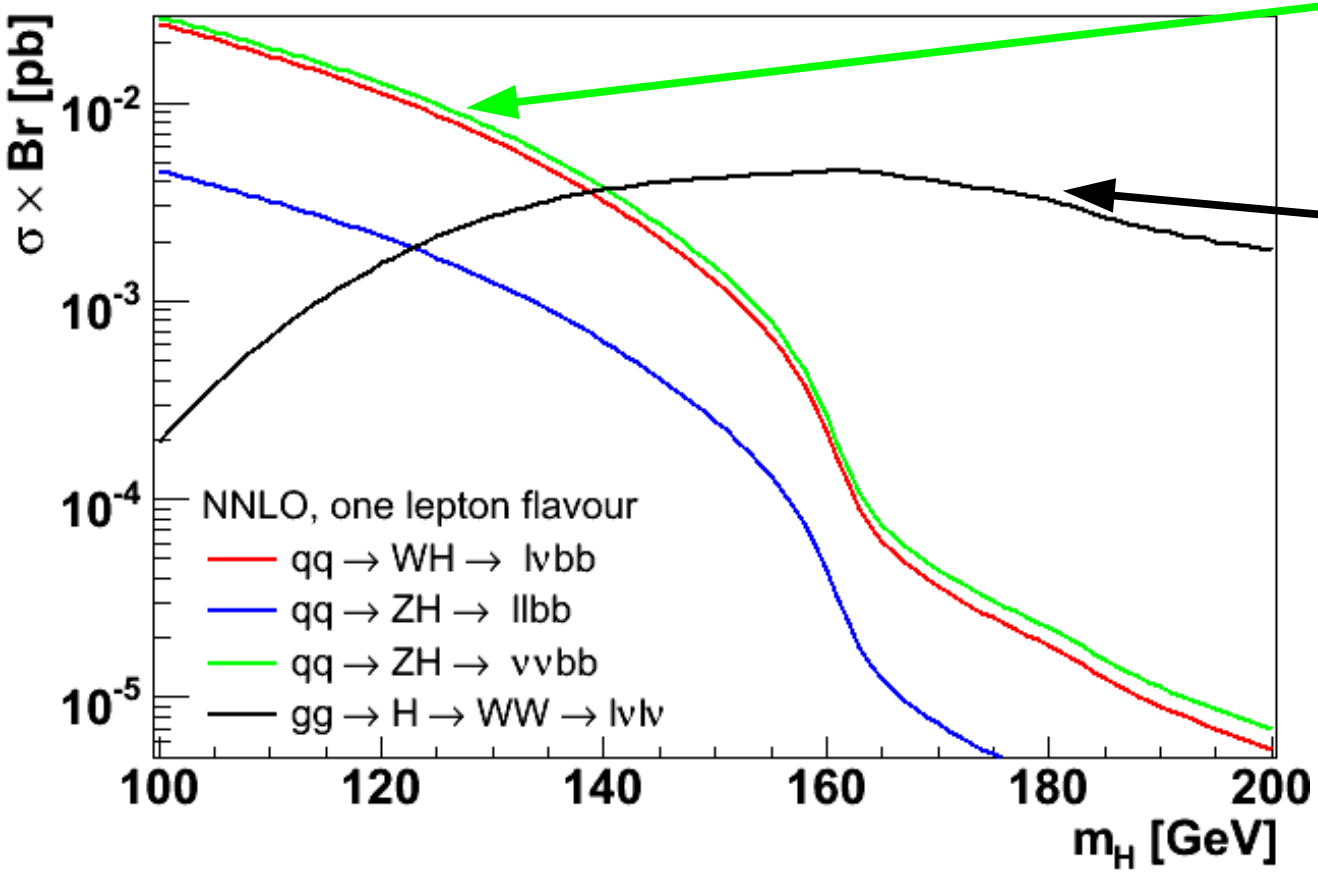
H→WW dominates at high mass



The Tevatron has a very comprehensive program searching in many Higgs channels to maximize sensitivity

SM Higgs at the Tevatron

Cross section x BR for key Higgs modes

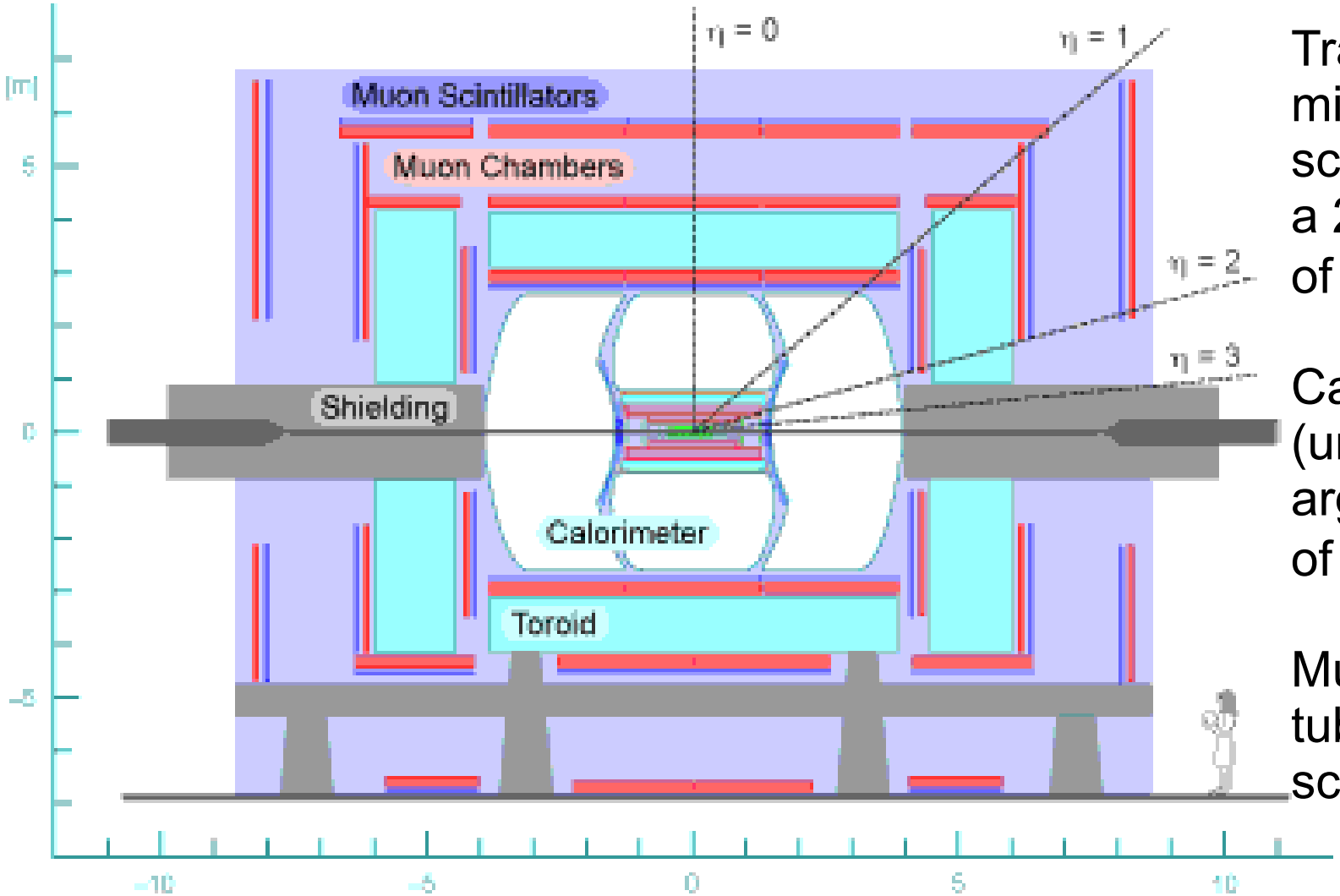


Updates to

Low mass ZH→$\nu\nu bb$ search (5.2 fb^{-1}, up from 2.1 fb^{-1})

H→WW search (5.4 fb^{-1}, up from 3-4.2 fb^{-1})

The DØ Detector



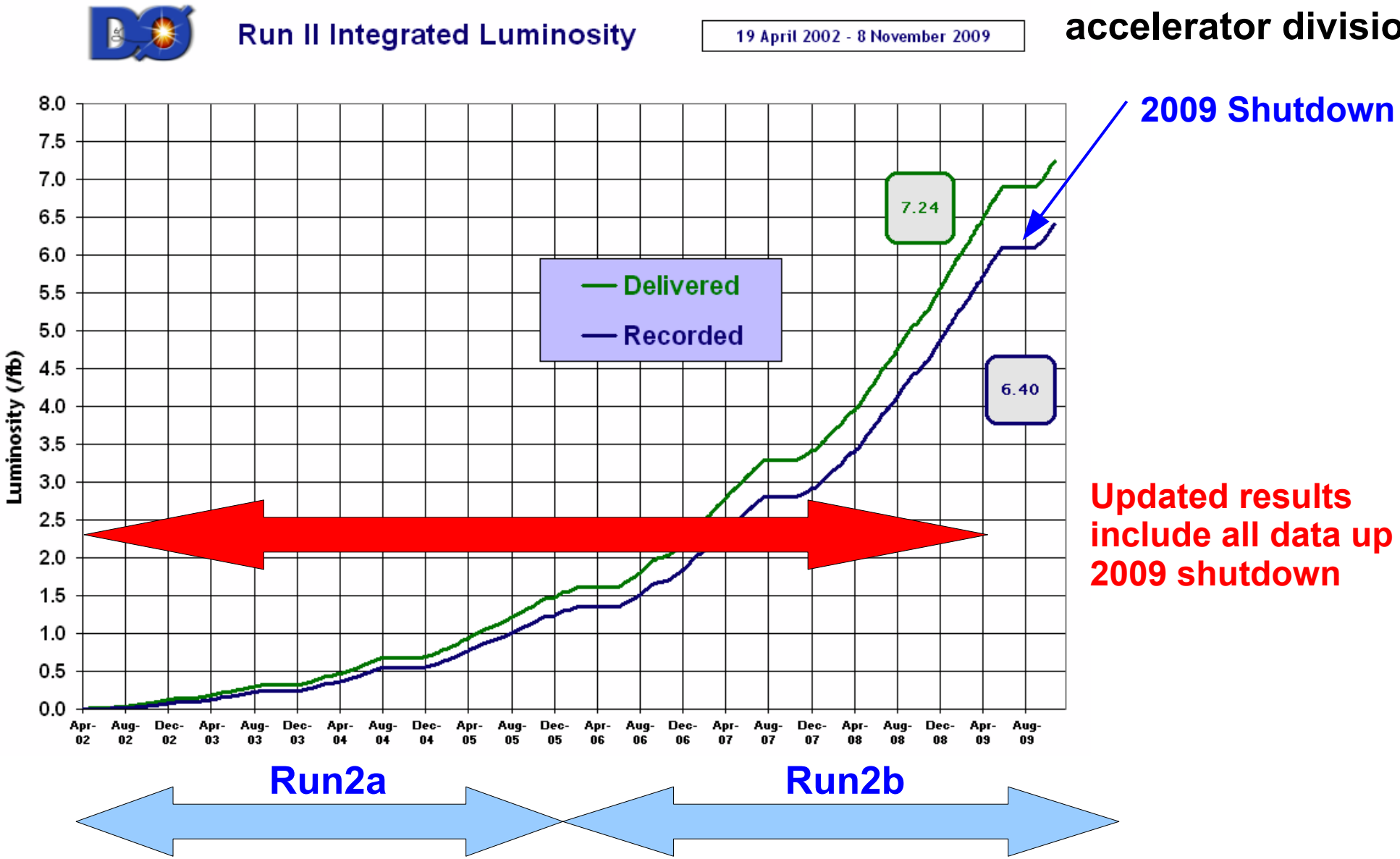
Tracking (silicon microstrips and scintillating fibers in a 2T solenoid) to η of ~2.5

Calorimetry (uranium/liquid argon sampling) to η of ~4.

Muon system (drift tubes and scintillators) to η of 2

Integrated Luminosity

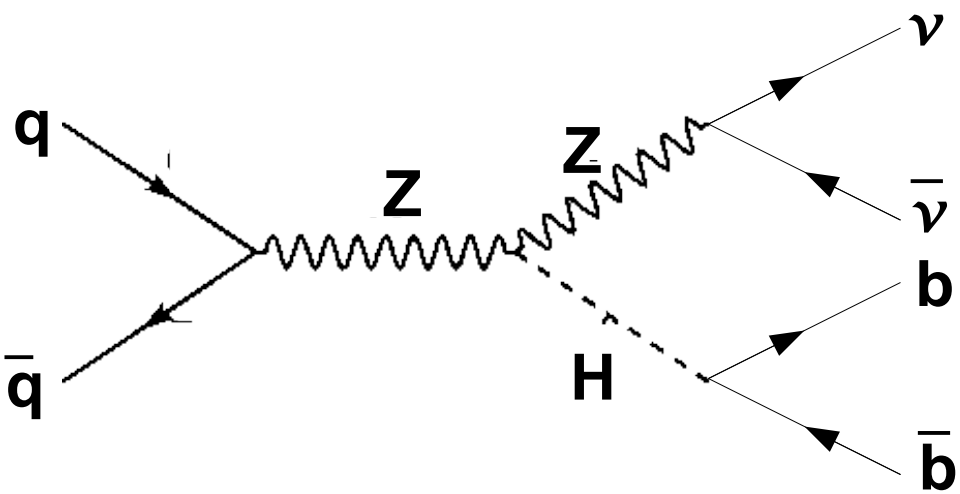
Our thanks to the accelerator division!



Updated results include all data up to 2009 shutdown

The ZH→$\nu\nu bb$ Search

Analysis Introduction



Also sensitive to WH, where the W decays leptonically and the charged lepton is not identified

- Final state is two *b*-jets and missing transverse energy (MET) from the neutrinos
- One challenge is in understanding the (substantial) multijet background
- Searches for Higgs masses between 100 GeV and 150 GeV
- Uses 5.2 fb^{-1} of data

Backgrounds

Background	Simulation
W+jets	Alpgen+Pythia
Z+jets	Alpgen+Pythia
Top pairs	Alpgen+Pythia
Single top	Comphep+Pythia
Dibosons (WW, WZ, ZZ)	Pythia
Multijet	Data

} W/Z pT reweighted to match DØ's unfolded measurement

Normalized with highest order cross section available (NLO or better)

See following slides

Improving Signal/Background

S/B ~10^{-9}

Events selected online
With Jets+MET triggers

Select events offline with
Jets and significant MET

S/B ~10^{-4}

Apply *b*-tagging

Select analysis sample
and orthogonal control
samples

S/B ~10^{-3}

Use multivariate technique
to reduce multijet background

Divide analysis sample
into orthogonal single-
double-tagged samples

S/B ~10^{-2}

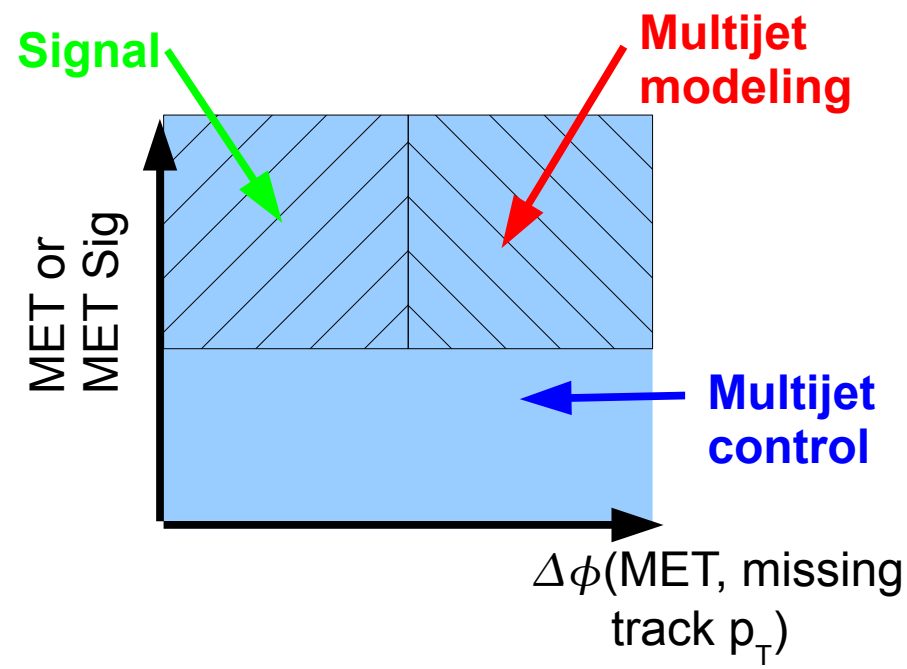
Use multivariate technique to
reduce SM backgrounds

