The Search for the Brout-Englert-Higgs Boson

New Results from the DØ Experiment

Joseph Haley
Northeastern University

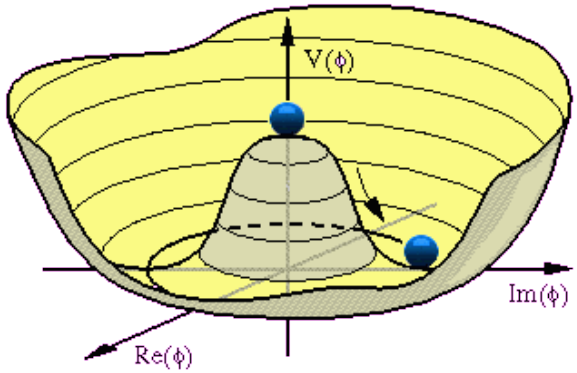
On Behalf of the
DØ Collaboration

Rencontres de Moriond
7 March 2012, La Thuile, Italy

Standard Model

- How can we break the EW symmetry?
- ⇒ The Brout-Englert-Higgs mechanism

F. Englert and R. Brout, Phys. Rev. Lett. **13**, 321 (1964).
P. Higgs, Phys. Rev. Lett. **13**, 508 (1964).
G. Guralnik, C.R. Hagen, T.W.B. Kibble, Phys. Rev. Lett. **13**, 585 (1964).



- Introduce complex doublet field
- With a "wine bottle" potential
- Expand around the ground state
  - ⇒ Three degrees of freedom give mass to the W^+, W^- , and Z bosons
    ⇒ One massive scalar boson (the "Higgs" boson)
    ⇒ Fermions obtain mass via coupling to BEH field

- We need to find this massive scalar boson to confirm the theory

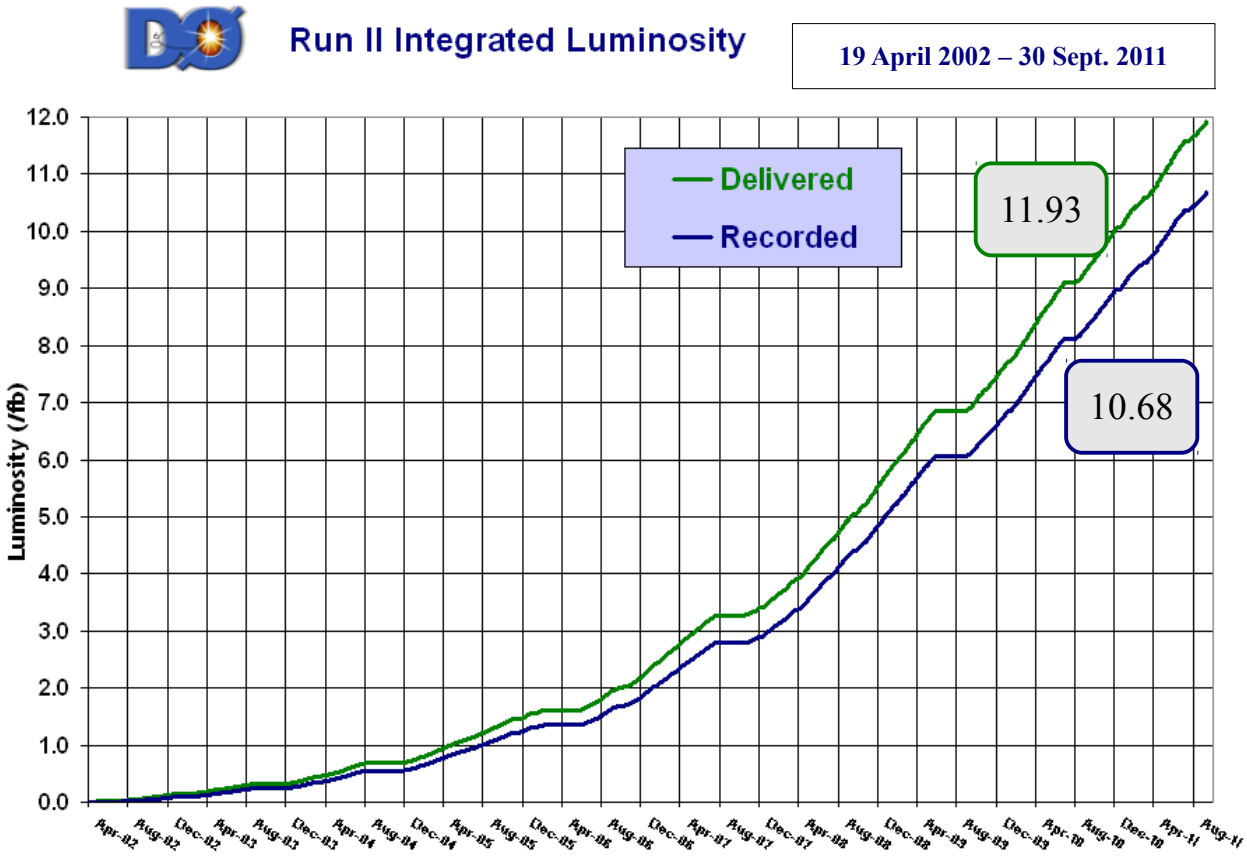
DØ Collaboration

Tevatron

Tevatron

$p\bar{p}$ collider with $\sqrt{s} = 1.96$ TeV

- Shutdown September 30, 2011 after 26 years of outstanding operation
- First superconducting accelerator
- Delivered ~11.9 fb^{-1}
- Recorded ~10.7 fb^{-1}
- Good Data Quality ~9.7 fb^{-1}



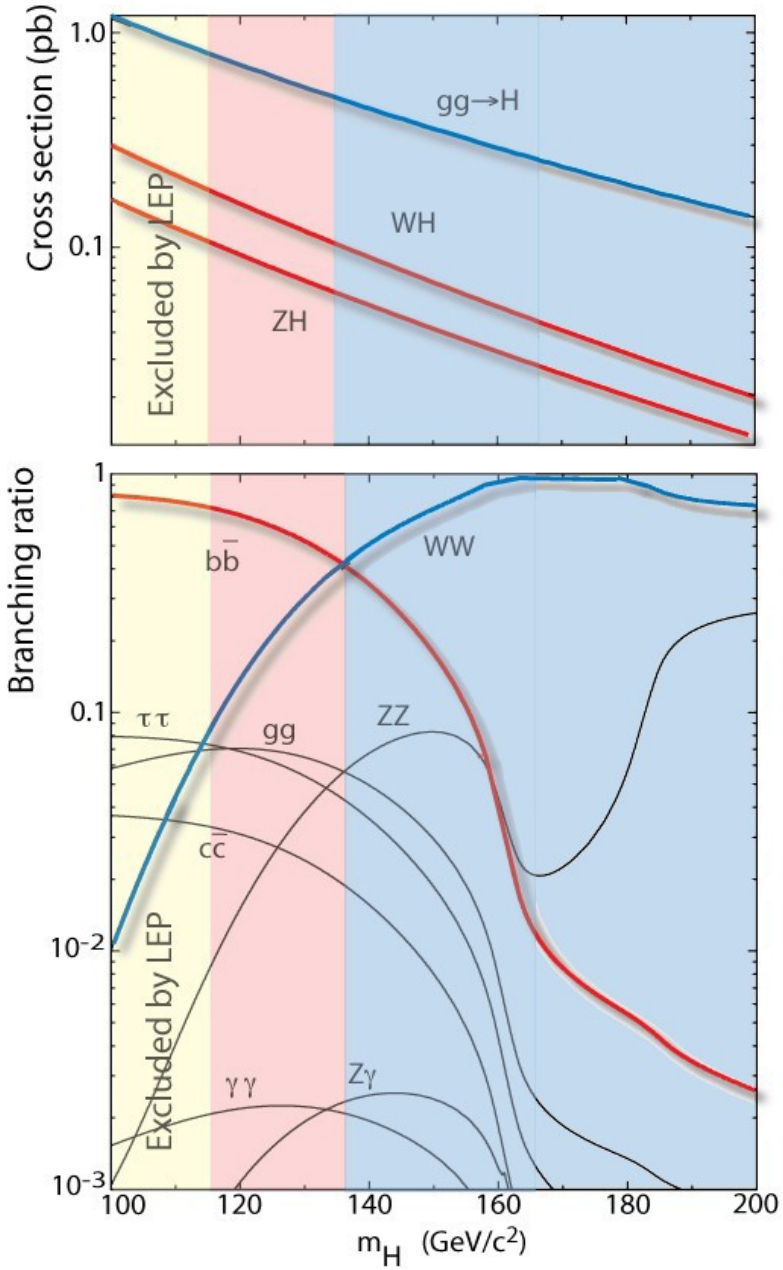
Search Strategy

No single channel has enough sensitivity
⇒ Divide and conquer

- Explore as many final states as possible
- Maximize acceptance
- Separate into sub-channels
  - Different signal purity
  - Different background composition
- Use multivariate techniques
  - Reduce/remove backgrounds
  - Best discrimination for measurement

Put it all back together

- Account for correlations between channels
- Perform statistical tests to see if the data are compatible with SM Higgs signal



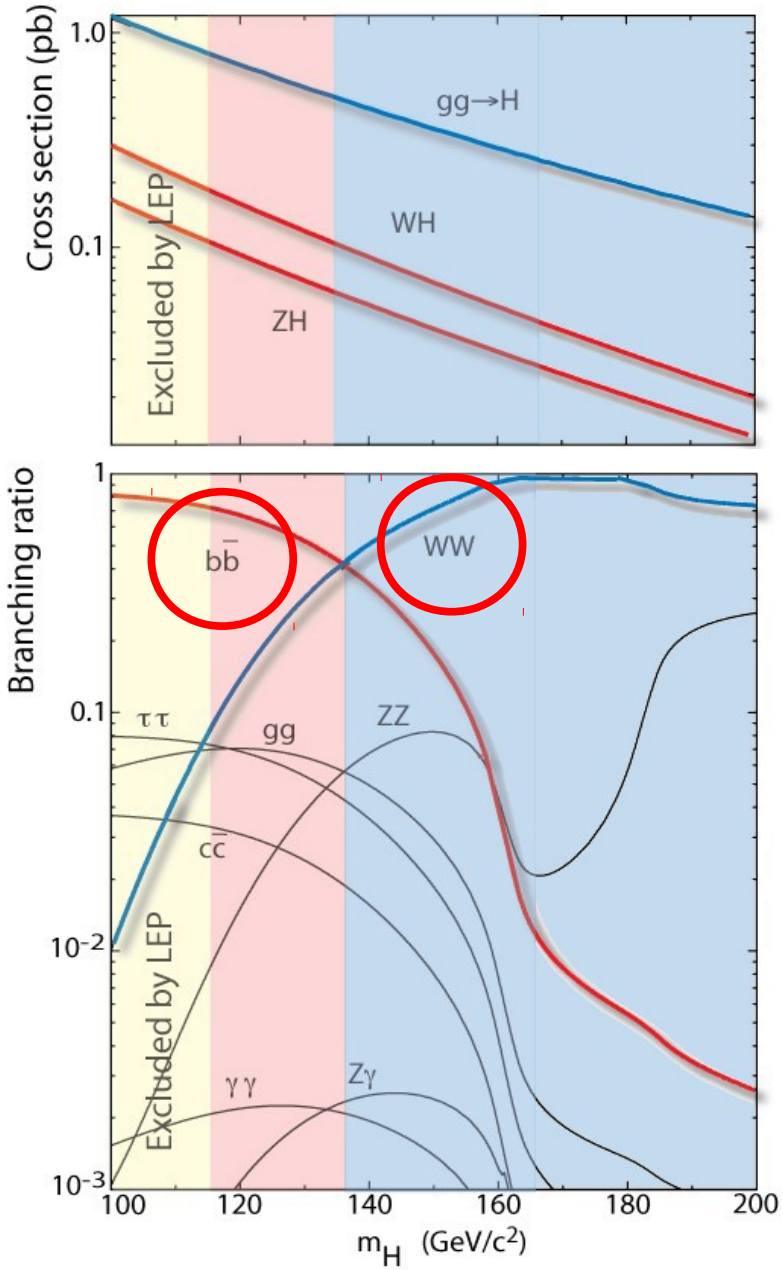
Search Strategy

No single channel has enough sensitivity
⇒ Divide and conquer

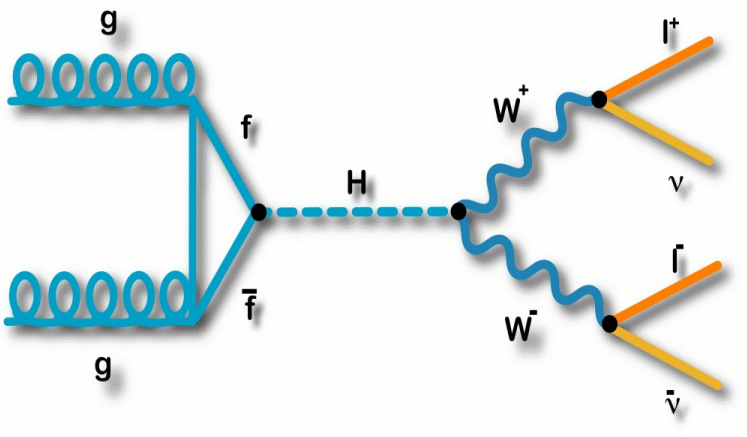
- Explore as many final states as possible
- Maximize acceptance
- Separate into sub-channels
  - Different signal purity
  - Different background composition
- Use multivariate techniques
  - Reduce/remove backgrounds
  - Best discrimination for measurement

Put it all back together

- Account for correlations between channels
- Perform statistical tests to see if the data are compatible with SM Higgs signal



