Combined search for the SM Higgs Boson at DØ

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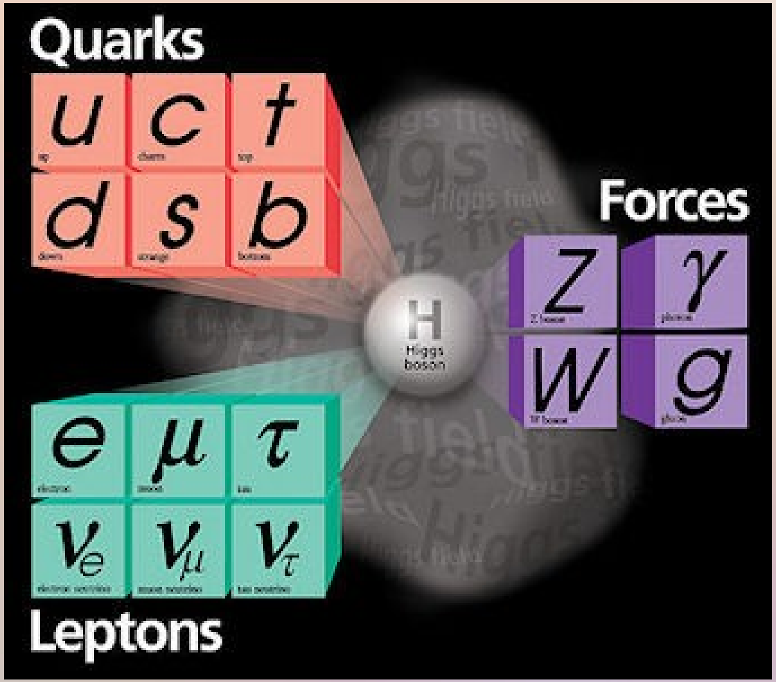
On behalf of the DØ Collaboration

The Higgs Boson in the Standard Model

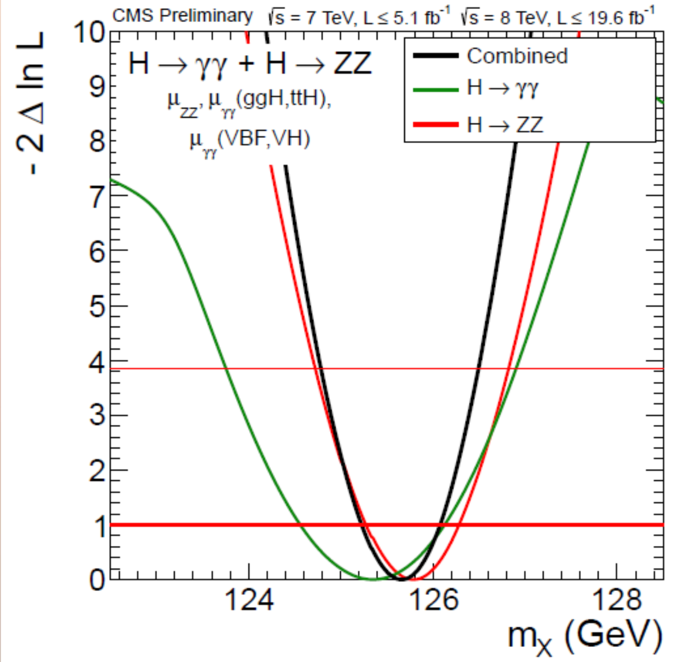
- Higgs mechanism responsible for electroweak symmetry breaking
- Interactions with Higgs field gives particles their masses
- Standard Model does not predict the Higgs mass

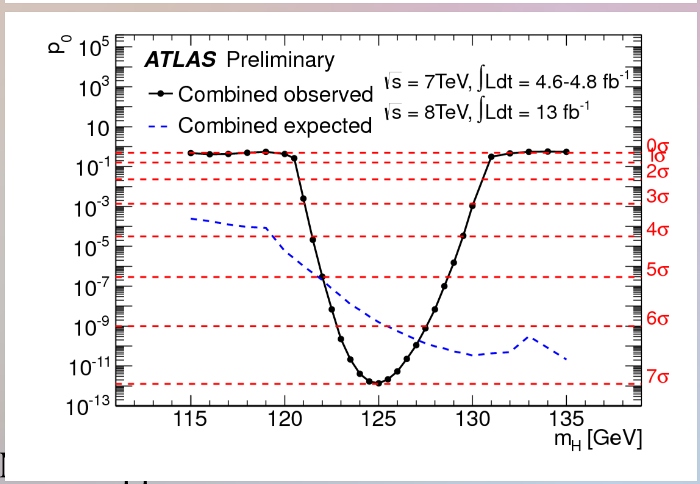


- CMS and ATLAS announced the discovery of a Higgs-like boson in the $H \rightarrow ZZ$ and $H \rightarrow \gamma\gamma$ channels in July 2012.

Standard Model Higgs Boson at LHC

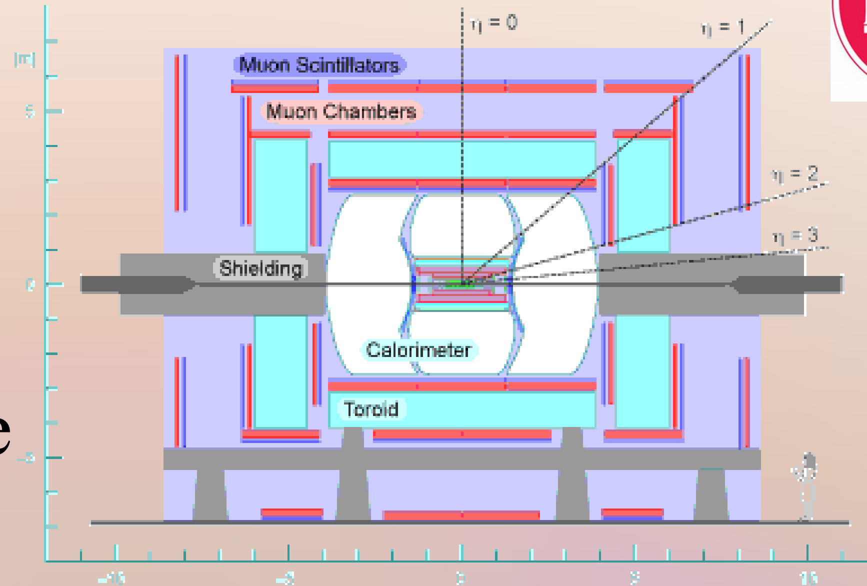
- The ATLAS and CMS collaborations announced the discovery of a new, Higgs-like particle at a mass of ~125 GeV in July 2012
- So far all properties are consistent with the SM Higgs boson.

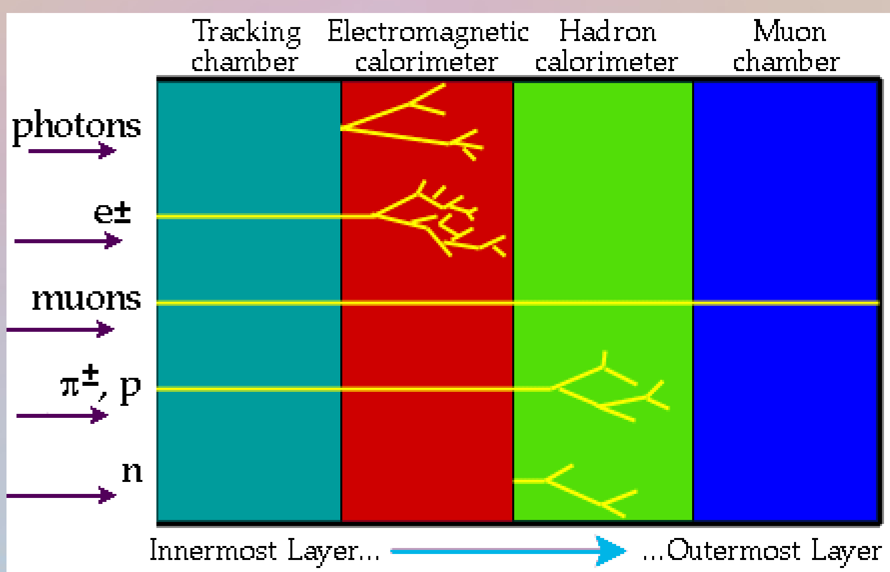


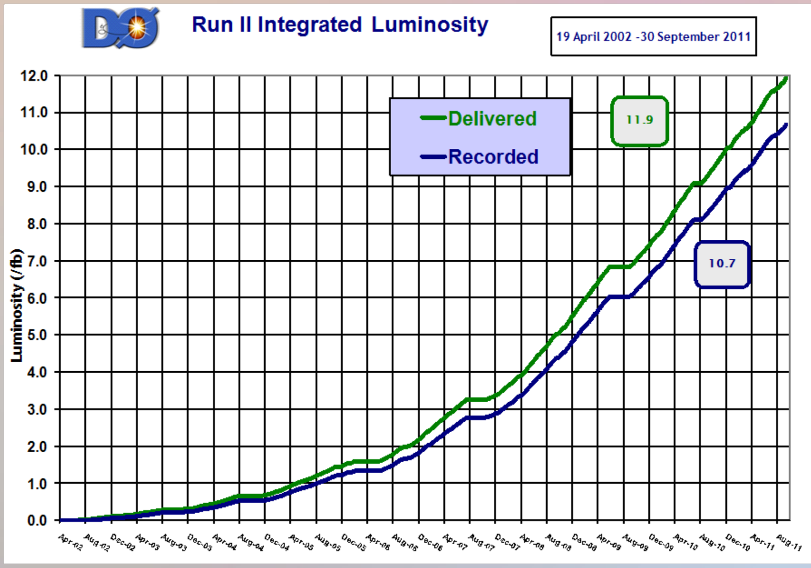


The DØ Experiment

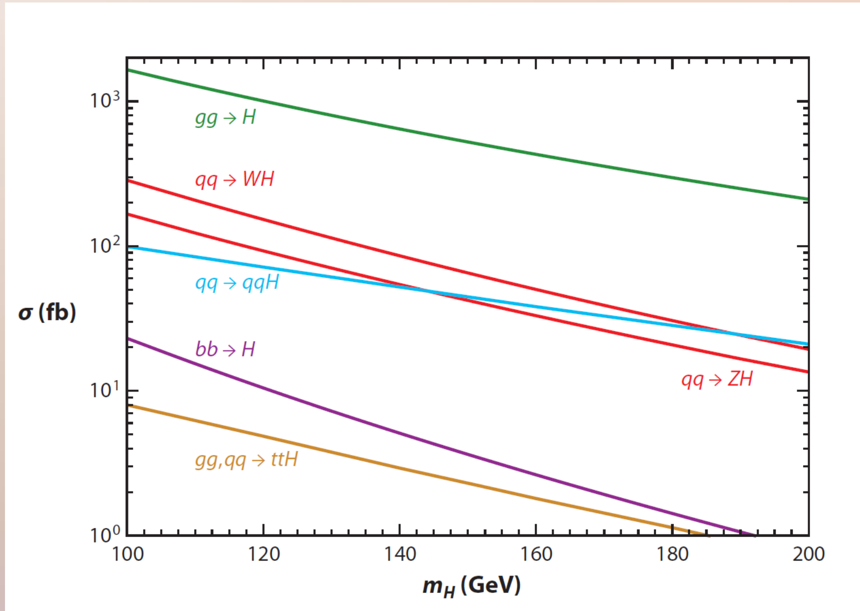
- A multipurpose particle detector
- Innermost detectors are the trackers, followed by calorimetry and muon chambers