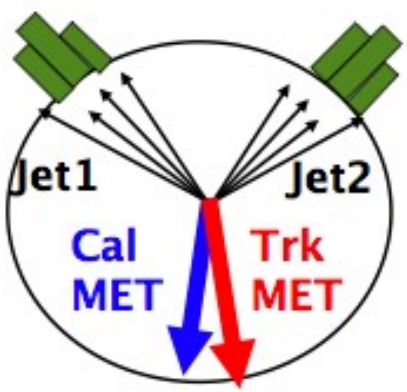
S/B ~10^{-1}

Preselection and Control Samples

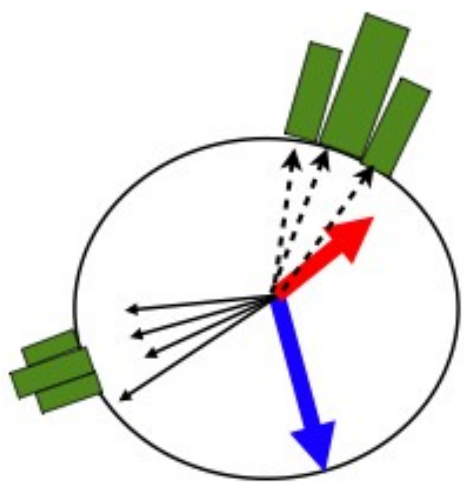
Preselection

- Missing transverse energy (MET) > 20 GeV
- 2 or 3 jets (0.5 cone)
  - $p_T > 20$, $|\eta| < 2.5$
  - $\Delta\phi < 165°$





Event with real MET

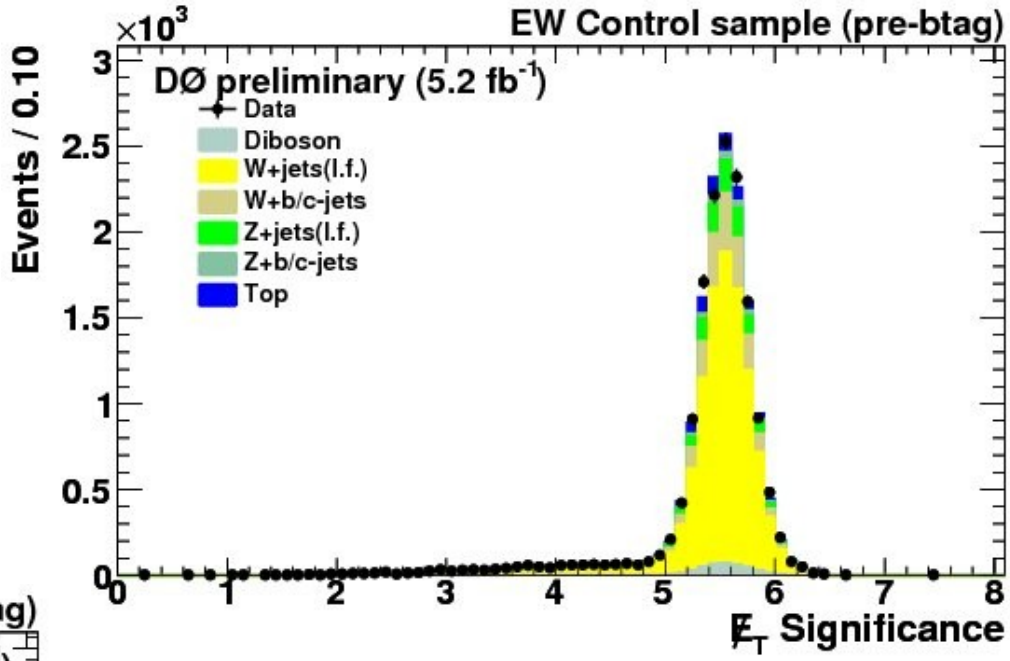


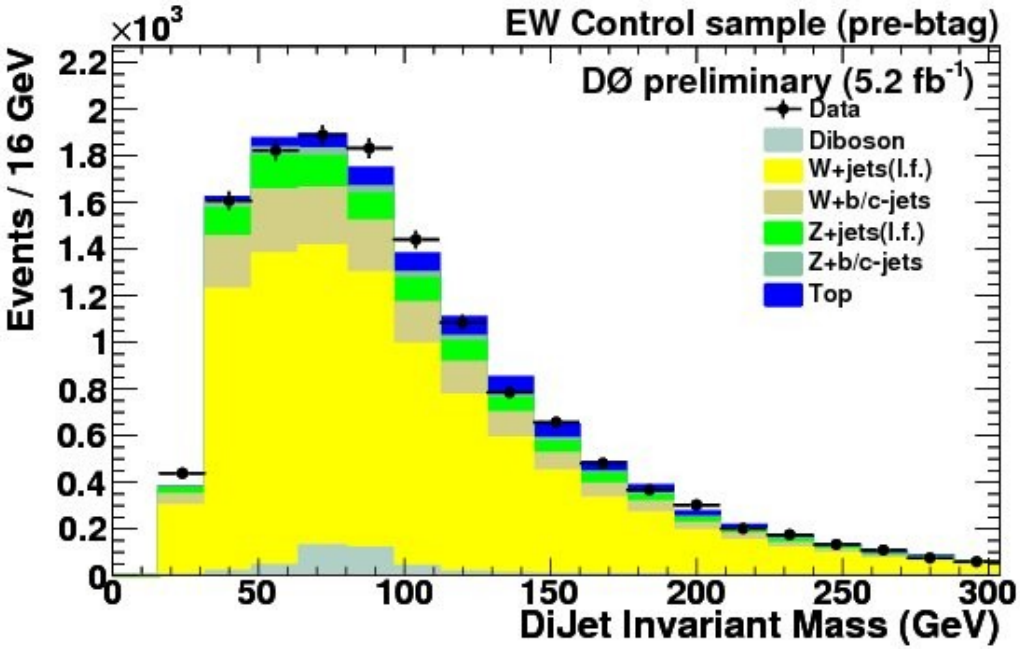
MET due to jet mismeasurement

- Missing track p_T
  - $-\Sigma_{tracks} \vec{p}_T$
- Use $\Delta\phi$ between MET and missing track p_T

Electroweak Control Sample

- Muon
  - p_T > 15 GeV
  - $|\eta|$ < 2.0
- MET > 40 GeV
- Transverse mass > 30 GeV



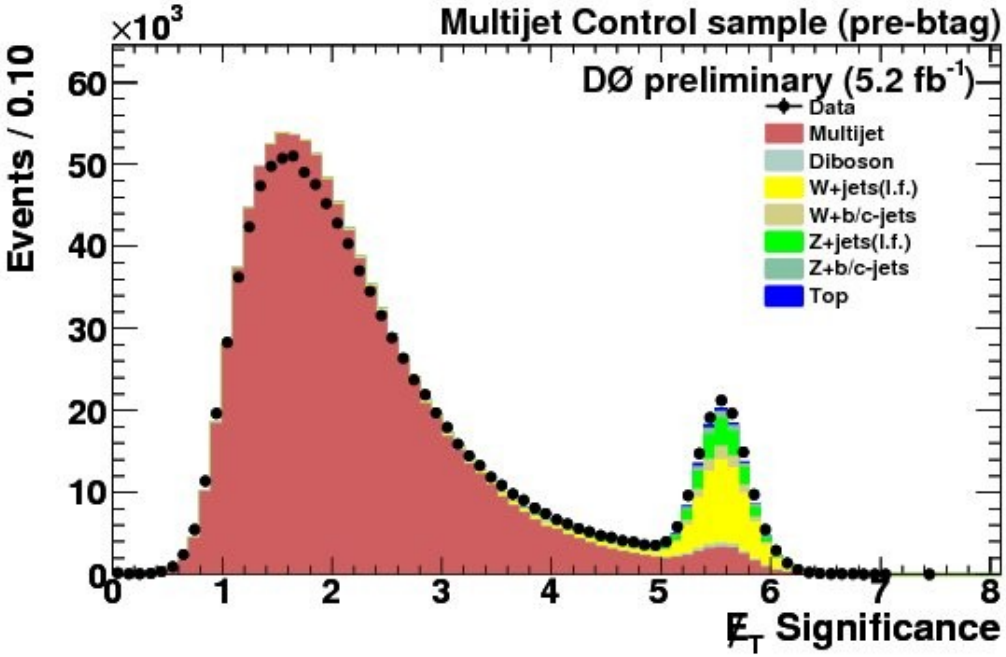


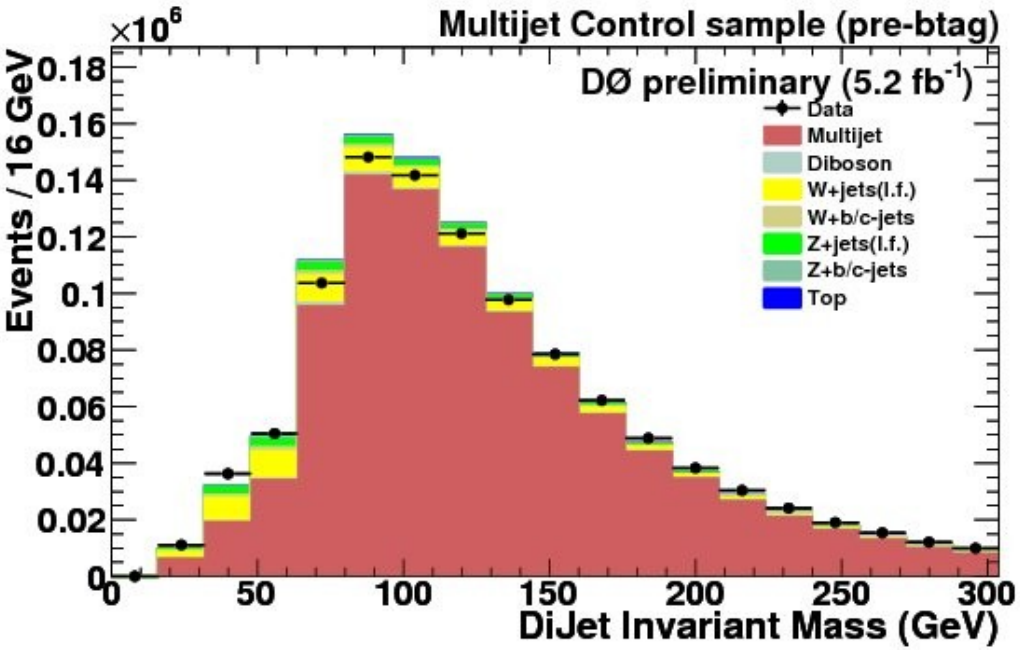
MET Significance compares MET to the expected resolution of the objects in the event

⇒ W+jets background is well-modeled

Multijet Control Sample

- Sample with $\Delta\phi$ between MET and missing track p_T > 90° to model multijet background
- Validate with sample
  - MET > 30 GeV
  - No requirement on MET significance

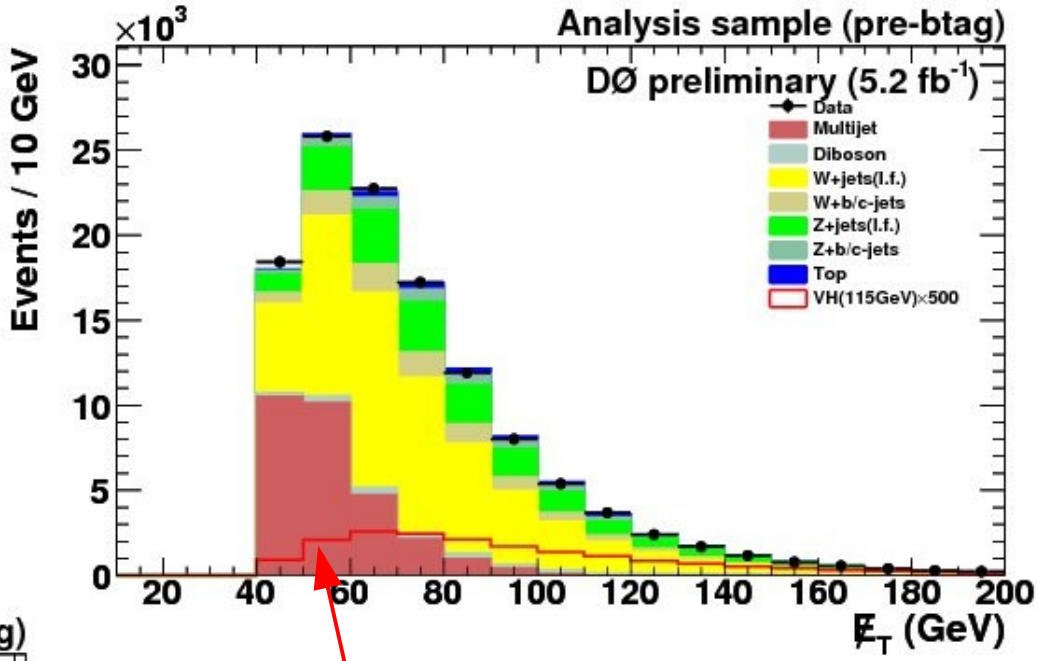


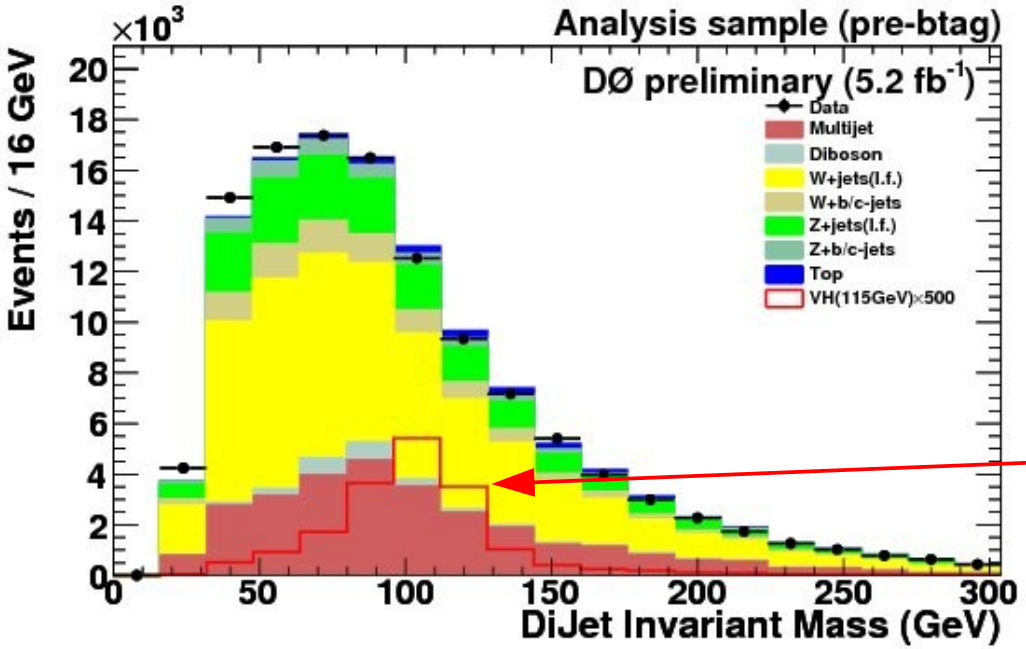


⇒ Multijet background is well-modeled

Analysis Sample

- MET > 40 GeV
- MET significance > 5
- $\Delta\phi$ between MET and missing track p_T < 90°
- Veto events with isolated electrons or muons