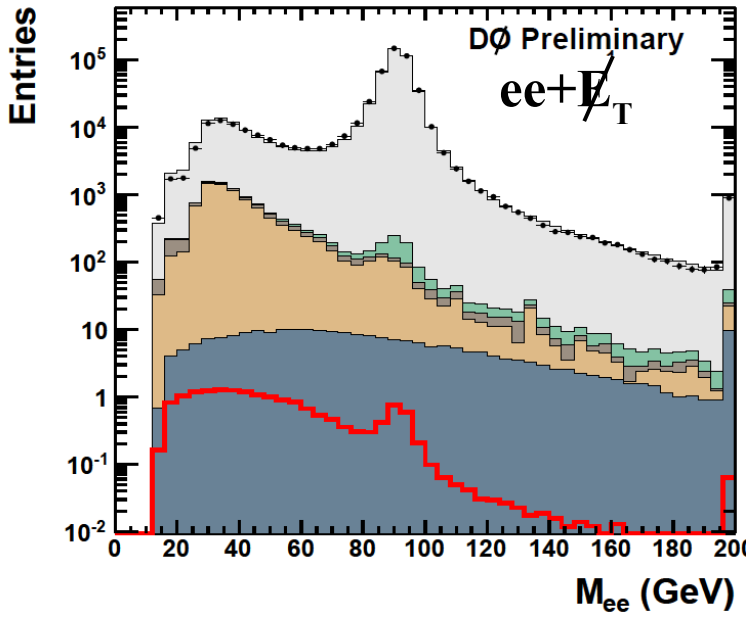
H → WW → lνlν

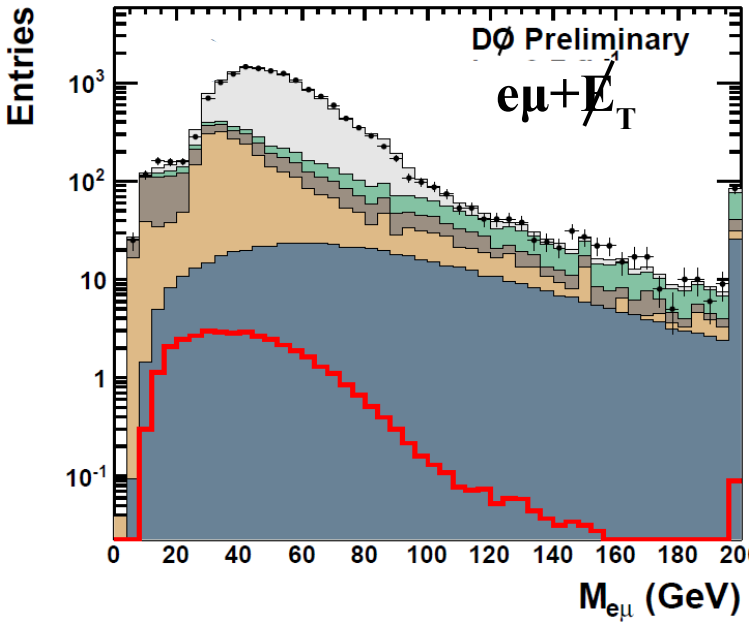


Two opposite charge high-p_T leptons

Sub-channels can optimize for different background compositions

- Lepton flavor
- Jet multiplicity

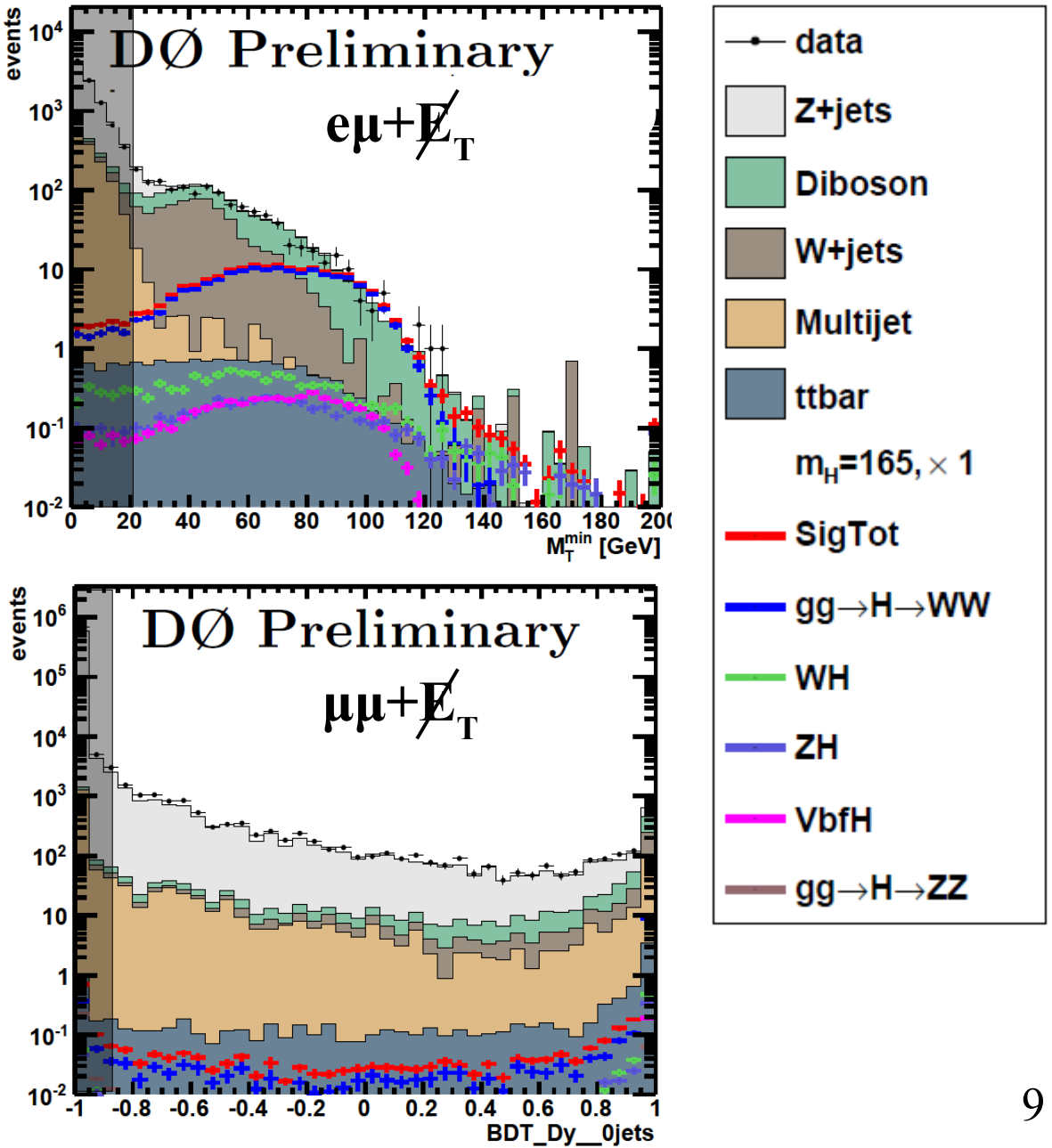




H → WW → lνlν

Discriminating against dominant Z/γ*

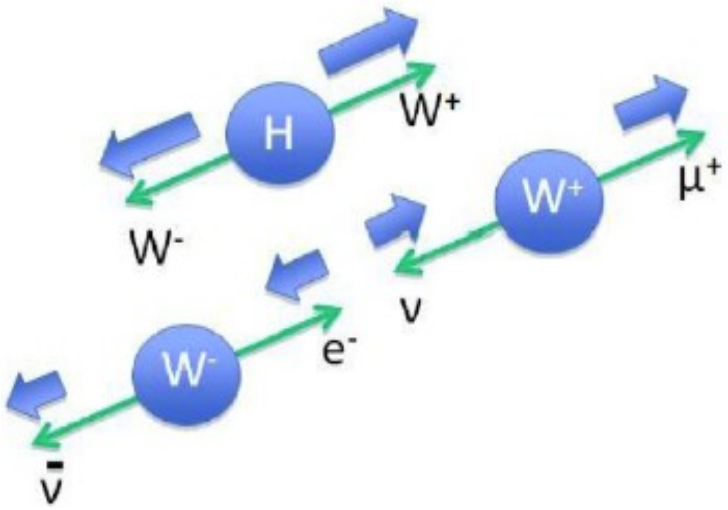
- Z/γ* events have little $\not\!\!E_T$
- eμ uses transverse mass variables
  - Removes 60–90% of background
  - Retains 80–90% of signal
- ee and μμ use multivariate discriminate based on $\not\!\!E_T$
  - Removes 95–99.9% of background
  - Retains 55–80% of signal

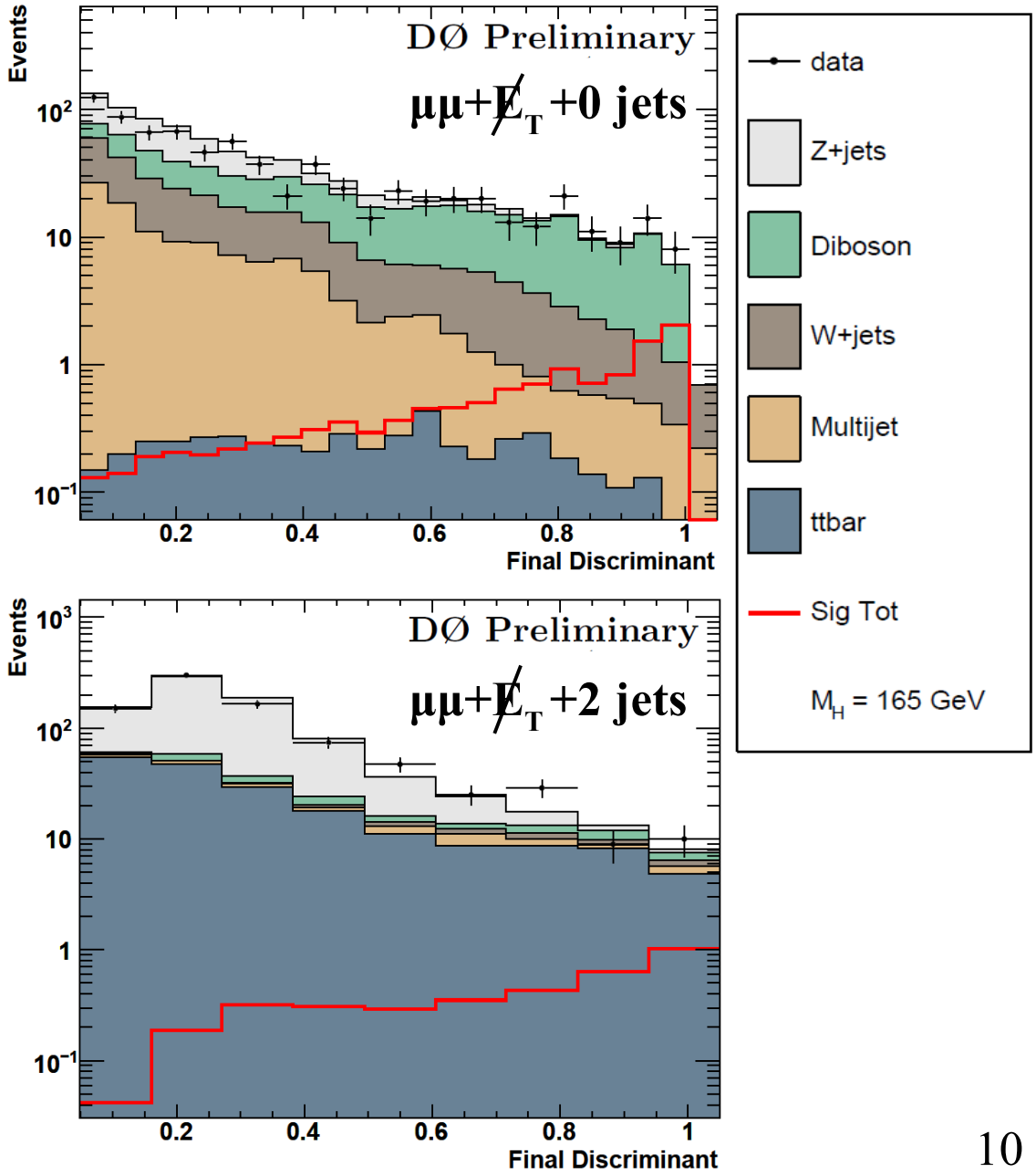


H → WW → lνlν

Final discriminants from multivariate classifiers

- For each sub-channel
- Capitalize on correlations
  - Kinematic differences
  - Spin correlations





Combined Limits for H → WW

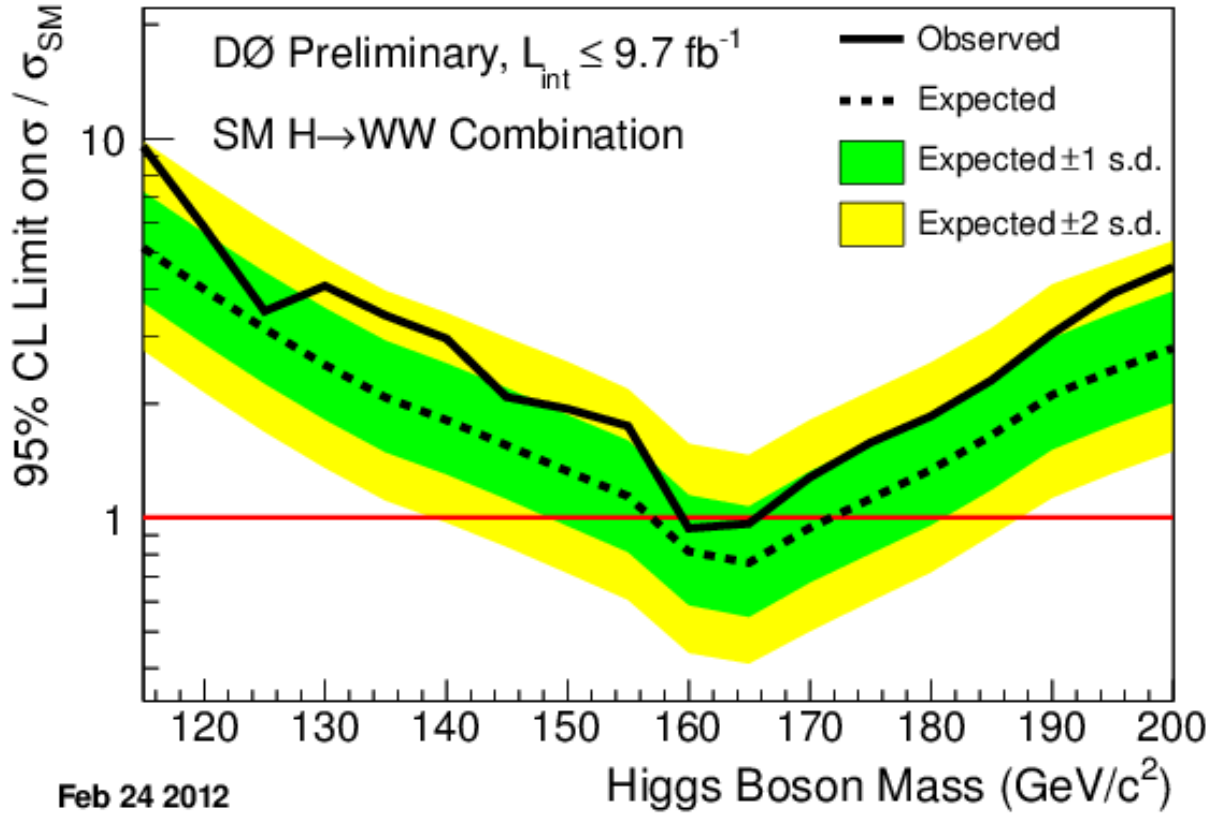
Combining all H → WW channels:

Expected exclusion:

- 157 GeV < m_H < 172 GeV

Observed exclusion:

- 159 GeV < m_H < 166 GeV

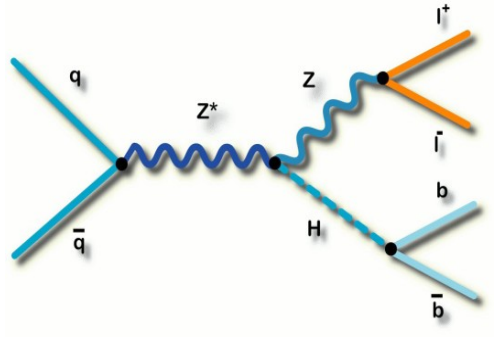


- ~20% more data than previous result ⇒ 9% improvement in sensitivity
- Additional 5% improvement at lower masses

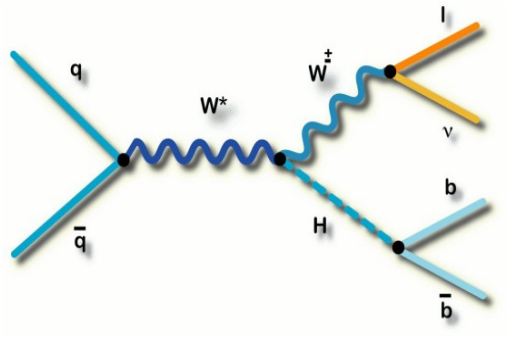
  Improved background modeling, increased acceptance, optimization of discriminants
- *Still* room for improving lepton ID and adding more final states