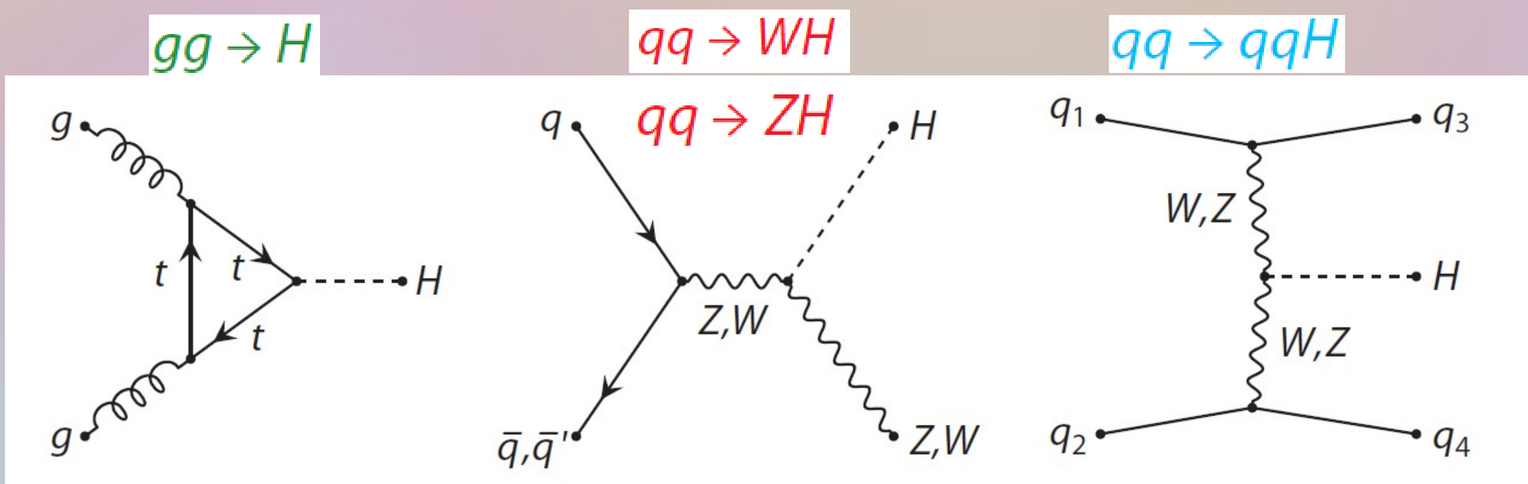




Higgs Production at the Tevatron

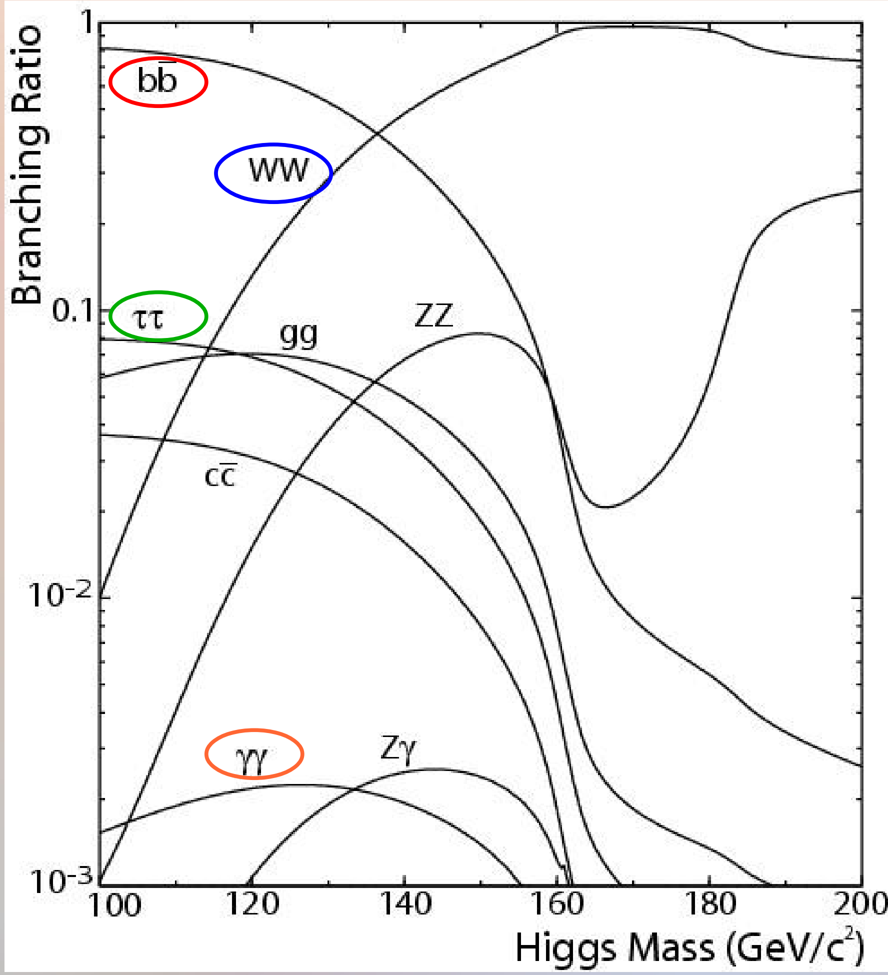


- The Higgs at Tevatron produced by gluon fusion (gg→H), associated production (qq→W/Z+H), and vector boson fusion (qq→qqH)



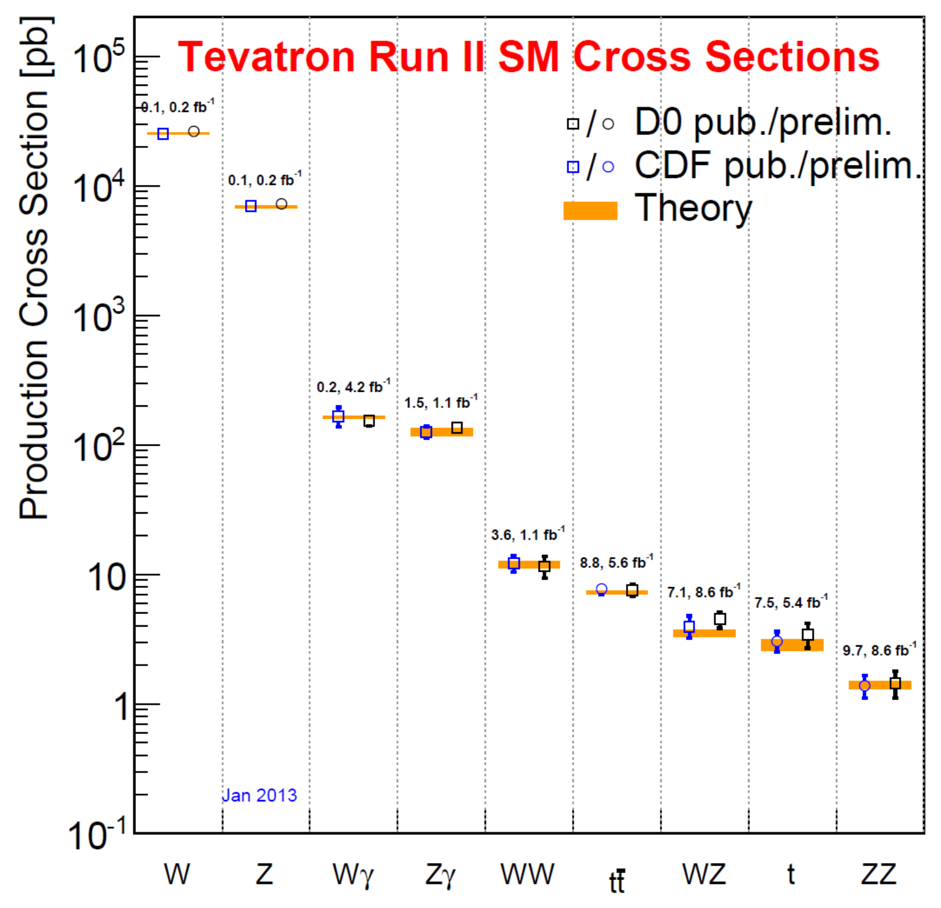
Higgs Decay Modes

- The Higgs decays primarily to bottom quarks at low mass, WW at higher mass
- The searches for the Higgs at the Tevatron focus on $H\rightarrow b\bar{b}$ at low mass, $H\rightarrow WW$ at high mass.
- Also use $H \rightarrow \tau\tau$, $H \rightarrow \gamma\gamma$ due to low backgrounds



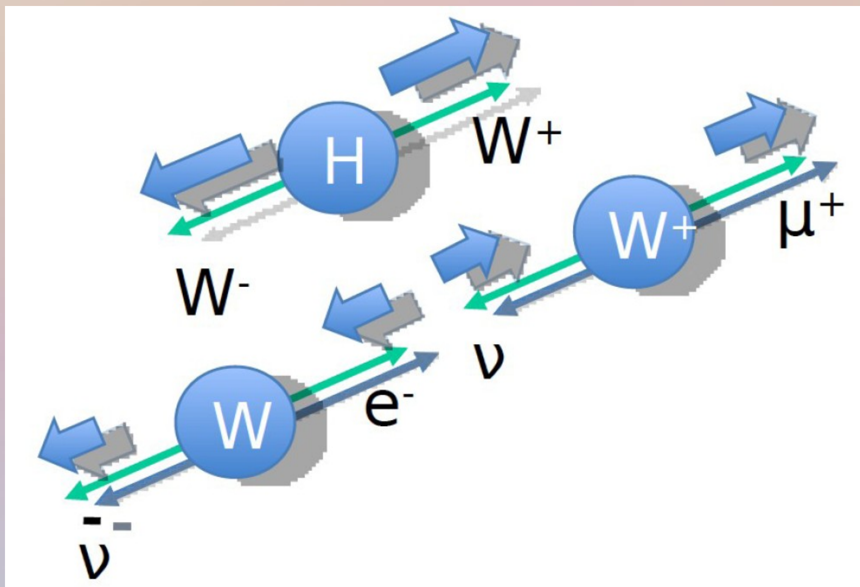
Higgs Backgrounds

- The rate of Higgs production is small compared to backgrounds
  - Bottom decays swamped by QCD background except for associated ZH/WH production
  - WW cleaner, but still large backgrounds
- These backgrounds are modeled with Alpgen+Pythia, Pythia, and CompHEP
  - Multijet and some other backgrounds modeled with data



Signal vs. Background

- Once we have a good background model, we look for differences between signal and background
- Example from H→WW – $\Delta\phi$ between leptons



- The Higgs is a spin-0 particle; W is spin-1

⇒ small opening angle in leptons from the W decays

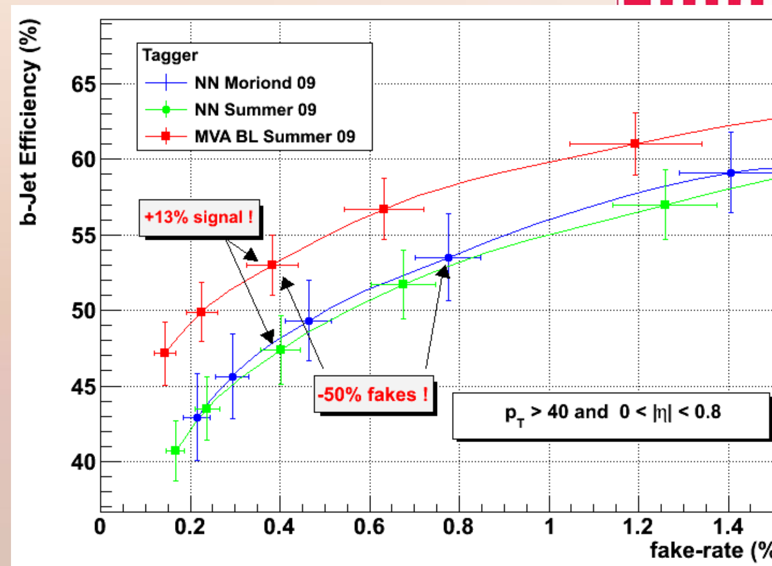
- Leptons from WW isotropic; from Z back-to-back

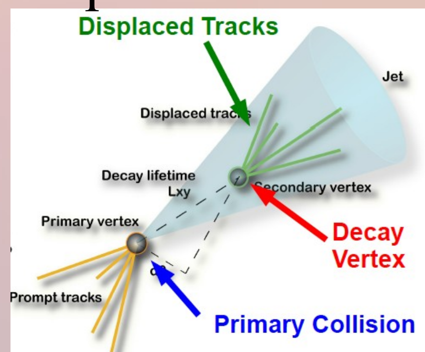
Signal vs. Background

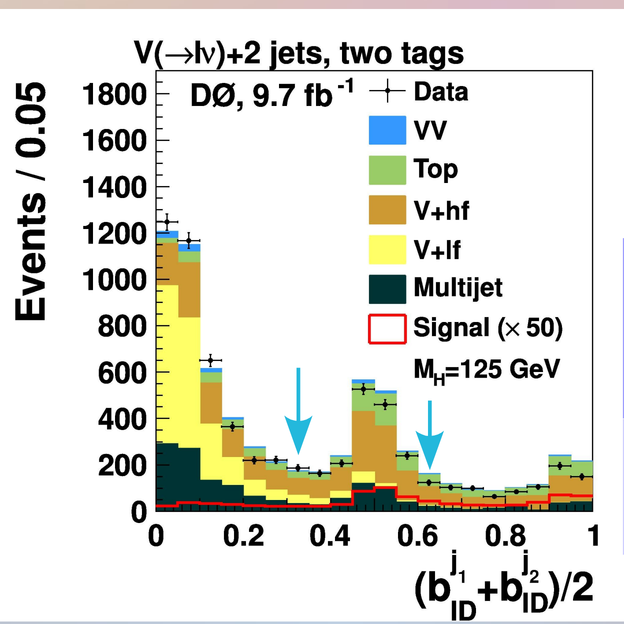
- Once we have a good background model, we look for differences between signal and background
- Example – $\Delta\phi$ between leptons
- The signal to background ratio is so small that any one variable will not be sufficient to isolate the Higgs
- Instead, we look at many variables associated with each event at once – multivariate analysis