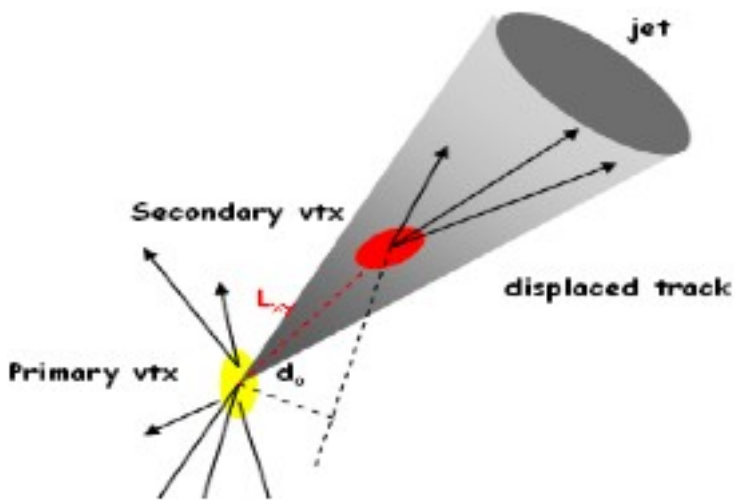


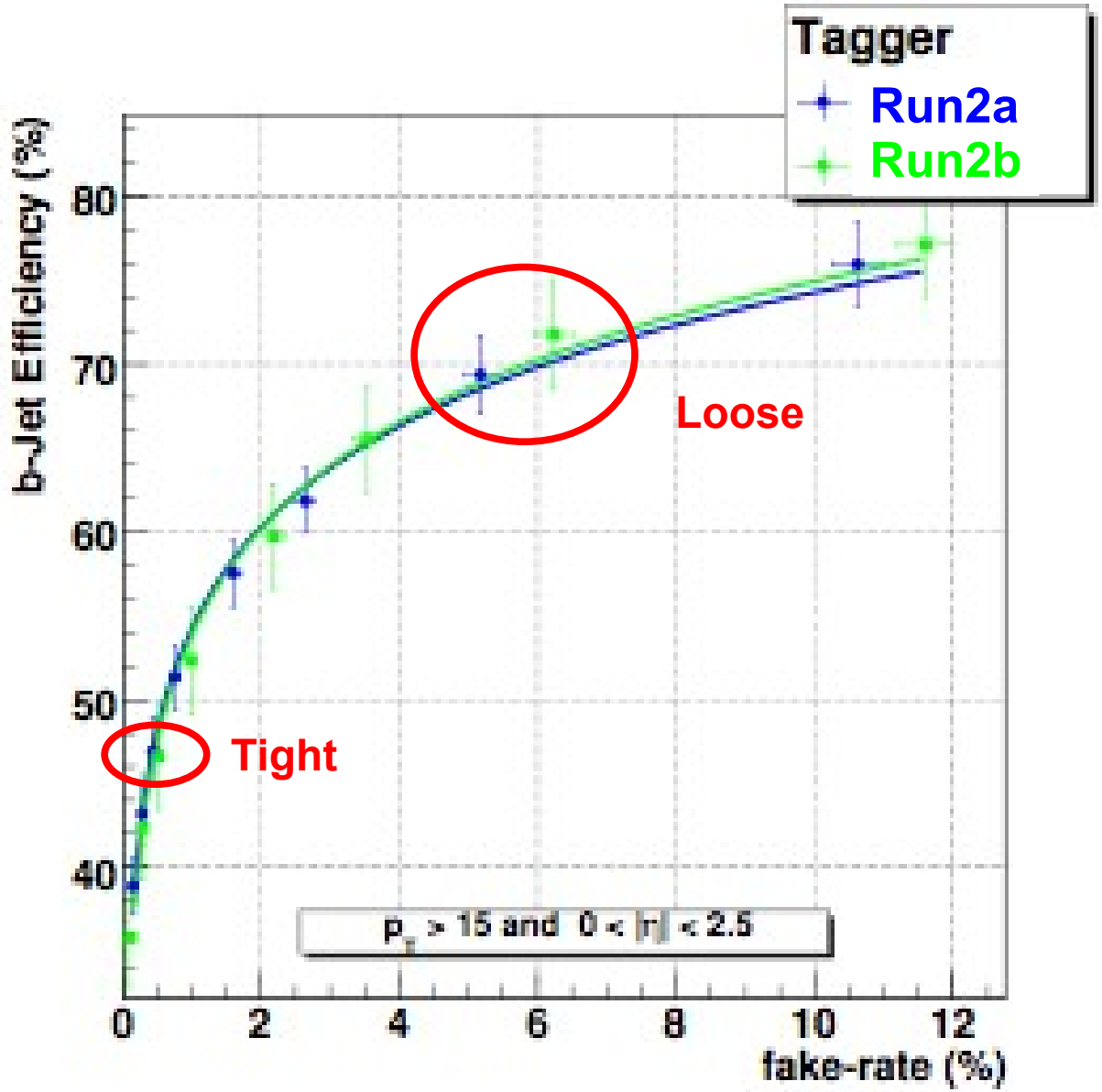


Higgs signal x 500

b Tagging

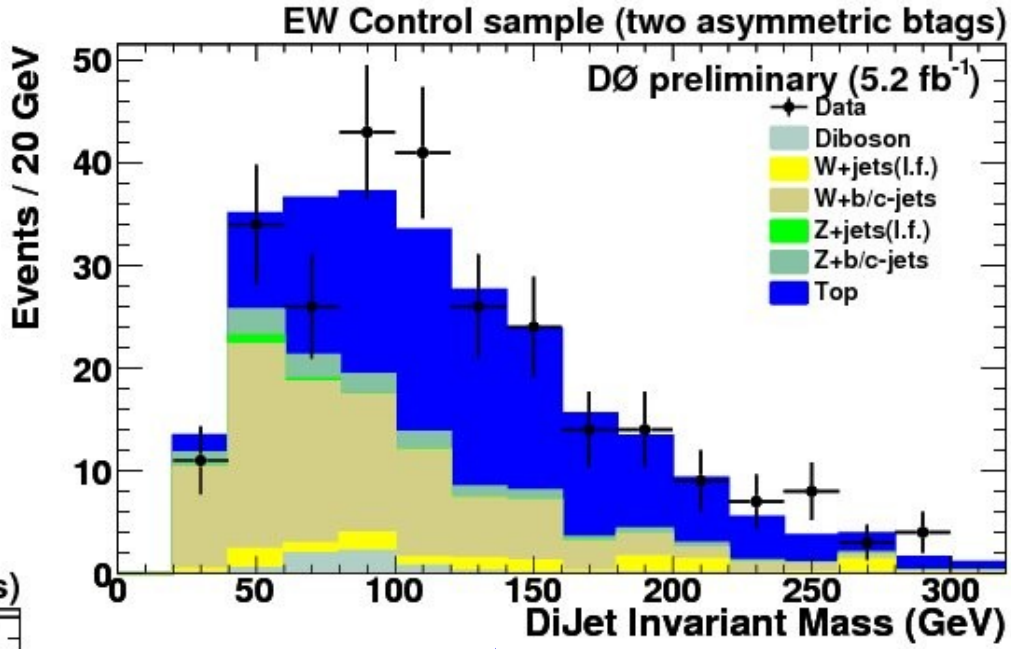
- Use multivariate method exploiting
  - Impact parameter
  - Jet lifetime
  - Secondary vertices
- Defines a range of operating points

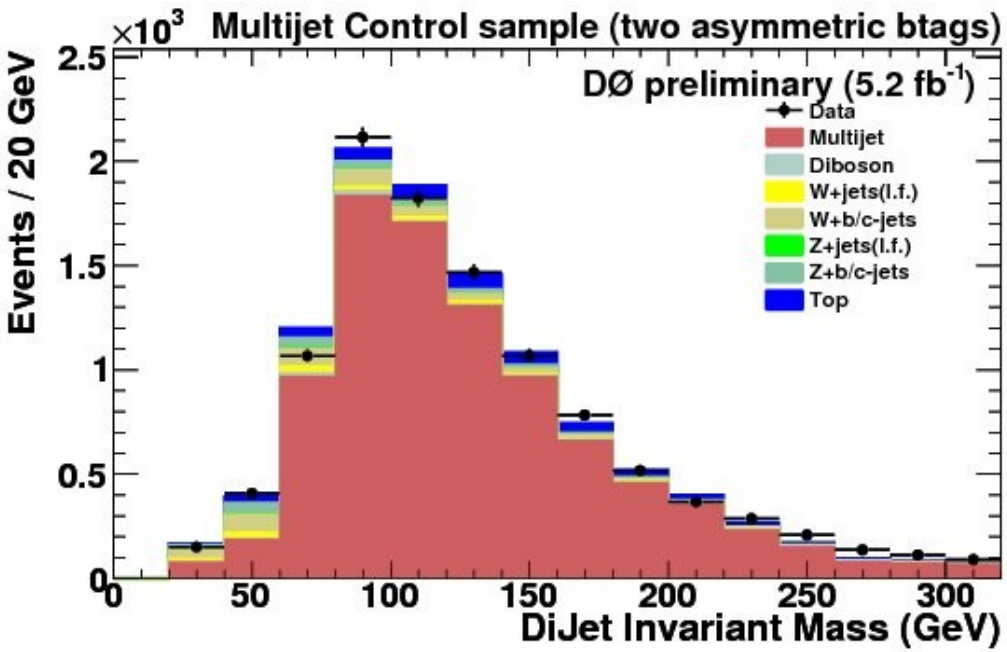




b Tagging

- Orthogonal samples
  - One tight, one loose tag
  - One tight tag (and NOT loose)



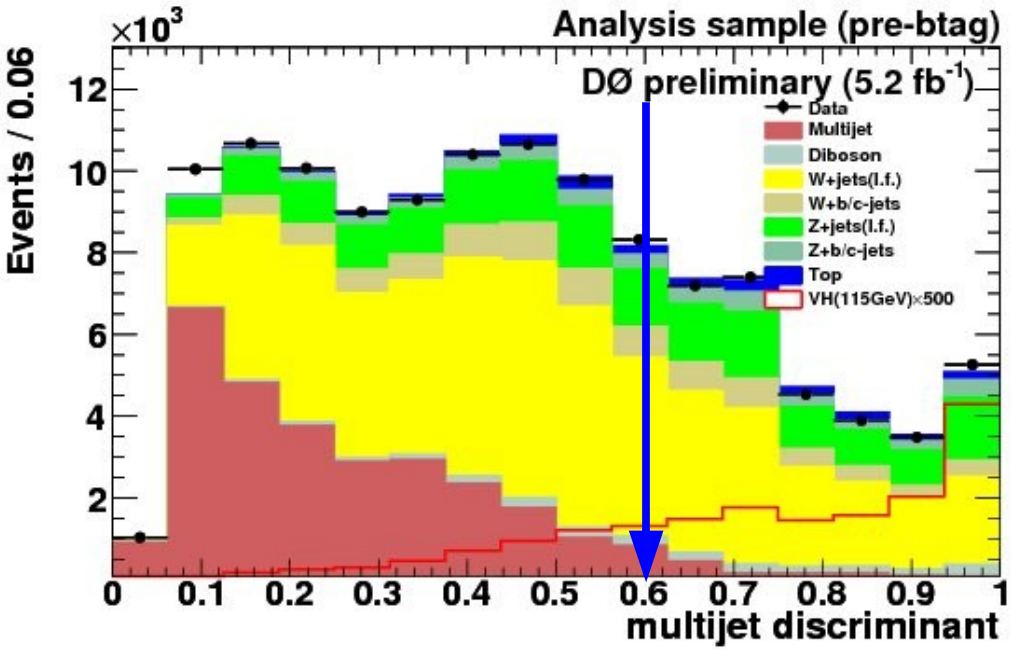


Electroweak control sample

Multijet control sample

Removing Multijet Background

- Multivariate method to further remove multijet background
  - Boosted decision tree (BDT)
  - 23 kinematic variables
  - Separate BDT for each Higgs mass considered
- Cut at 0.6 to remove 95% of multijet background, 65% of other backgrounds, while keeping 70% of signal

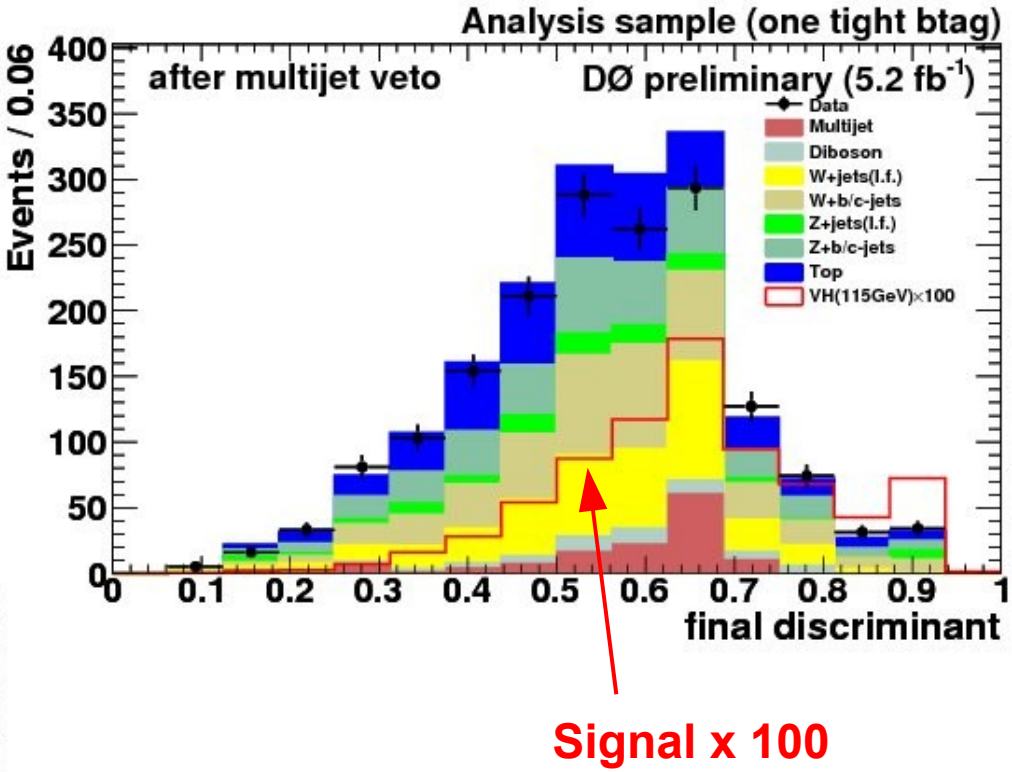


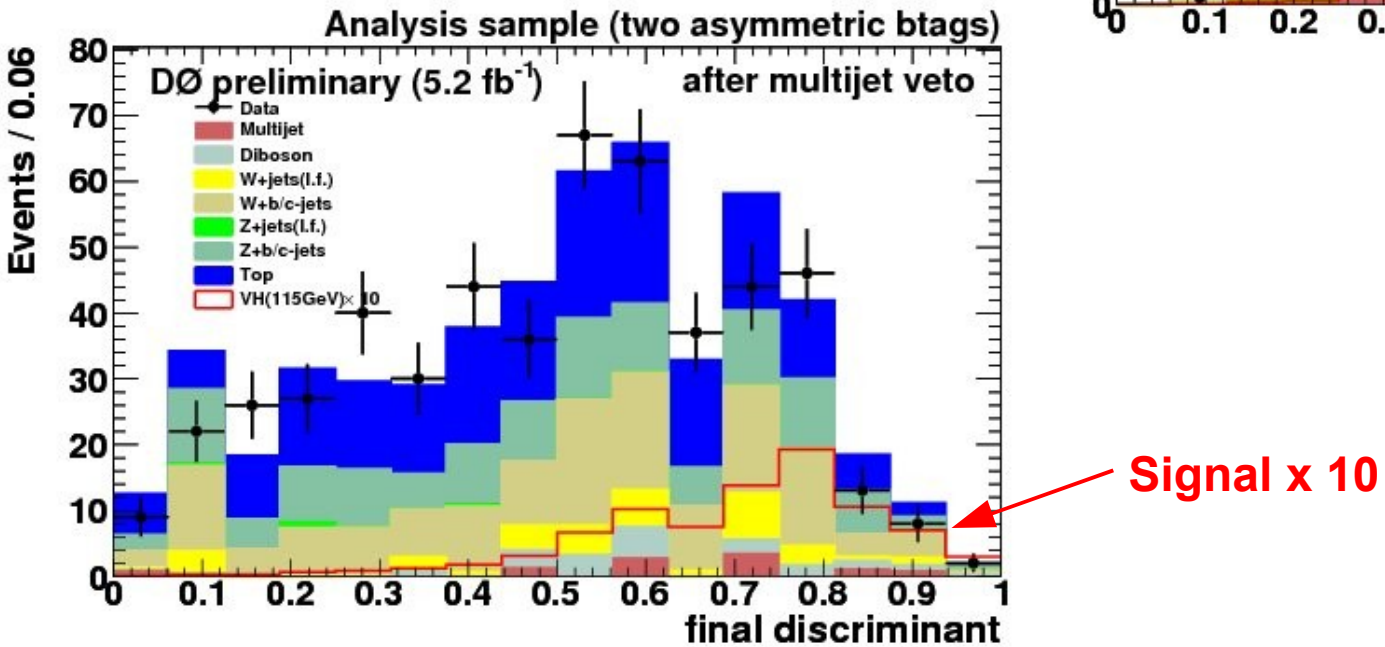
Sample	Signal	Background	Data
pretag	25	32,125±163	31,718
1-tag	7.7	1821±38	1712
2-tag	8.6	530±11	514