$H \to b\bar{b}$

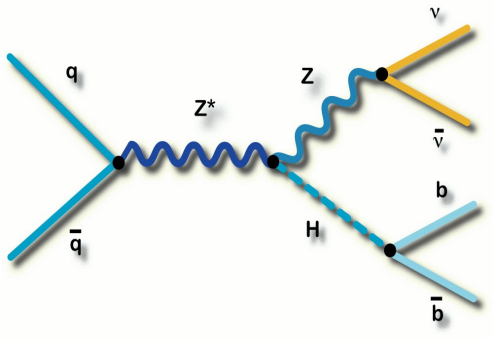
$ZH \to l^+l^-b\bar{b}$



$WH \to l^{\pm}\nu b\bar{b}$

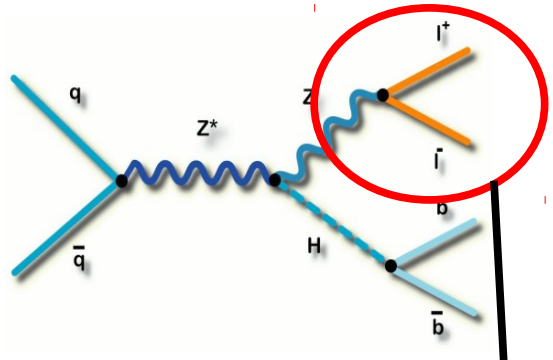


$ZH \to \nu\bar{\nu}b\bar{b}$

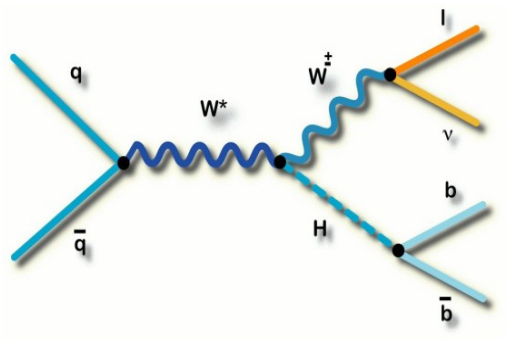


$H \to b\bar{b}$

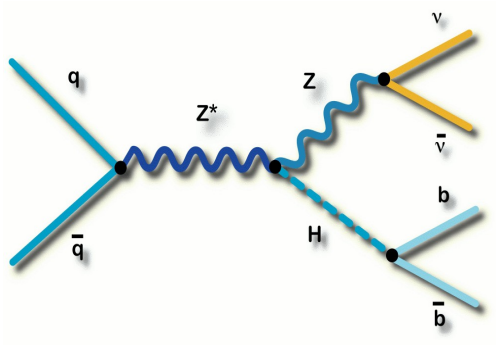
$ZH \to l^+l^-b\bar{b}$



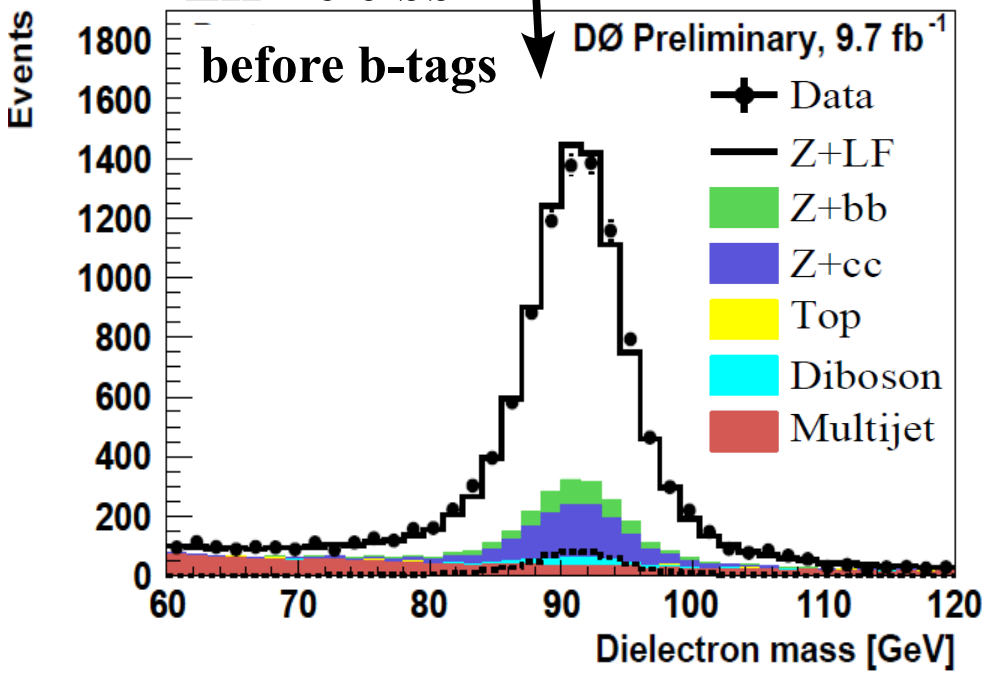
$WH \to l^{\pm}\nu b\bar{b}$



$ZH \to \nu\bar{\nu}b\bar{b}$

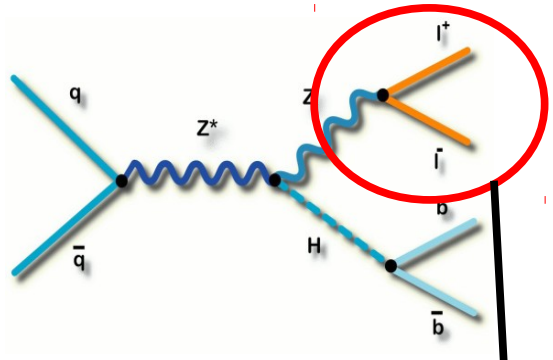


$ZH \to e^+e^-b\bar{b}$

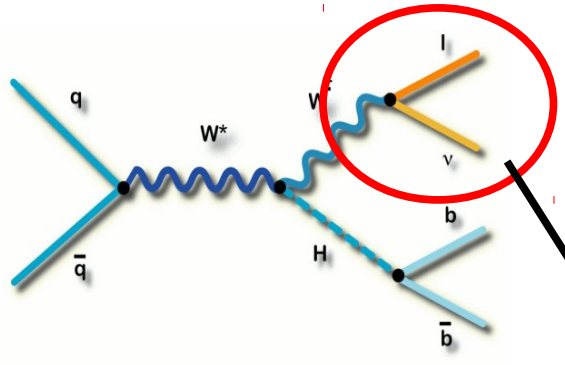


$H \to b\bar{b}$

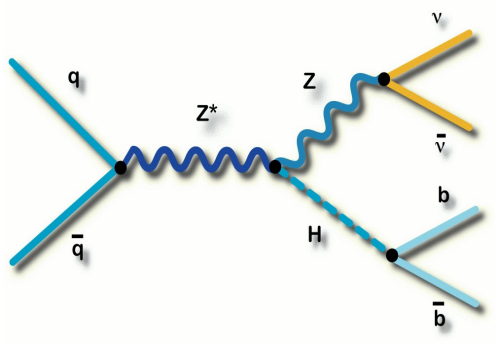
$ZH \to l^+l^-b\bar{b}$



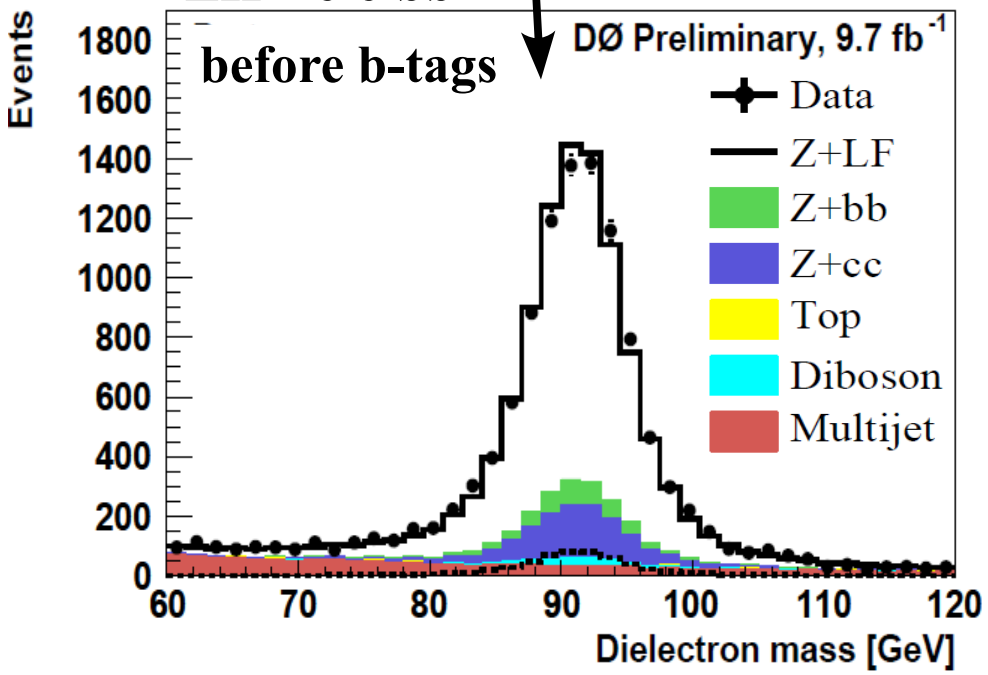
$WH \to l^{\pm}\nu b\bar{b}$

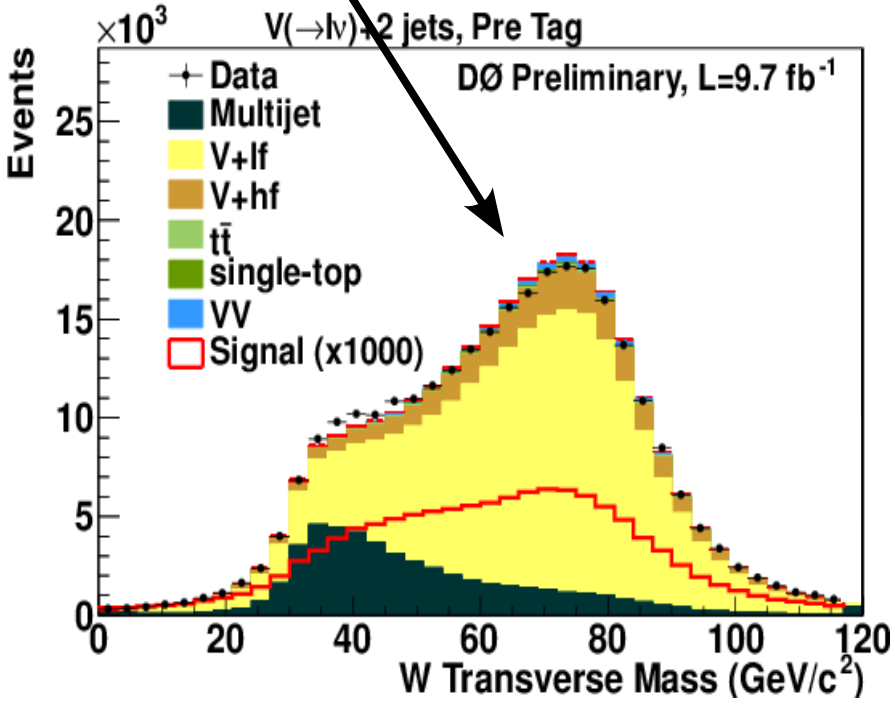


$ZH \to \nu\bar{\nu}b\bar{b}$



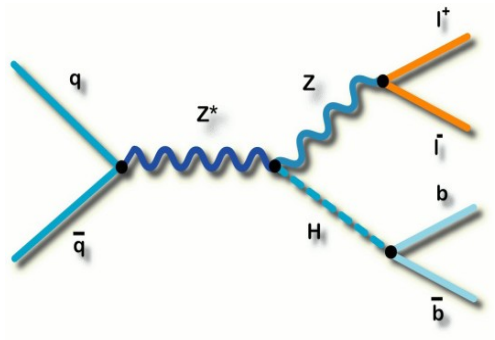
$ZH \to e^+e^-b\bar{b}$



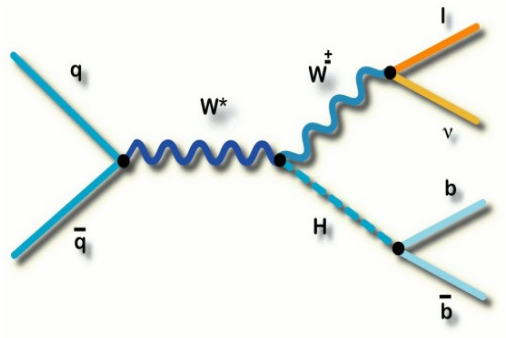


$H \to b\bar{b}$

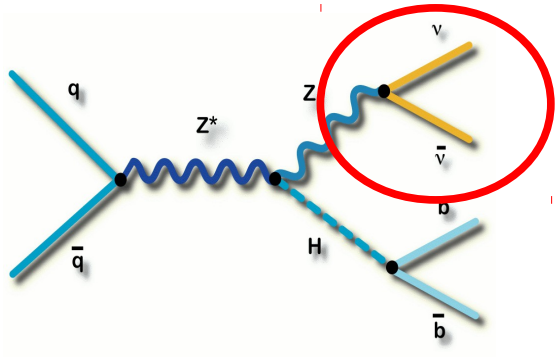
$ZH \to l^+l^-b\bar{b}$



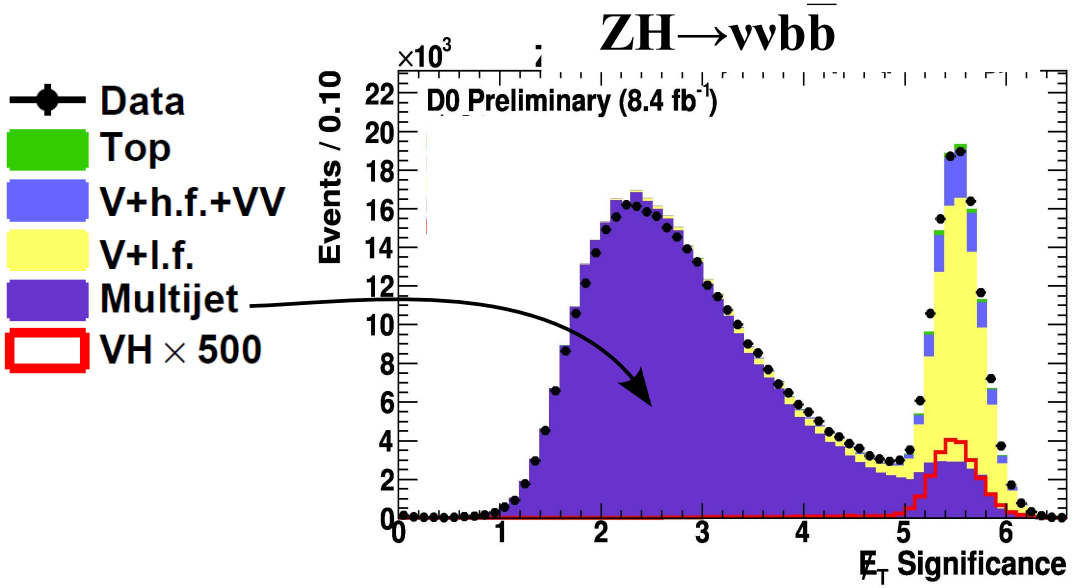
$WH \to l^{\pm}\nu b\bar{b}$



$ZH \to \nu\bar{\nu}b\bar{b}$

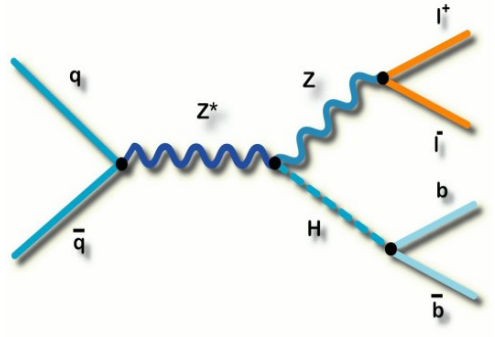


$ZH \to \nu\bar{\nu}b\bar{b}$

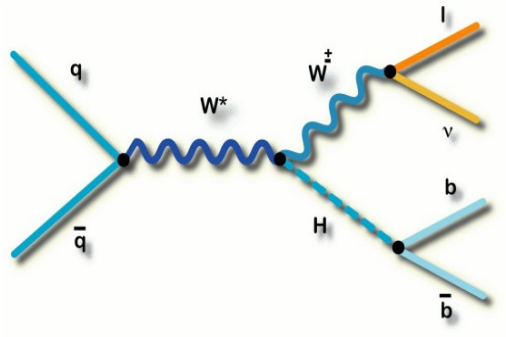


$H \to b\bar{b}$

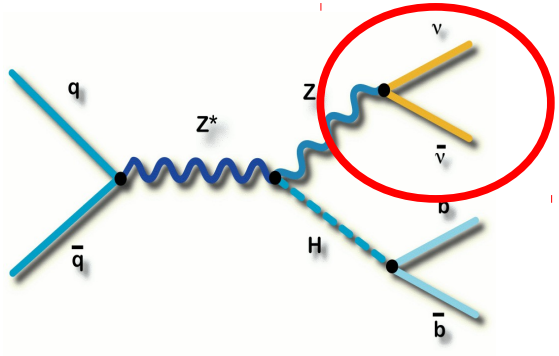