S vs. B in VH → Vbb

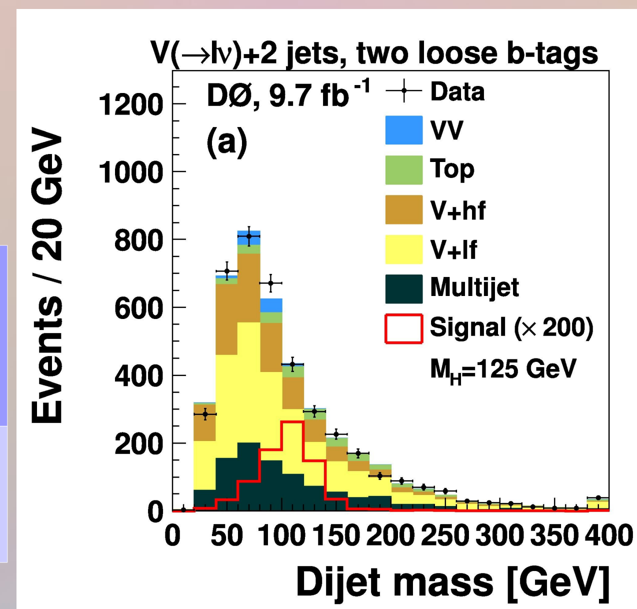
- Important:
  - Jet energy resolution Δm/m~15%
  - b-tagging
  - Multivariate techniques







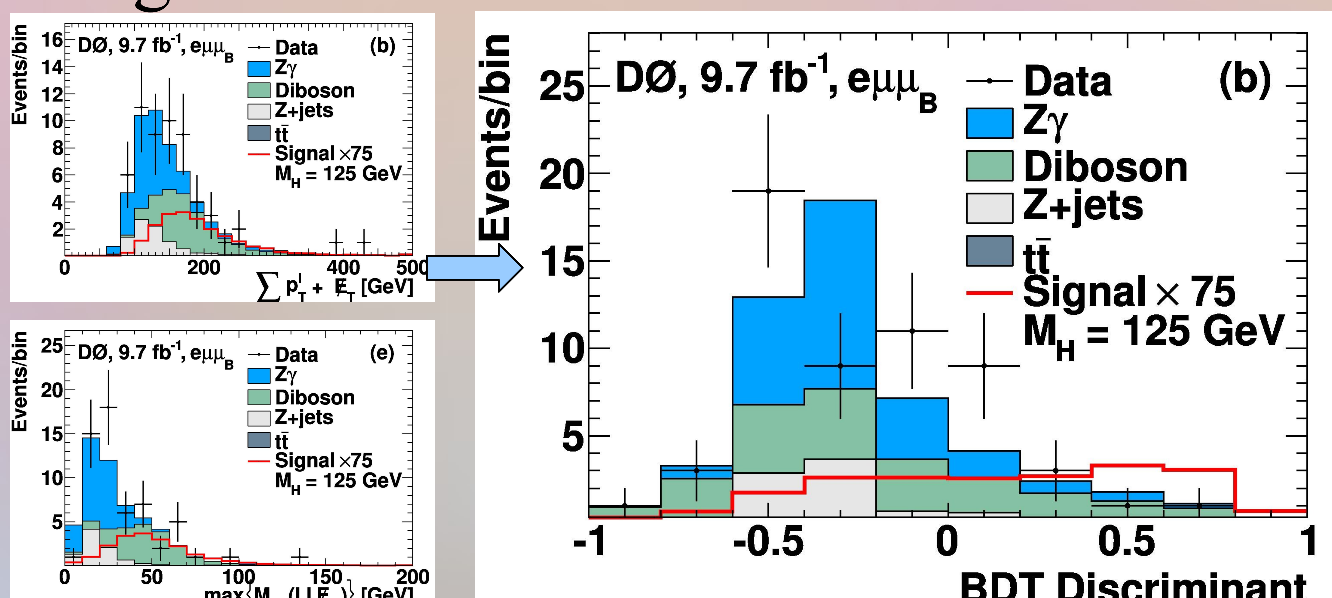
	Before b-tagging	2 loose tags
s/b	1/7000	1/1400



Multivariate Analysis

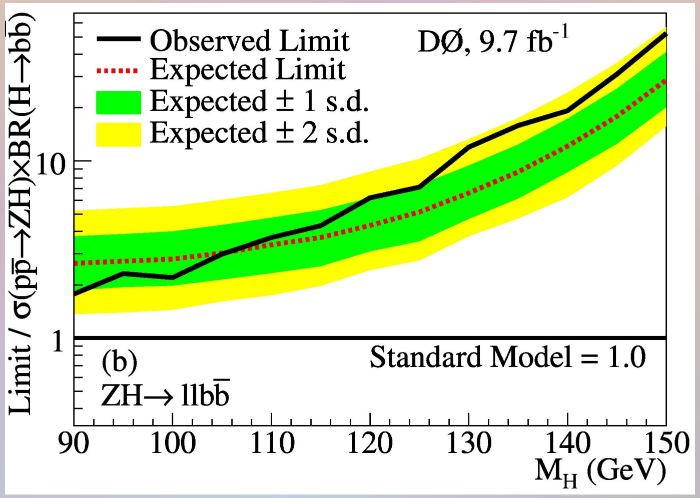
- Take multiple variables, each of which has some separating power
- Combine them into one variable that separates the signal and background

14 variables +



DØ Combination

- We have limited sensitivity in any one final state
  - We therefore look at $ZH \rightarrow ll b\bar{b}$, (link)



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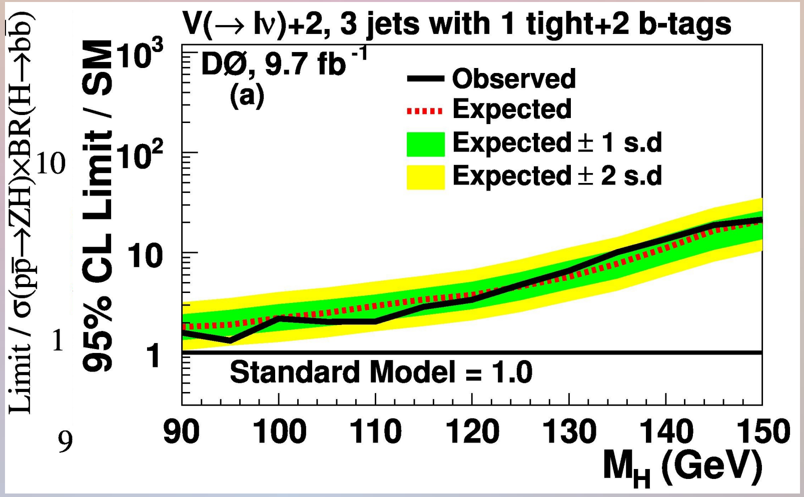

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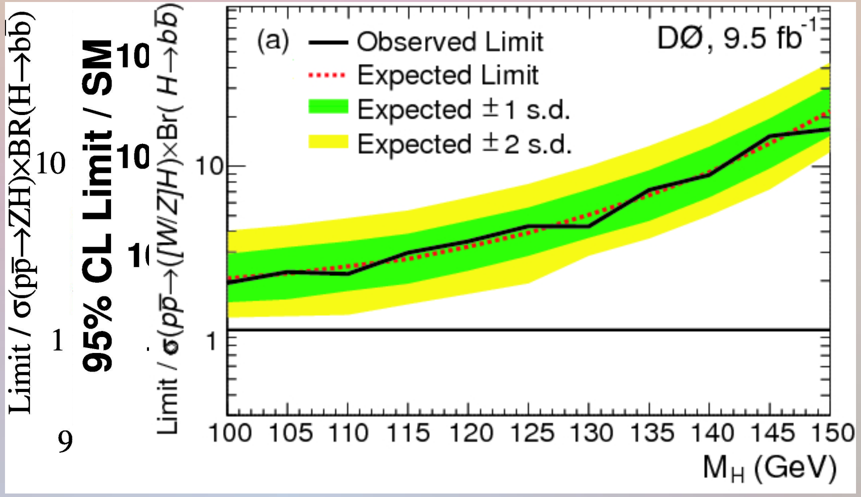

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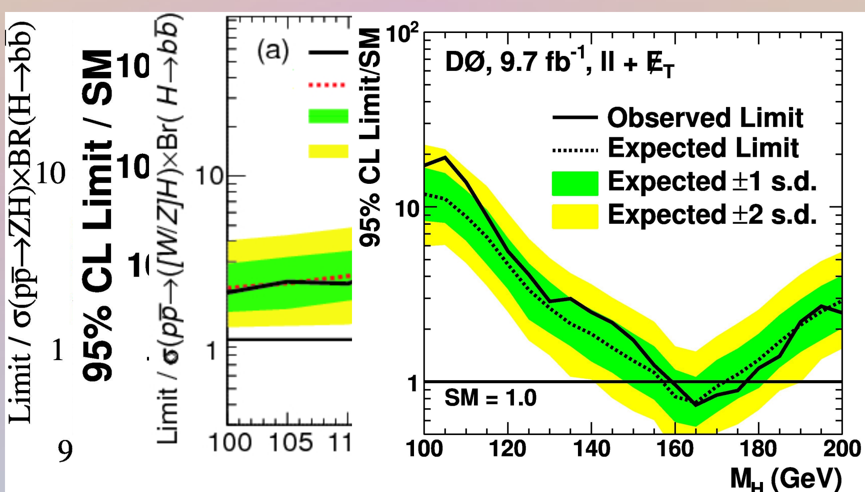

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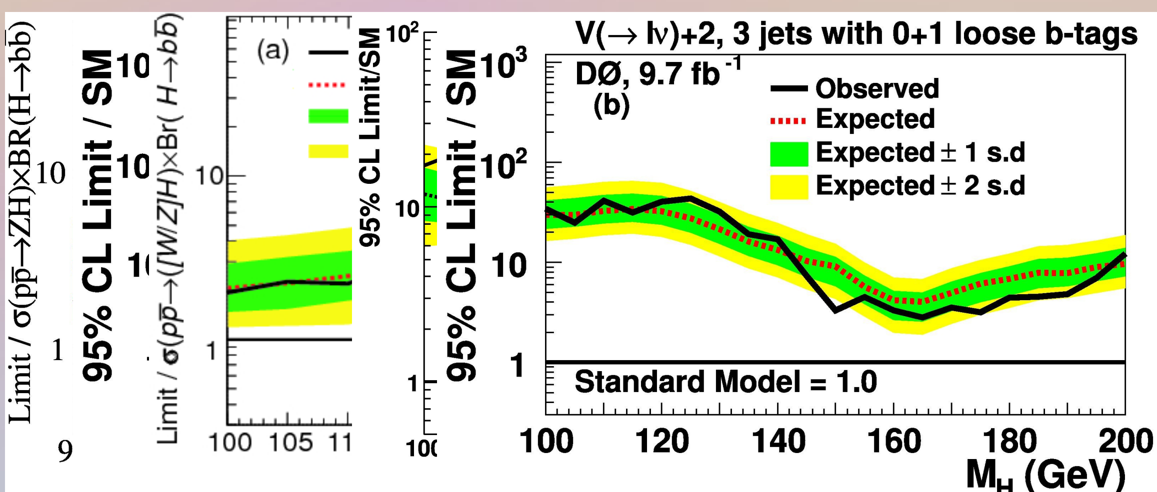

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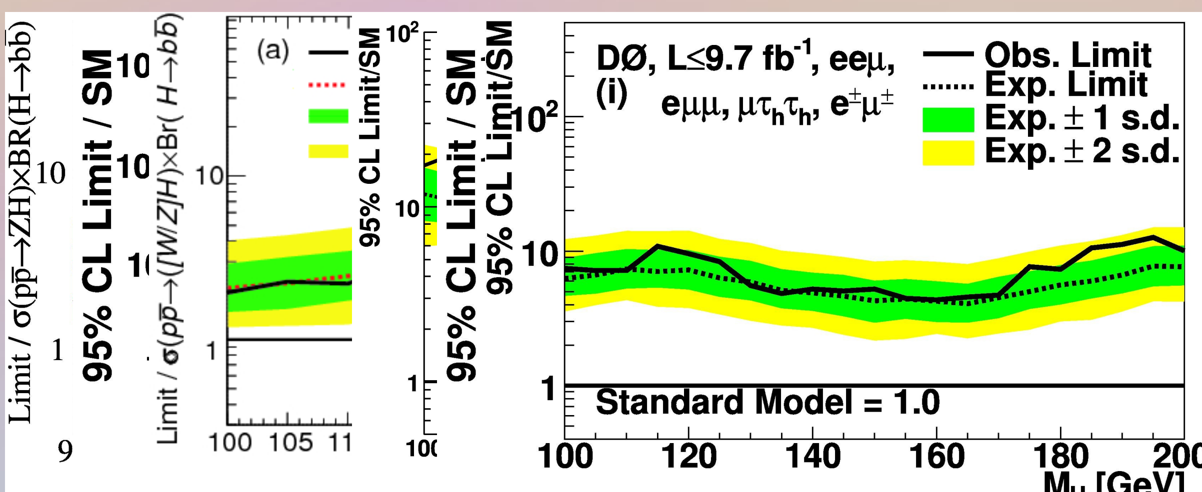