Statistical uncertainty only

Removing Standard Model Background

- Another multivariate method for remaining SM background
  - Same inputs for multijet discriminant





Systematic Uncertainties

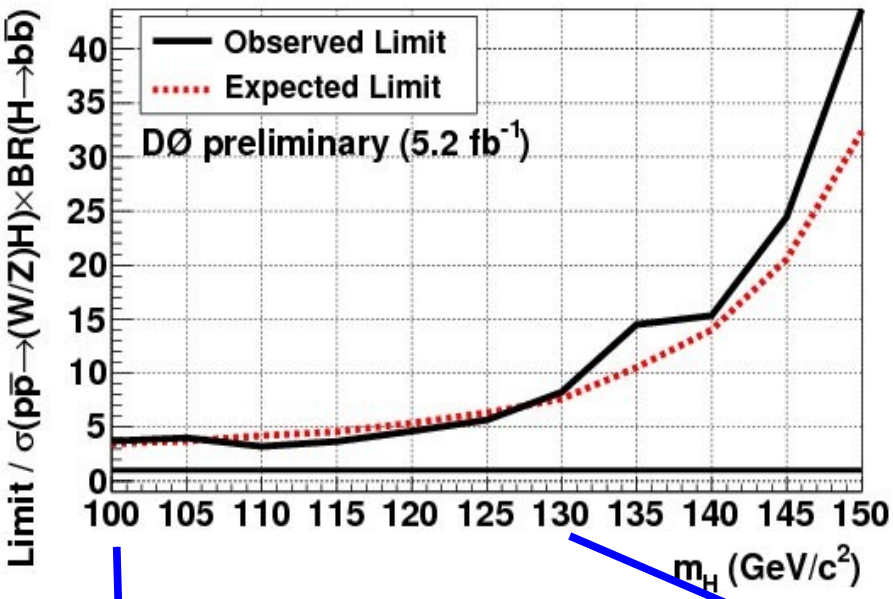
Systematic Uncertainty	Type	Signal	Background
Jet Energy Scale	Shape & Norm	2.7	3.5
Jet Reco*ID	Shape & Norm	0.4	0.8
Jet Resolution	Shape & Norm	0.9	0.8
Cross Sections	Flat Norm	6.0	7.5
Mulit-jet Normalization	Flat Norm	–	1.5
Heavy Flavor Fraction	Flat Norm	–	9.8
Parton Distribution Function	Shape only	–	–
Vertex Confirmation	Shape & Norm	2.5	1.5
Taggability	Shape & Norm	3.6	3.3
b-Tagging	Shape & Norm	8.7	7.9
Trigger Efficiency	Shape & Norm	3.5	3.4
μ ID	Shape & Norm	1.1	1.5
EM ID	Shape & Norm	0.2	0.3
Alpgen MLM	Shape only	–	–
Alpgen Event Scale	Shape only	–	–
Alpgen Underlying Event	Shape only	–	–
Luminosity	Flat Norm	6.1	6.1

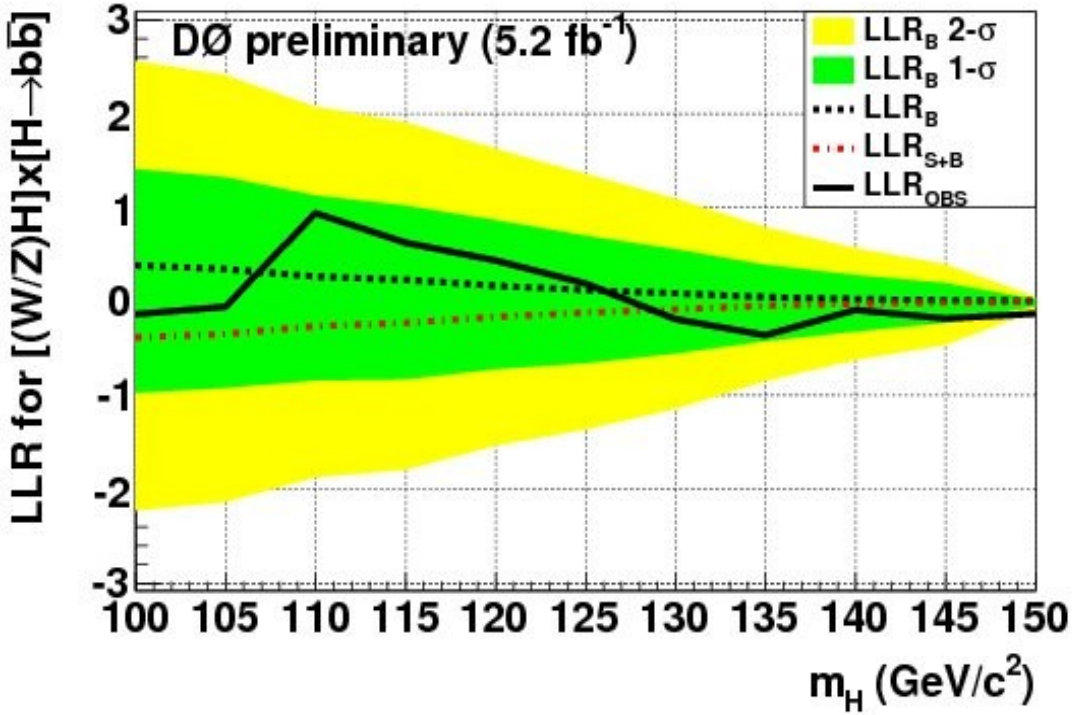
Shift jet quantities by $\pm 1\sigma$, propagate through analysis to determine effect on shape and normalization

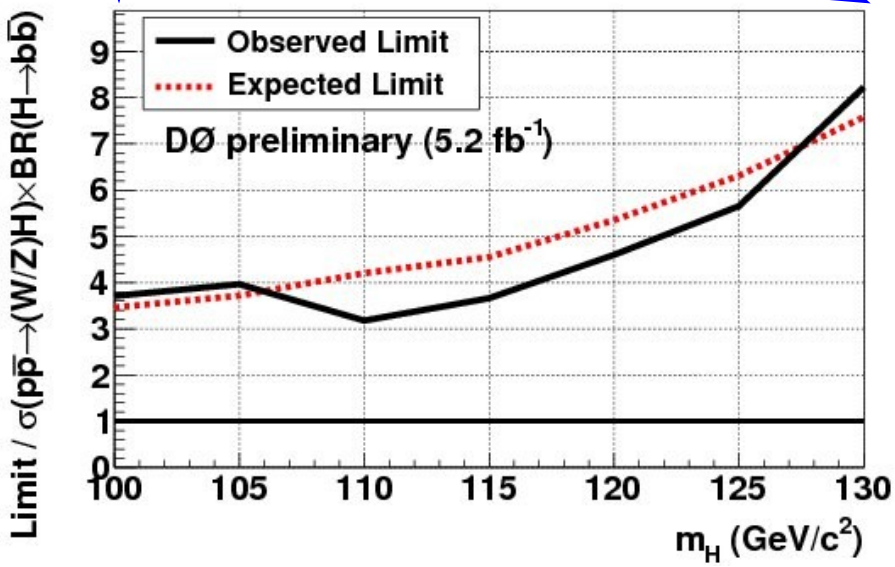
For b-id systematics, shift Measured efficiencies by $\pm 1\sigma$ and propagate through analysis to find effect on shape and normalization

Relative uncertainties in %

Limit Setting





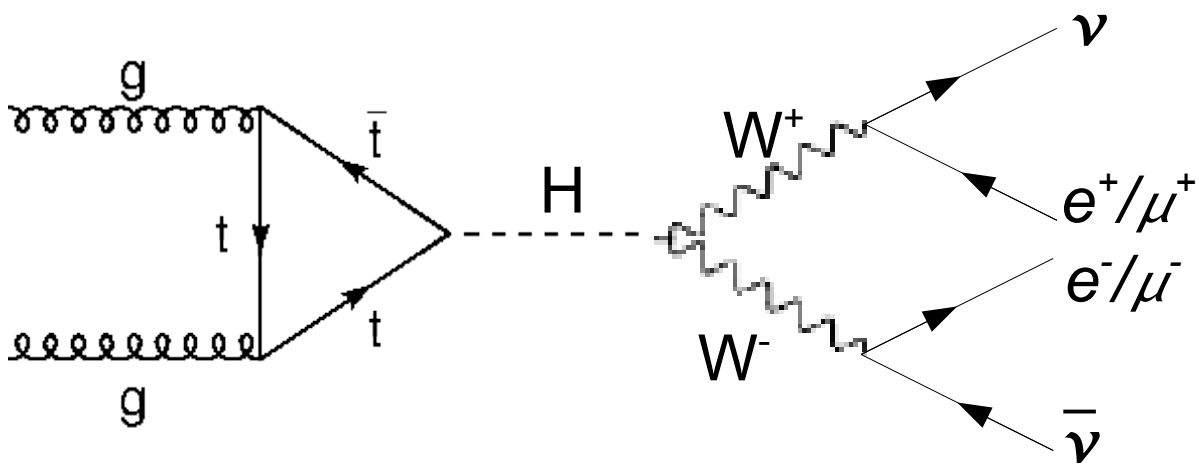


At 115 GeV, limit is
4.6 (expected)
3.7 (observed)

15% improvement beyond that expected from additional luminosity alone

The Dilepton + MET Search

Analysis Introduction

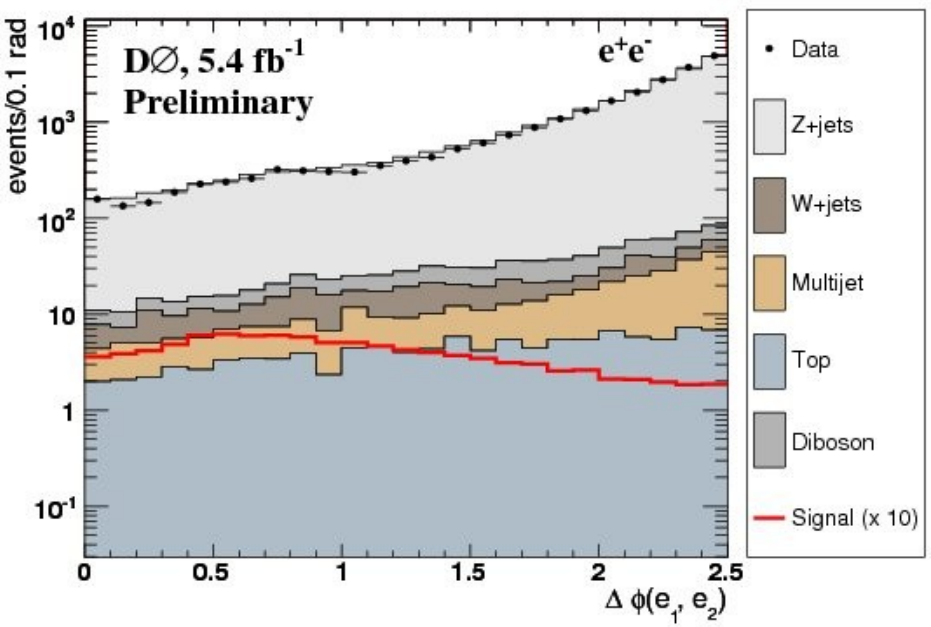


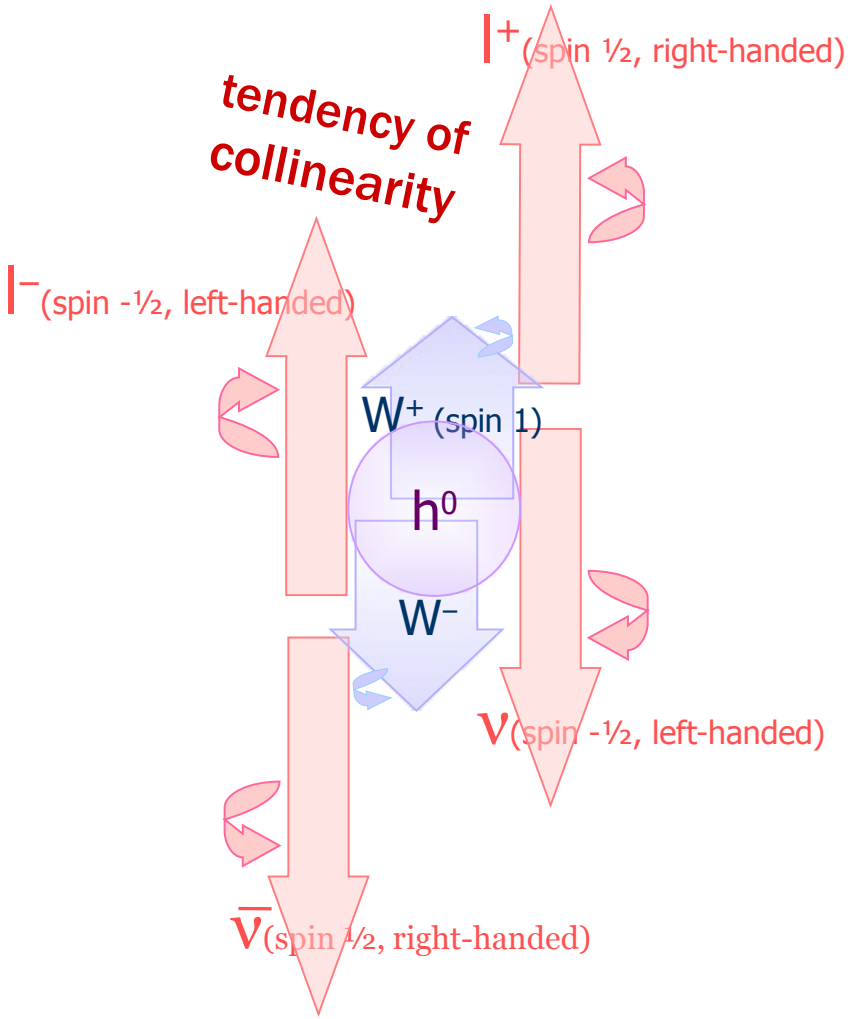
Consider all final states with 2 leptons and MET, including vector boson fusion and associated production

- Final state is two leptons plus MET
  - Three channels considered: e^+e^-, $e^\pm\mu^\mp$, and $\mu^+\mu^-$
- Most difficult background is SM WW production
- Most sensitive channel for high mass Higgs
- Search for Higgs masses from 115 to 200 GeV
- Uses 5.4 fb^{-1} of data

Analysis Strategy

- All channels trigger using "OR" of all single and dilepton triggers
- Offline, require 2 oppositely charged leptons
- Remove Z background with selection cuts
- Remove other SM backgrounds with multivariate method