$ZH \to l^+l^-b\bar{b}$

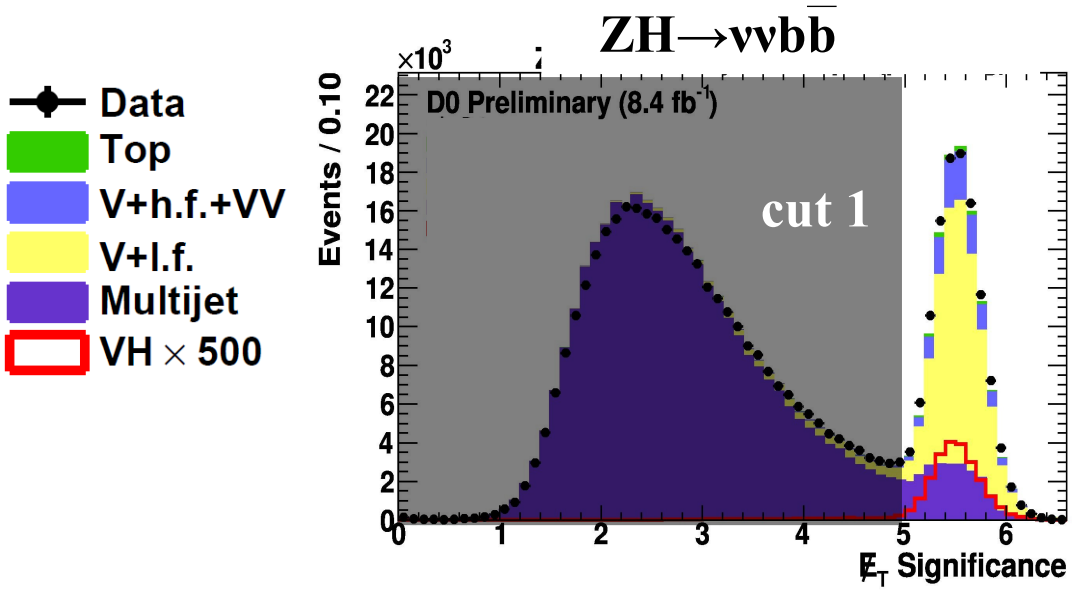


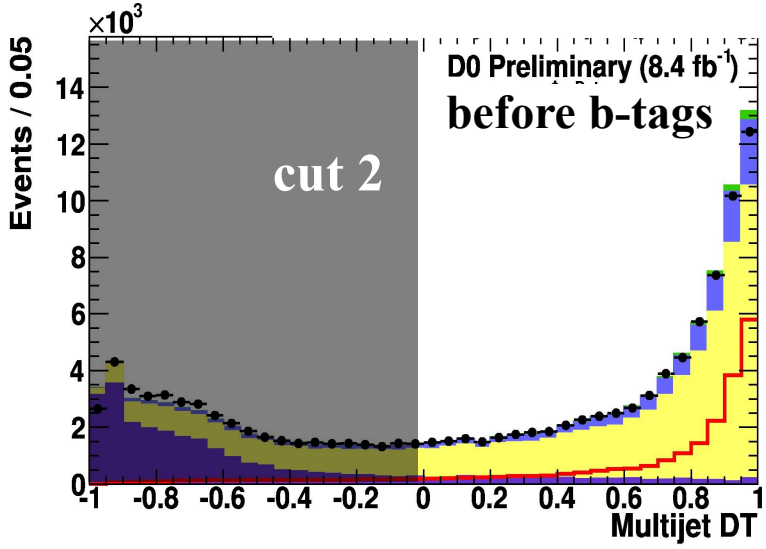
$WH \to l^{\pm}\nu b\bar{b}$



$ZH \to \nu\bar{\nu}b\bar{b}$



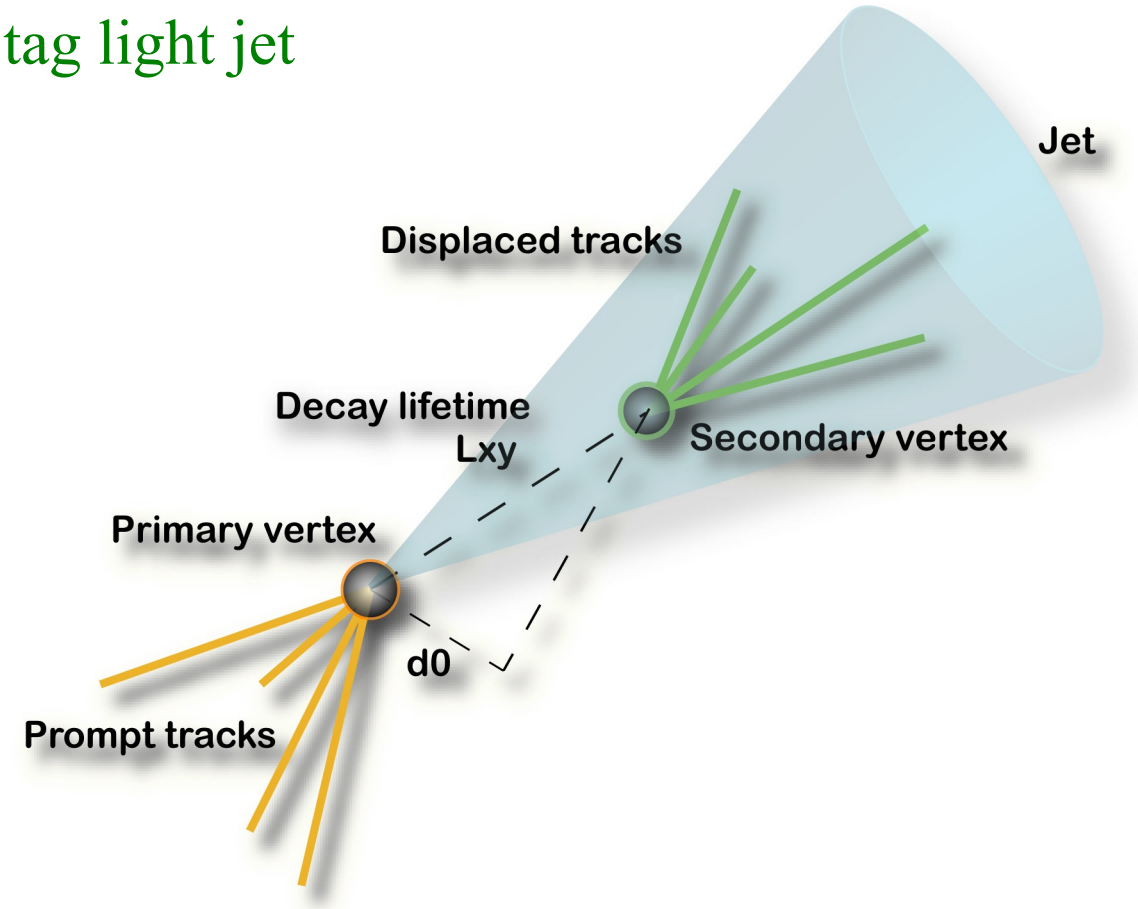




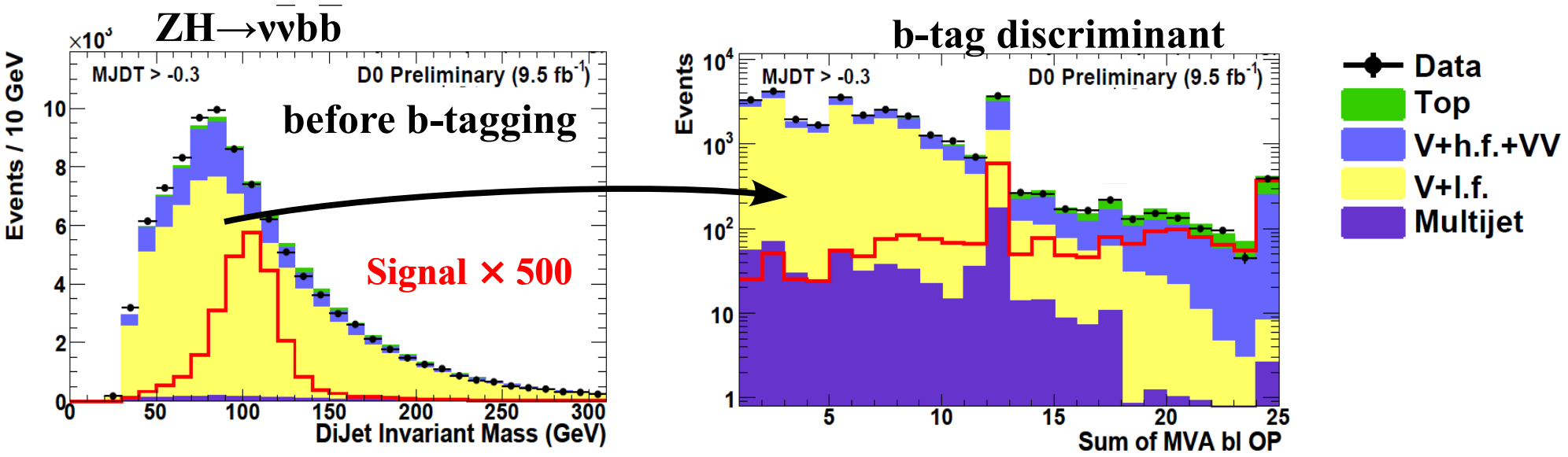
b-tagging

Enhance H → bb by requiring jets to be "b-tagged"

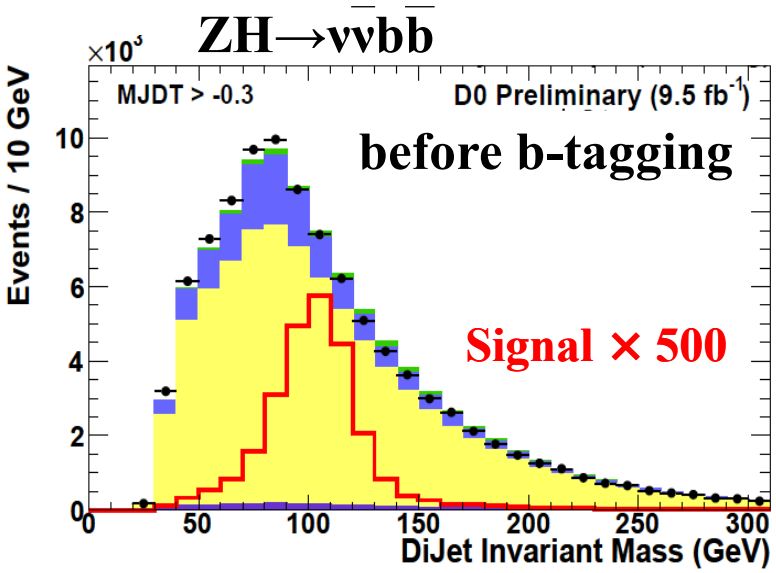
- 50 – 80% efficiency to tag b-jet
- 0.5 – 10% chance to tag light jet

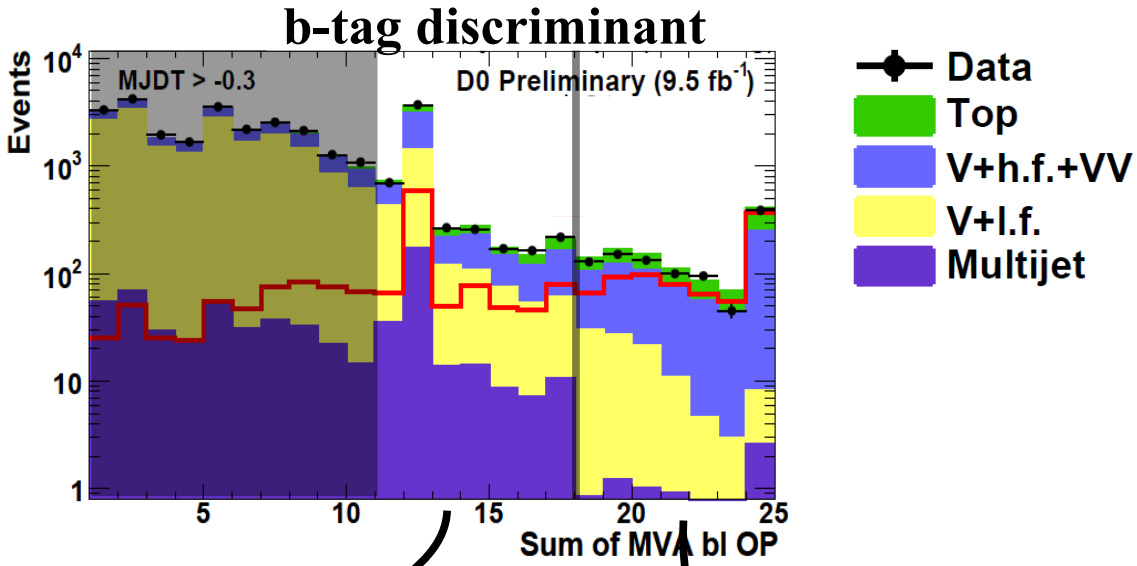


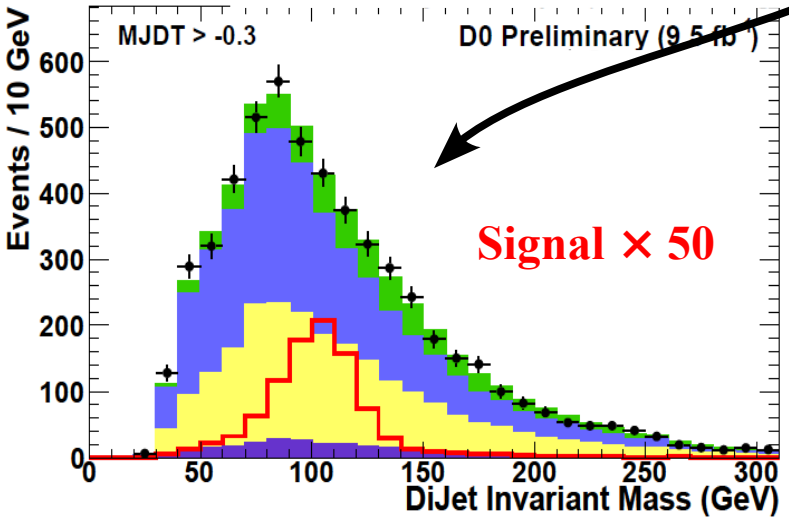
b-tagging In Action

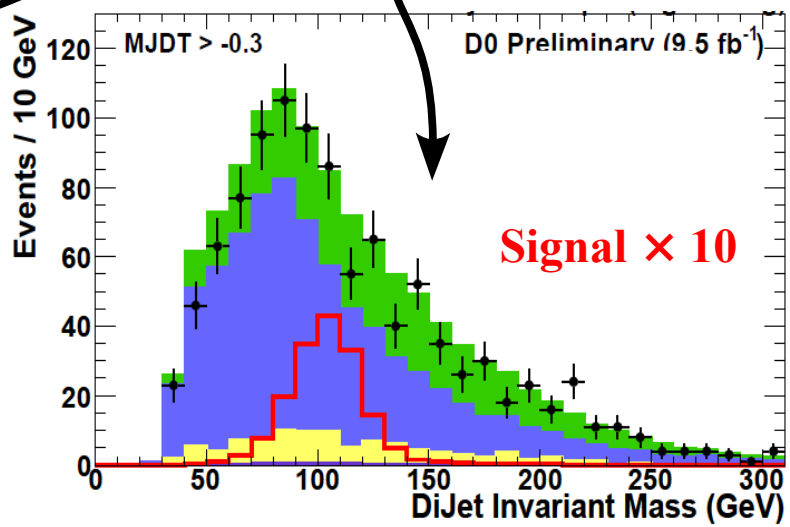


b-tagging In Action









Improvements Since Summer

~12% more data ⇒ ~6% improvement

Increased lepton efficiency / acceptance

- WH → lνbb̄: new multivariate electron identification ⇒ ~5% improvement
- WH → lνbb̄: increased muon acceptance ⇒ 5-10% (in progress)
- FSR and semi-leptonic jet corrections ⇒ ~1%

Improved multivariate discrimination

- 2–10% depending on analysis (room for more in the future)

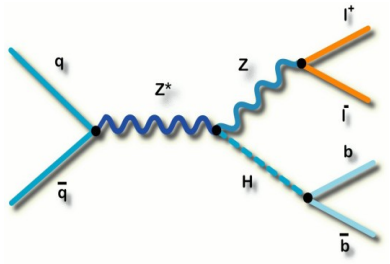
More optimized b-tag categories

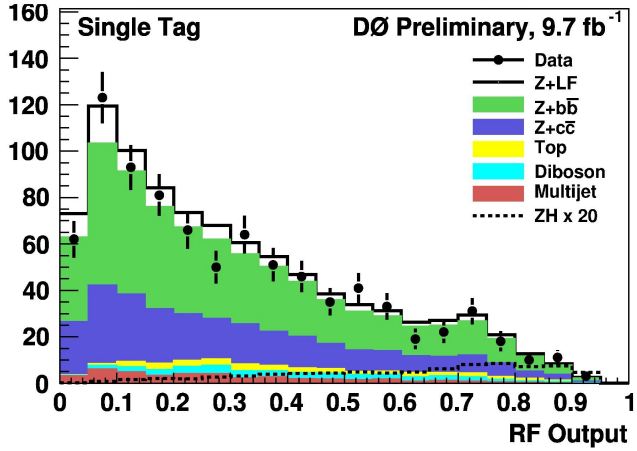
- ZH → νν̄bb̄: b-tag outputs sum to define b-tag bins ⇒ ~15%
- WH → lνbb̄: three b-tag channels ⇒ ~5%