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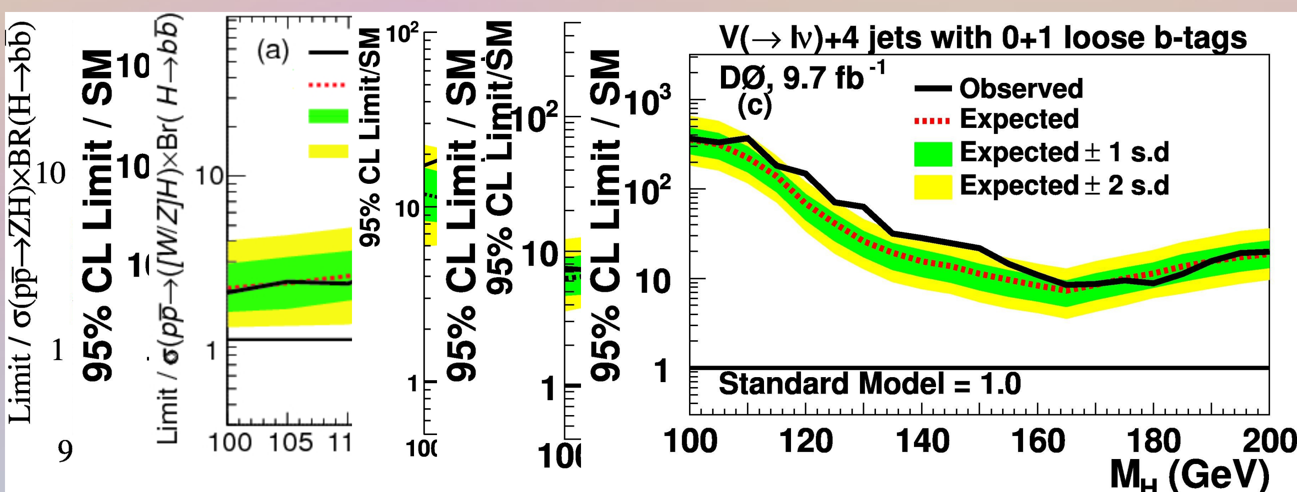

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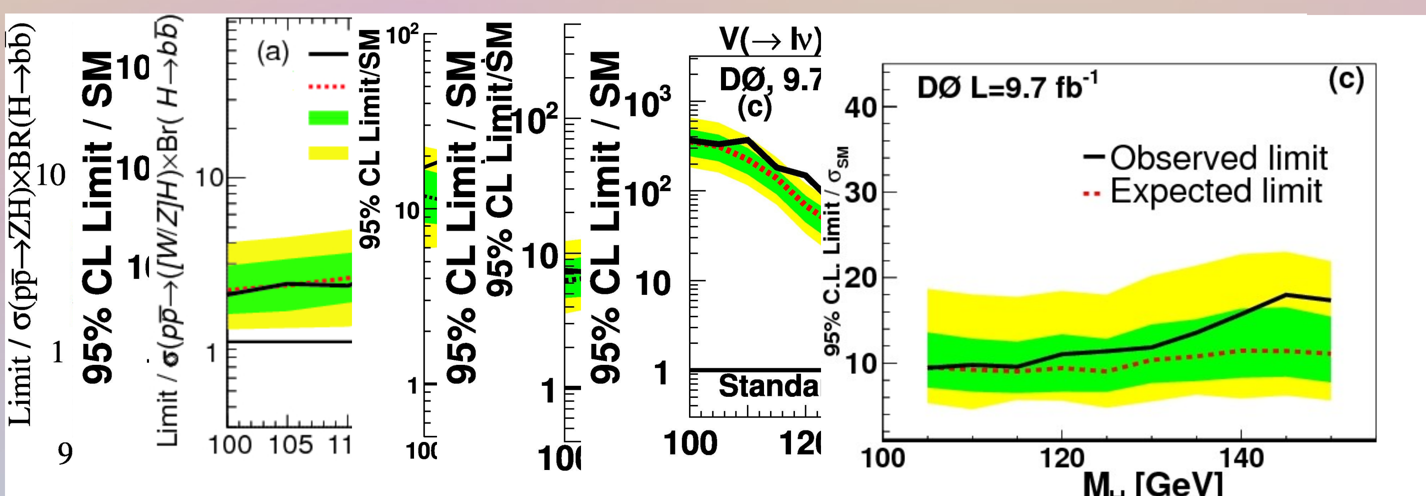

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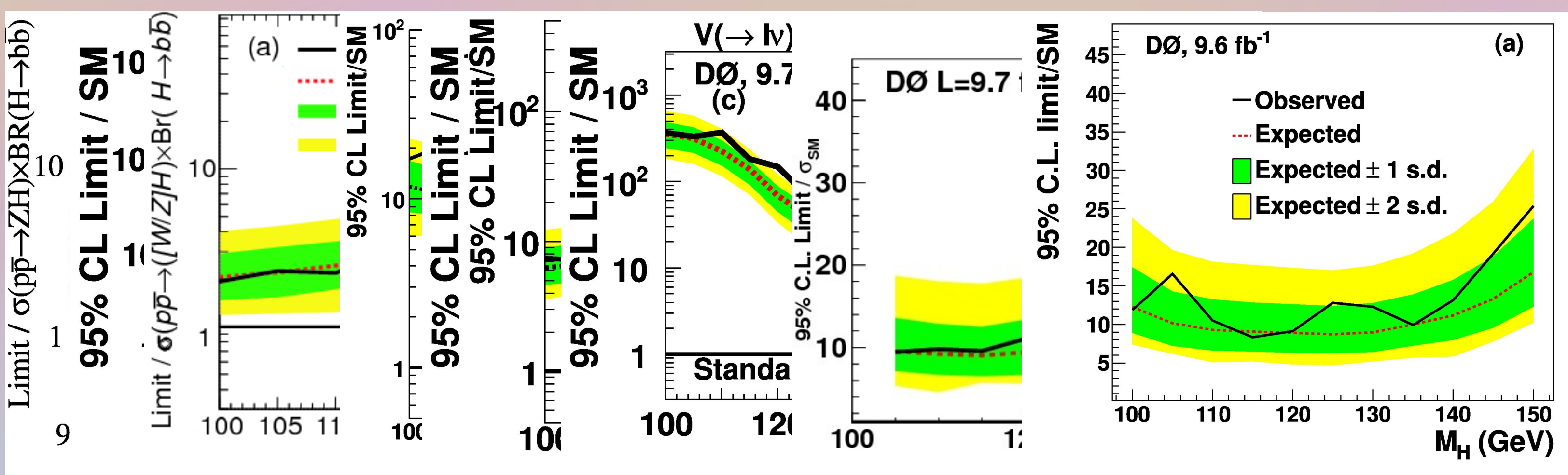

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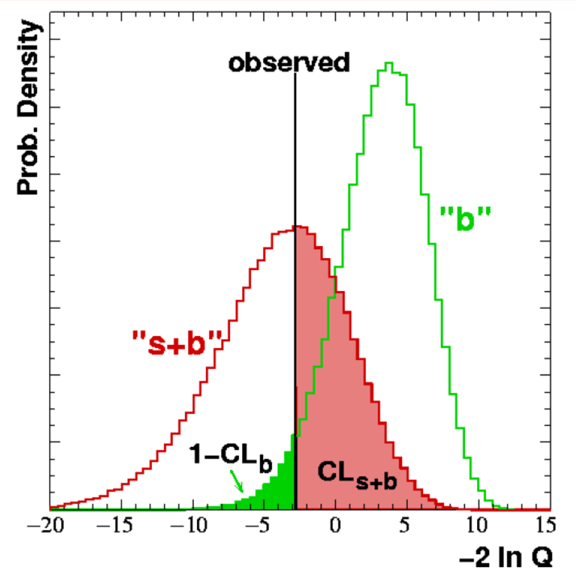
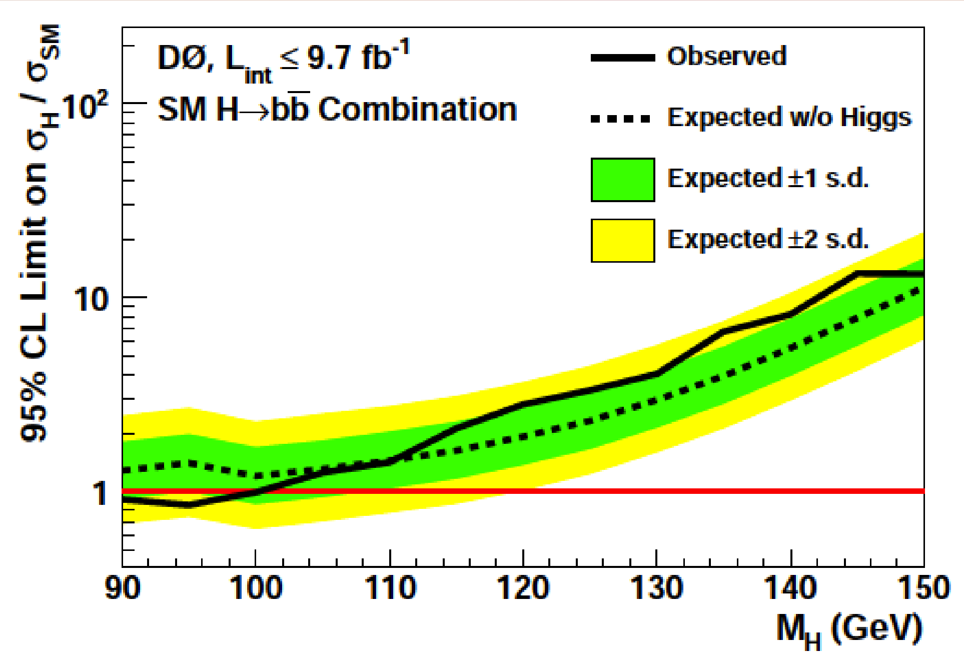
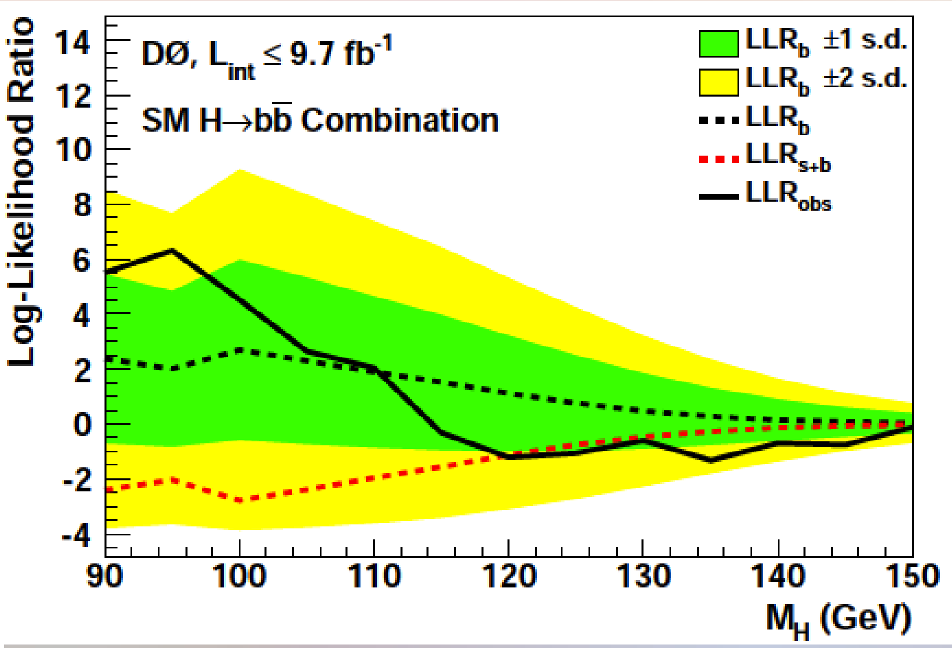
Channel ($V = W, Z$ and $\ell = e, \mu$)		Luminosity (fb^{-1})	M_H (GeV)
$WH \rightarrow \ell\nu bb$		9.7	90–150
$ZH \rightarrow \ell\ell b\bar{b}$	$H \rightarrow b\bar{b}$	9.7	90–150
$ZH \rightarrow \nu\bar{\nu}b\bar{b}$		9.5	100–150
$H \rightarrow W^+W^- \rightarrow \ell^+\nu\ell^-\bar{\nu}$		9.7	100–200
$H + X \rightarrow W^+W^- \rightarrow \mu^\pm\tau_h^\mp + \leq 1$ jet		7.3	155–200
$H \rightarrow W^+W^- \rightarrow \ell\nu q'\bar{q}$		9.7	100–200
$VH \rightarrow ee\mu/\mu\mu e + X$	$H \rightarrow W^+W^-$	9.7	100–200
$VH \rightarrow e^\pm\mu^\pm + X$		9.7	100–200
$VH \rightarrow \ell\nu q'\bar{q}q'\bar{q}$		9.7	100–200
$VH \rightarrow \tau_h\tau_h\mu + X$	$H \rightarrow \tau^+\tau^-$	8.6	100–150
$H + X \rightarrow \ell\tau_h jj$		9.7	105–150
$H \rightarrow \gamma\gamma$		9.7	100–150

VH → Vbb Results

Expected sensitivity @125 GeV: 2.3×SM; observed 3.5×SM







H→WW Result

Dilepton only:

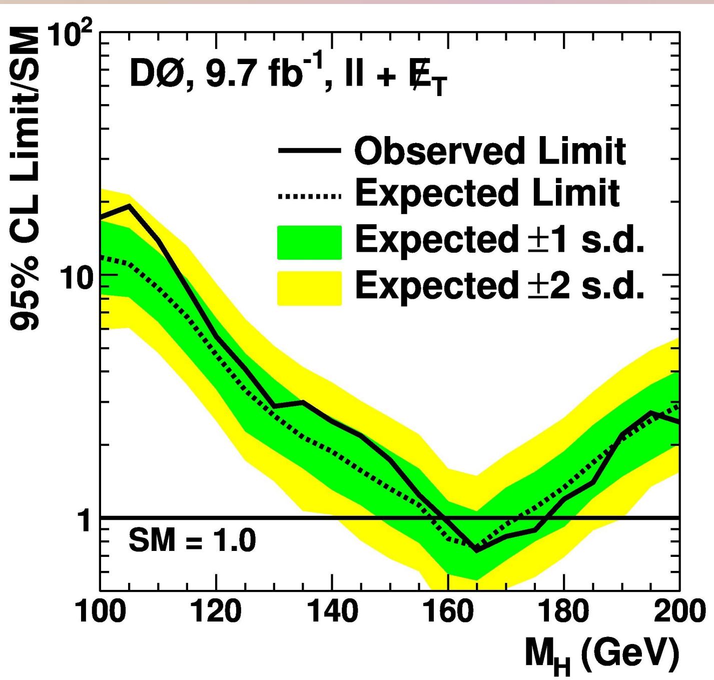
Exclude 159–176 GeV

For 125 GeV, exp. 3.4×SM, obs. 4.1×SM

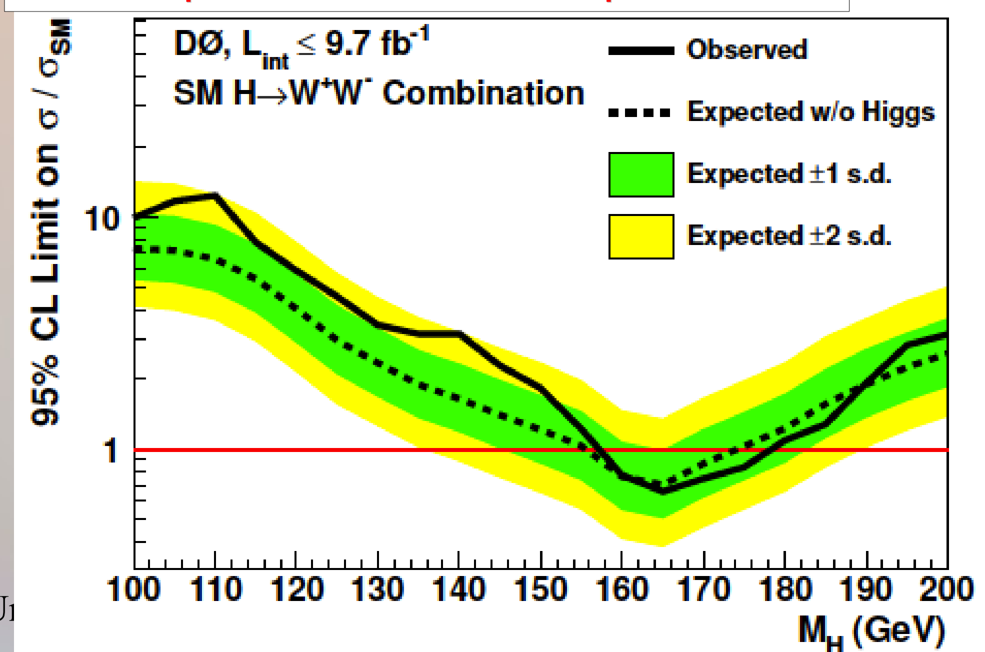
Full H→WW:

Exclude 157–-178 GeV

For 125 GeV, exp. 2.9×SM, obs. 4.6×SM



15% improvement over dilepton alone



$H \rightarrow \tau\tau$ and $H \rightarrow \gamma\gamma$ Results

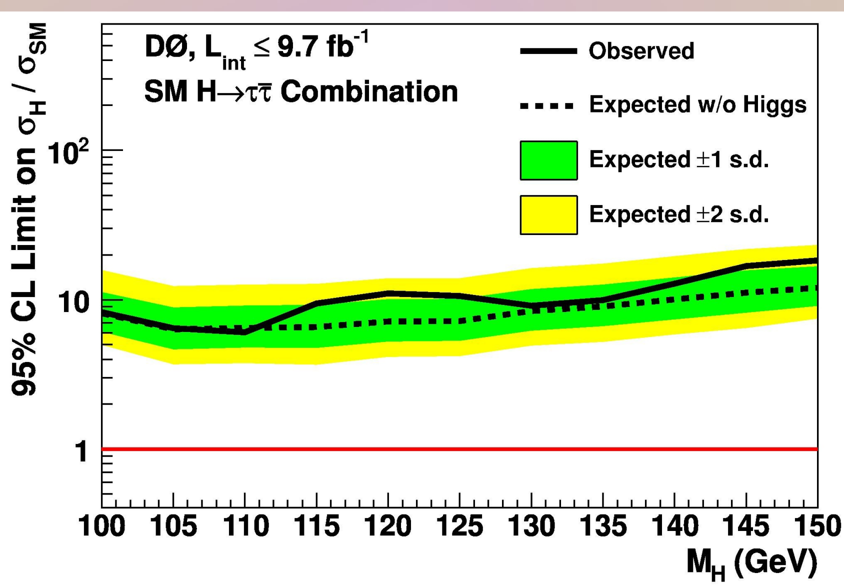
$H \rightarrow \tau\tau$:

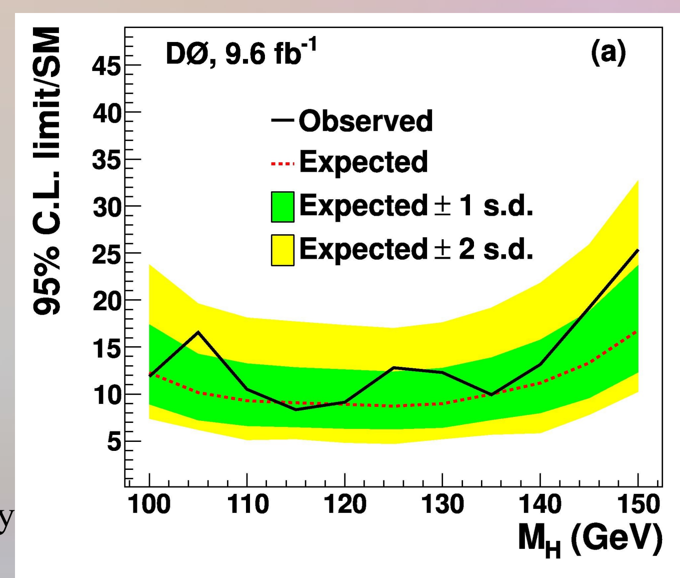
For 125 GeV, exp 7.25×SM
obs 10.4×SM

$H \rightarrow \gamma\gamma$:

Expect a narrow resonance, but small branching ratio

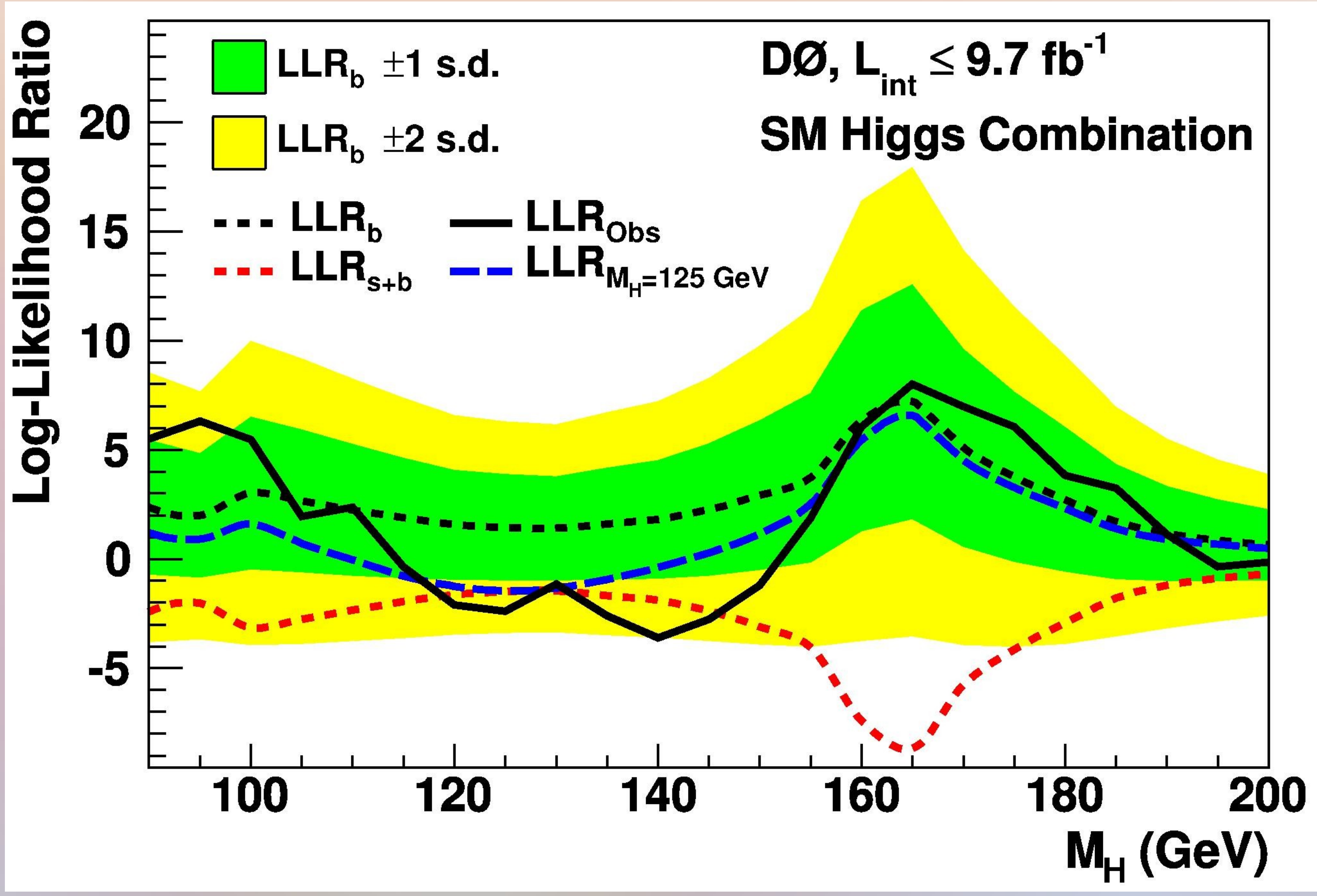
For 125 GeV, exp 8.7×SM
obs 12.8×SM





DØ Combination

The blue dashed line is the expected LLR for background + Higgs boson signal having a mass of 125 GeV with expected SM cross section.



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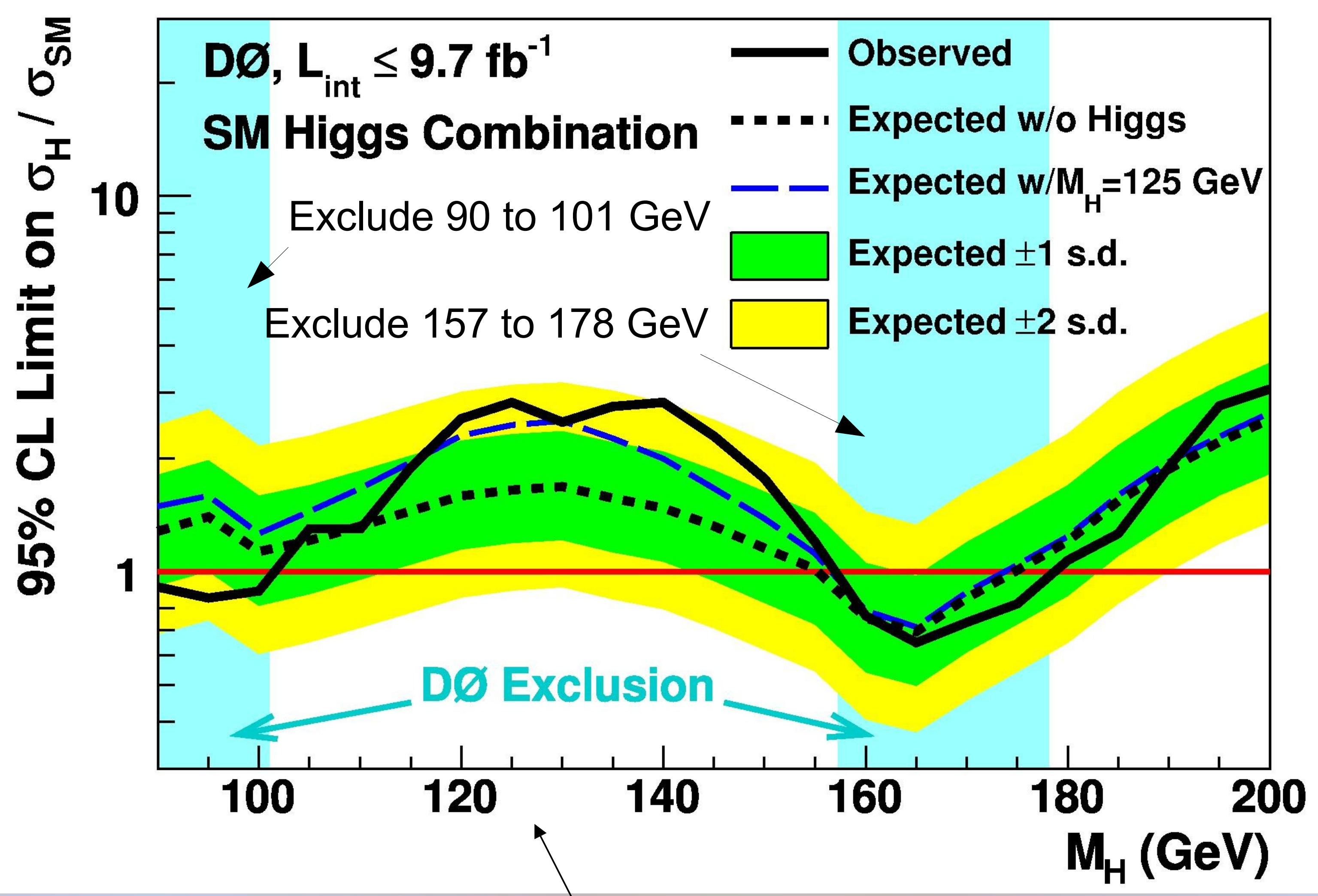
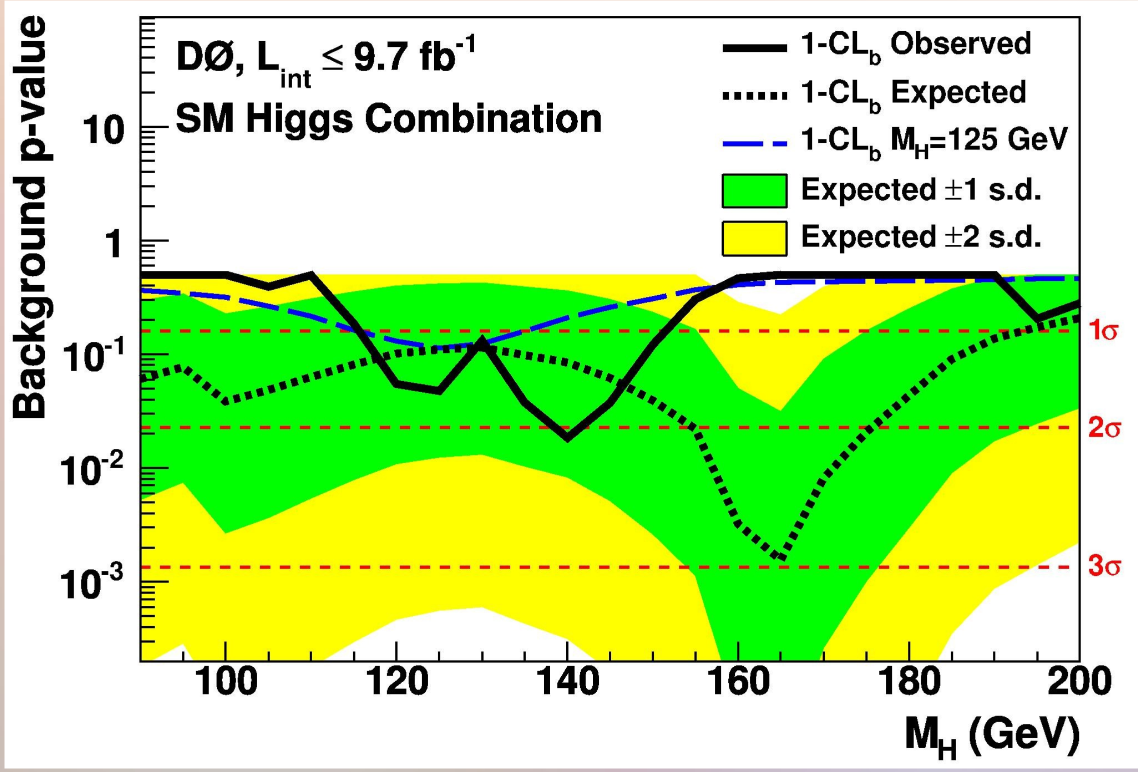


We expect a 95% CL limit of 1.66x SM expectation at m_H = 125 GeV, measure a limit of 2.92x SM expectation

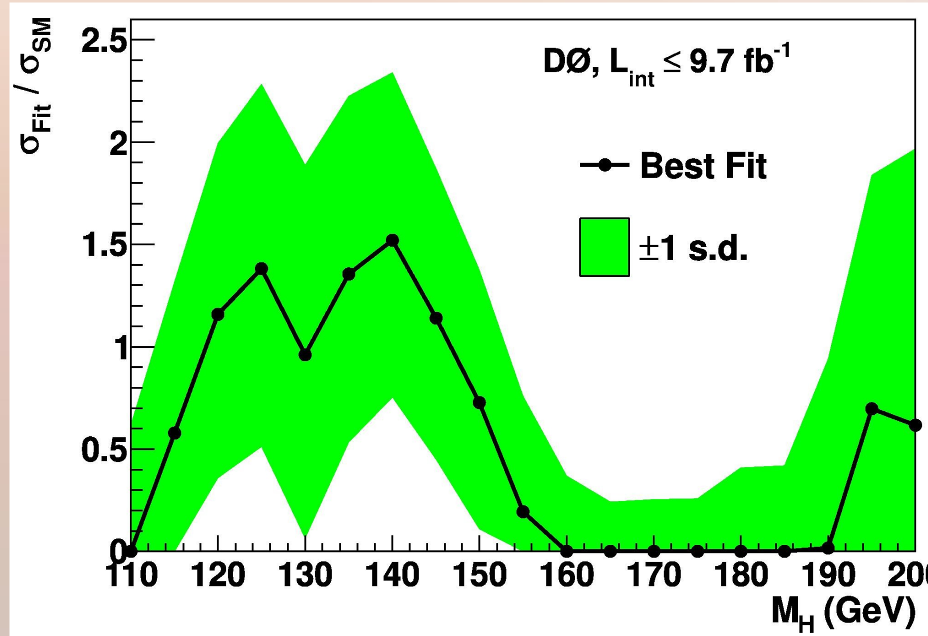
Magnitude of Excess

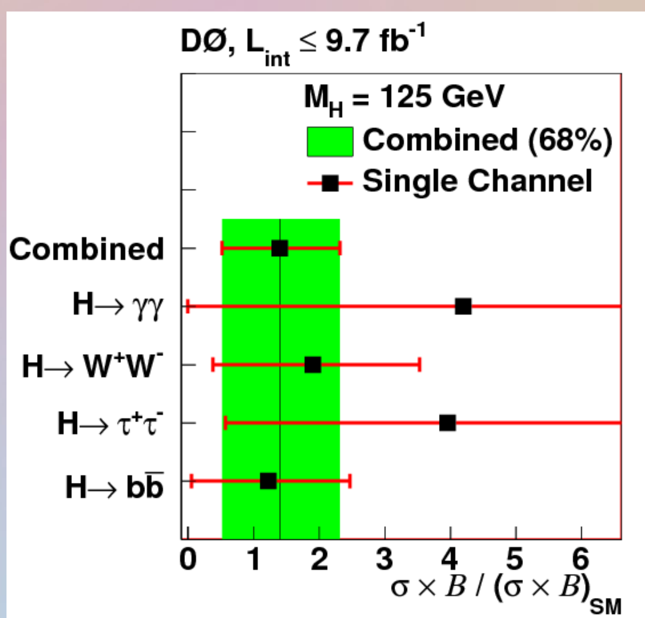
- Between M_H 120–145 GeV, up to a 2σ excess



Favored Cross Sections

- With M_H=125 GeV, best fit cross-section is 1.4× SM cross-section
  - Excess in all 4 main subchannels





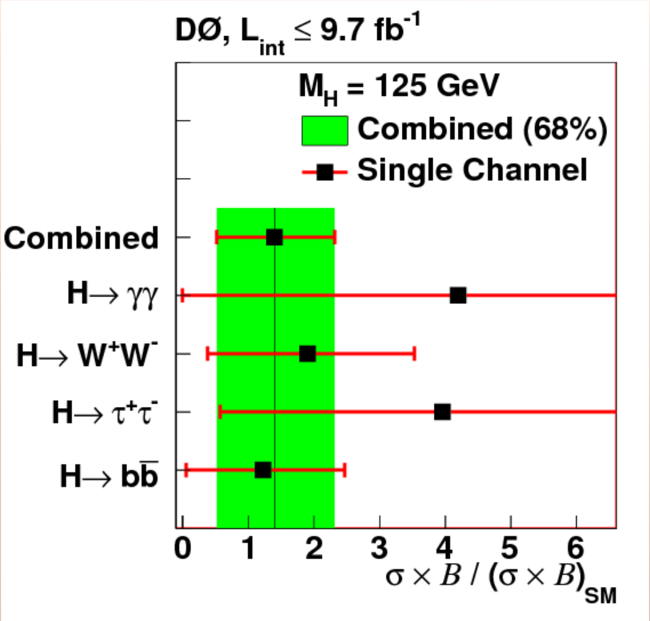
Combined	$1.40^{+0.92}_{-0.88}$
$H \to \gamma\gamma$	$4.20^{+4.60}_{-4.20}$
$H \to W^+W^-$	$1.90^{+1.63}_{-1.52}$
$H \to \tau^+\tau^-$	$3.96^{+4.11}_{-3.38}$
$H \to b\bar{b}$	$1.23^{+1.24}_{-1.17}$

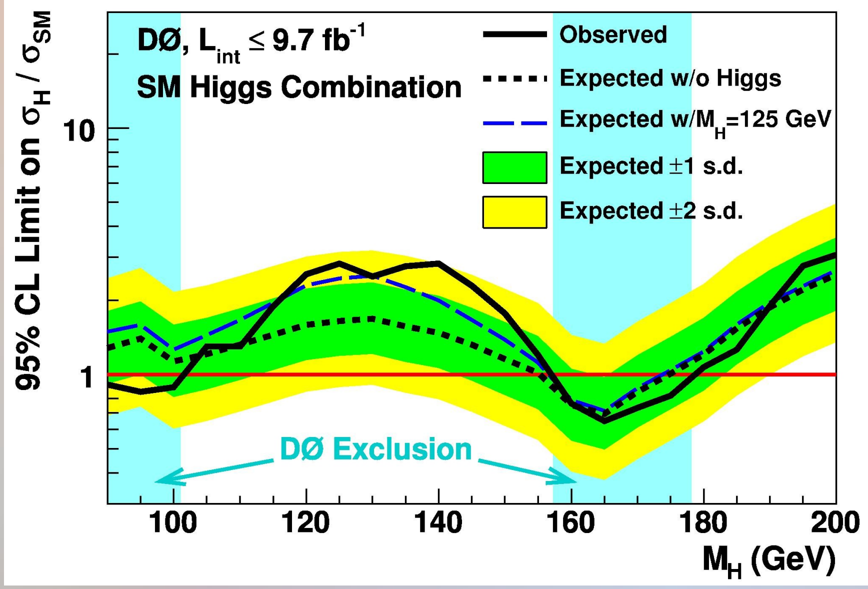
Conclusions

- Have set limits on SM Higgs boson production at DØ

Sub. to PRD (arXiv:1303.0823)

- With M_H=125 GeV, best fit cross-section is 1.4× SM cross-section
  - Excess seen in all four main subchannels
- DØ excludes Higgs boson masses between 90–101 GeV and 157 – 178 GeV @ 95% CL





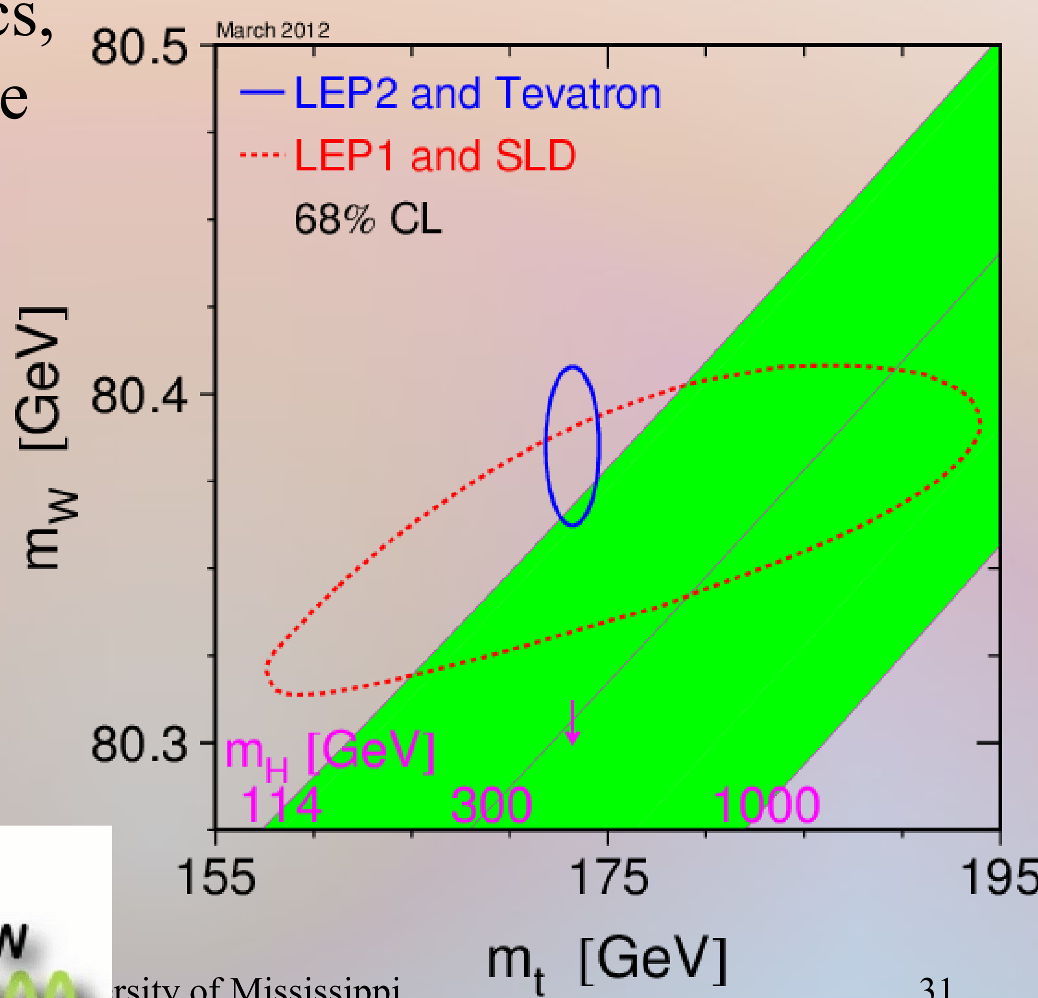
Backup Slides

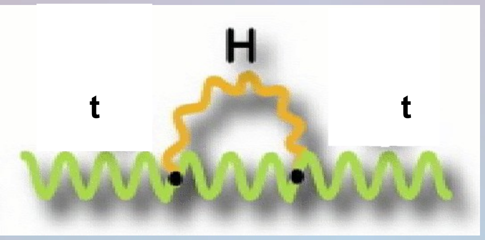
Indirect Measurements

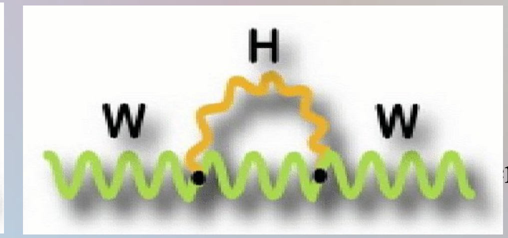
Because of quantum mechanics, the Higgs bosons can influence other particles without being directly detected

More mass ⇒ more interactions with virtual Higgs bosons

Measuring the mass of the W boson and top quark can tell us about the Higgs boson







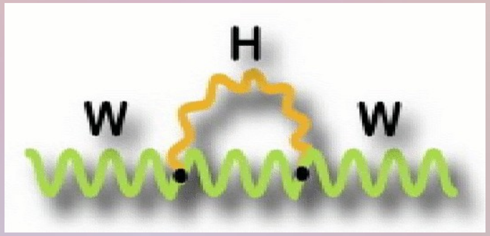
Indirect Measurements

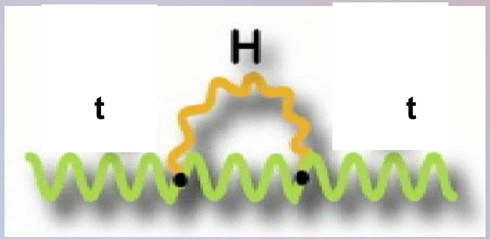
Fit to the precision EW data

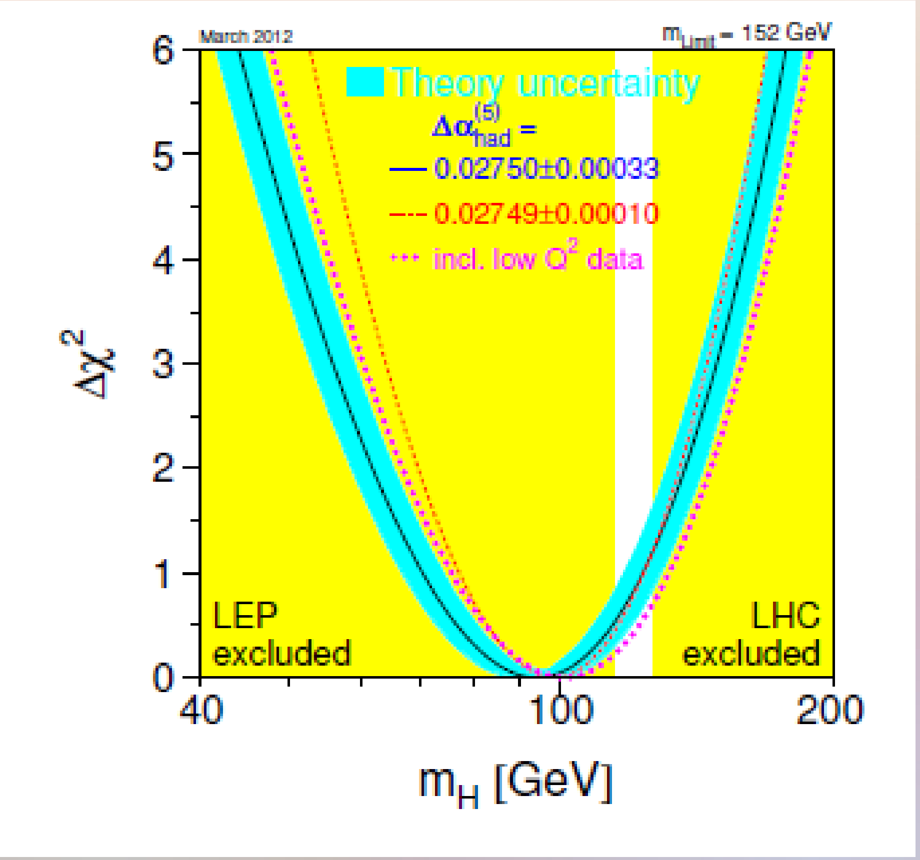
Prefers a low mass Higgs

$\Rightarrow M_H \approx 94$ GeV

$\Rightarrow M_H \leq 152$ GeV at 95% CL

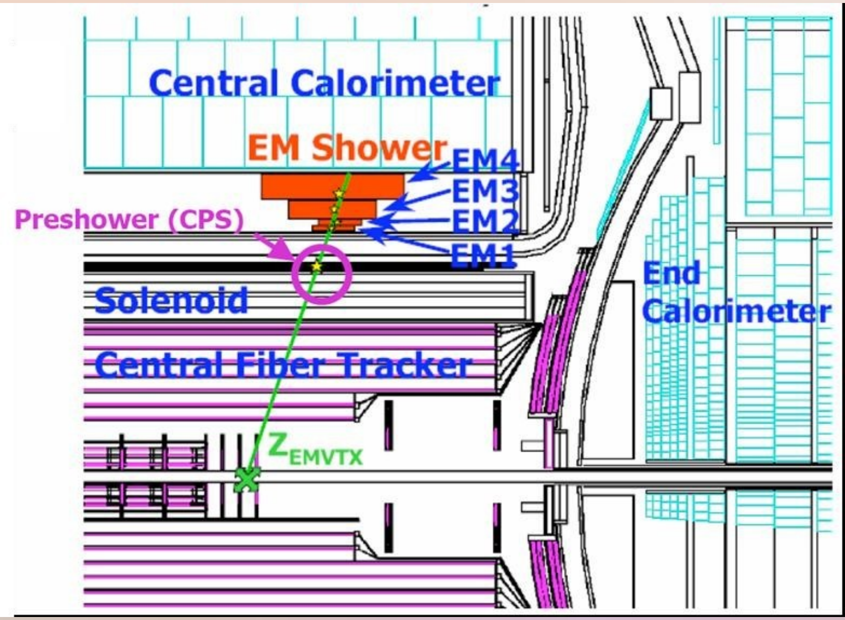


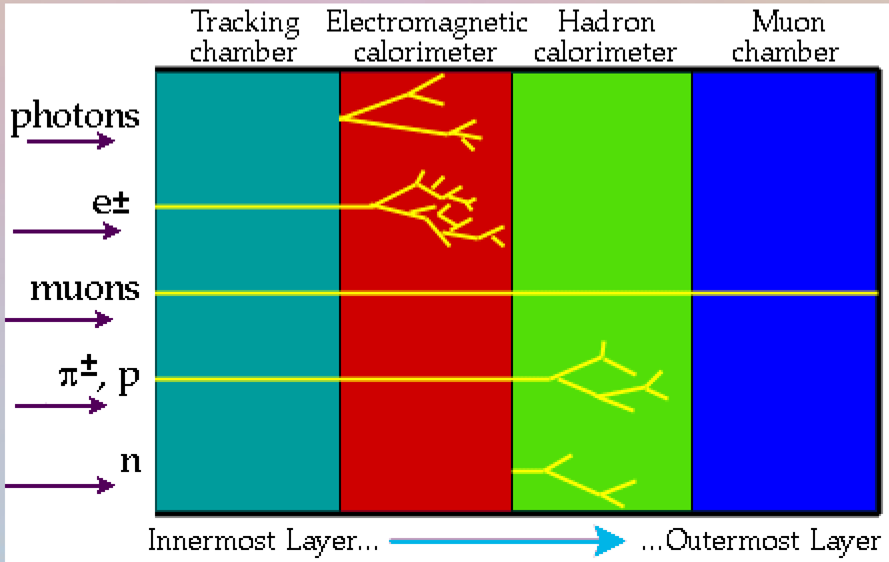




Electrons, Photons

- Lighter particles (e, γ) are stopped in the first few layers of the the calorimeter
- Hadrons make it farther into the detector

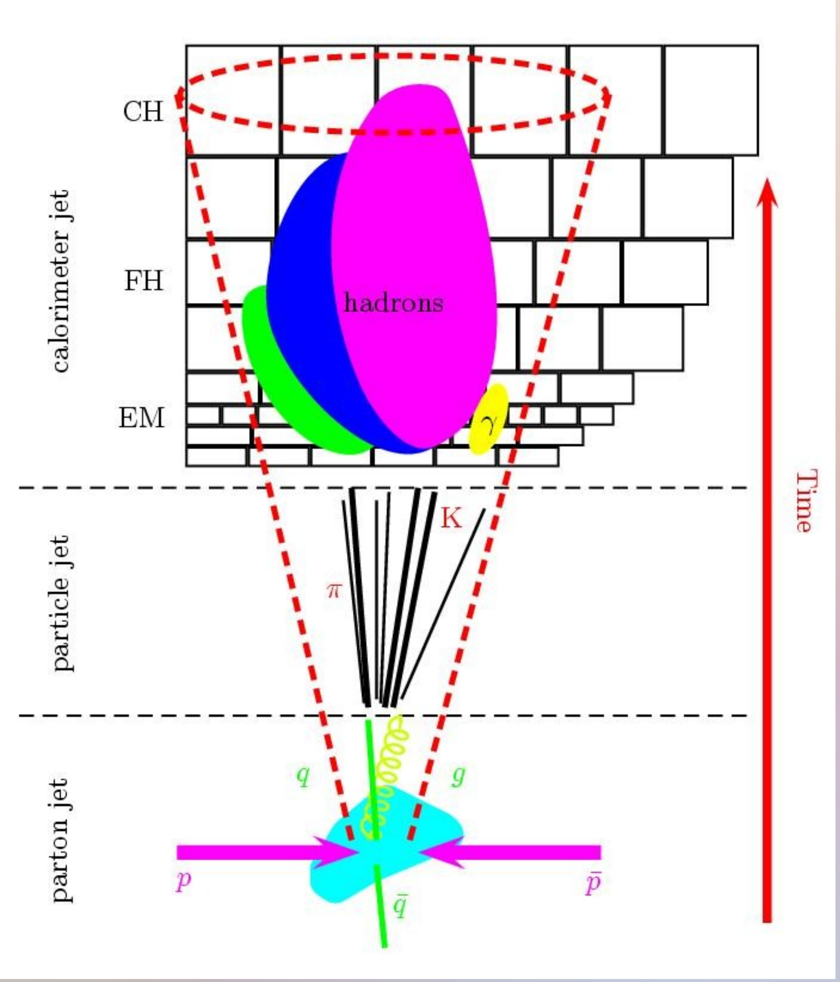


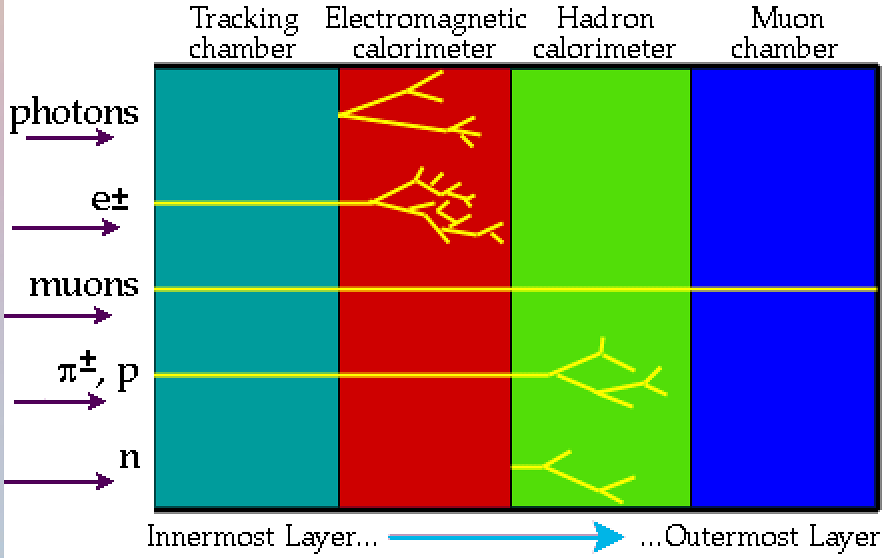


- Only charge particles leave tracks
- Track matching allow us to distinguish e from γ

Hadronic Jets

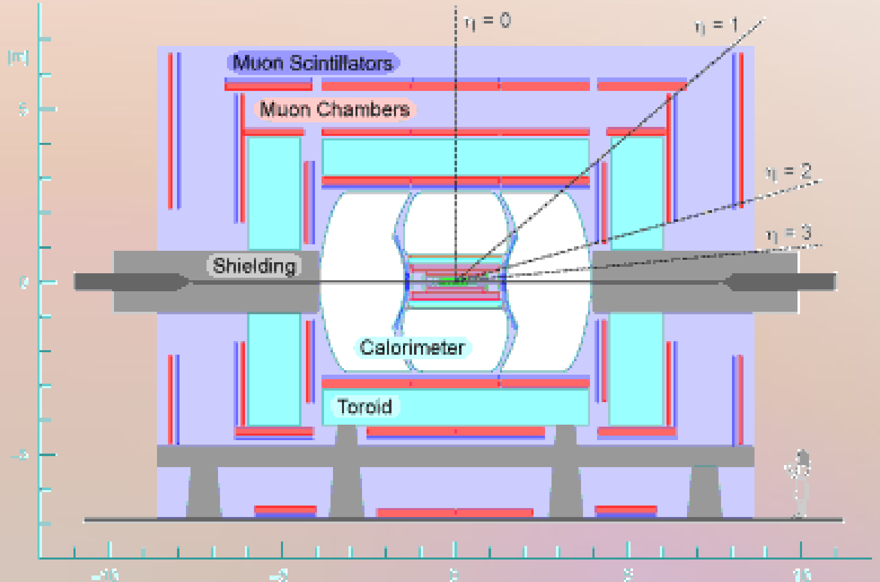
- When a high momentum quark or gluon is produced in a collision, results in a jet of hadronic particles into the detector

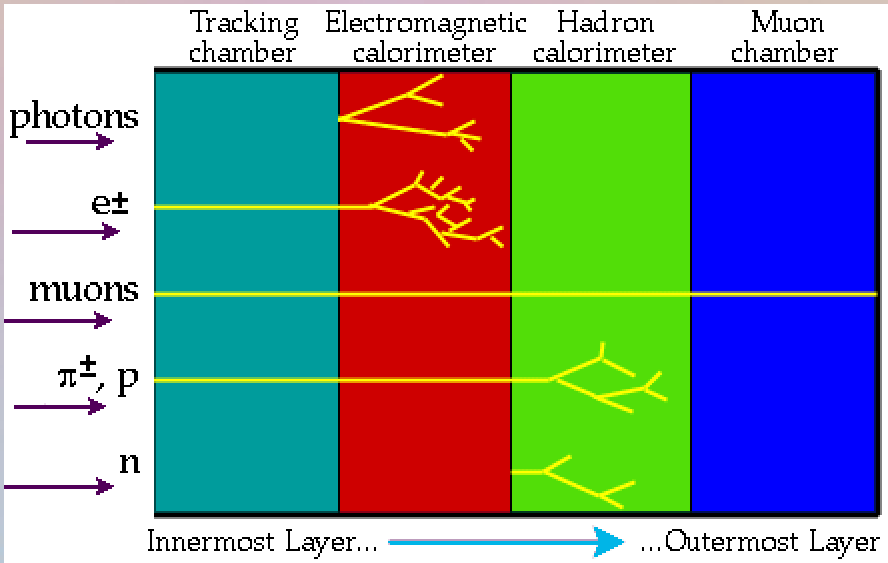




Muons

- Muons can pass through our entire detector
  - μ are massive enough not to be stopped like e or γ in EM calorimeter
  - Don't feel strong force, so hard interactions are rare

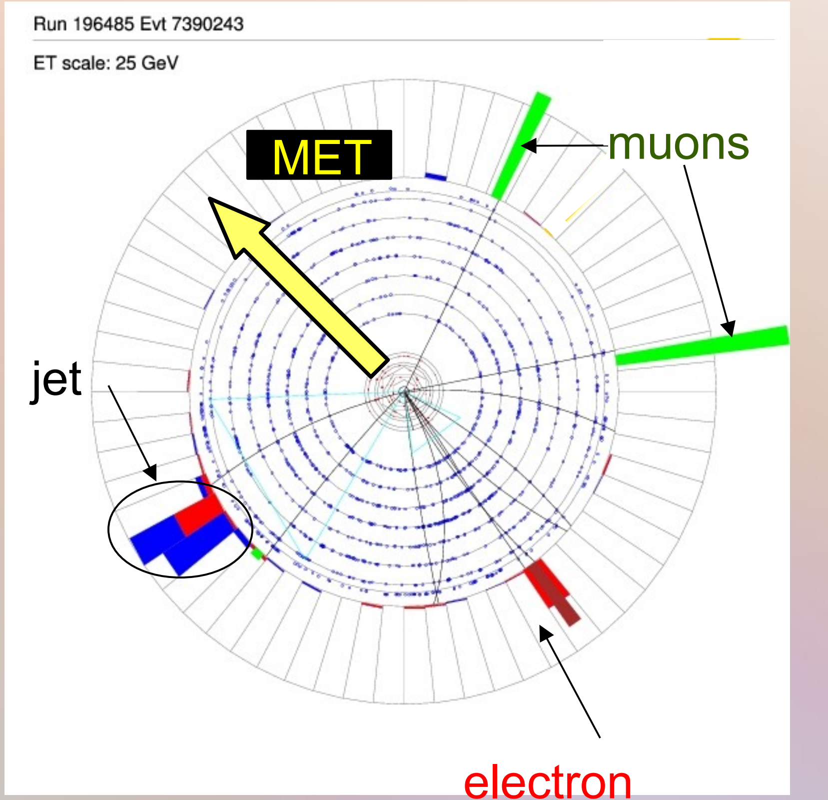




- Muons are charged, so they leave tracks
- Place trackers outside the calorimeter to detect passage, and match to a track in inner tracker

Missing Transverse Energy

- Neutrinos do not interact with our detector
  - Infer their presence through missing transverse energy
  - Transverse = ⊥ to beamline
- To conserve momentum,
- vector sum SpT = 0
  - If non-zero, then either
    - Energy Mis-measurement
    - Missed one or more particles (usually neutrinos)

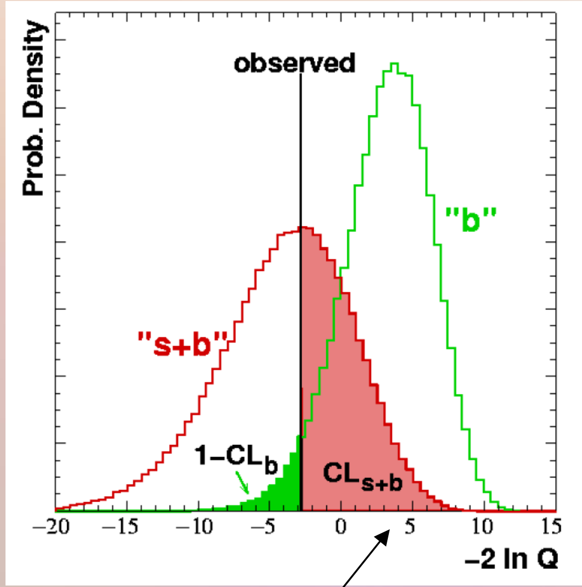


How We Set Limits

- Based on log-likelihood ratio

$$-2\ln Q \equiv LLR \equiv -2\ln\left(\frac{L(\text{data}\,|\,s+b,\hat{\theta})}{L(\text{data}\,|\,b,\hat{\theta})}\right)$$

  - L is the Poisson likelihood that the $s+b$ (b) correctly models the data
  - θ represents the systematic uncertainties on the measurements (luminosity, energy scale, etc.)



- Calculate probability density of LLR based on models of signal and background

How We Set Limits

- Based on log-likelihood ratio

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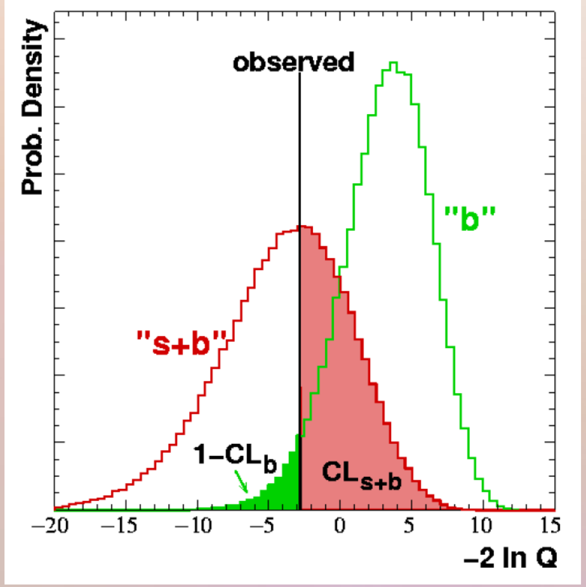

- CL_b and CL_{s+b} are given by the integrals of the *b* and *s*+*b* LLR distributions above observed LLR
  - Represents how well the given model agrees with data
- We vary the signal content of the *s*+*b* model to find where $CL_s = CL_{s+b}/CL_b < 0.05$
  - We exclude those points at the 95% Confidence Level (CL)