Spin correlations are a powerful tool to remove SM backgrounds

Backgrounds

Background	Simulation
W+jets	Alpgen+Pythia
Z+jets	Alpgen+Pythia
Top pairs	Pythia
Dibosons (WW, WZ, ZZ)	Pythia
Multijet	Data

Normalized with highest order cross section available (NLO or better)

W/Z pT reweighted to match DØ's unfolded measurement

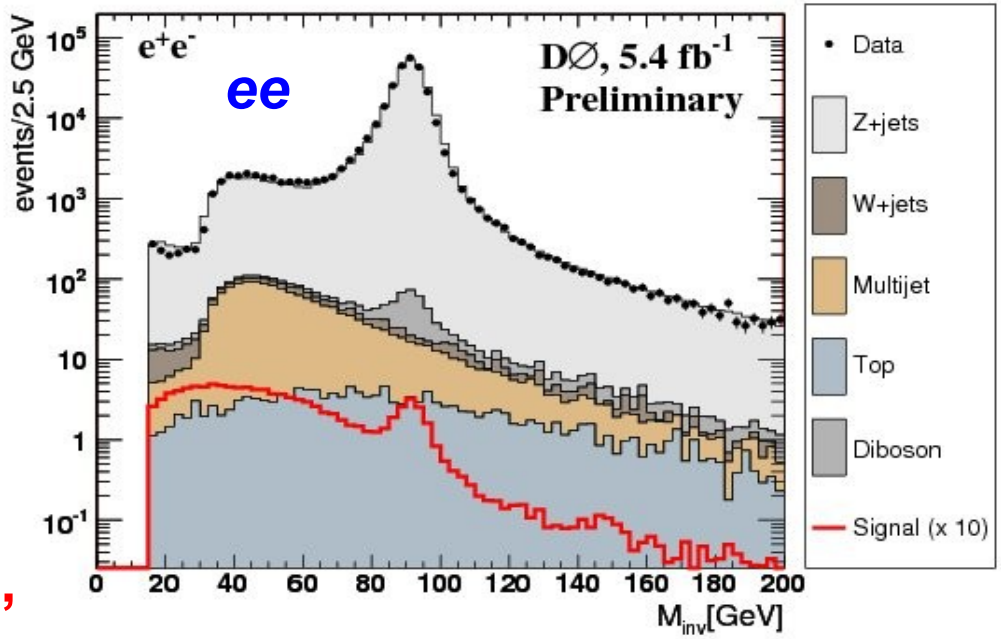
Reweight WW to match MC@NLO

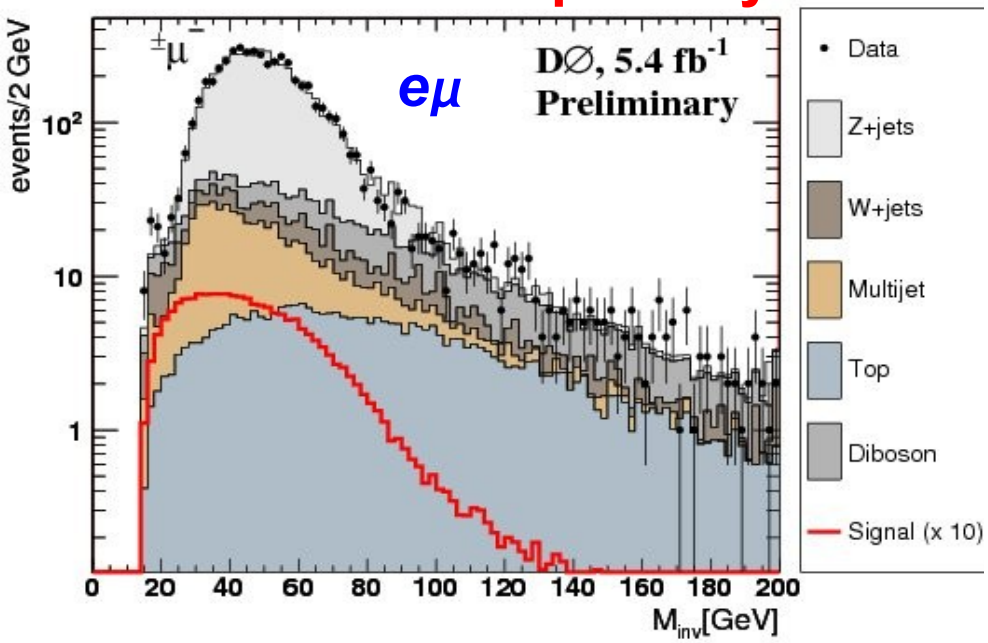
From data

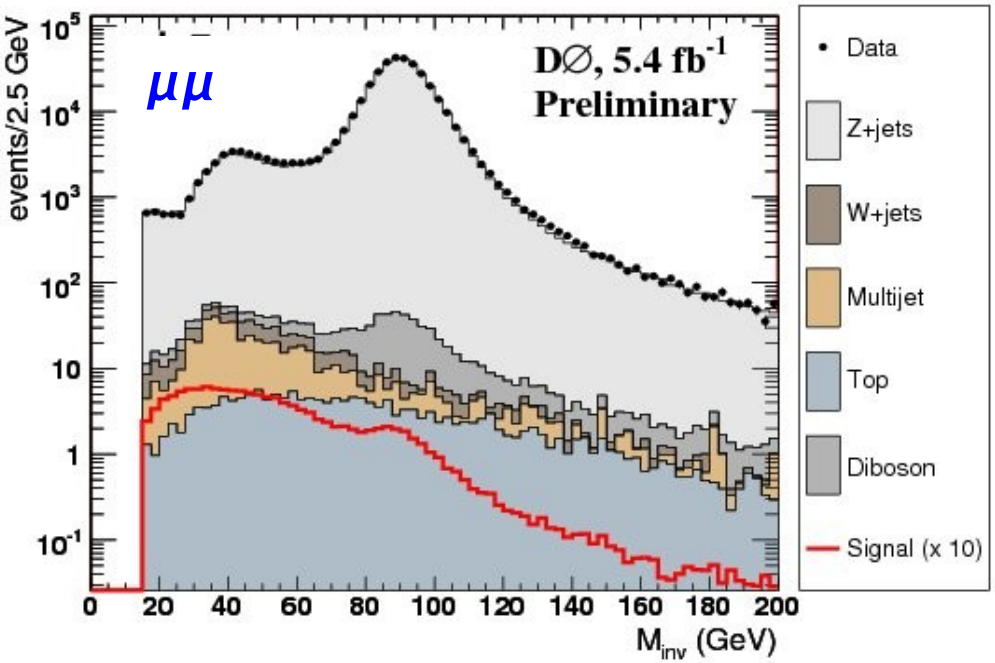
Preselection

- Two isolated, oppositely charged leptons with p_T
  - 15, 15 GeV in *ee*
  - 15, 10 GeV in *eμ*
  - 20, 10 GeV in *μμ*
- Invariant mass > 15 GeV

165 GeV Higgs signal, multiplied by 10

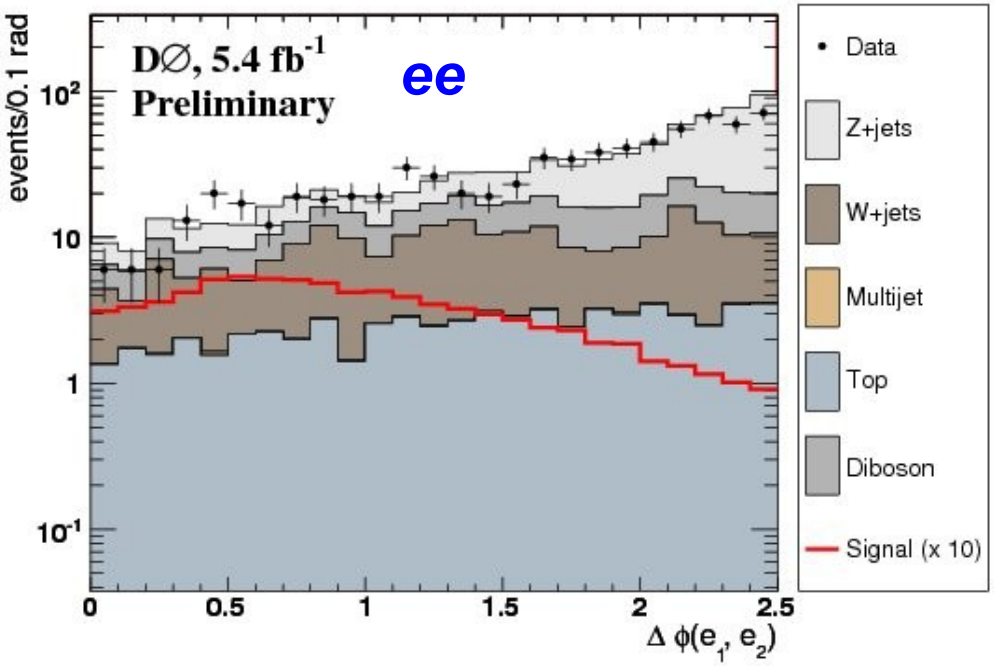


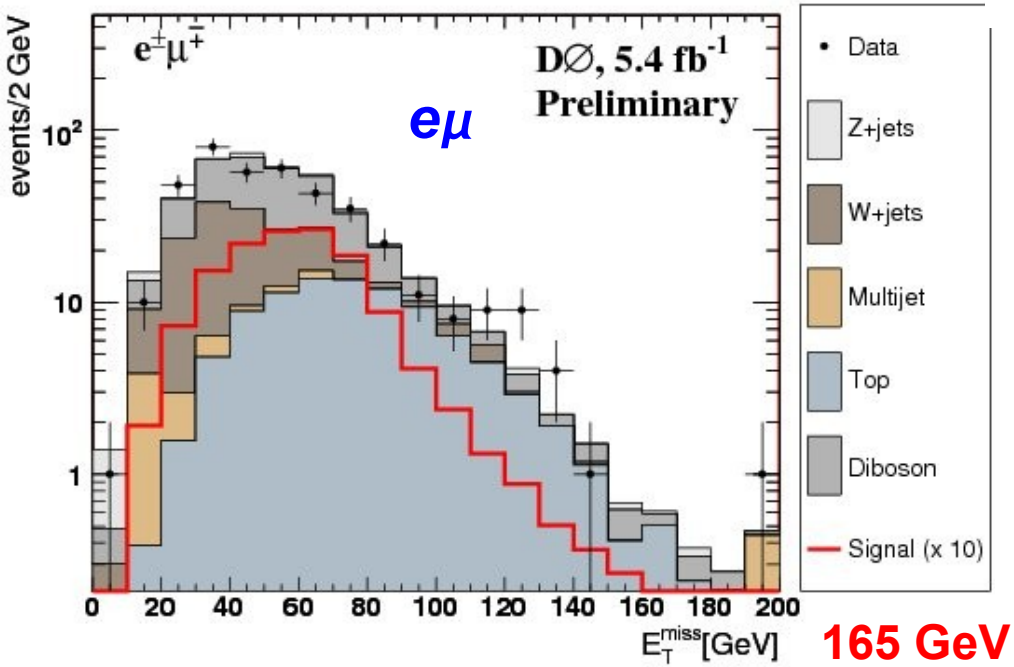


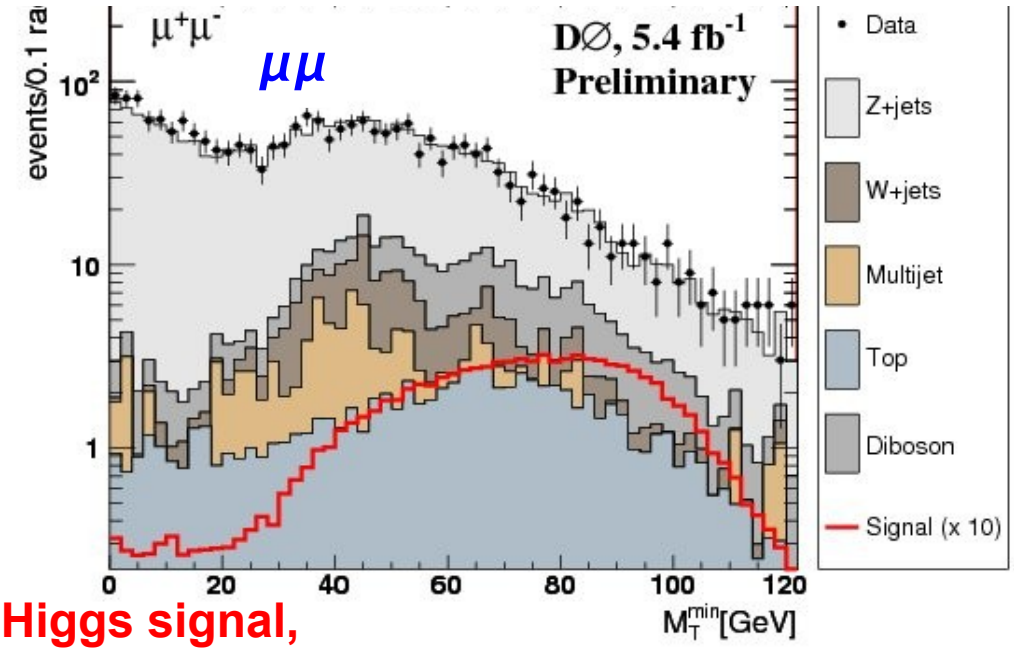


Further Selection

- S/B now ~10^{-5} (10^{-3} for $e\mu$)
- Require
  - $\Delta\phi$ between leptons < 2.0
  - MET > 20 GeV (25 in $\mu\mu$)
  - Scaled MET > 6 GeV (ee and $e\mu$ only)
  - Minimum transverse mass > 20 GeV
- S/B now ~10^{-2}