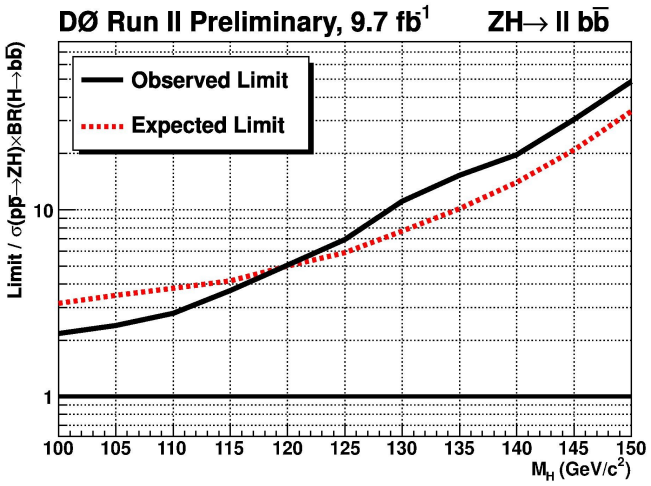
  (Future improvements with c-jet discrimination)

Individual Limits for H → $b\bar{b}$

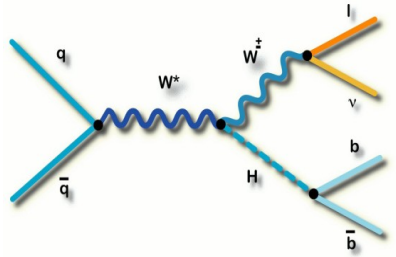
$ZH \to l^+l^-b\bar{b}$

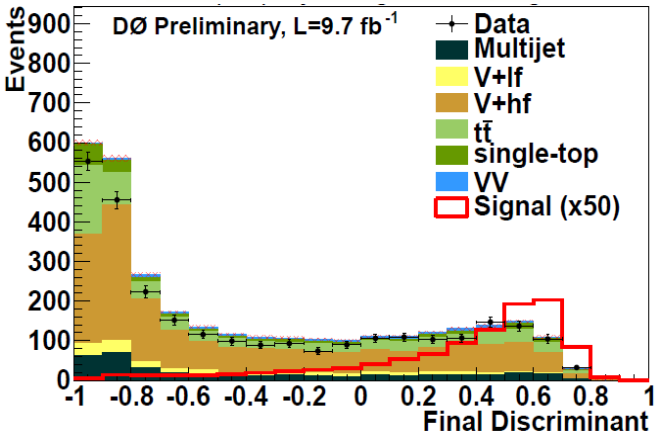


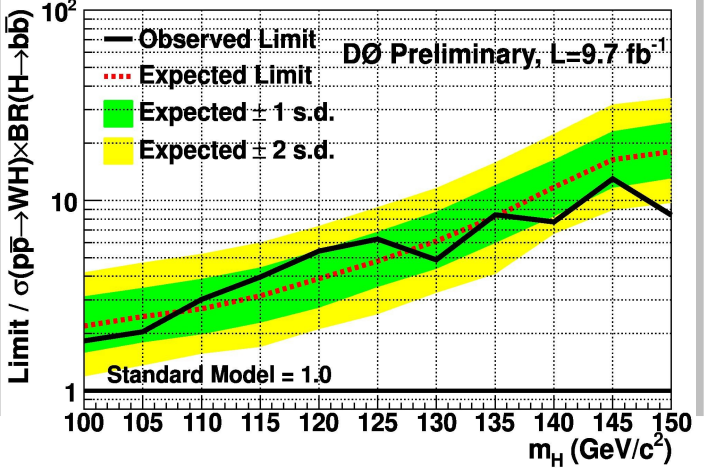




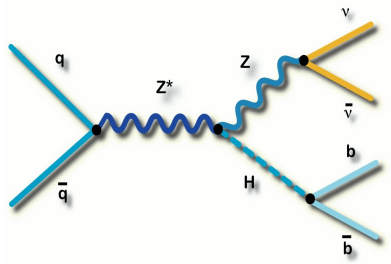
$WH \to l^{\pm}\nu b\bar{b}$

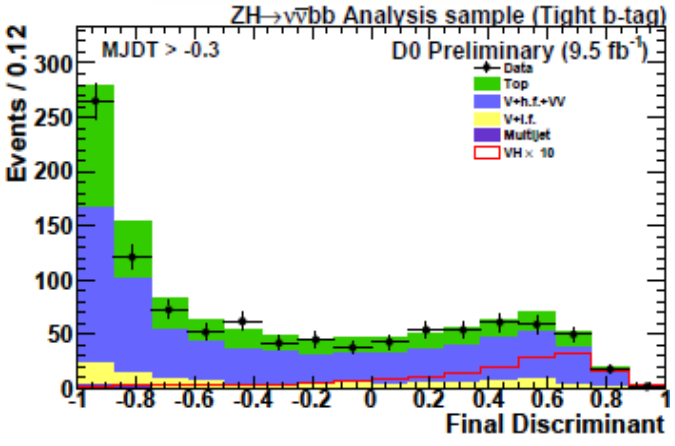


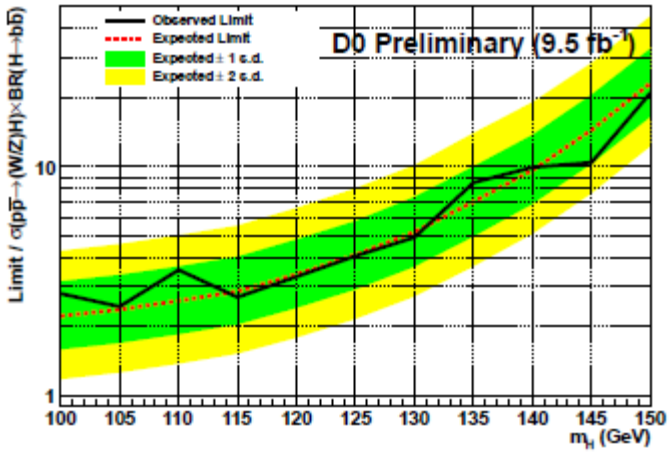




$ZH \to \nu\bar{\nu}b\bar{b}$

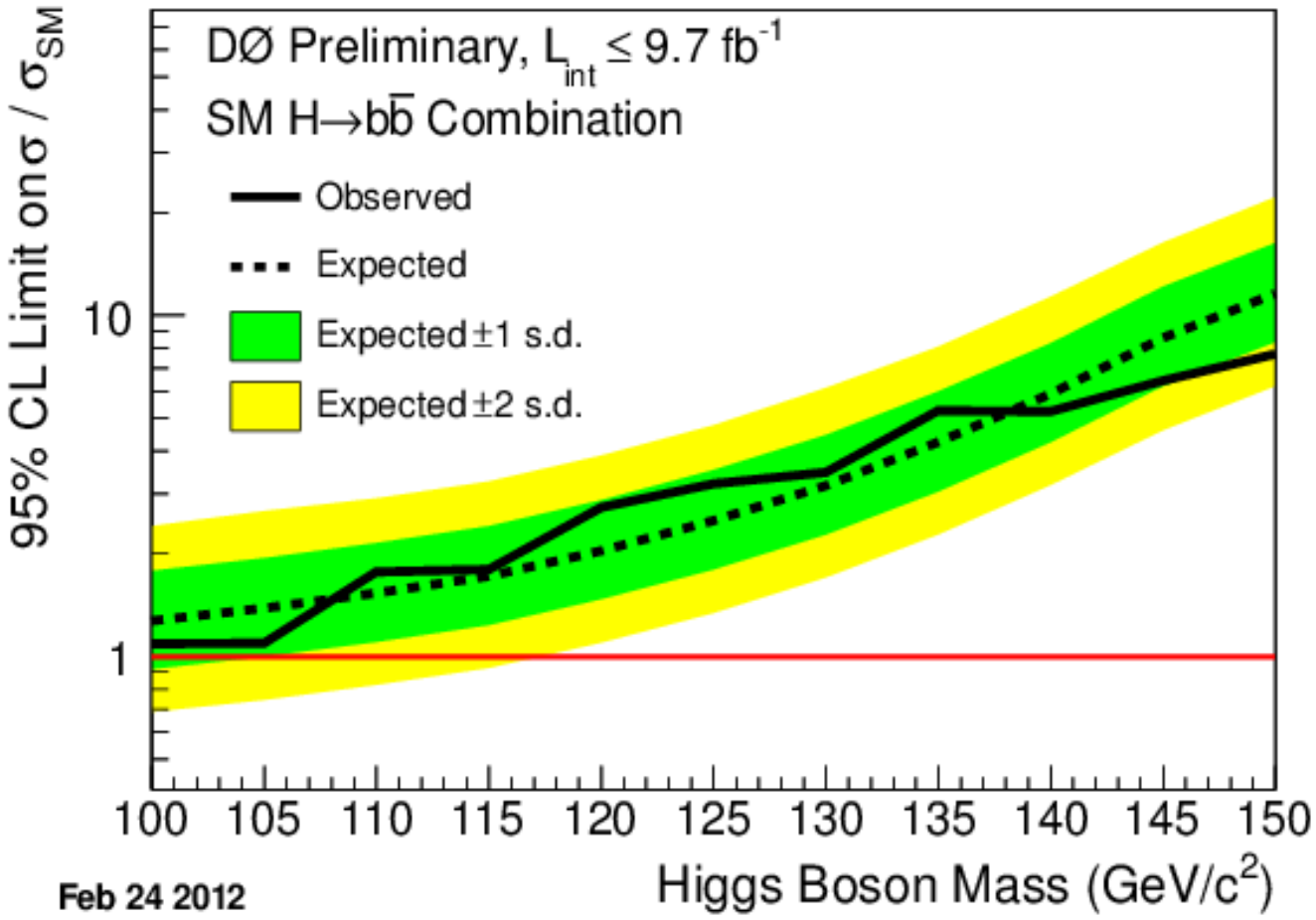






Combined Limits with H → bb

Combining all H → $b\bar{b}$ channels:



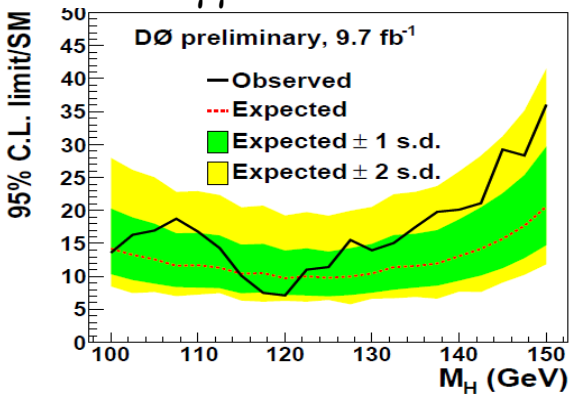
Limits for m_H = 115 GeV

- Observed: 1.79 × σ_{SM}
- Expected: 1.71 × σ_{SM}
- ~16% improvement from summer result

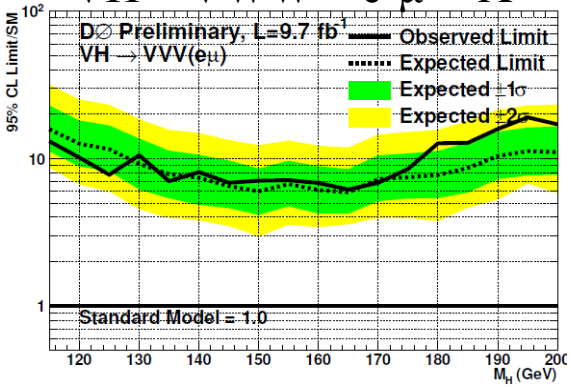
Many More Analyses

- Full combination includes many more analyses

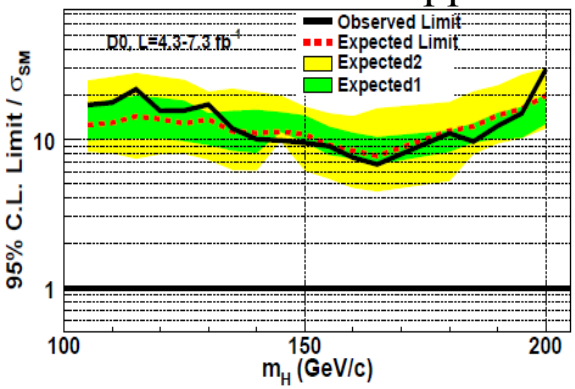
$H \to \gamma\gamma$



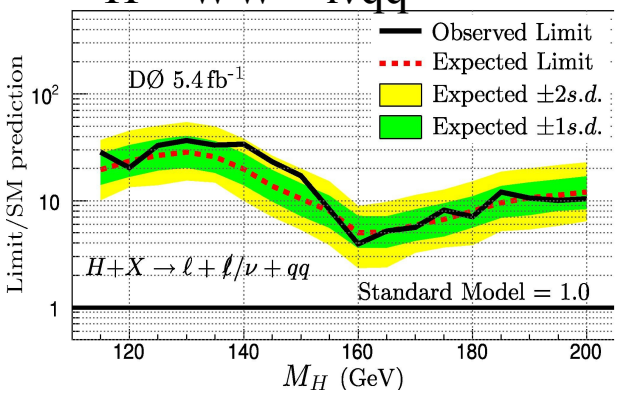
$VH \to VWW \to e^{\pm}\mu^{\pm} + X$



$H \to \tau\tau + VH \to qq\tau\tau$



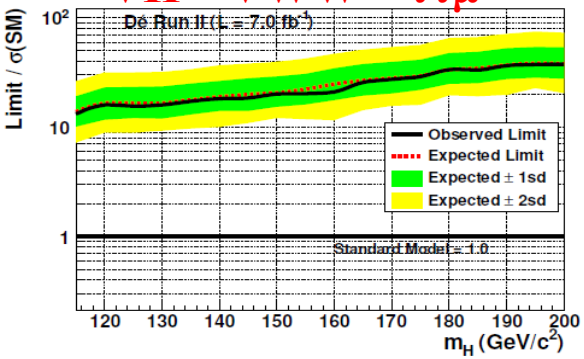
$H \to WW \to l\nu qq$



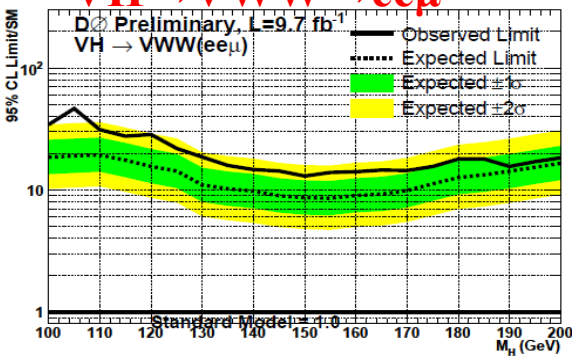
- Less sensitive, but every bit of sensitivity adds up

New analyses!

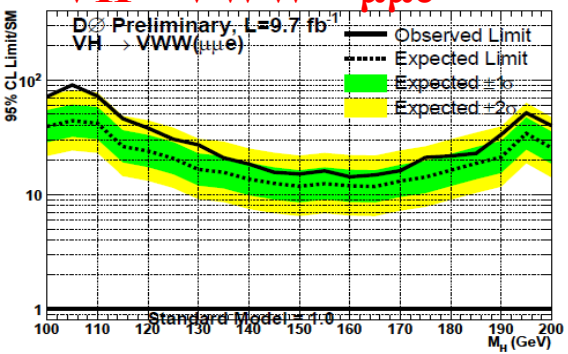
$VH \to VWW \to \tau\tau\mu$



$VH \to VWW \to ee\mu$



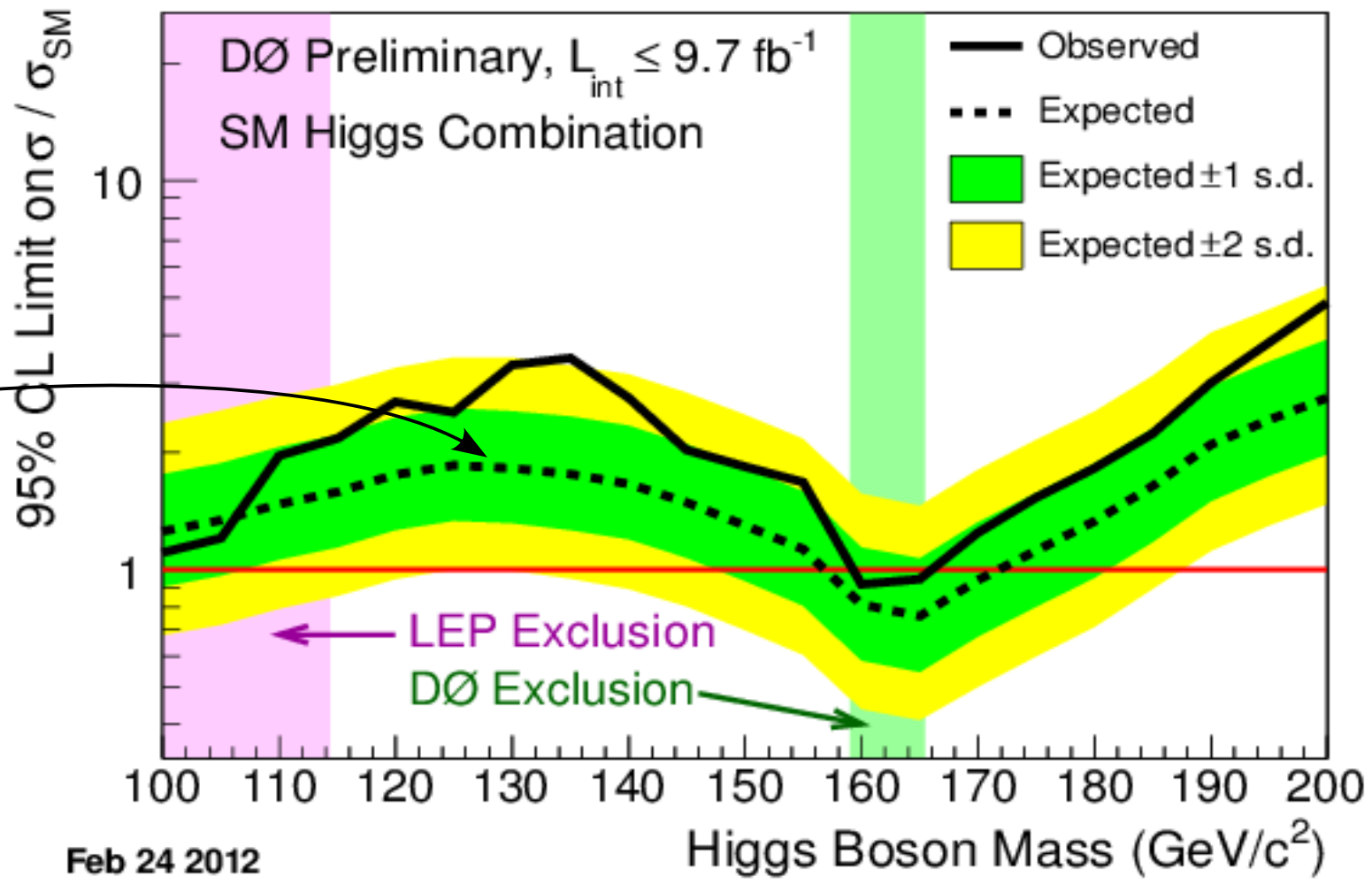
$VH \to VWW \to \mu\mu e$



Conclusion

Combining all of the analyses:

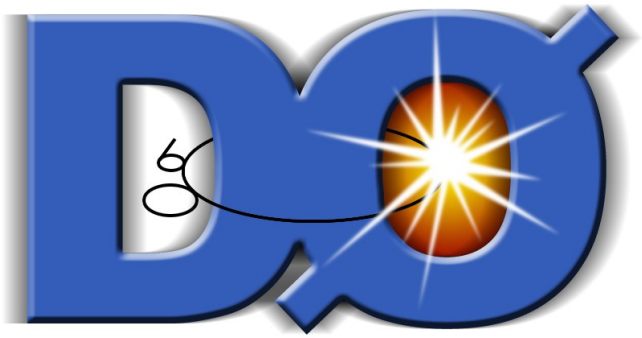
Expected limit within $1.85 \times \sigma_{SM}$



Excess at the level of 1–2 standard deviations in the mass range 115–145 GeV

More improvements to come

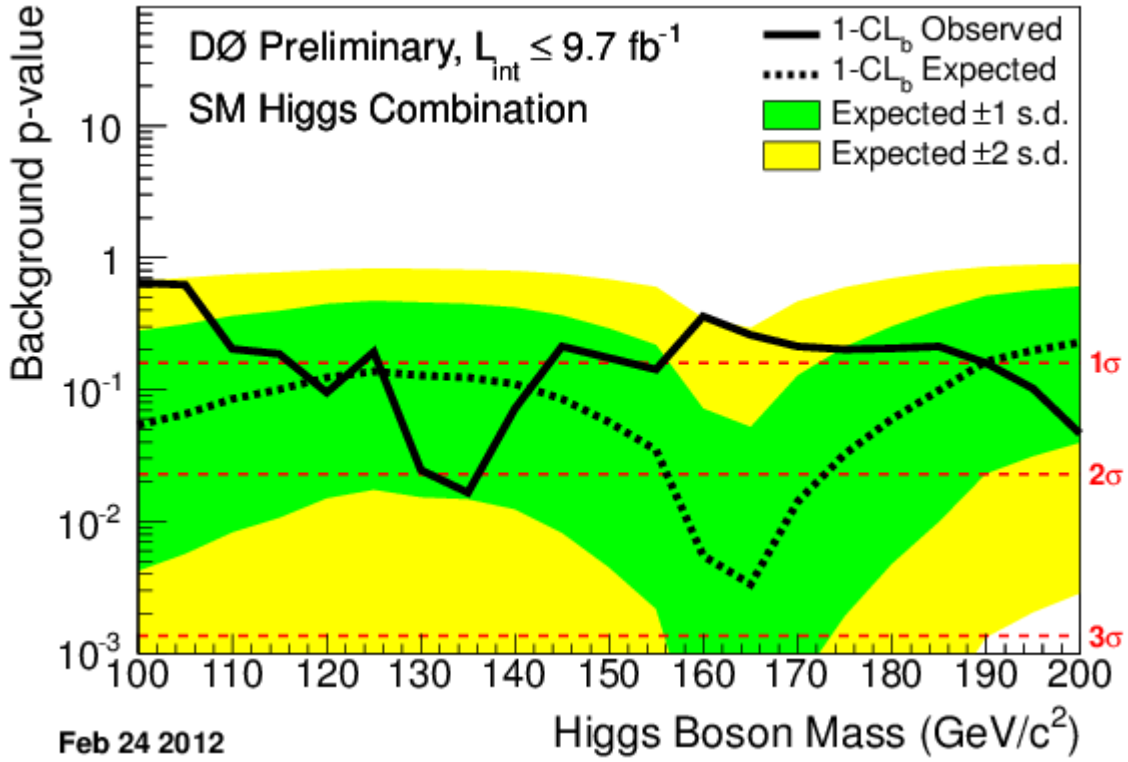
Thank you



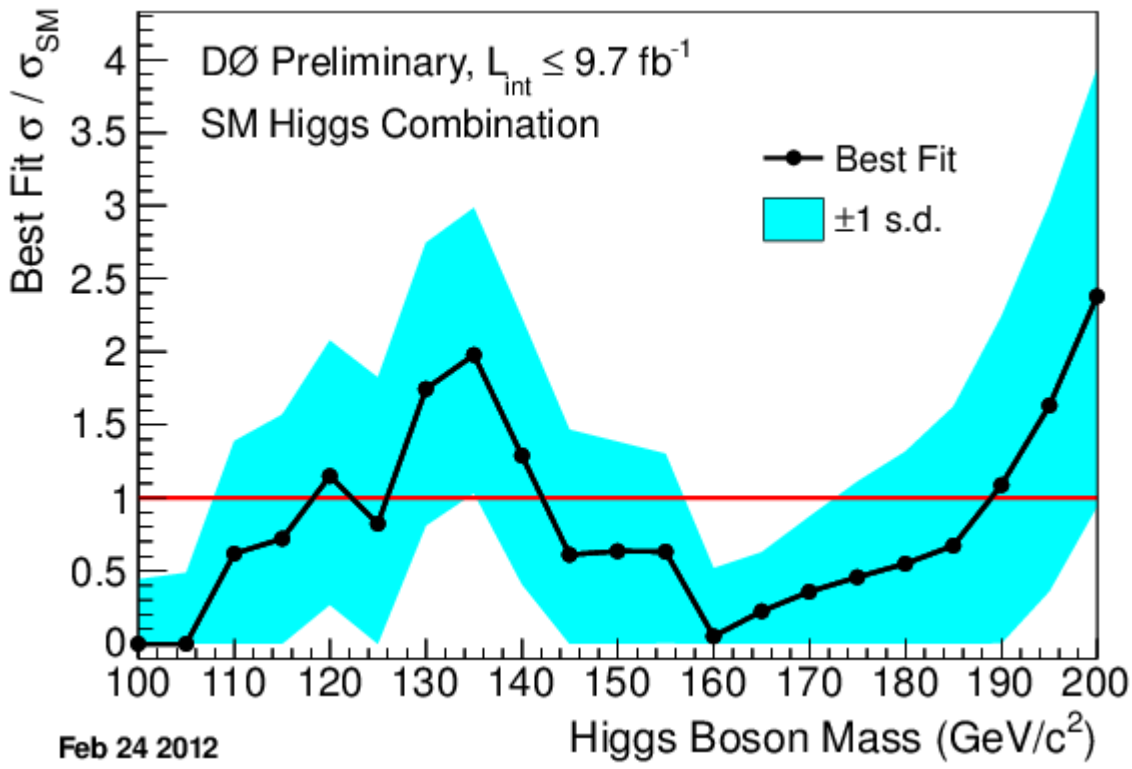
- For additional details see
  - Tevatron: http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_12/
  - CDF: http://www-cdf.fnal.gov/physics/new/hdg/Results.html
  - D0: http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.html

- Thanks to everyone at DØ who contributed to this update!
- Bigger thanks to everyone who designed, built, or operated DØ!
- FNAL Computing Division: Thanks for all the computing power and software!
- FNAL Beams Division: Thanks for all the collisions!
- Photographs of Fermilab and its wildlife were taken by Reidar Hahn, FNAL VMS