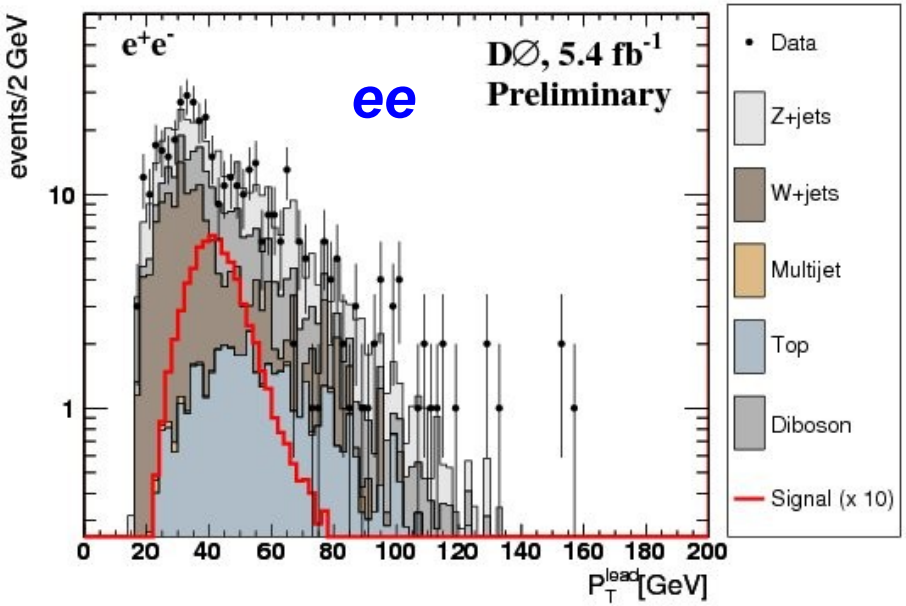


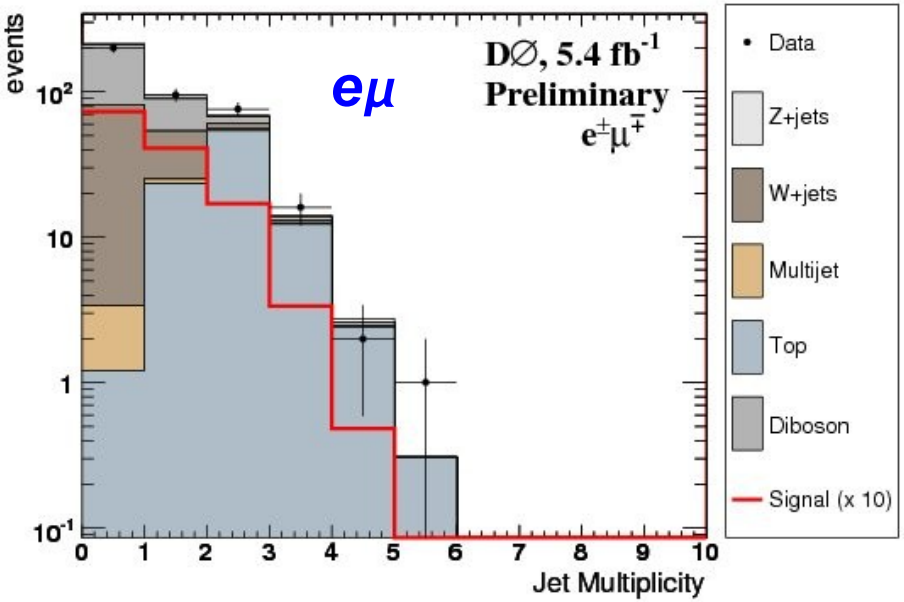


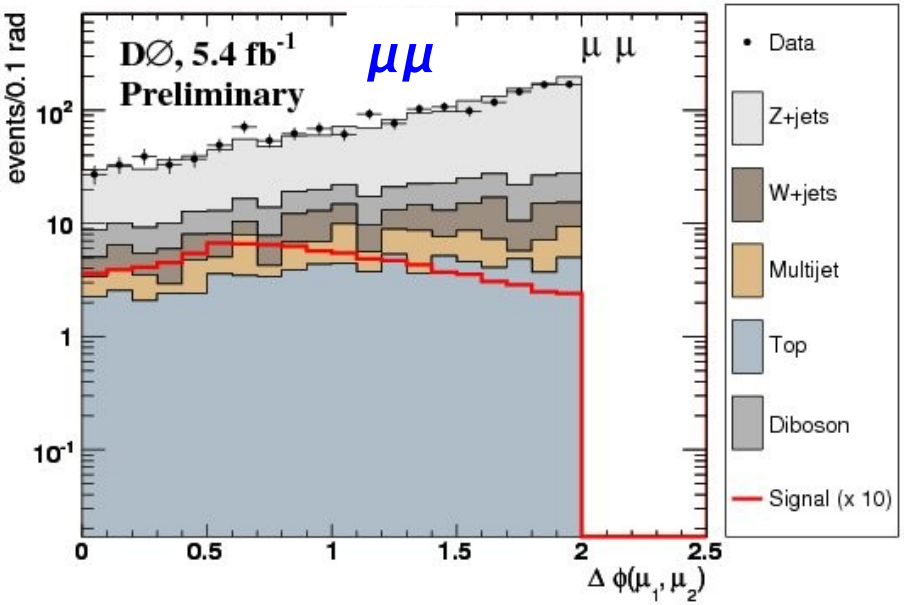
165 GeV Higgs signal, multiplied by 10

Multivariate Selection

- Multivariate technique to further separate background
  - Neural Network (NN)
  - 12 input variables
    topological and kinematic
- A new NN is trained for each Higgs mass considered

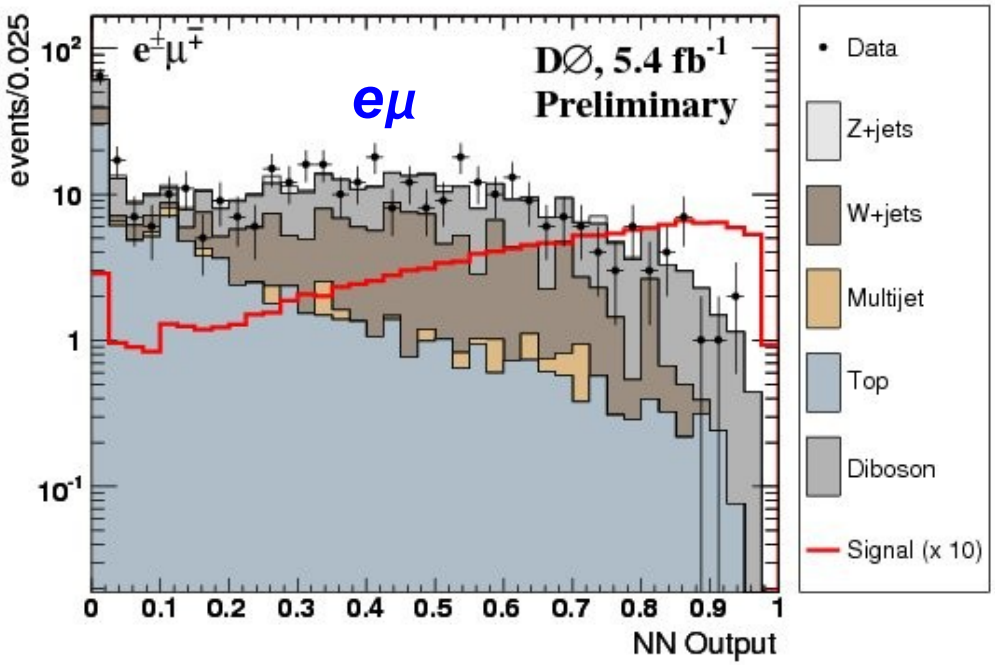


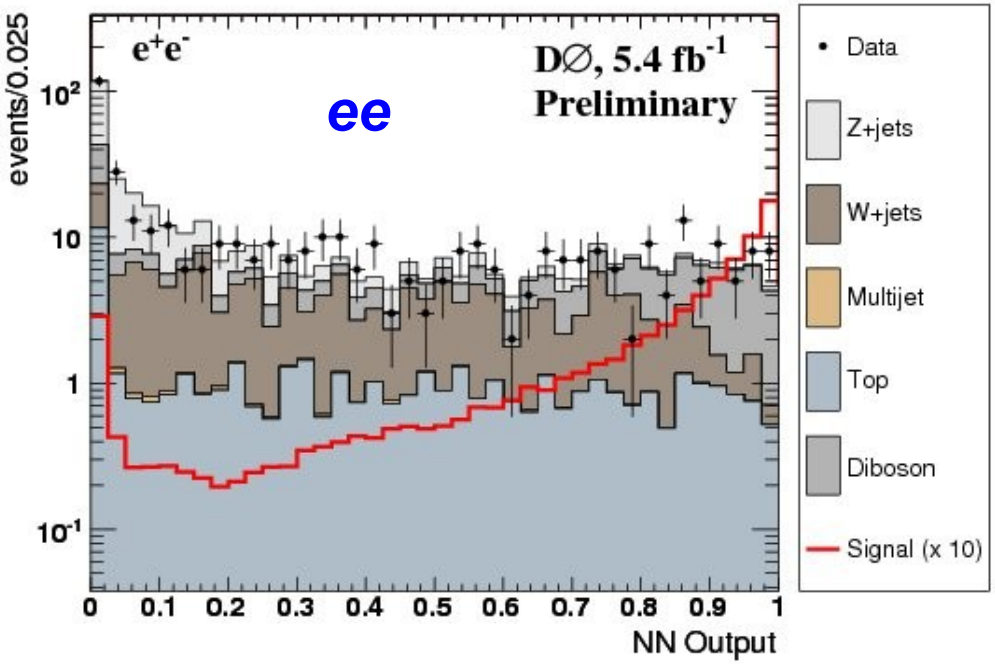


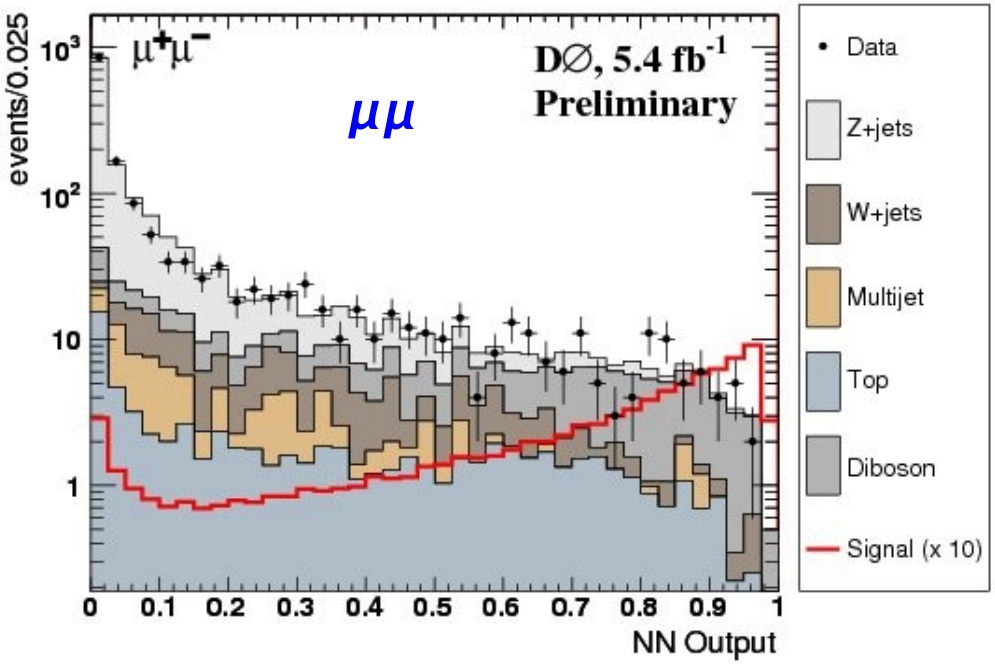


165 GeV Higgs signal, multiplied by 10

Multivariate Results (I)

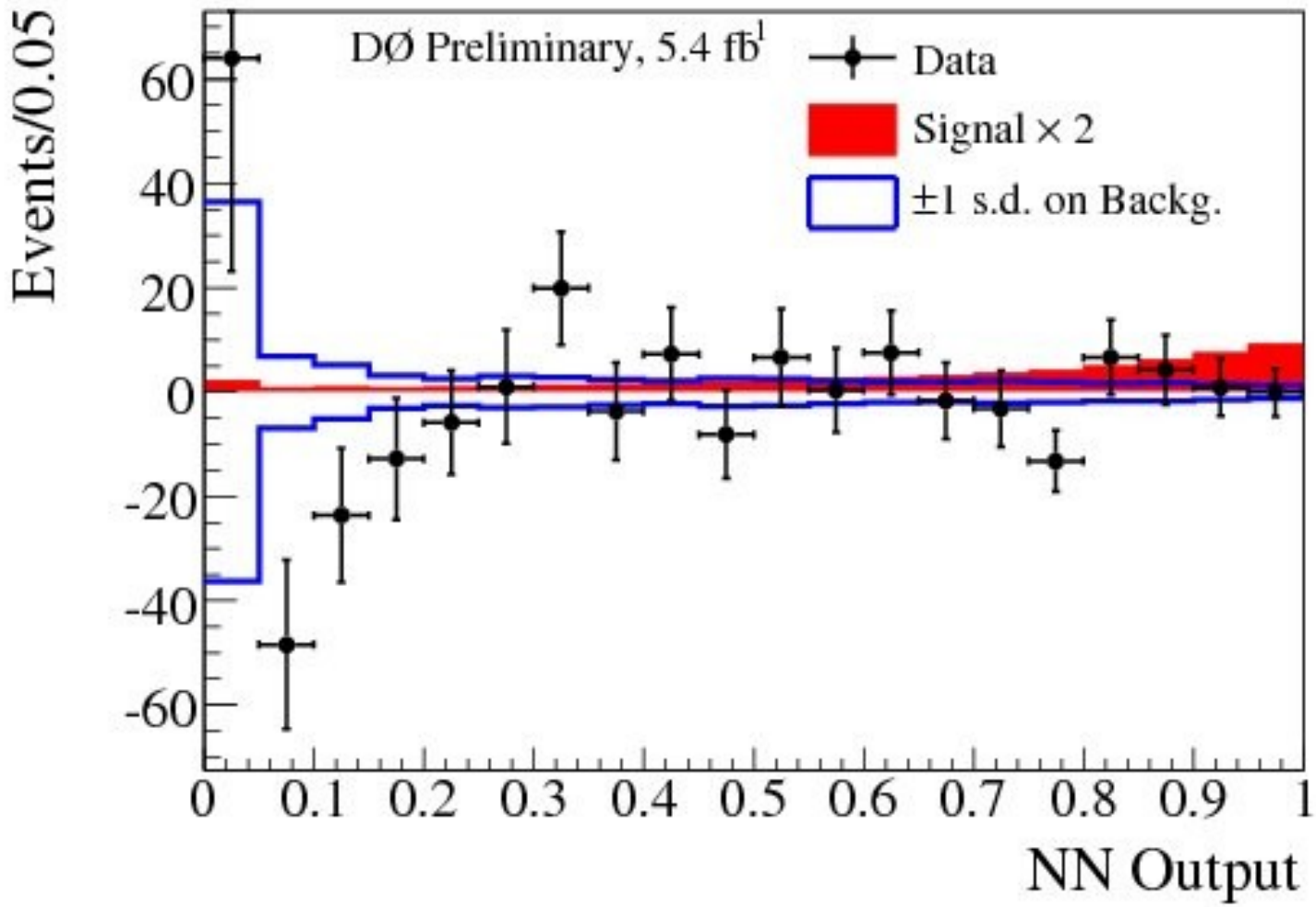






165 GeV Higgs signal, multiplied by 10

Multivariate Results (II)



Background-subtracted neural network output for all three channels combined for a Higgs mass of 165 GeV

Systematic Uncertainties

Sample of systematics considered

Systematic Uncertainty	Type	Value
Jet Energy Scale	Shape & Norm	3-17
Jet ID Efficiency	Shape & Norm	6-18
Jet Resolution	Shape & Norm	2
Cross Sections	Flat Norm	6-10
Multijet Background	Flat Norm	2-20
Parton Distribution Function	Flat Norm	8
Lepton ID	Flat Norm	2.5-4
Lepton Momentum Scale	Shape & Norm	2-8
p_T of WW/H/Z	Shape & Norm	1-5
Luminosity	Flat Norm	6.1