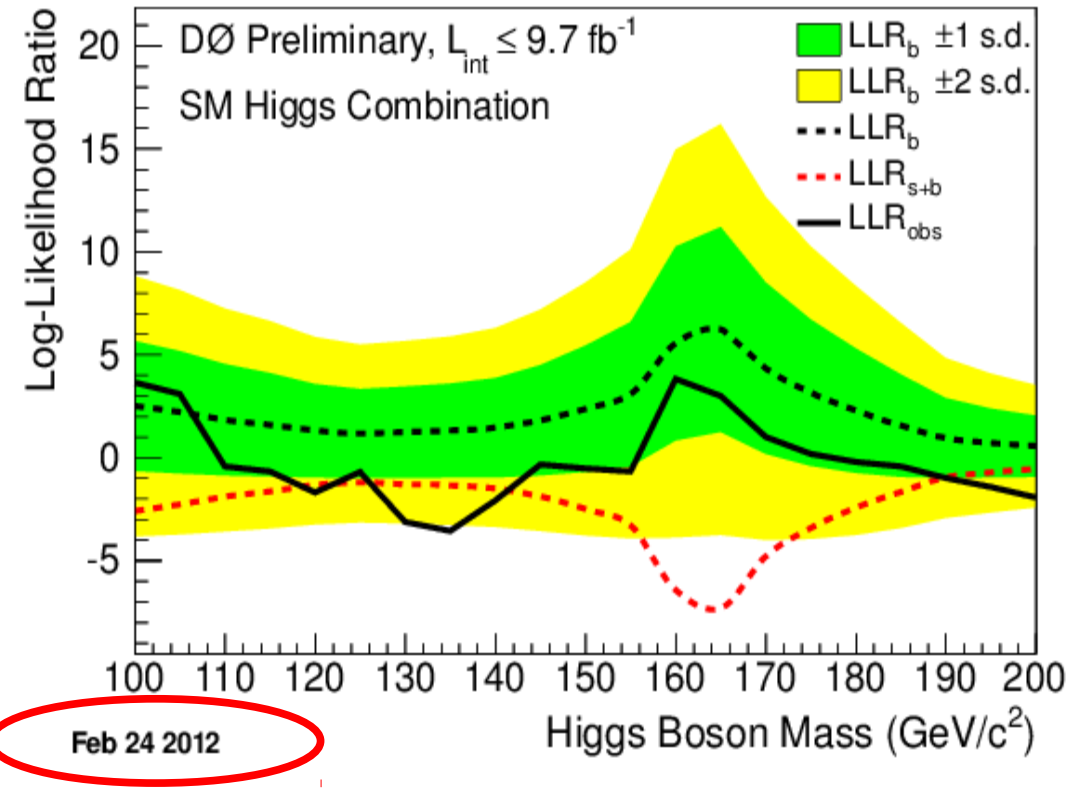
Background p-Value

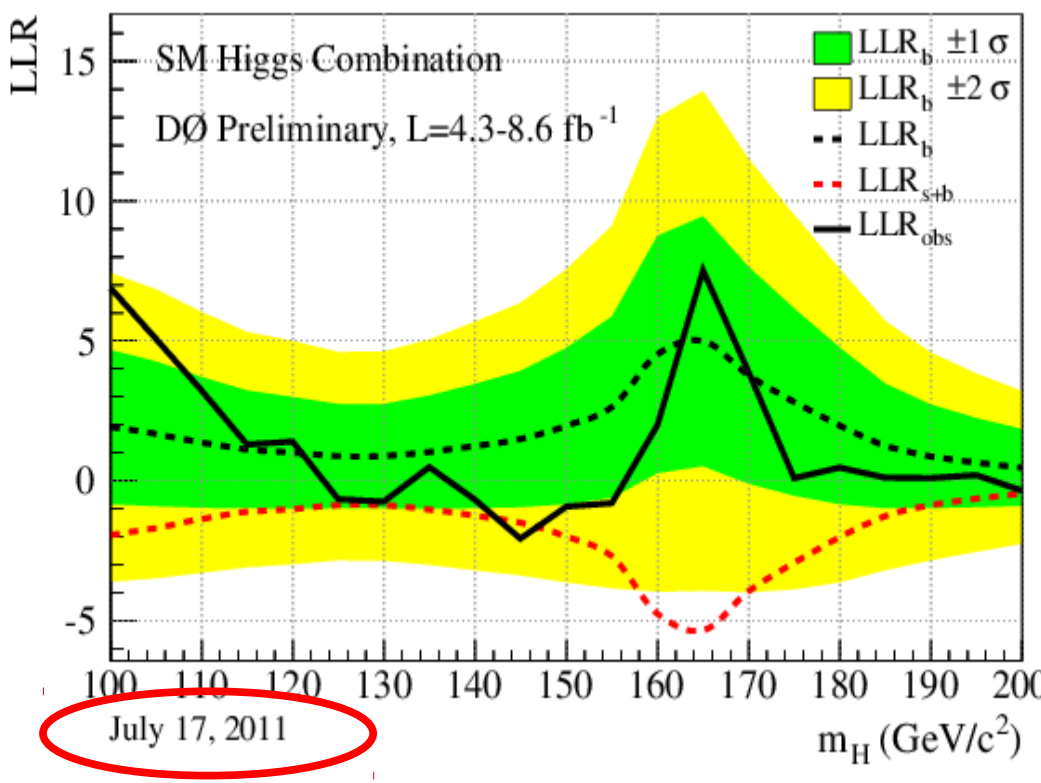


Higgs Cross Section Fit

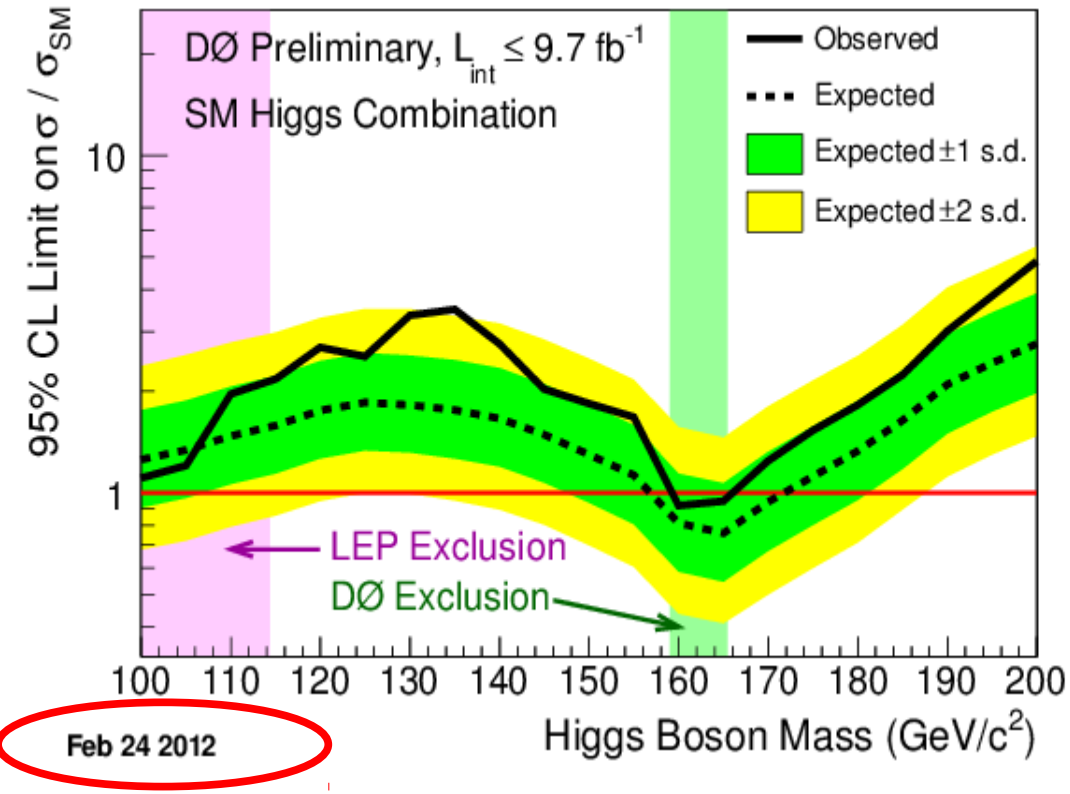


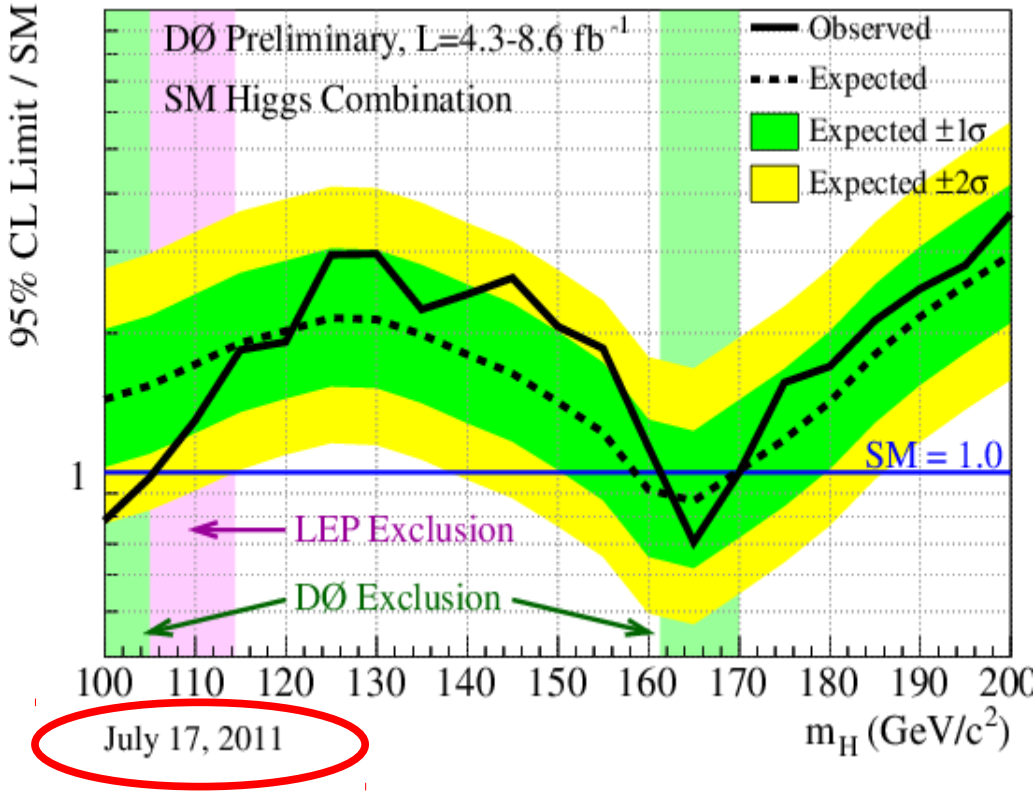
Log Likelihood Ratio



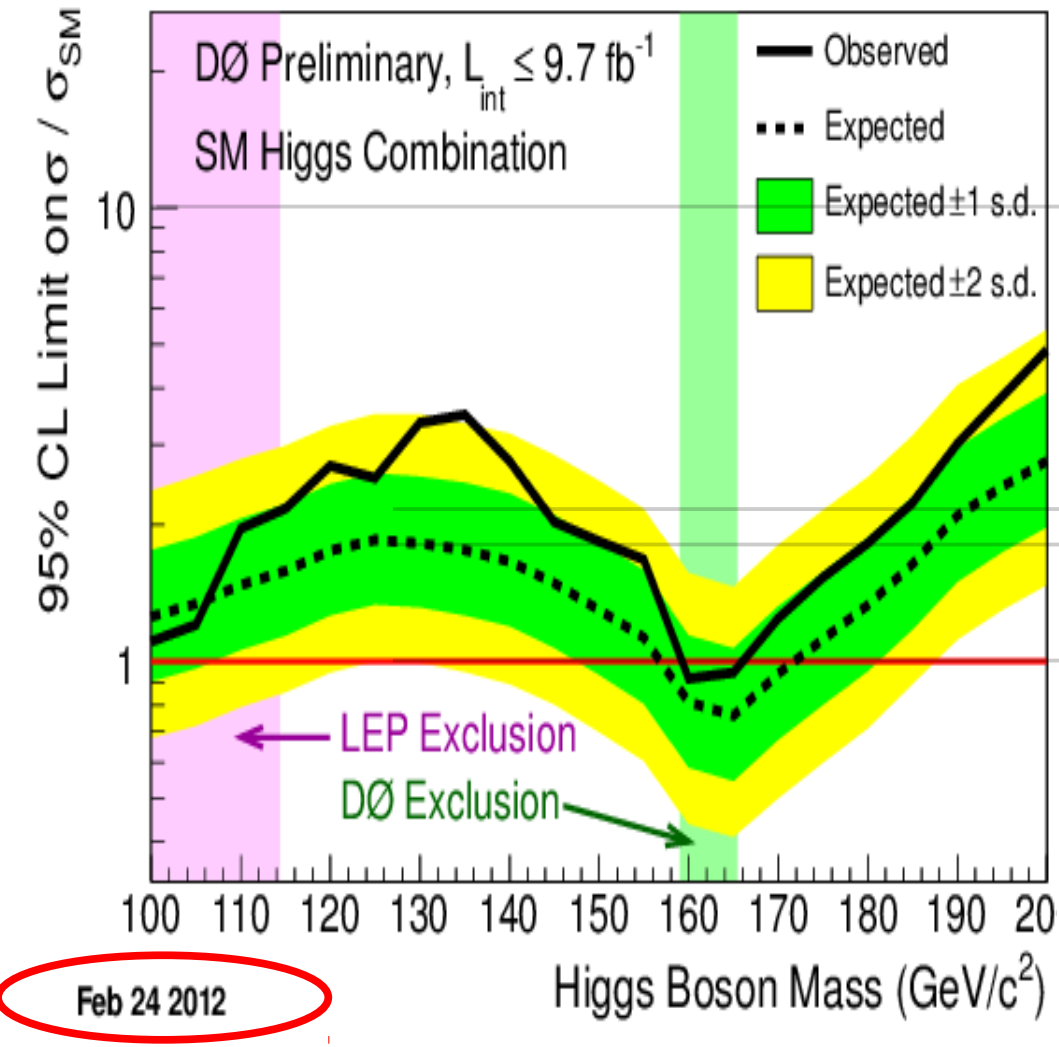


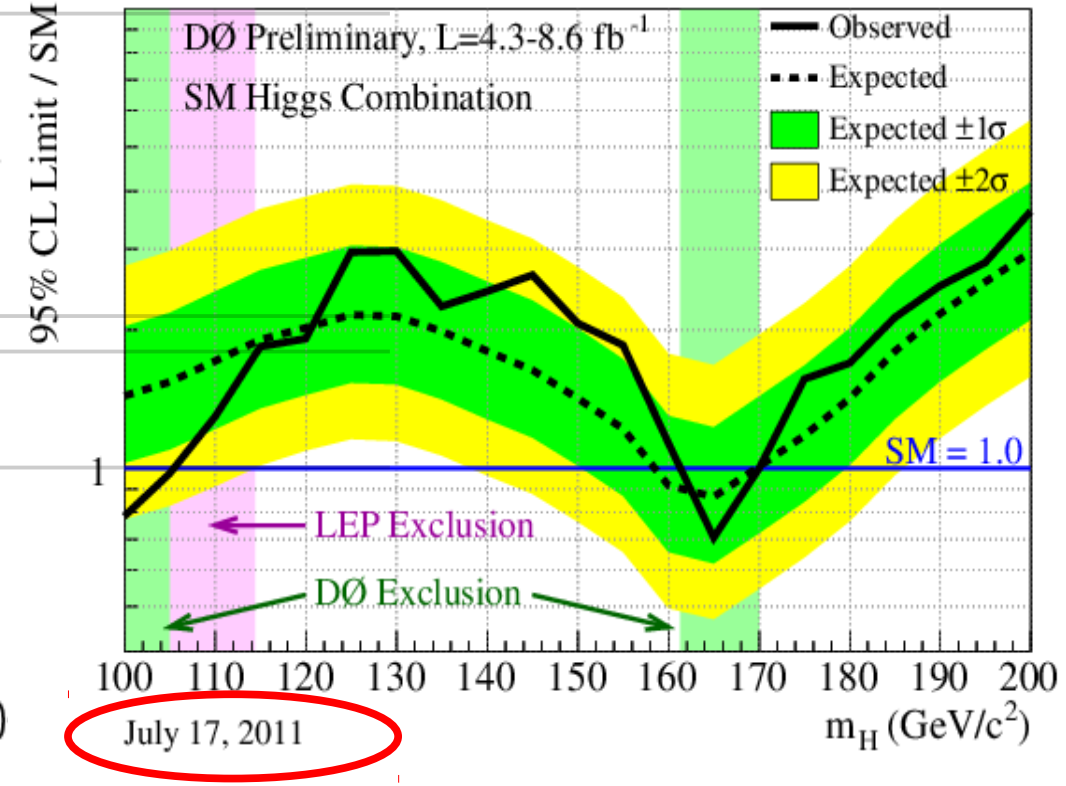
Cross Section Limits



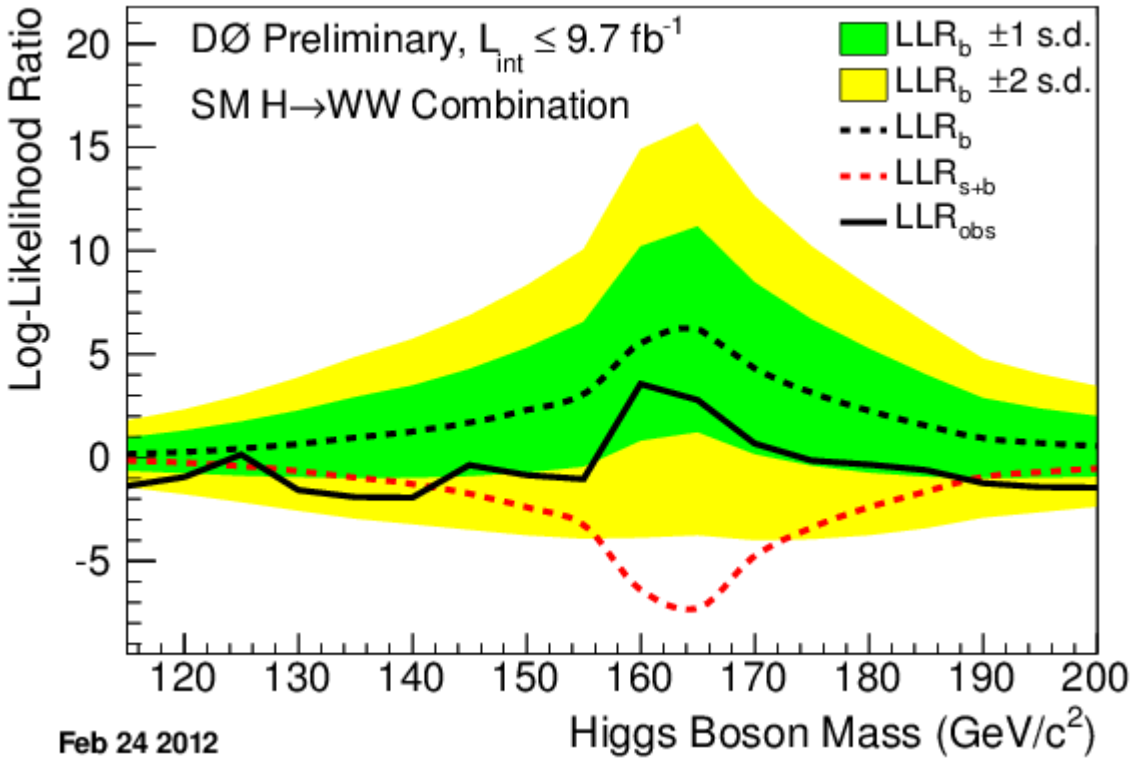


Cross Section Limits

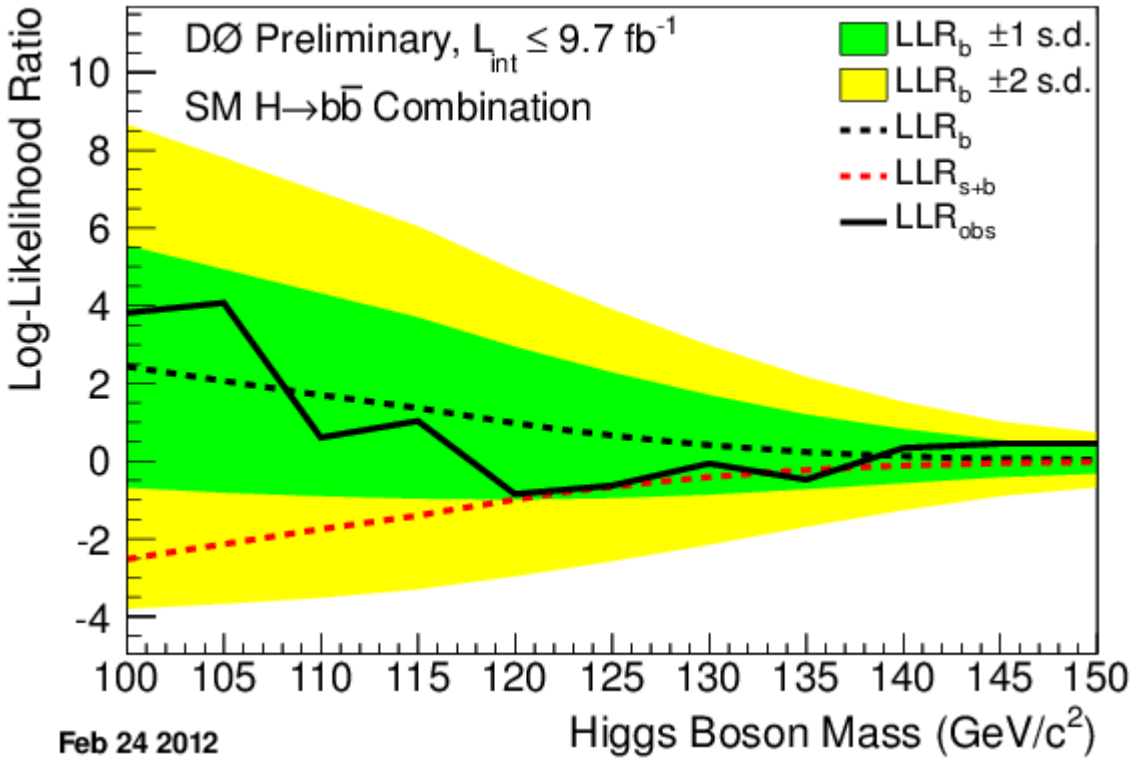




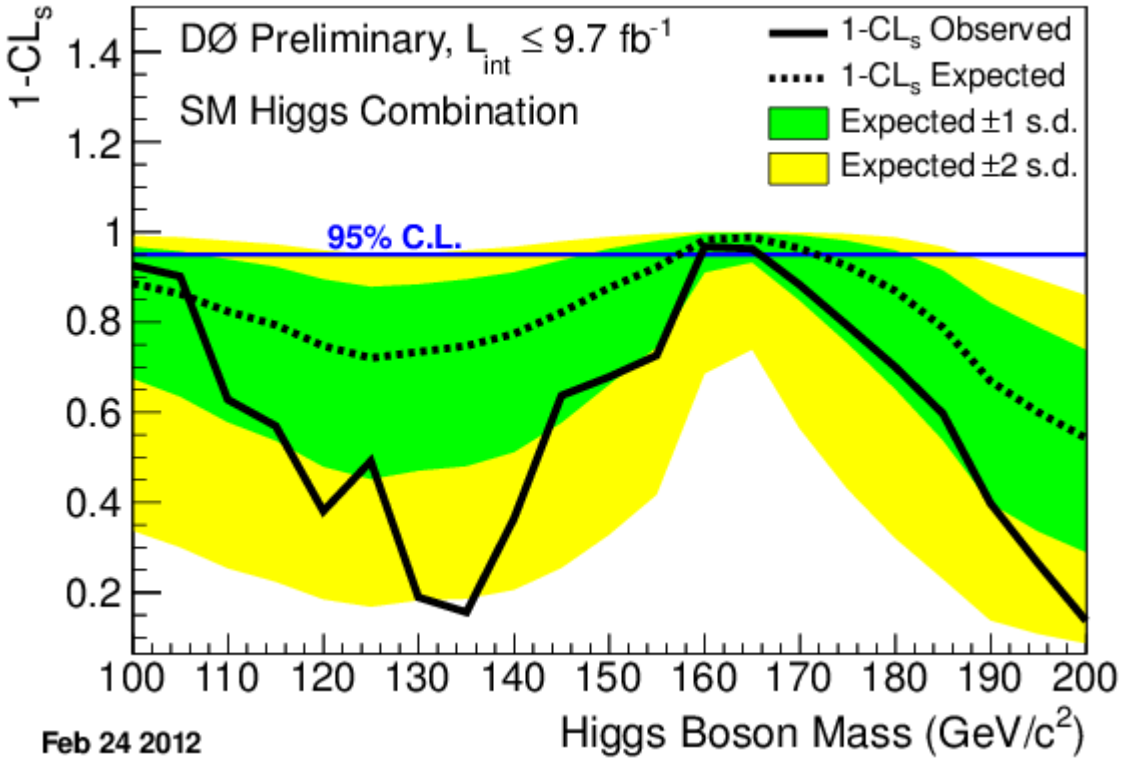
LLR for H → WW Only

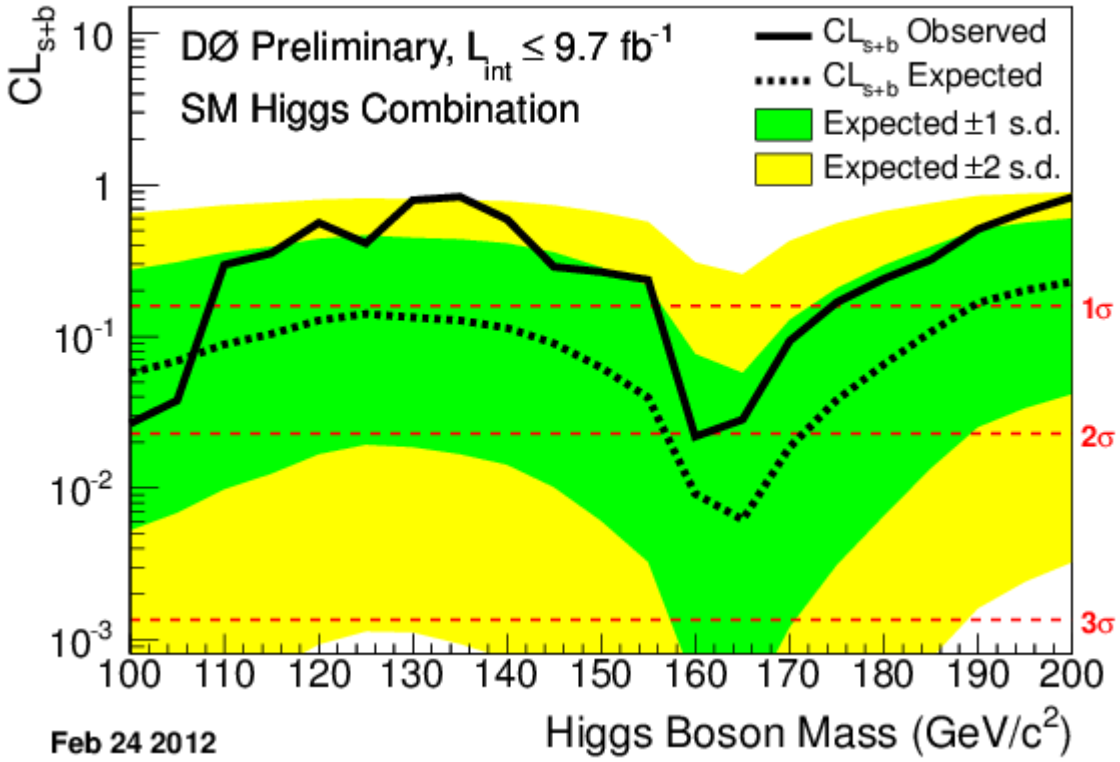


LLR for H → $b\bar{b}$ Only



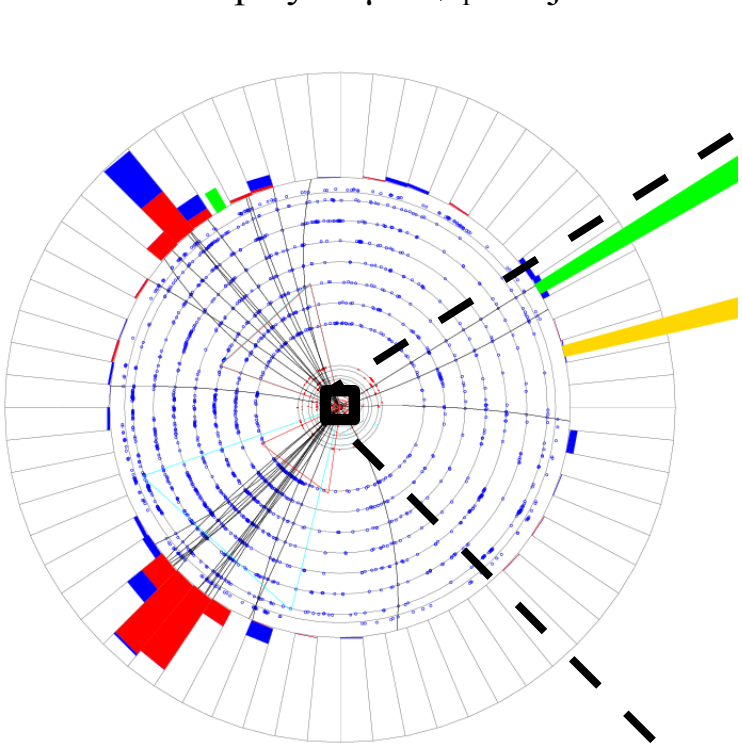
1 - CL_s

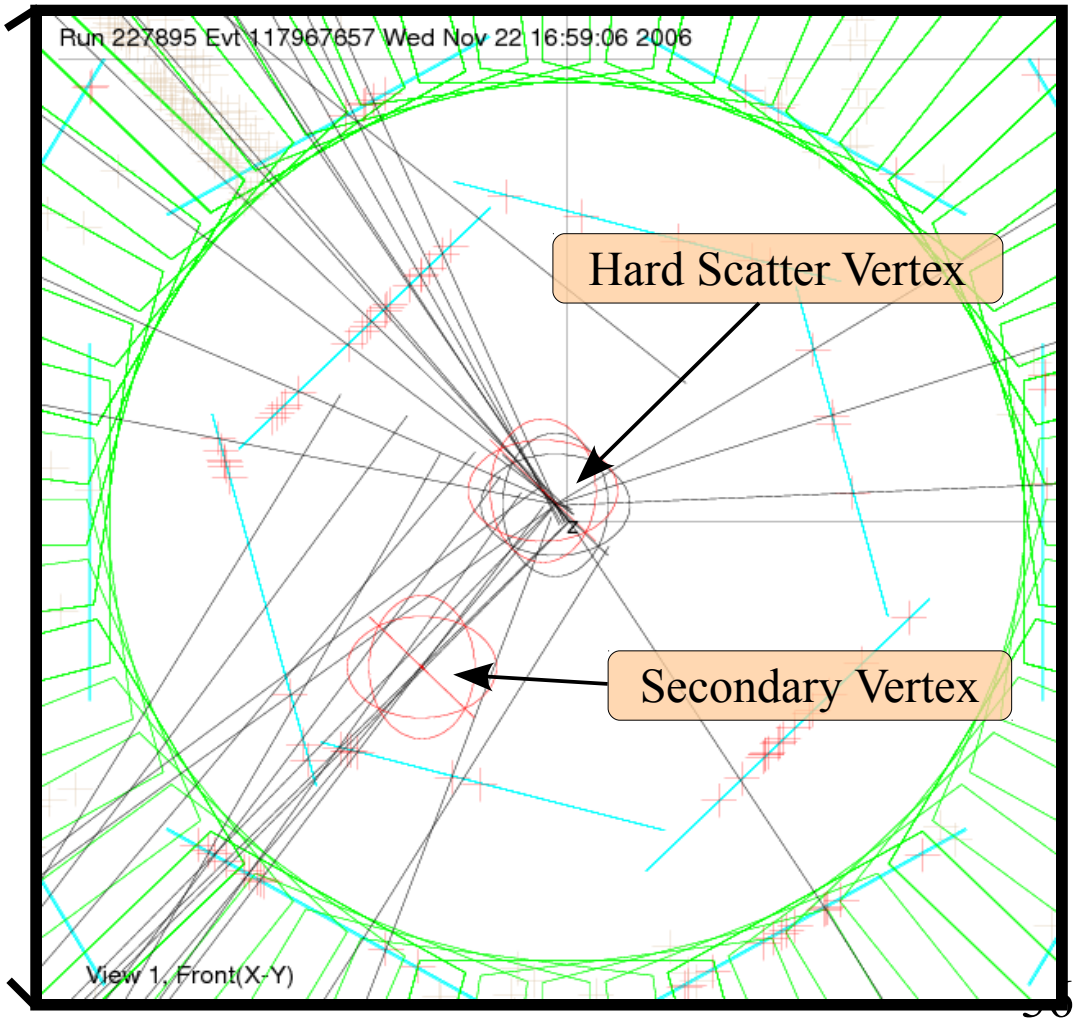

1-CL_s
DØ Preliminary, L_int ≤ 9.7 fb^-1
SM Higgs Combination
1-CL_s Observed
1-CL_s Expected
Expected ±1 s.d.
Expected ±2 s.d.
95% C.L.
1.4
1.2
1
0.8
0.6
0.4
0.2
100 110 120 130 140 150 160 170 180 190 200
Higgs Boson Mass (GeV/c^2)
Feb 24 2012


CL_s+b
10
1
10^-1
10^-2
10^-3
DØ Preliminary, L_int ≤ 9.7 fb^-1
SM Higgs Combination
CL_s+b Observed
CL_s+b Expected
Expected ±1 s.d.
Expected ±2 s.d.
1σ
2σ
3σ
100 110 120 130 140 150 160 170 180 190 200
Higgs Boson Mass (GeV/c^2)
Feb 24 2012

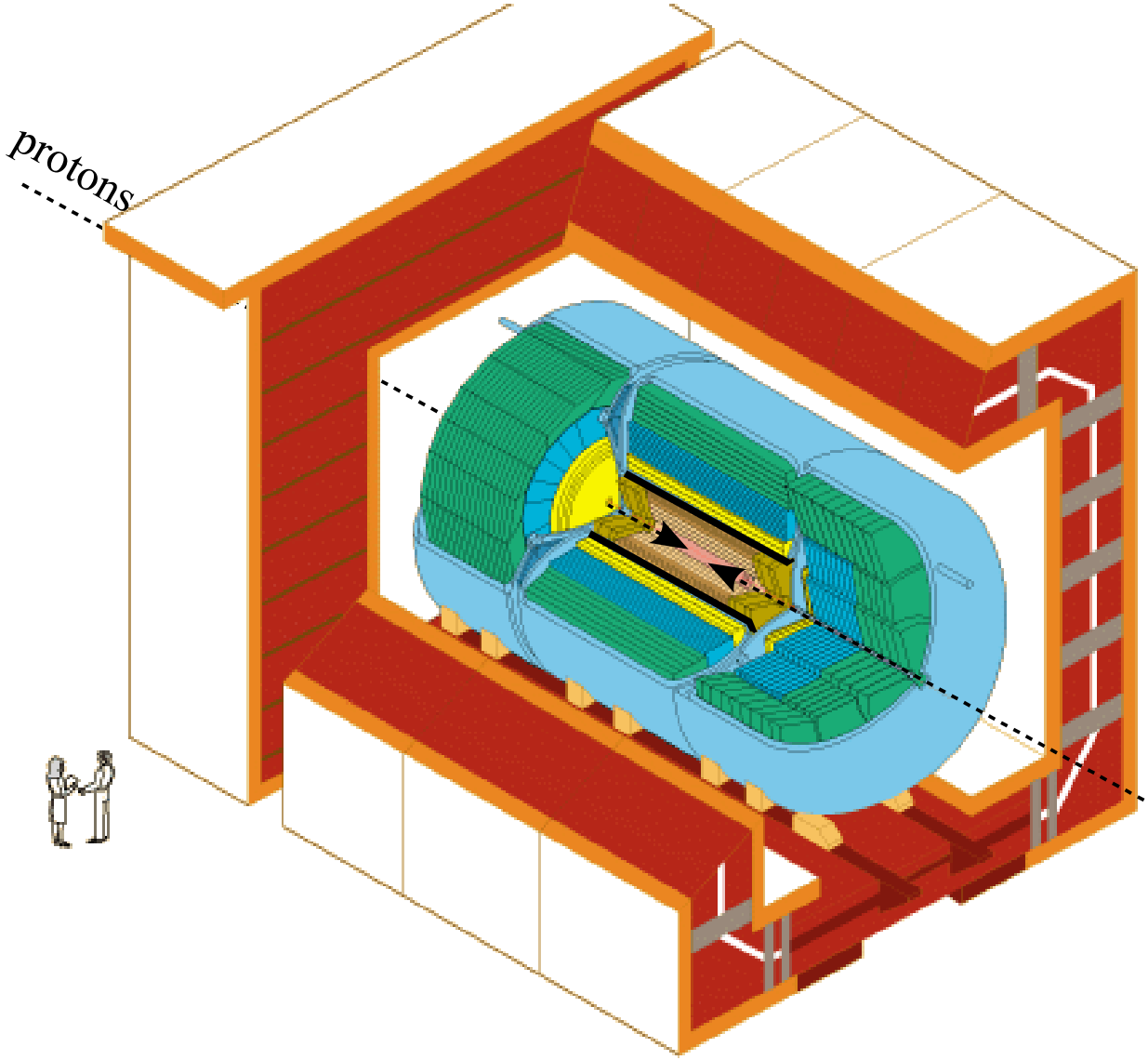
Enhance H → bb by requiring jets to be "b-tagged"

DØ event display of $\mu + \not{E}_T + 2$ jets event





DØ Detector



- Central Tracking System
  - Silicon Micro-strip Tracker
  - Central Fiber Tracker
  - 2 T Solenoid Magnet
- Calorimeters
  - Central Calorimeter (CC)
  - End Calorimeters (EC)
- Muon System
  - 3 sets of detectors
    - Scintillating tiles
    - Gas Drift Tubes
  - 1.8 T Toroid Magnets