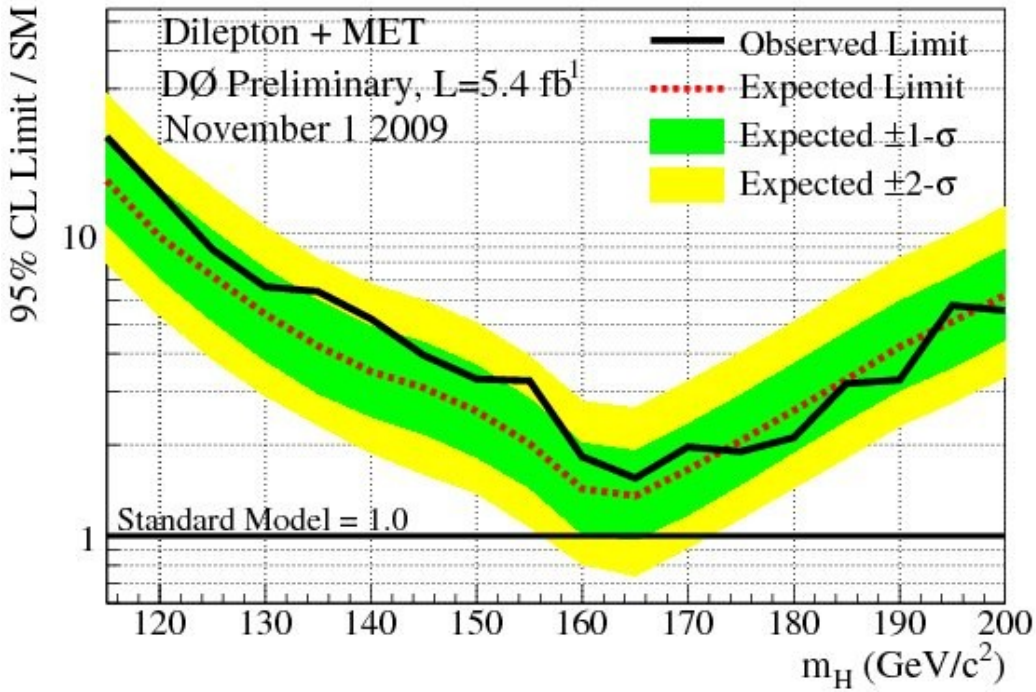
Relative uncertainty in %

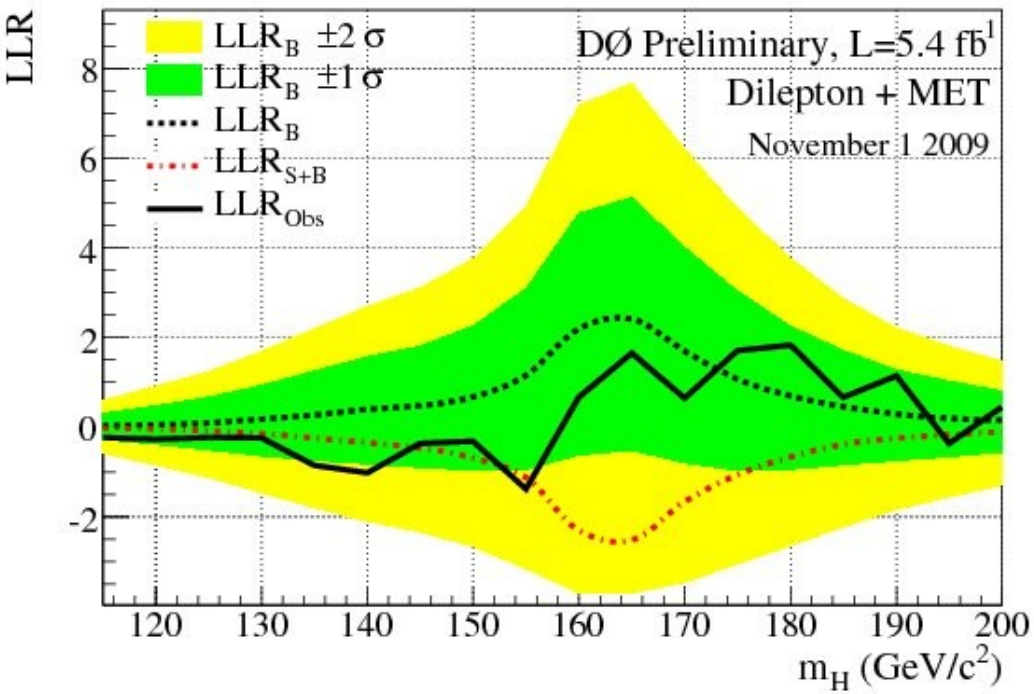
WW p_T – central value from MC@NLO, $\pm 1\sigma$ from MC@NLO studies

Higgs p_T – Central value from Sherpa, $\pm 1\sigma$ from Pythia

Z p_T – Central value from DØ measurement, $\pm 1\sigma$ from Alpgen

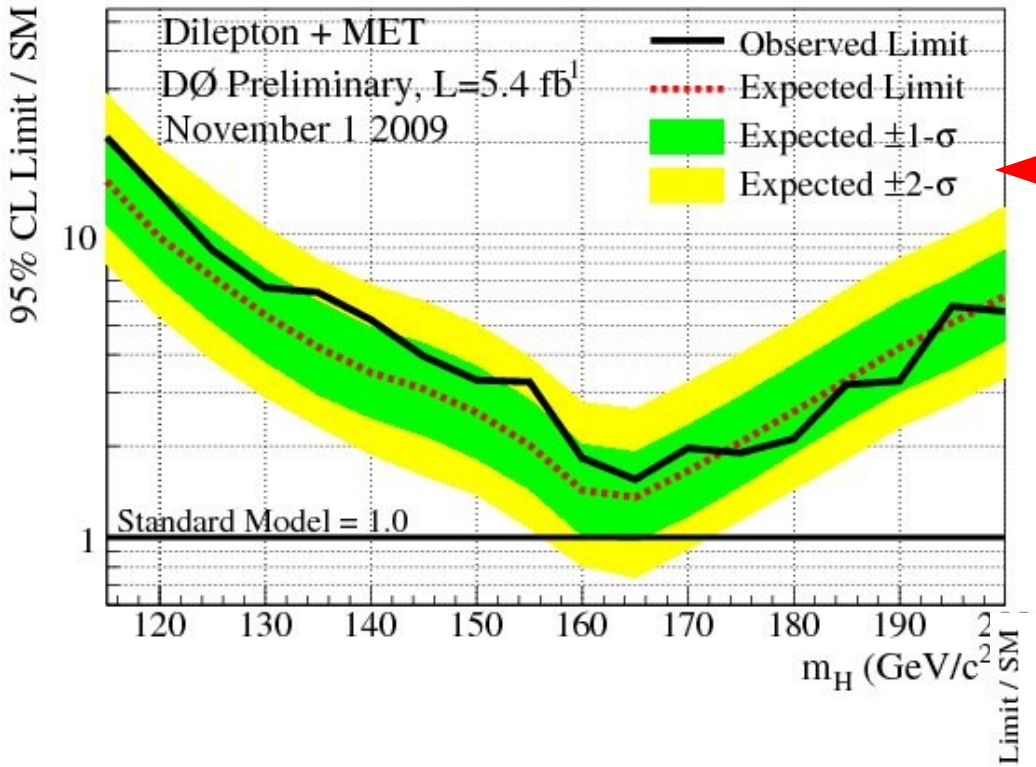
Limit Setting





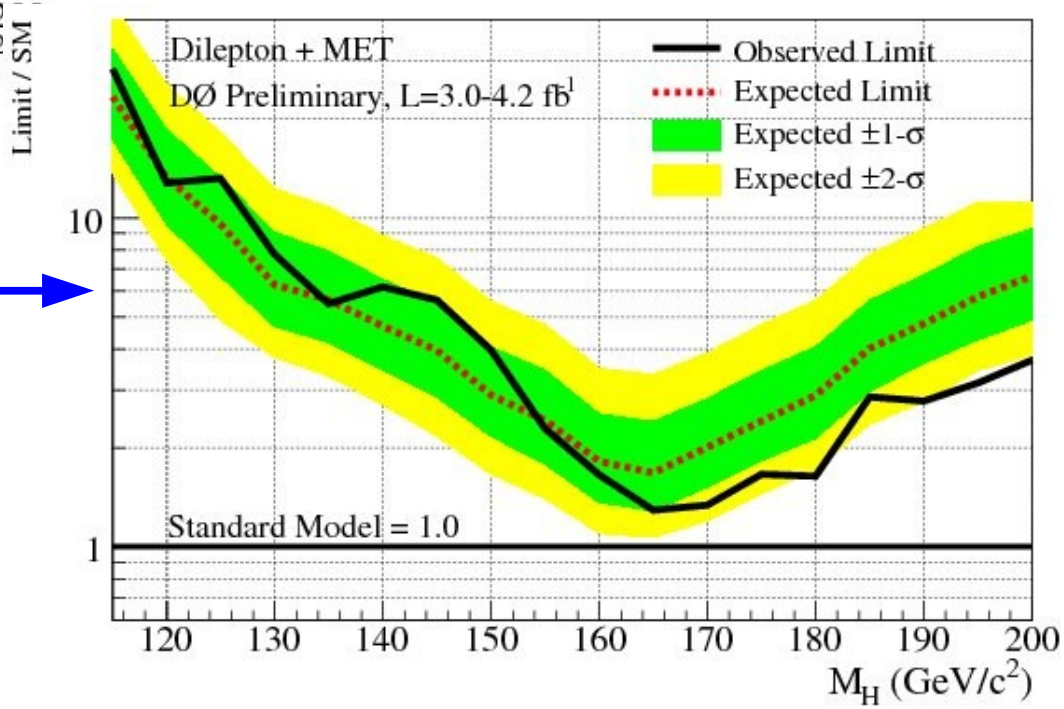
Limit at 165 GeV
1.36 (expected)
1.55 (observed)

Comparison to Previous Result (I)

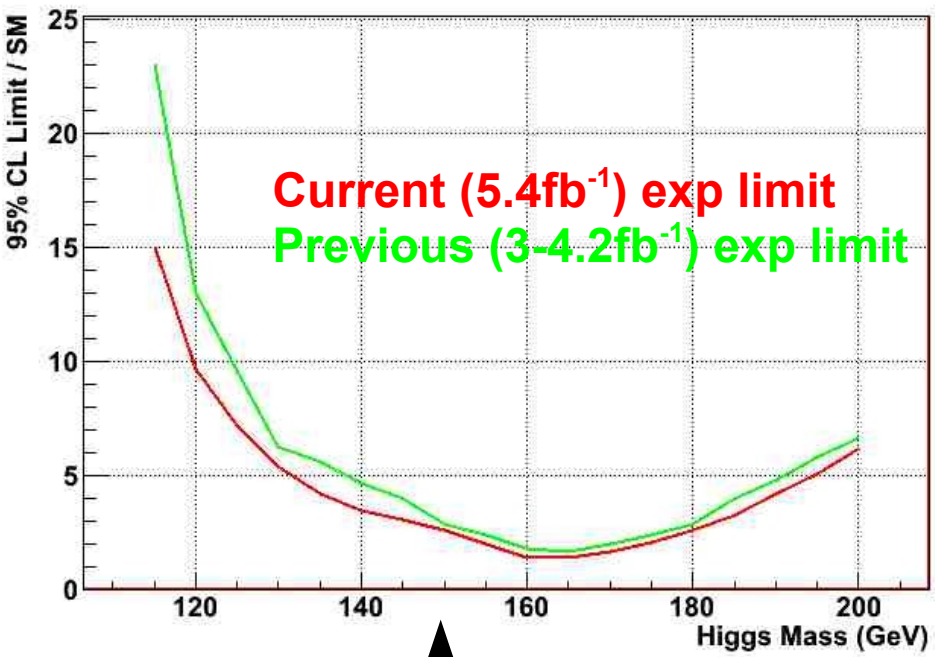


Current result at 165 GeV
1.36 (expected)
1.55 (observed)

Previous result at 165 GeV
1.7 (expected)
1.3 (observed)



Comparison to Previous Result (II)

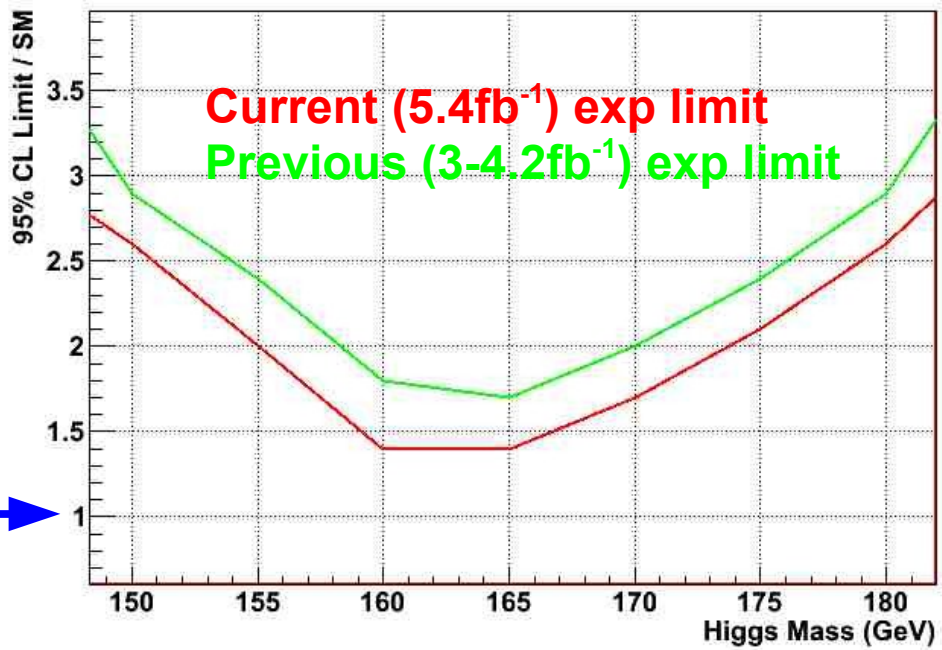


Two reasons for change in observed limit:

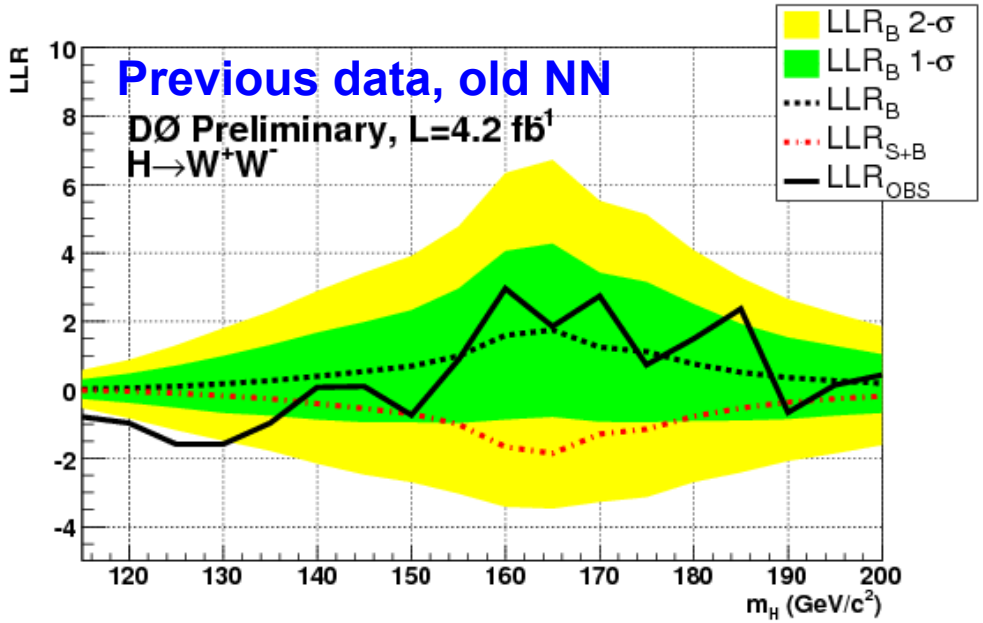
- **Increase in data sample (1.2 fb^{-1} in *ee*, *eμ*; 2.4 fb^{-1} in *μμ*)**
- **Change in neural network**

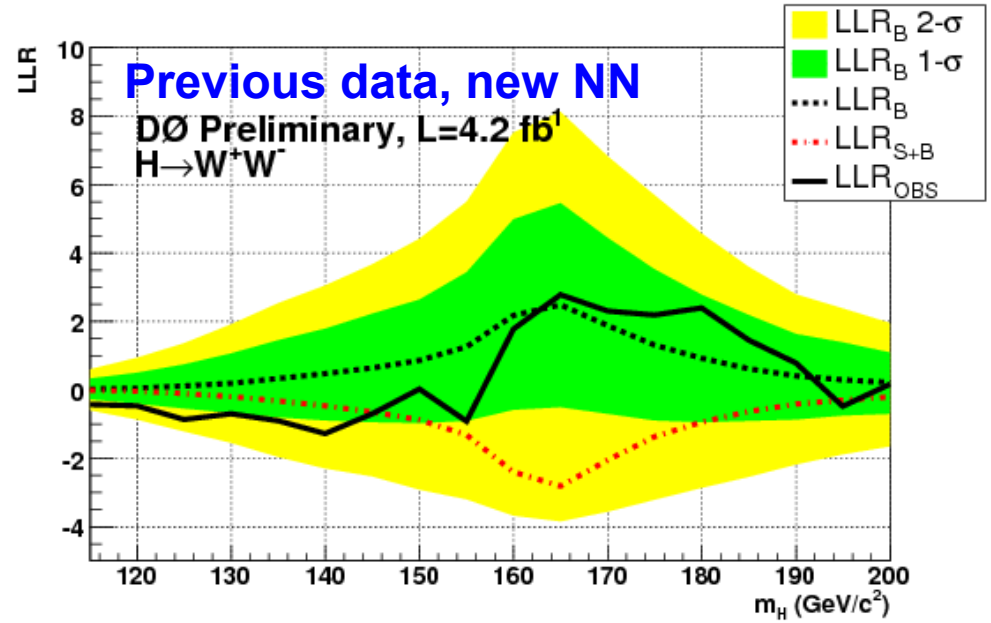
Expected limit shows improvement across entire mass range

15-20% improvement over most sensitive mass range

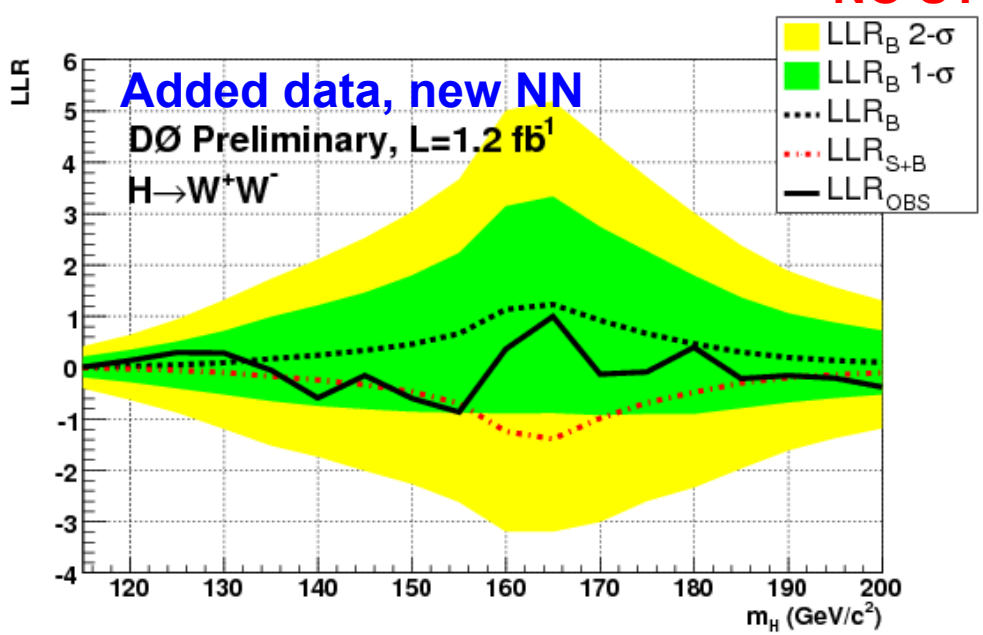


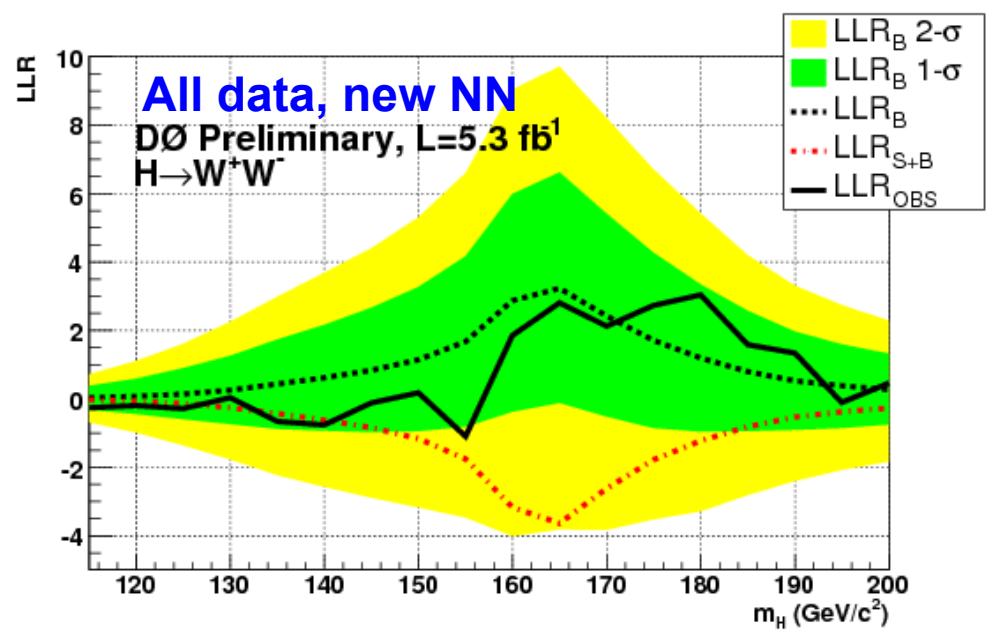
Comparisons (No Systematics!)





NO SYSTEMATICS!





The DØ Higgs Limit Combination

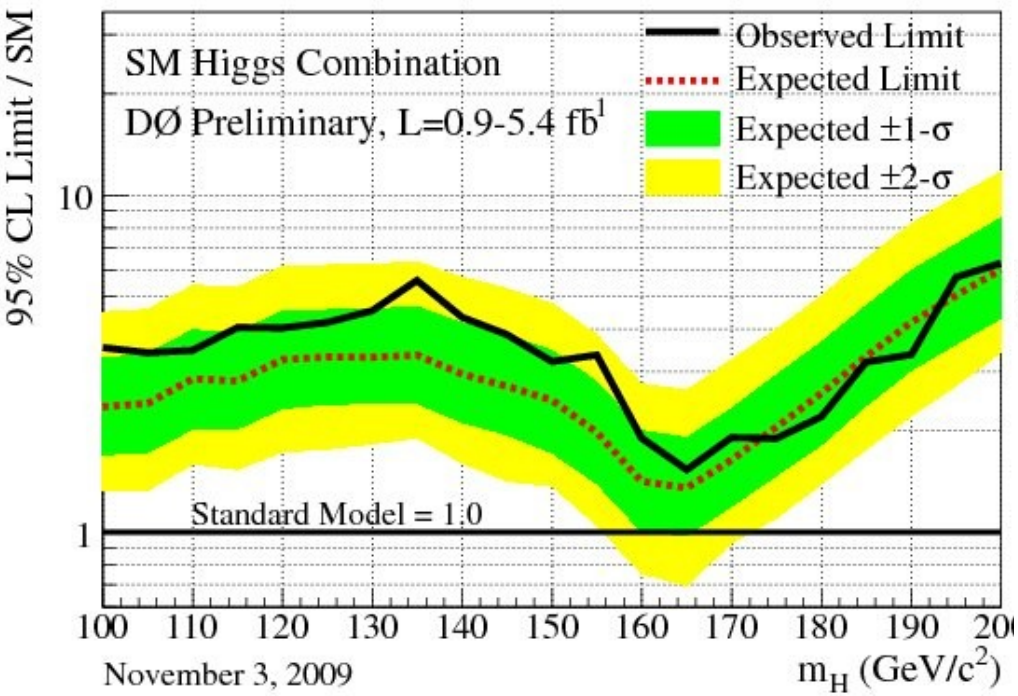
The DØ Combination

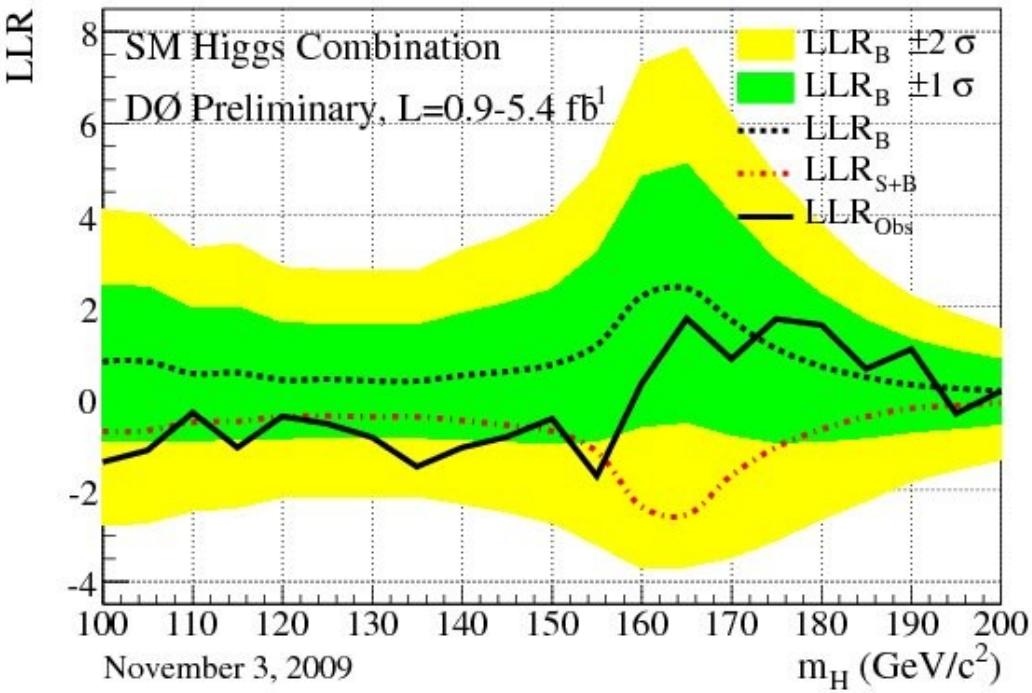
- The results of all SM Higgs searches are combined
  - Results use from 2.1 – 5.4 fb^{-1} of data
  - A total of 54 analysis subsets used, all are mutually exclusive
- Covers a Higgs mass range from 100-200 GeV

Updated results

Channel	Data Epoch	Luminosity (fb^{-1})	Final Variable	# Sub-Channels
$WH \to \ell\nu b\bar{b}$, ST/DT, W+2 jet	Run IIa+Run IIb	5.0	NN discriminant	8
$WH \to \ell\nu b\bar{b}$, ST/DT, W+3 jet	Run IIa+Run IIb	5.0	Dijet Mass	8
$H+X \to \tau\tau b\bar{b}/q\bar{q}\tau\tau$	Run IIa	1.0	NN discriminant	1
$H+X \to \tau\tau b\bar{b}/q\bar{q}\tau\tau$	Run IIb	3.9	DTree discriminant	1
$ZH \to \nu\bar{\nu}b\bar{b}$, ST/DT	Run IIa+Run IIb	5.2	DTree discriminant	4
$ZH \to e^+e^-b\bar{b}$, ST/DT	Run IIa	1.1	NN discriminant	2
$ZH \to \mu^+\mu^-b\bar{b}$, ST/DT	Run IIa	1.1	NN discriminant	2
$ZH \to e^+e^-b\bar{b}$, ST/DT	Run IIb	3.1	DTree discriminant	6
$ZH \to \mu^-\mu^-b\bar{b}$, ST/DT	Run IIb	3.1	DTree discriminant	2
$ZH \to \mu^\pm$+track $b\bar{b}$, ST/DT	Run IIa+Run IIb	4.2	DTree discriminant	2
$WH \to WW^+W^-$	Run IIa	1.1	2-D Likelihood	3
$WH \to WW^+W^-$	Run IIb	2.5	1-D Likelihood	3
$H \to W^+W^-$ ($\mu^+\mu^-$)	Run IIa+Run IIb	5.4	NN discriminant	1
$H \to W^+W^-$ ($e^\pm\mu^\mp$)	Run IIa+Run IIb	5.4	NN discriminant	1
$H \to W^+W^-$ (e^+e^-)	Run IIa+Run IIb	5.4	NN discriminant	1
$H \to \gamma\gamma$	Run IIa+Run IIb	4.2	Di-photon Mass	1
$t\bar{t}H \to t\bar{t}b\bar{b}$	Run IIa+Run IIb	2.1	Scaled H_T	12

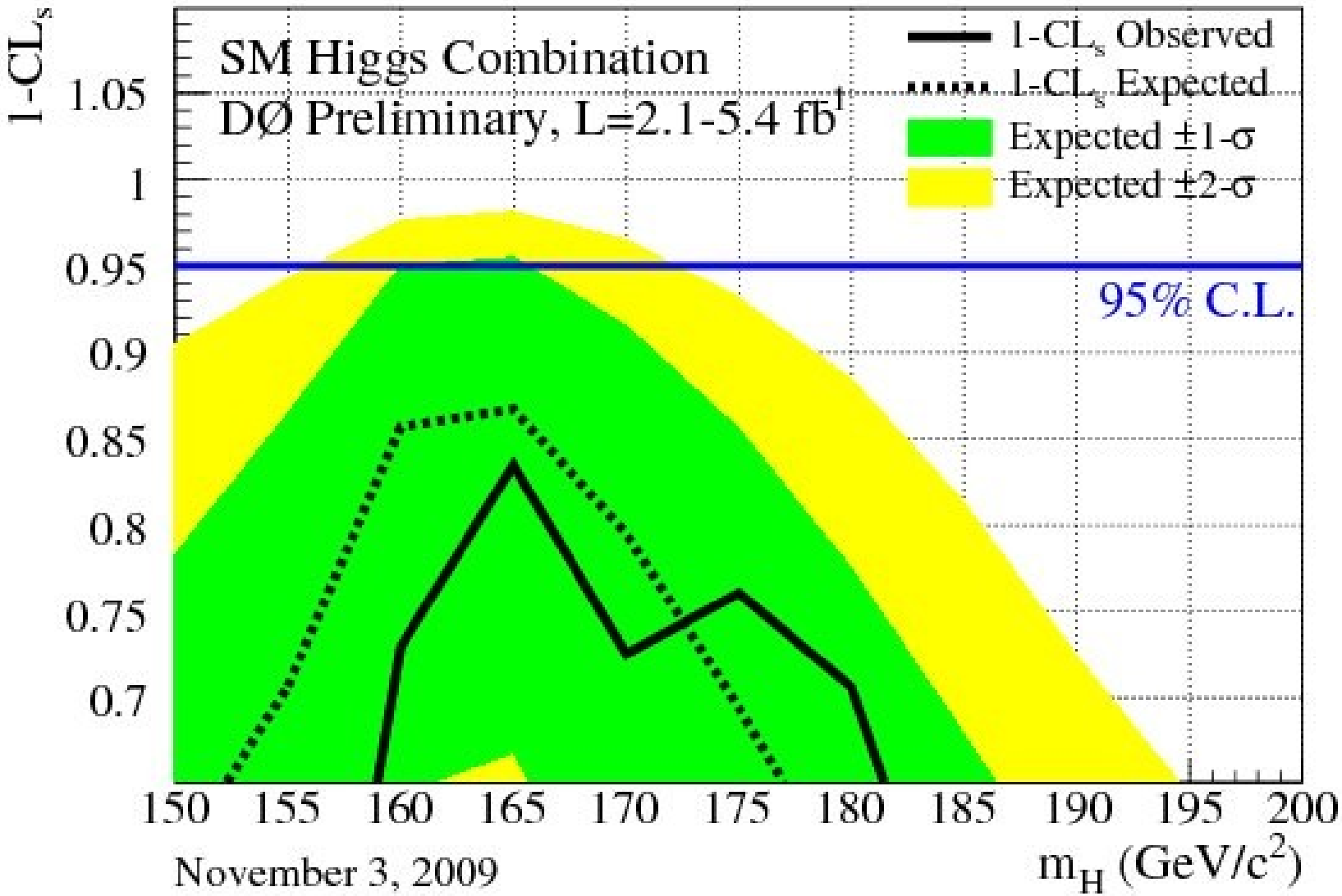
The Combined Limit





Limit at 115 GeV
2.80 (expected)
4.05 (observed)
Limit at 165 GeV
1.35 (expected)
1.53 (observed)

Exclusion Probability



Summary

- The Tevatron continues to take data and continues to search for the Higgs boson
  - Our thanks to Fermilab, the accelerator division, and the many funding agencies for making this possible
- An update to the $ZH \rightarrow \nu\nu bb$ search has excluded a SM Higgs with a cross section of 3.7 times the SM value (at m_H = 115 GeV)
- An update to the dilepton plus MET search has excluded a SM Higgs with a cross section of 1.55 times the SM value (at m_H = 165 GeV)
- Both analysis to be submitted for publication in ~weeks
- Combining all Higgs searches, we have excluded 4.05 (at m_H = 115 GeV) and 1.53 (at m_H = 165 GeV)
- A new Tevatron combination expected for in next few weeks

All DØ Higgs results available at

http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm