Search for the Higgs in $VH \rightarrow VWW \rightarrow$ leptons+X at the Tevatron

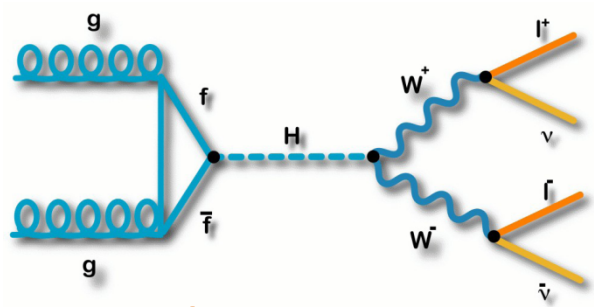
Michael Cooke Fermilab

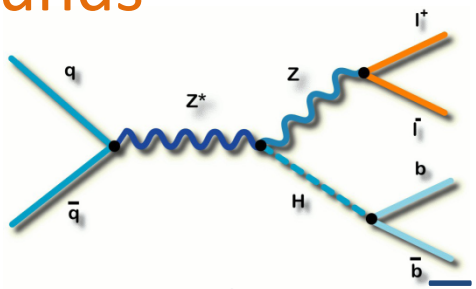
On behalf of the CDF II and DØ Collaborations

2011 Meeting of the Division of Particles and Fields of the American Physical Society

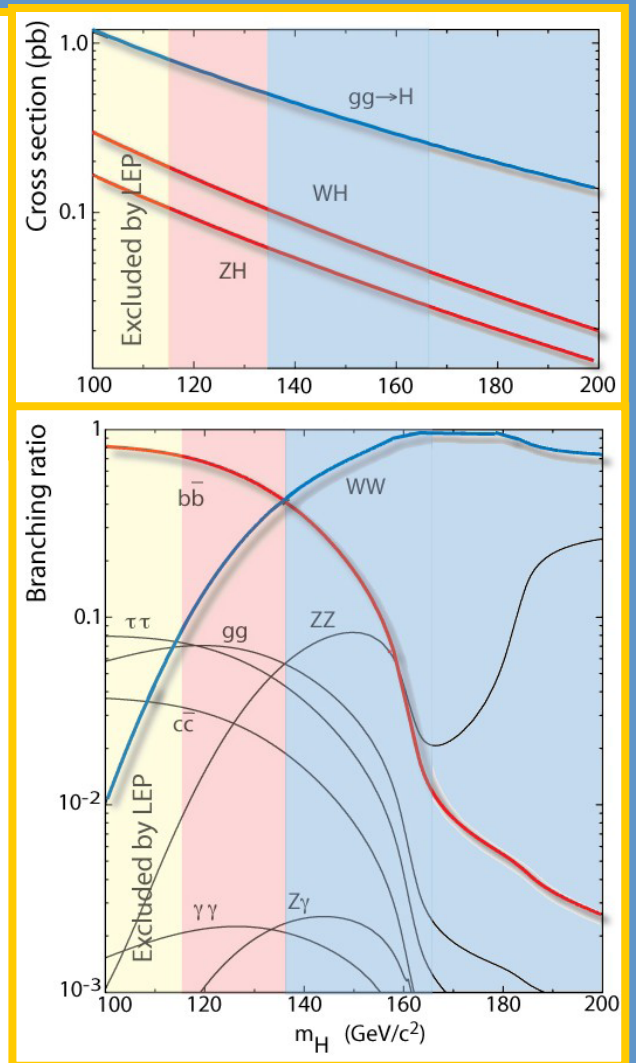
The Life and Death of a Higgs

- Gluon fusion dominates production
  - Hard to tell $H \longrightarrow b\bar{b}$ from multijet backgrounds

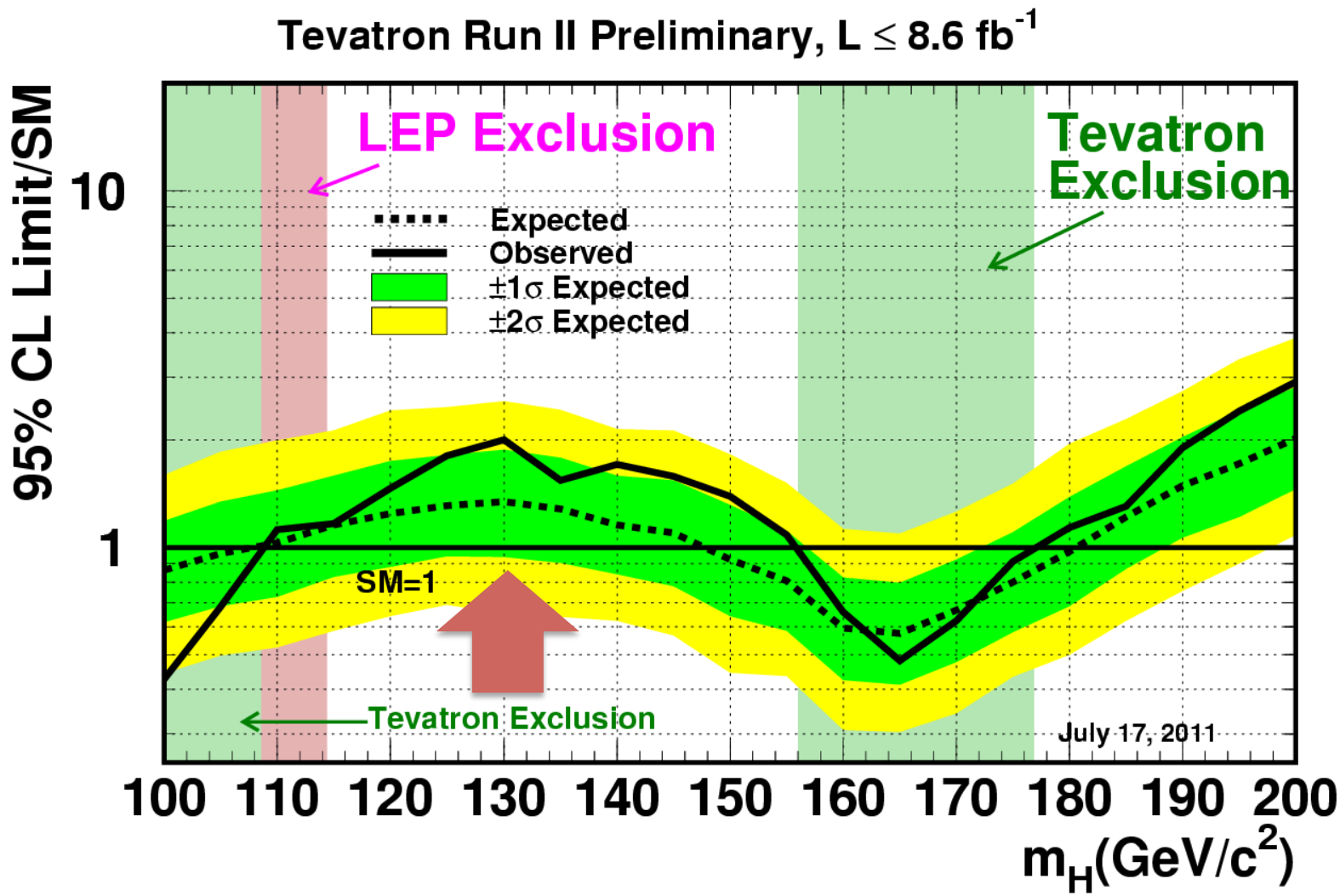




- Associated production ($H \longrightarrow b\bar{b}$) most sensitive at low mass
  - Why $VH \longrightarrow VWW$? …

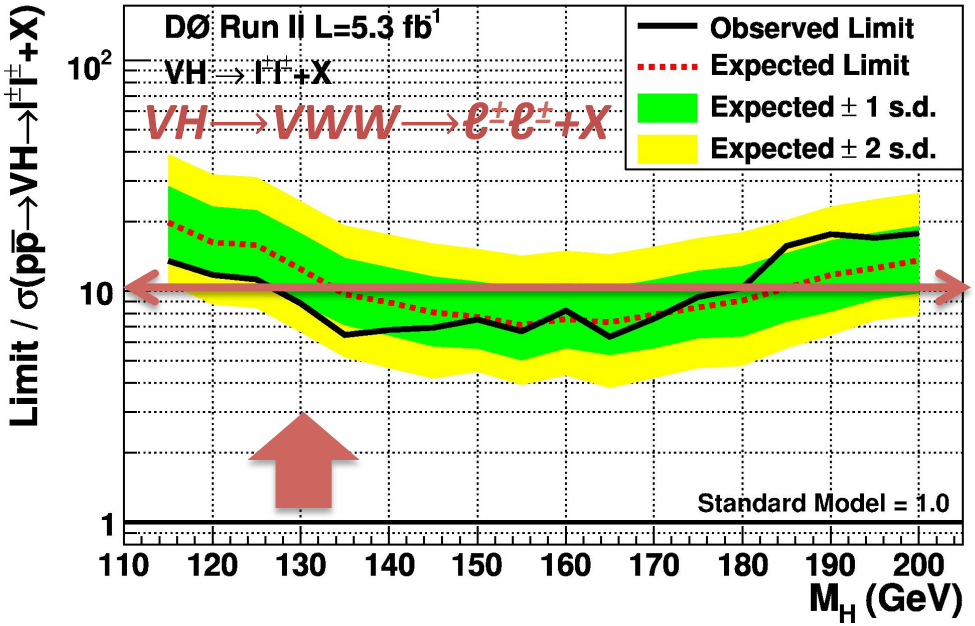


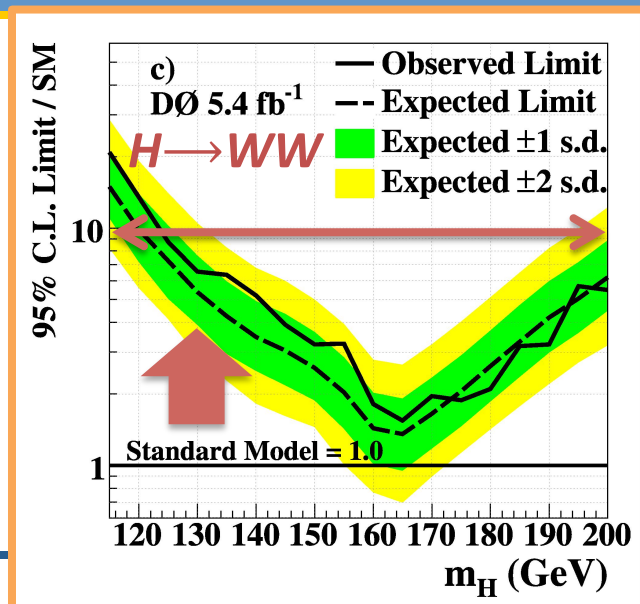
Intermediate Importance

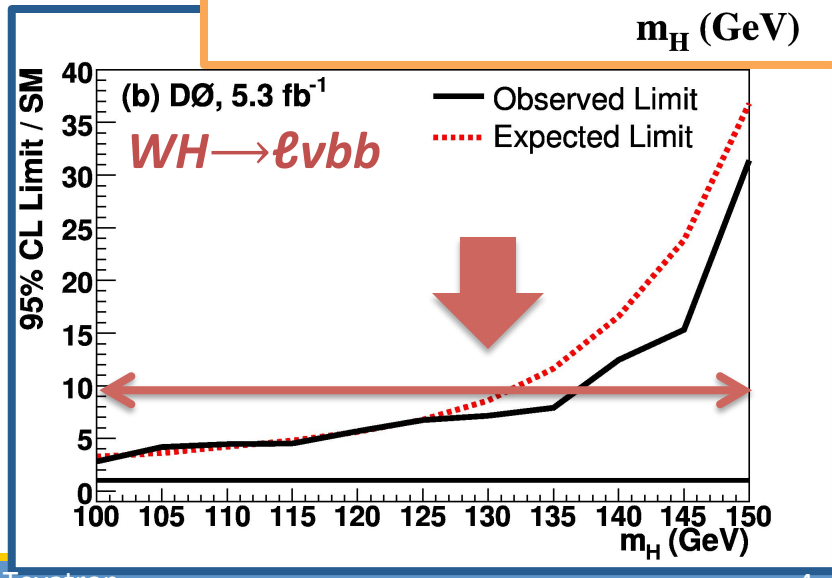


Complimentary Search

- Not many sources of same-sign leptons or trileptons in SM
  - Low bkgd leads to important contribution at intermediate m_H

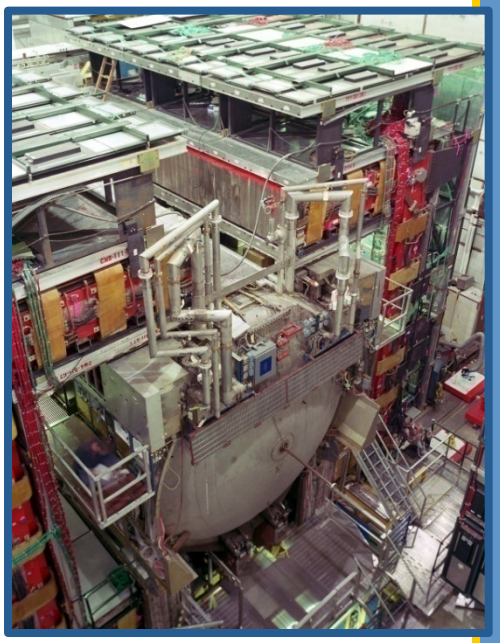


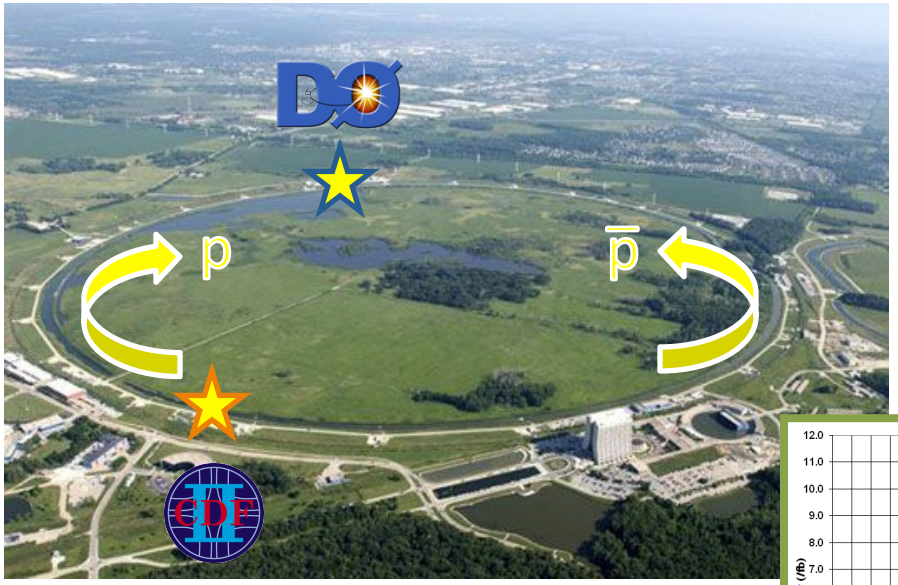




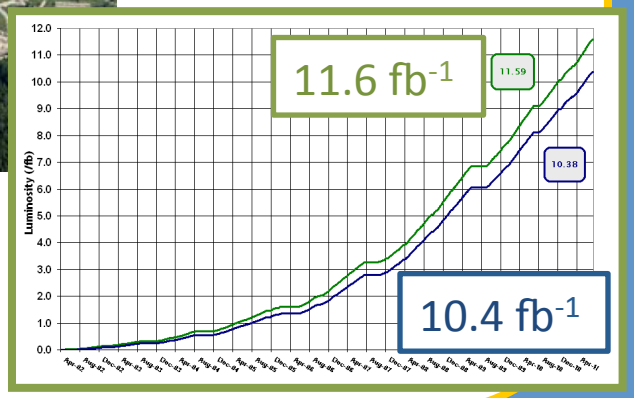
Creating the Higgs at Fermilab

The Tevatron produces $p\bar{p}$ collisions at CM energy ($\sqrt{s}$) 1.96 TeV

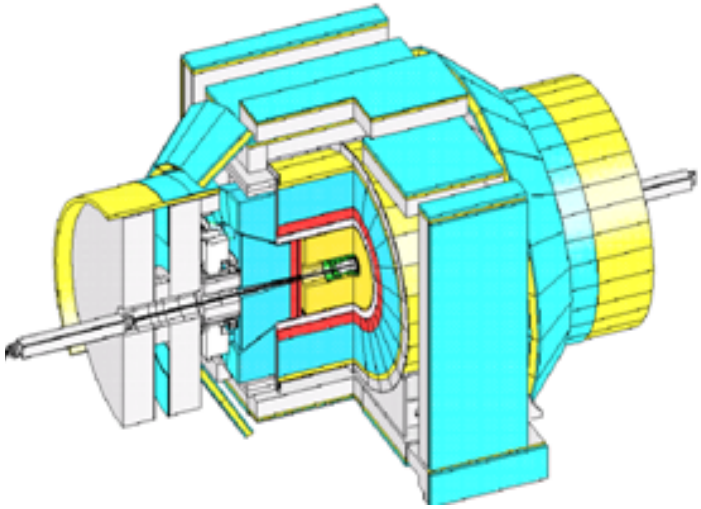




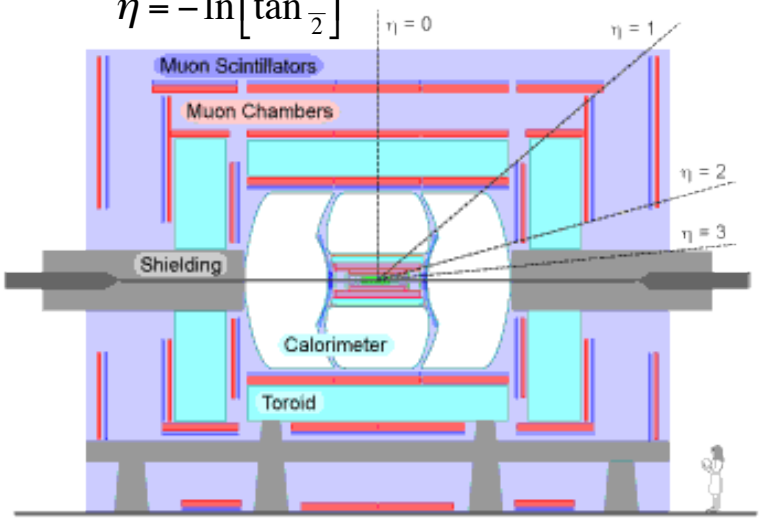
Thanks to the Accelerator Division for providing excellent performance!



The CDF and DØ Detectors



$$\eta = -\ln\left[\tan\frac{\theta}{2}\right]$$



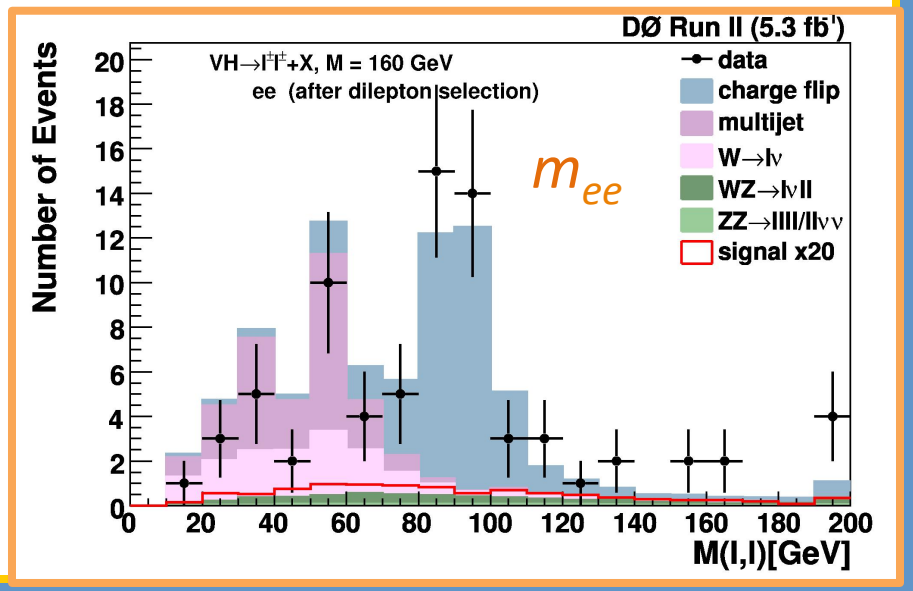
- Silicon vertex detector
- Wire drift chamber tracking
- Pb/Fe-scintillator calorimeter
- Muon chambers

- Silicon vertex detector
- Scintillating fiber tracking
- LAr-U calorimeter
- Muon chambers

Submitted to Phys. Rev. D (arXiv:1107.1268 [hep-ex]), 5.3 fb^{-1}

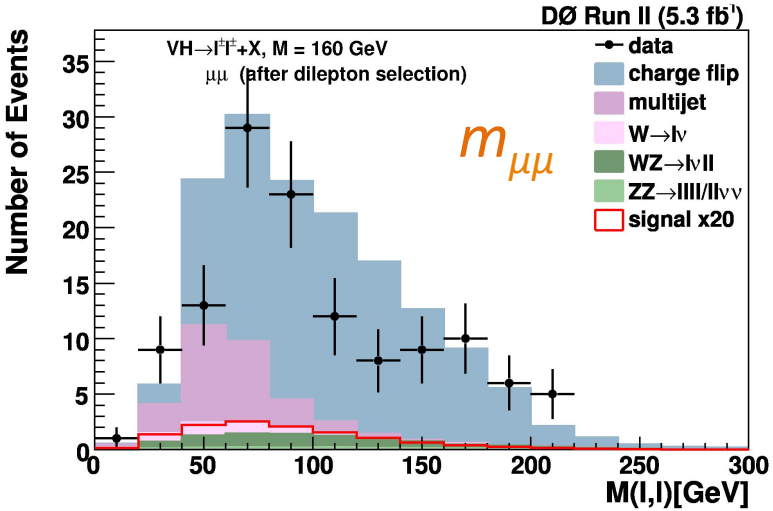
$VH \longrightarrow VWW \longrightarrow \ell^{\pm}\ell^{\pm}+X$ at DØ

- Three channels (ee, $e\mu$, $\mu\mu$) considered:
  - Central lepton within CFT, with SMT hits
    - SS ℓ's $|\eta_e| < 1.1$, $|\eta_\mu| < 1.8$; Extra ℓ's $|\eta_e| < 2.5$, $|\eta_\mu| < 2.0$
  - Max p_T^{ℓ}, $m_{\ell\ell}$ cuts ensure good charge measurement
    - SS ℓ's $15 < p_T^{\ell} < 200$ GeV, $15 < m_{\ell\ell} < 250$ GeV
- Instrumental bkgds dominate
  - Charge-flip of OS pairs
  - W+jet/γ
  - Multijet



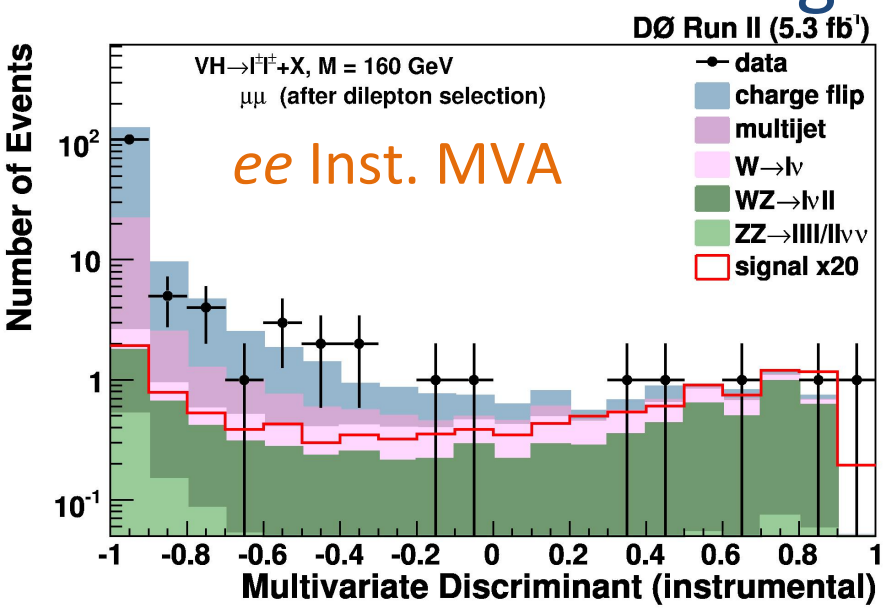
Estimating Charge-Flip

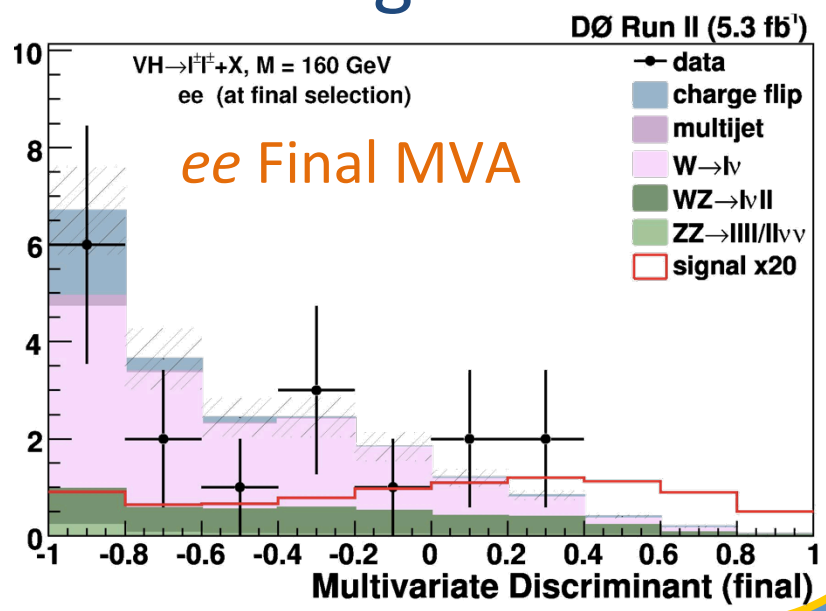
- *ee*: Flip rate measured in Z⟶*ee* control sample, then applied to unlike-sign data
- *μμ*: Central tracking and muon system yield independent charge measurements
  - Eff. of local muon charge assignment measured with $Z \longrightarrow \mu\mu$ as fn. of $1/p_T$
  - Count of central vs. local muon charge discrepancy used to determine true same-sign lepton count



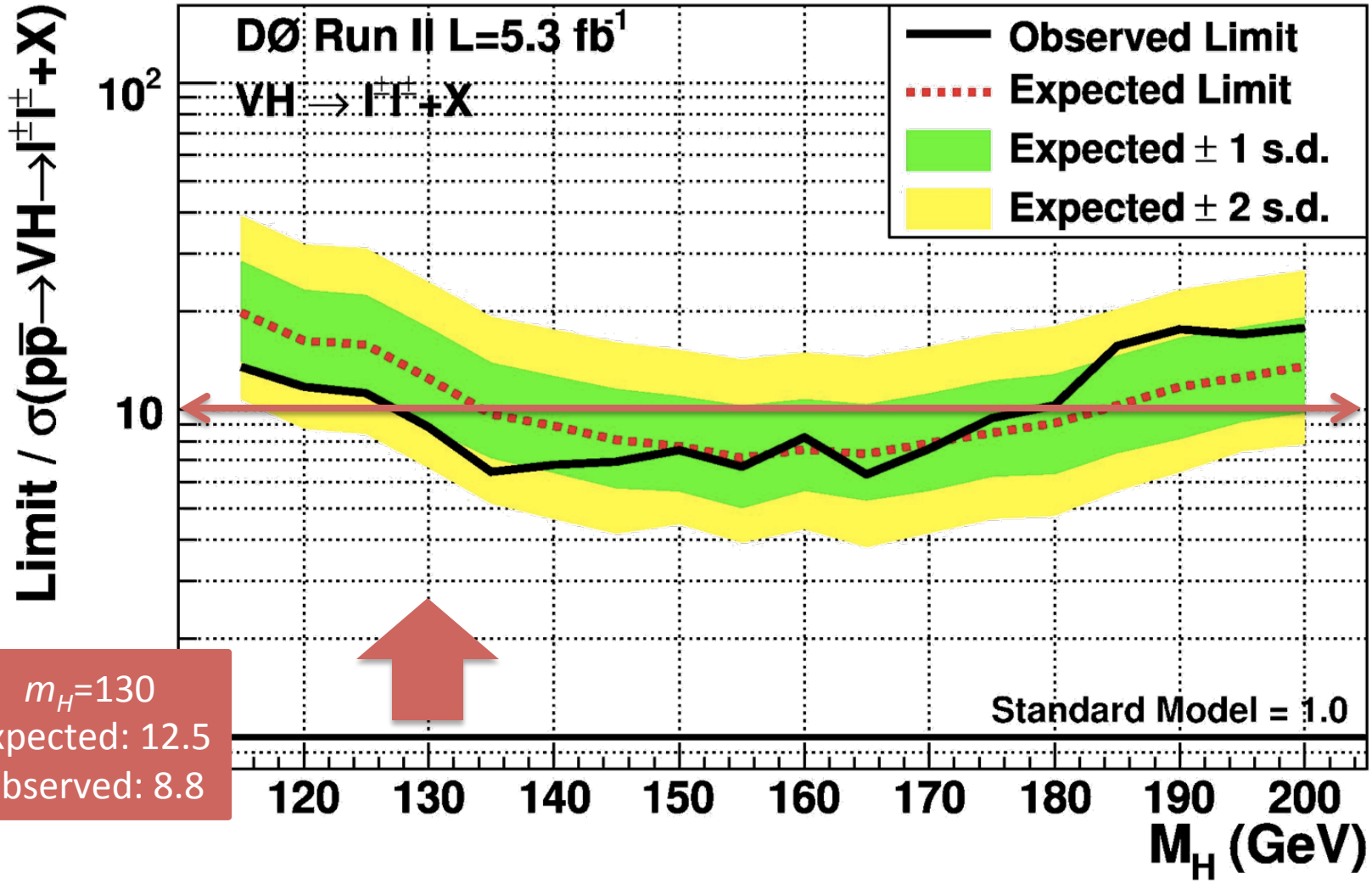
Two Stage MVA Analysis

- First MVA trains against instrumental bkgd
  - Charge-flip and MJ for *ee*, *μμ*; W+jet/γ and MJ for *eμ*
  - Apply cut tuned to keep signal efficiency near 90%
- Final MVA trained against all backgrounds





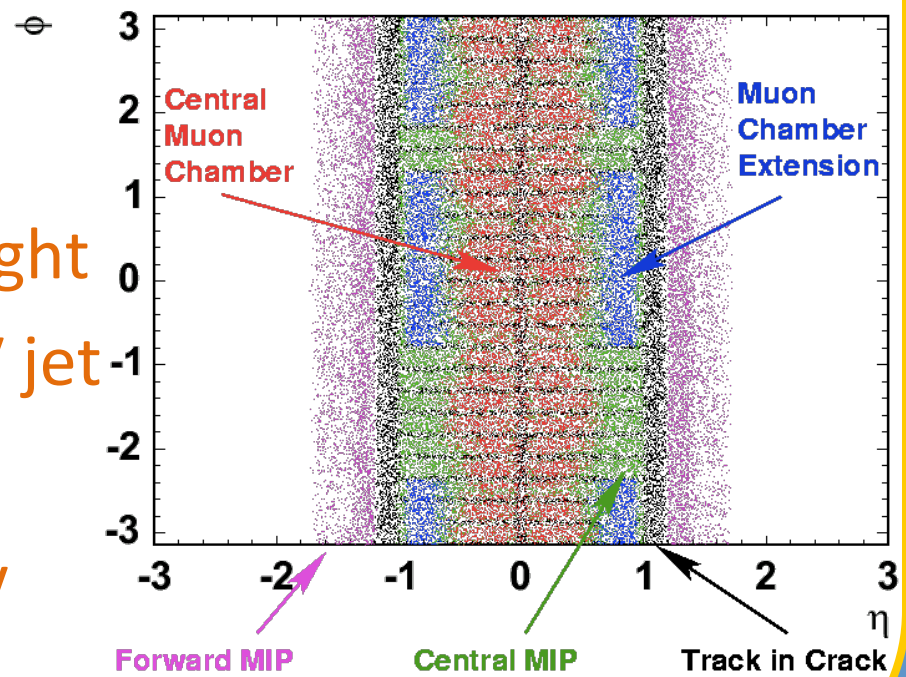
$VH \longrightarrow VWW \longrightarrow \ell^{\pm}\ell^{\pm}+X$ at DØ



m_H=130
Expected: 12.5
Observed: 8.8

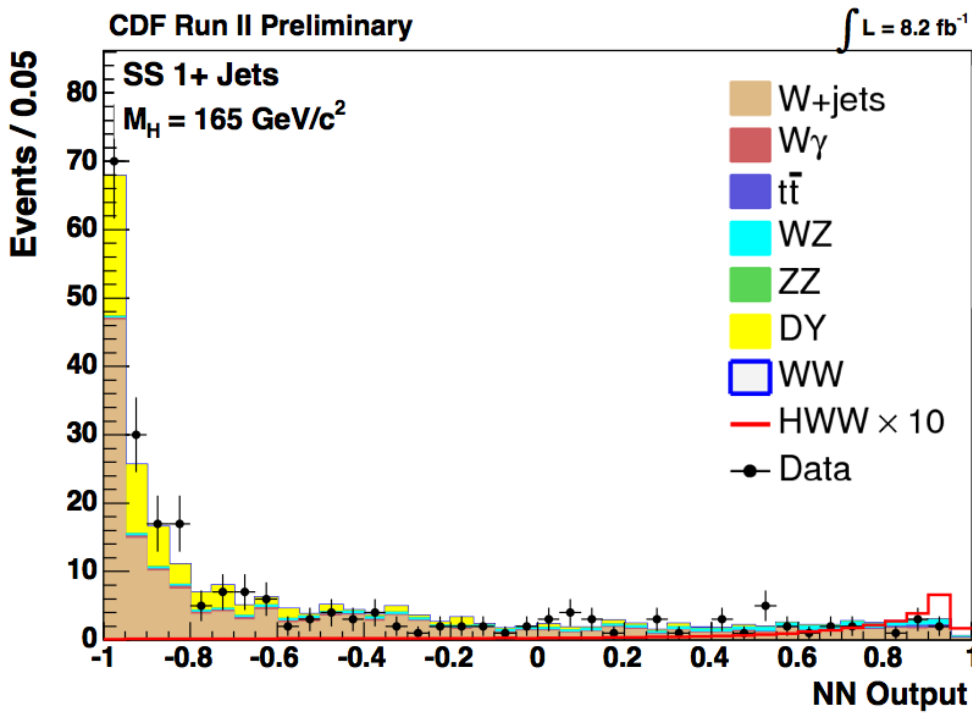
SS Dileptons & Trileptons at CDF

- Both are subchannels to main $H \longrightarrow WW^*$ result
  - Many lepton definitions used to increase acceptance
- SS dilepton requires:
  - 2 leptons, $p_T > 20$ GeV
  - e must be central and tight
  - At least one $p_T > 15$ GeV jet
- Trilepton requires:
  - $p_T^{\ell 1} > 20$, $p_T^{\ell 2,3} > 10$ GeV
  - Can't all have same charge



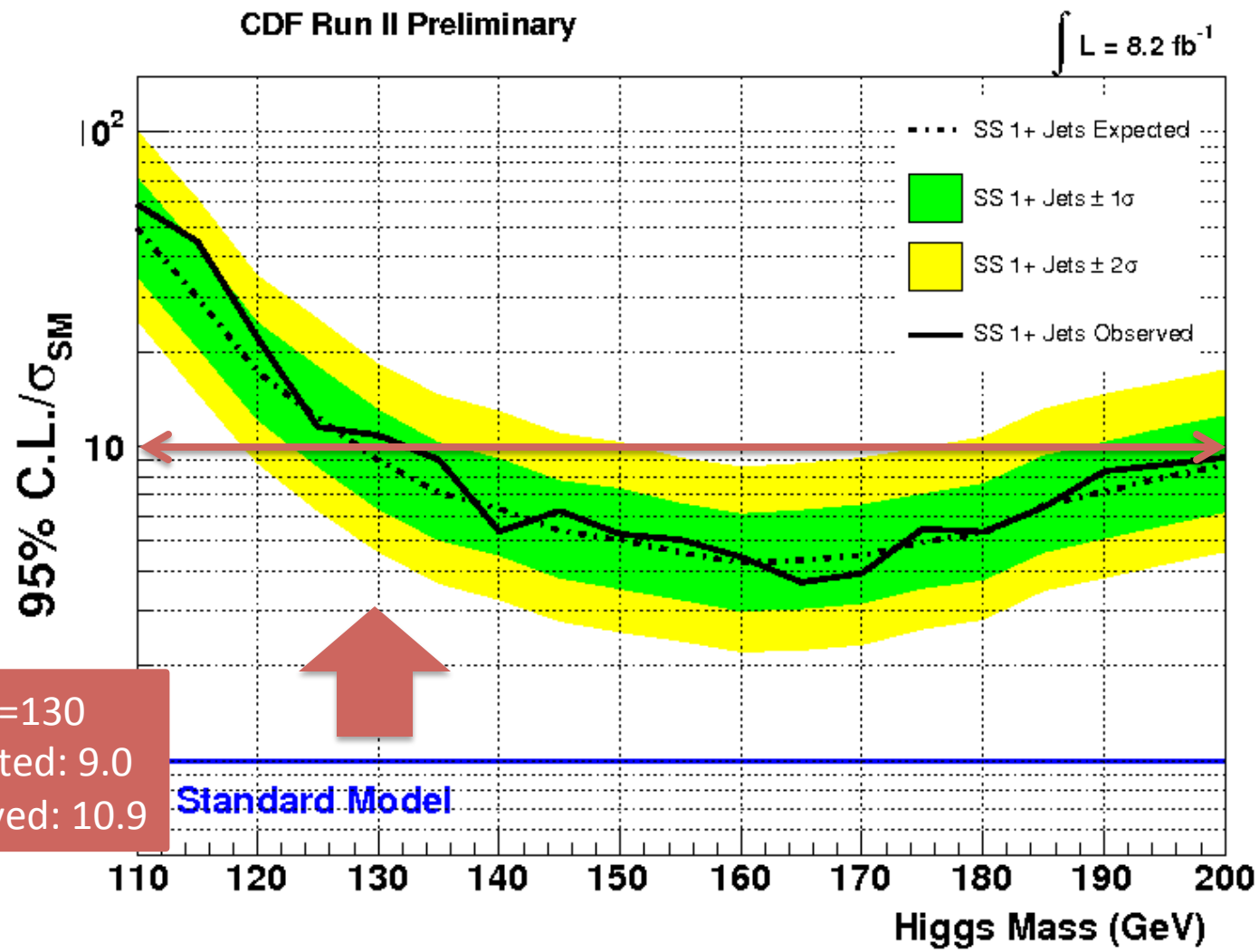
Same-sign Dileptons at CDF

- Majority of background is instrumental
- Neural Network output used to set limits



CDF Run II Preliminary $\int \mathcal{L} = 8.2$ fb^{-1}			
$M_H = 165$ GeV/c^2			
$t\bar{t}$	2.08	$\pm$	0.30
DY	79	$\pm$	34
WW	0.169	$\pm$	0.075
WZ	14.8	$\pm$	2.0
ZZ	2.80	$\pm$	0.39
W+jets	92	$\pm$	35
$W\gamma$	6.7	$\pm$	1.1
Total Background	198	$\pm$	49
WH	2.73	$\pm$	0.36
ZH	0.404	$\pm$	0.054
Total Signal	3.13	$\pm$	0.42
Data	224		

Same-sign Dileptons at CDF



m_H=130
Expected: 9.0
Observed: 10.9

Trileptons at CDF

- Divided into subchannels to optimize analysis
  - Two opposite-sign like-flavor leptons near *Z* mass
    - One or more jets required, events form separate channels
  - All events not in other categories are *WH* candidates
    - Additionally require missing E_T > 20 GeV

ZH 1 jet

CDF Run II Preliminary $\int \mathcal{L} = 8.2\ \mathrm{fb}^{-1}$		
$M_H = 165\ \mathrm{GeV}/c^2$		
$t\bar{t}$	0.105 ±	0.047
WZ	12.1 ±	2.0
ZZ	4.98 ±	0.71
Z+jets	7.9 ±	1.9
$Z\gamma$	6.5 ±	1.4
Total Background	31.6 ±	3.8
WH	0.0380 ±	0.0058
ZH	0.270 ±	0.042
Total Signal	0.308 ±	0.046
Data	35	

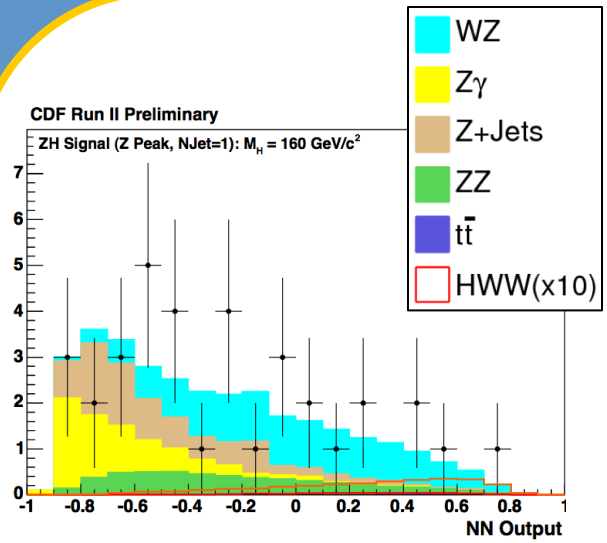
ZH 2+ jet

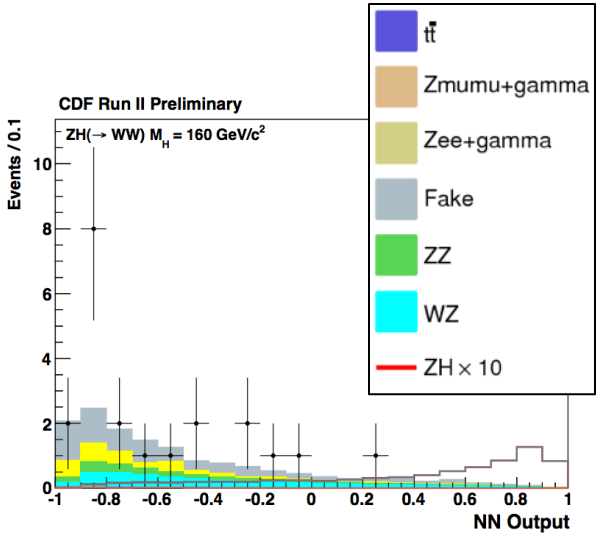
CDF Run II Preliminary $\int \mathcal{L} = 8.2\ \mathrm{fb}^{-1}$		
$M_H = 165\ \mathrm{GeV}/c^2$		
$t\bar{t}$	0.141 ±	0.038
WZ	3.65 ±	0.84
ZZ	1.91 ±	0.38
Z+jets	6.4 ±	1.6
$Z\gamma$	2.55 ±	0.66
Total Background	14.6 ±	2.4
WH	0.0133 ±	0.0034
ZH	0.72 ±	0.11
Total Signal	0.74 ±	0.11
Data	21	

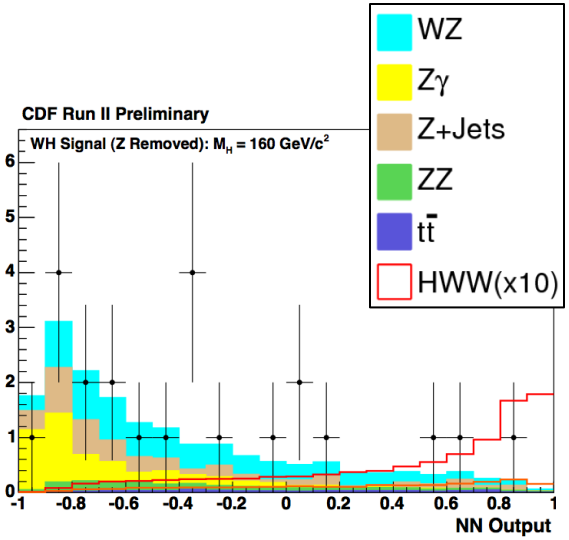
WH

CDF Run II Preliminary $\int \mathcal{L} = 8.2\ \mathrm{fb}^{-1}$		
$M_H = 165\ \mathrm{GeV}/c^2$		
$t\bar{t}$	0.64 ±	0.20
WZ	7.1 ±	1.0
ZZ	1.61 ±	0.23
Z+jets	3.84 ±	0.89
$Z\gamma$	4.21 ±	0.84
Total Background	17.4 ±	1.9
WH	0.89 ±	0.12
ZH	0.203 ±	0.028
Total Signal	1.09 ±	0.15
Data	15	

Trileptons at CDF







ZH 1 jet

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Data	35		

ZH 2+ jet

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ZZ	1.91	±	0.38
Z+jets	6.4	±	1.6
$Z\gamma$	2.55	±	0.66
Total Background	14.6	±	2.4
WH	0.0133	±	0.0034
ZH	0.72	±	0.11
Total Signal	0.74	±	0.11
Data	21		

WH

CDF Run II Preliminary $\int \mathcal{L} = 8.2$ fb^{-1}			
$M_H = 165$ GeV/c^2			
$t\bar{t}$	0.64	±	0.20
WZ	7.1	±	1.0
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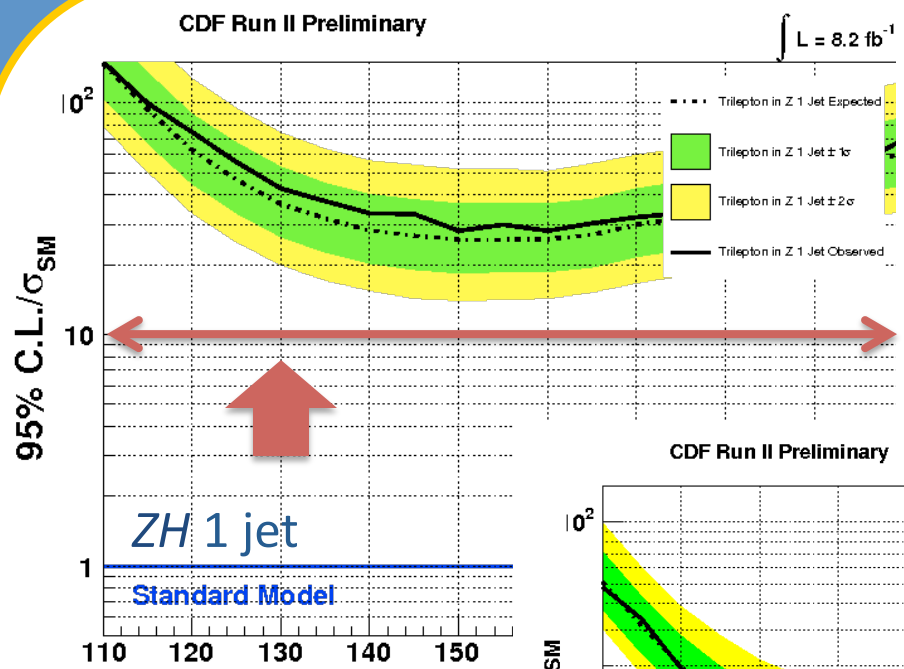
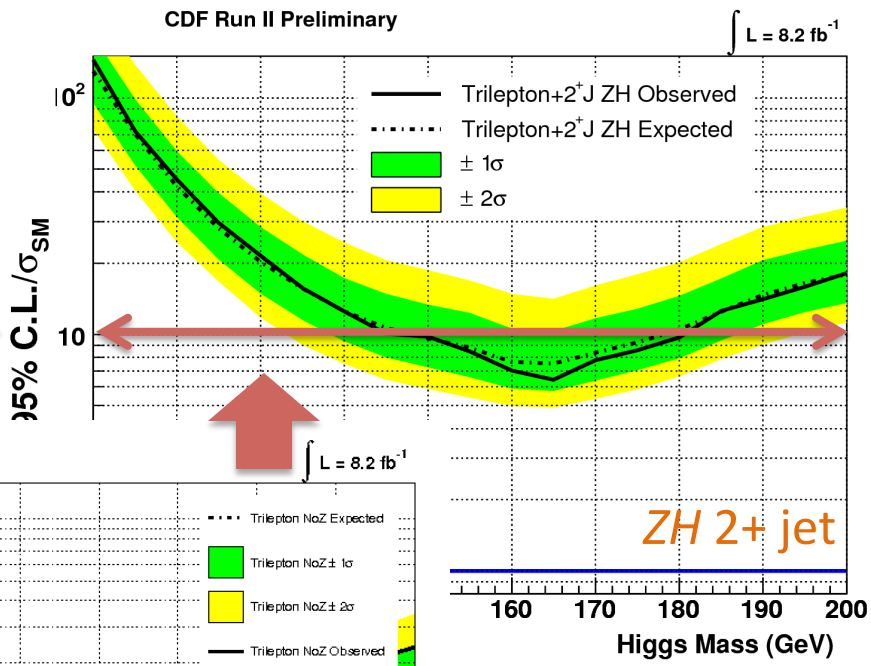
Data	15		

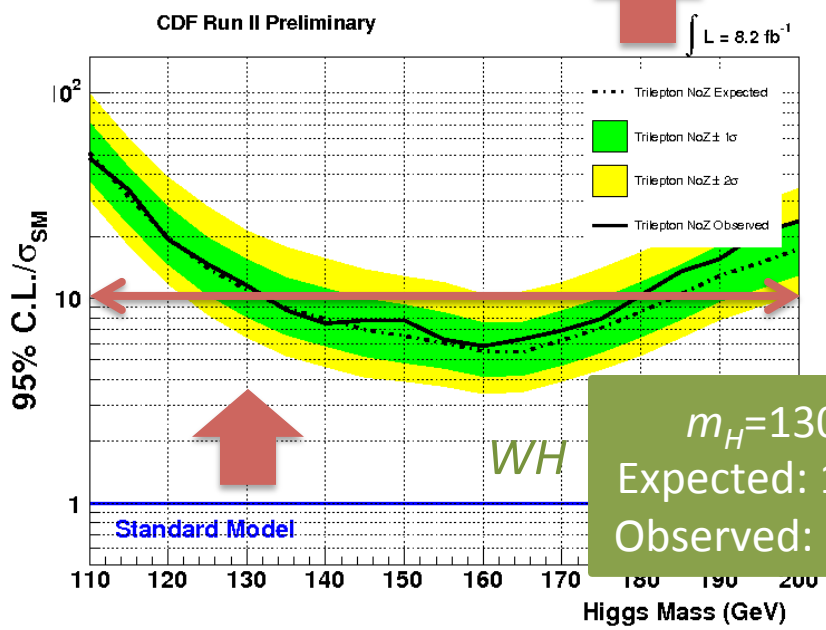
Trileptons at CDF



m_H=130
Expected: 10.9
Observed: 11.6



m_H=130
Expected: 20.3
Observed: 21.5

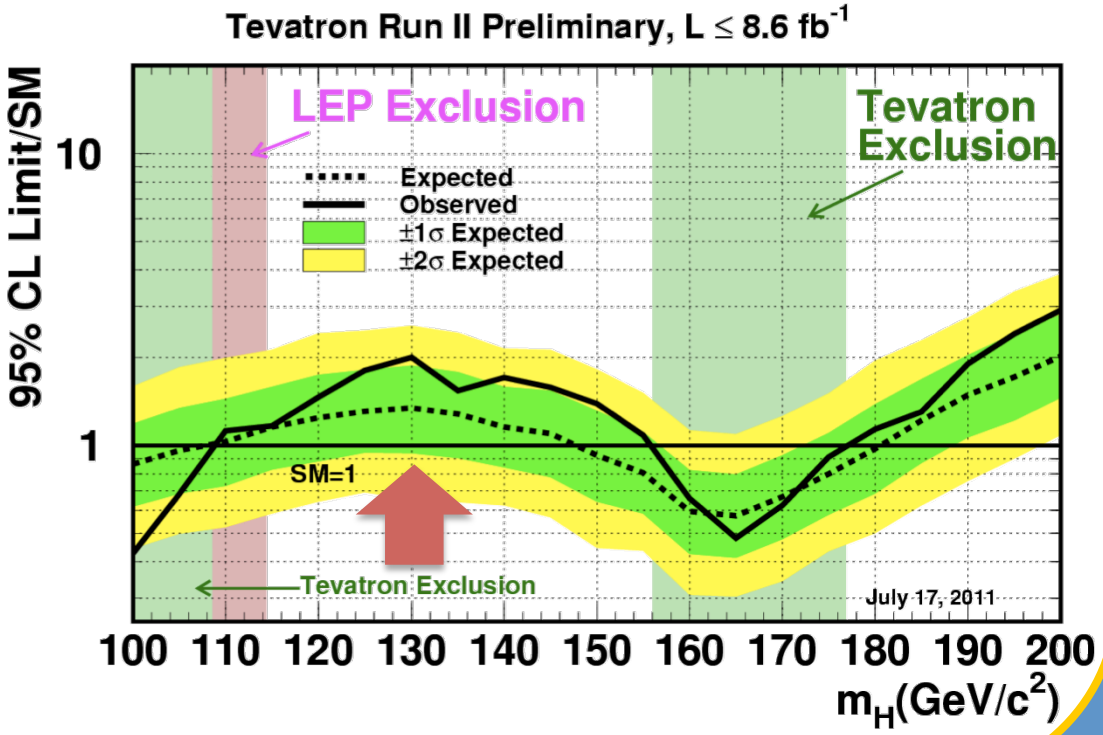


m_H=130
Expected: 10.9
Observed: 11.6

$VH \longrightarrow VWW \longrightarrow$ leptons+X

- Higgs search for $m_H \approx 130$ will be very interesting
  - Same-sign dilepton and trilepton channels are important here!

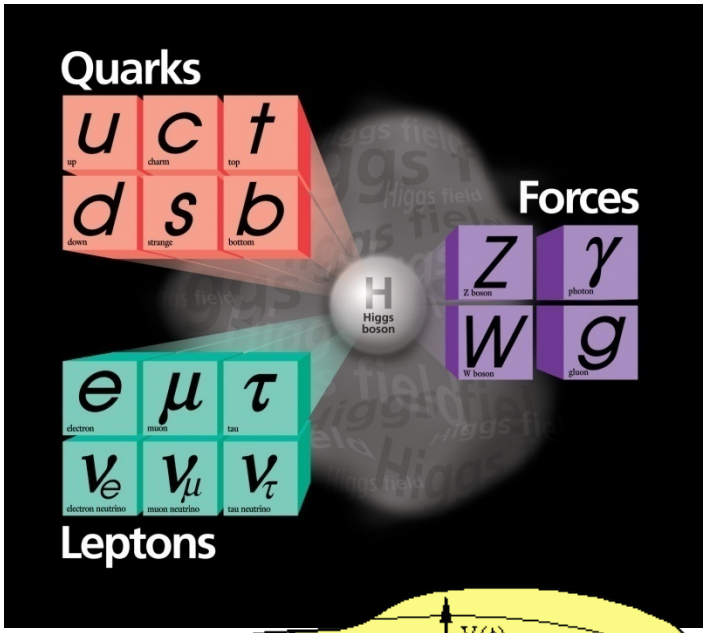
Channel	$\int \mathcal{L}$ (fb^{-1})	m_H=130 Exp Lim
DØ $\ell^\pm\ell^\pm$	5.3	12.5
CDF $\ell^\pm\ell^\pm$	8.2	9.01
CDF $\ell\ell\ell$ (ZH, 1j)	8.2	36.8
CDF $\ell\ell\ell$ (ZH, 2j)	8.2	20.3
CDF $\ell\ell\ell$ (WH)	8.2	10.9

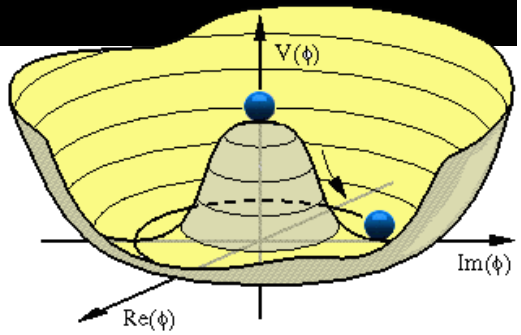


Search for the Higgs in $VH \rightarrow VWW \rightarrow$ leptons+X at the Tevatron

The Standard Model

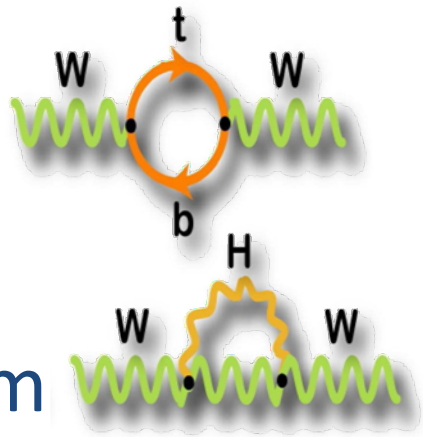
- Describes the interactions between quarks & leptons
  - Mediated by gauge bosons
- The EM (γ) and weak ($W^{\pm}$,Z) forces are unified under a broken symmetry
  - The Higgs field is introduced to cause EWSB & generate W, Z mass
  - Either a SM Higgs particle exists or there is new physics that causes EWSB

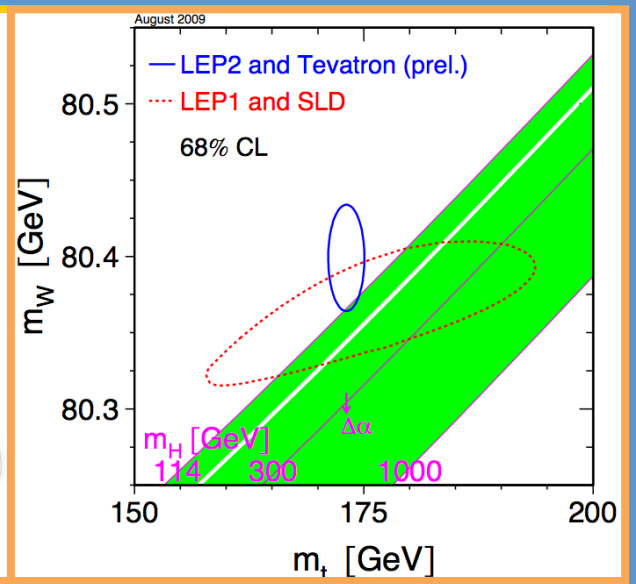


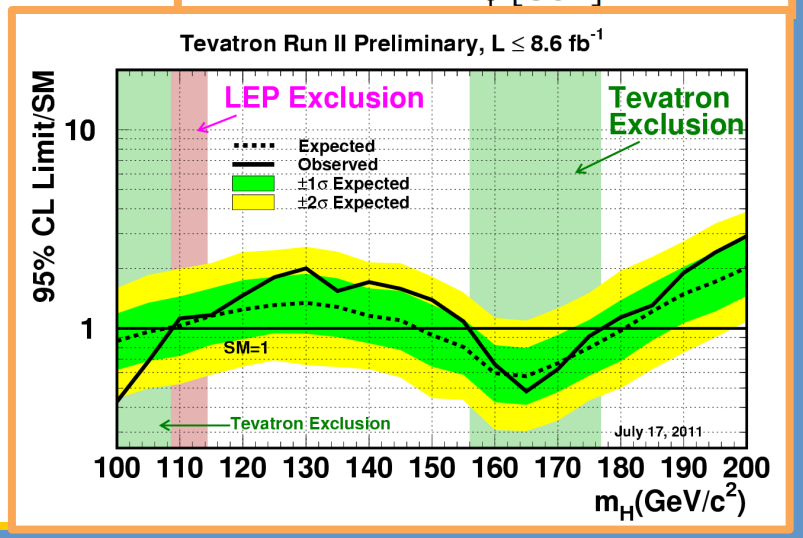


Where to Look for a Higgs

- Indirect limits from EW precision measurements
- Direct exclusion from LEP & Tevatron
  - m_H > 114.4 GeV (LEP)
  - m_H not in [156,177] (TeV)
  - Indirect + LEP: m_H < 185 GeV

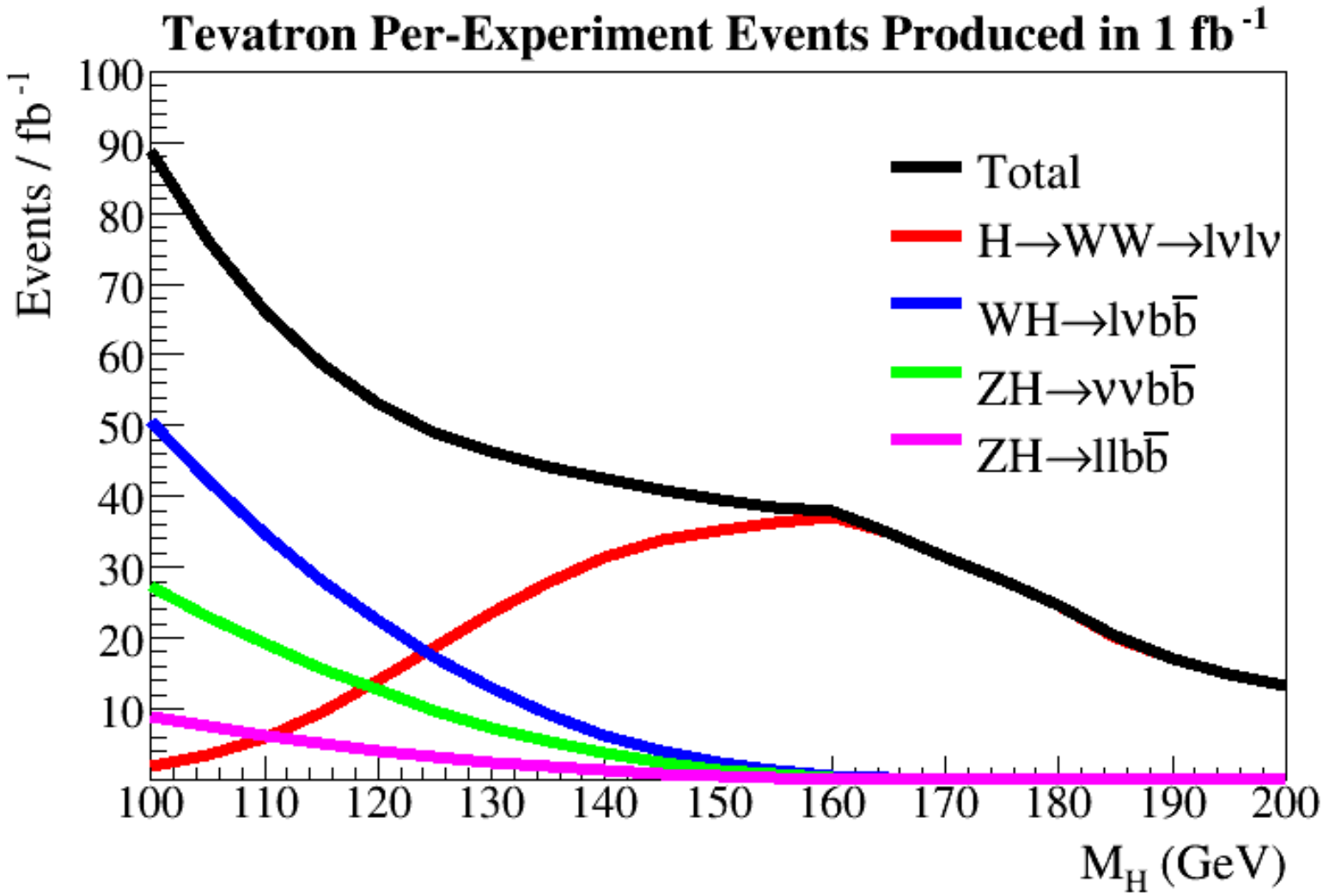






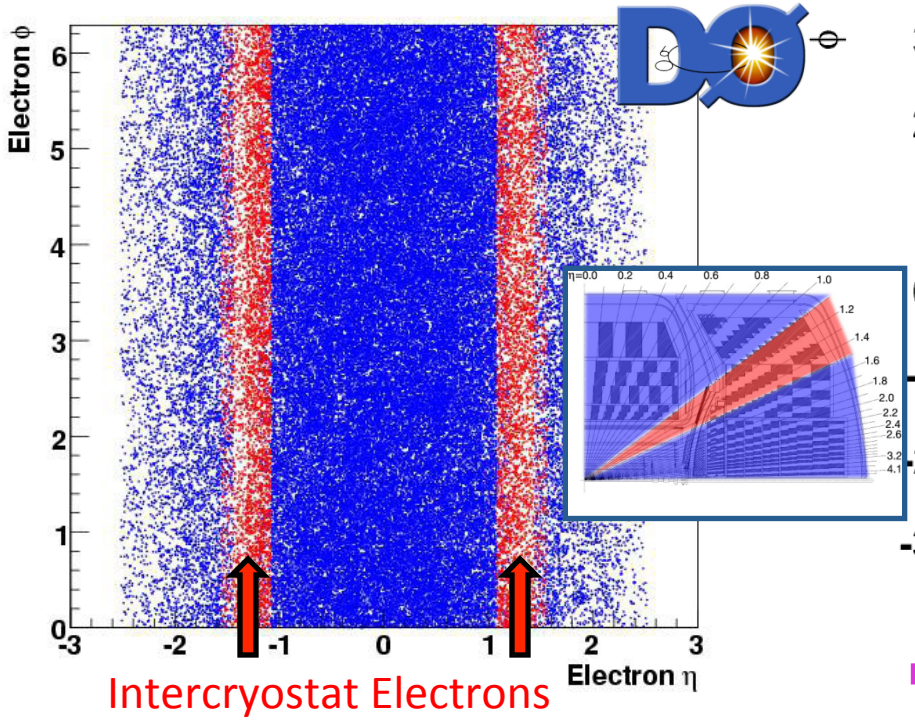
95% C.L. as of July 2011

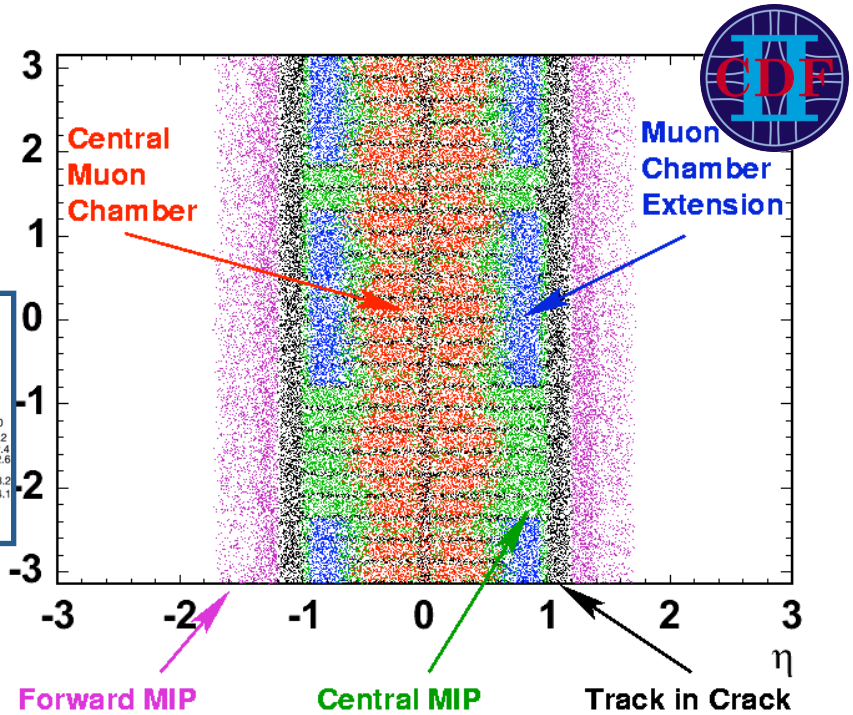
Higgs Events in 1 fb^{-1}



Improving Acceptance

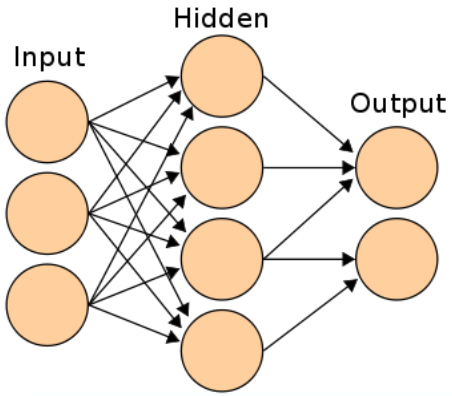
- Gains in trigger efficiency and lepton acceptance are key to increasing our sensitivity

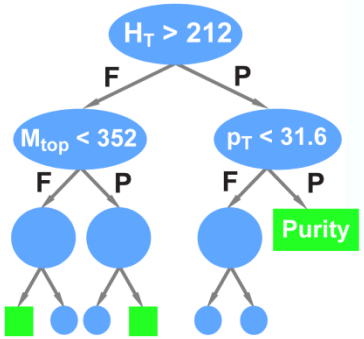


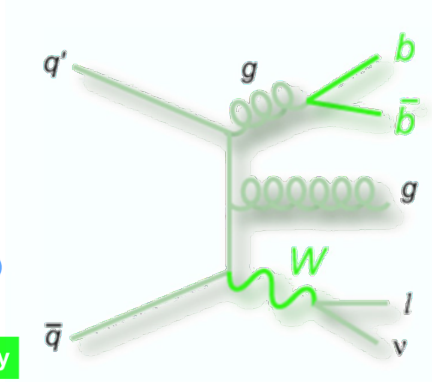


Multivariate Analysis Techniques

- Gain sensitivity by combining many variables into one powerful discriminant
  - Use full discriminant output to set limit
- Neural Networks
- Matrix Element Method
  - Use differential cross sections of signal and major backgrounds to estimate signal likelihood
- Decision Trees
  - Recover events that fail a normal cut-based analysis

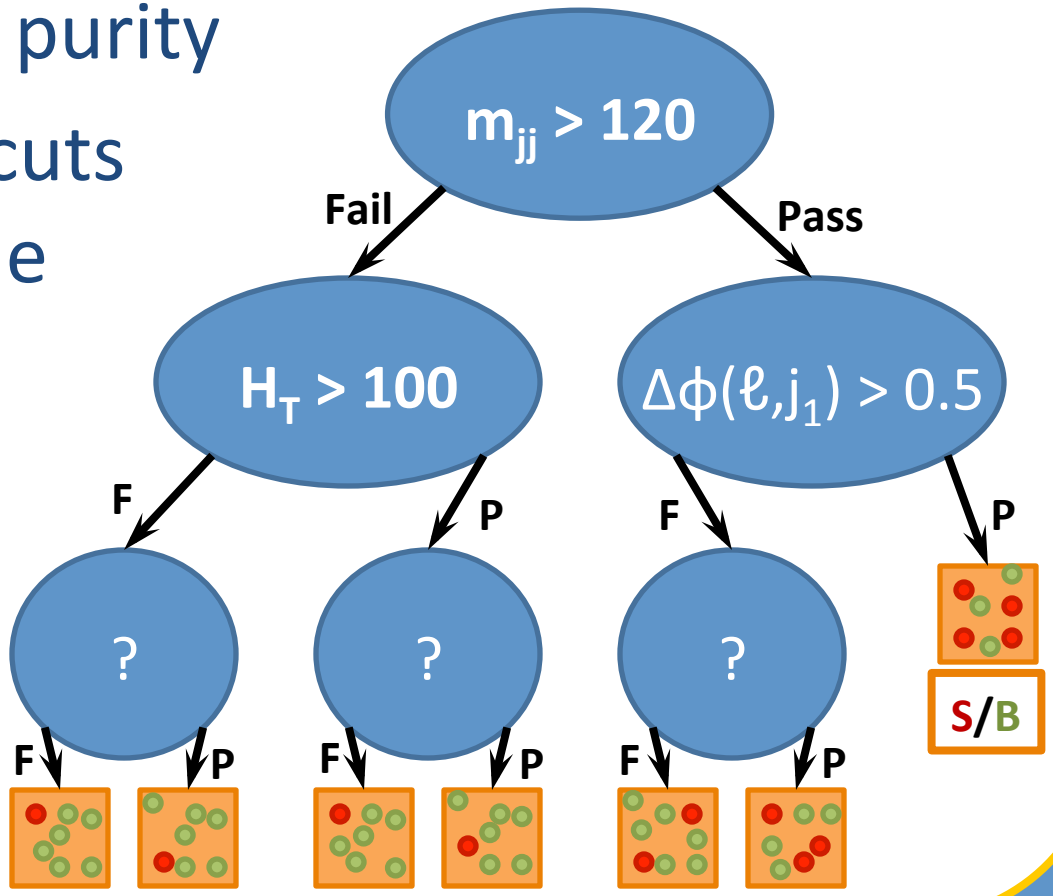






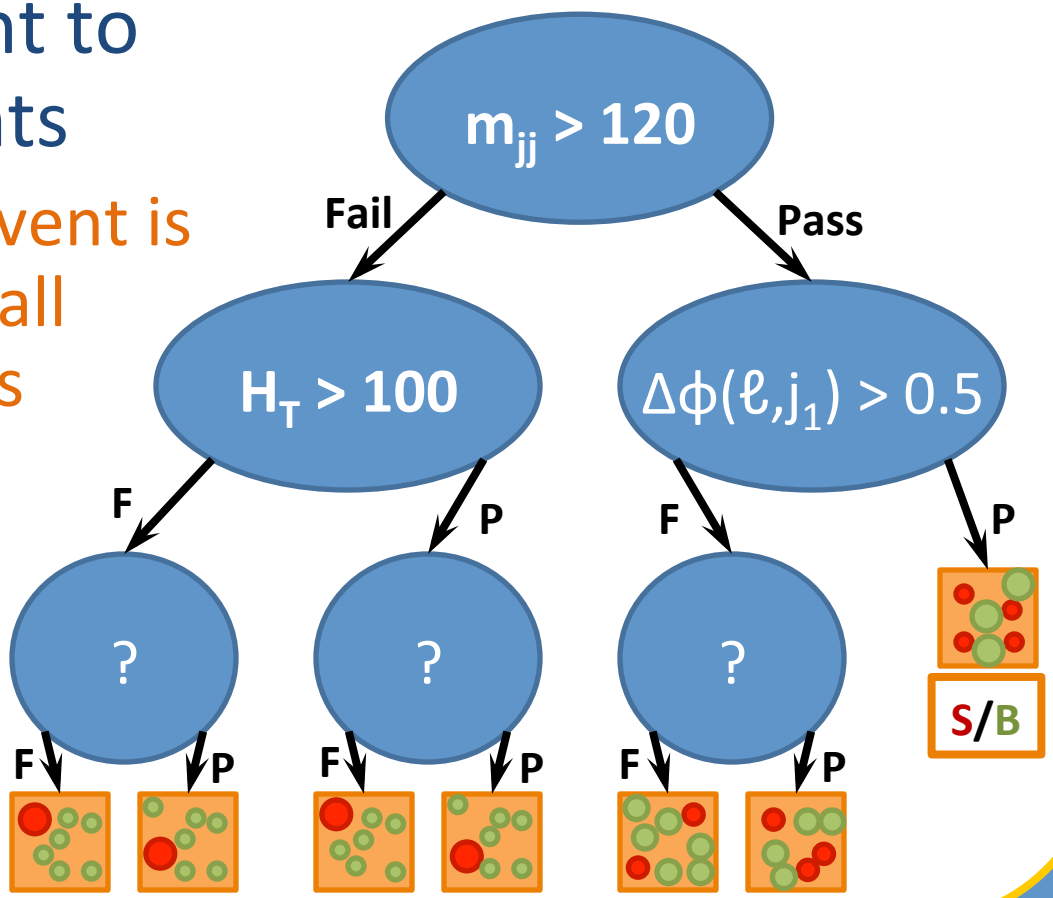
Decision Trees

- Start by making best cut to optimize signal purity
- Continue placing cuts on each subsample
  - Enhancing purity with each step
- Each final leaf produces a purity weight

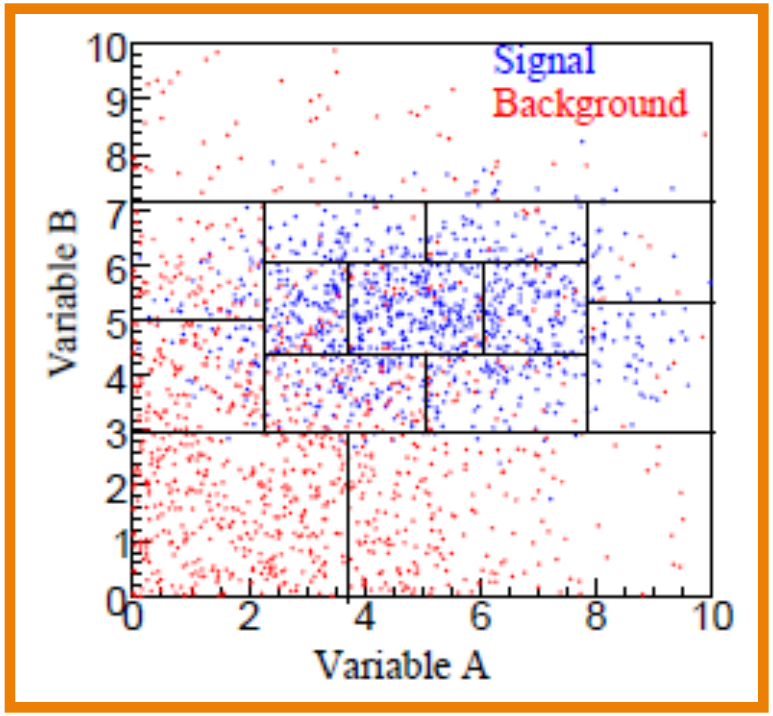


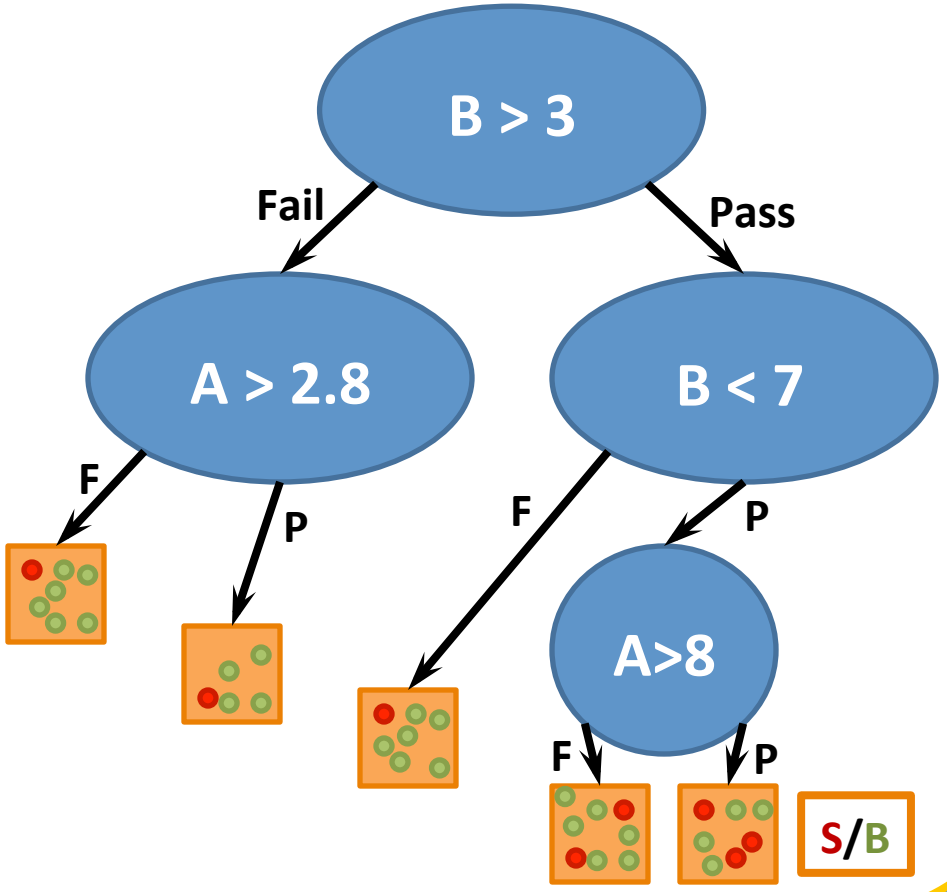
Advanced Decision Trees

- Boost a tree by retraining, giving more weight to misclassified events
  - Final output for event is a combination of all tree classifications
- Random Forest
  - Random subset of inputs and training samples make many trees



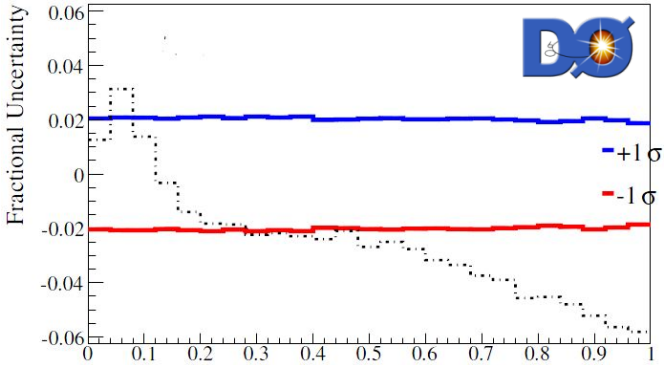
Sample Two Variable Decision Tree





Systematics

- Can be flat or shaped, asymmetric, correlated…
  - Inelastic *pp* cross section, top & diboson production cross sections correlated between CDF & DØ
  - Within each collaboration, lepton ID, *b*-ID, jet energy scale & resolution are correlated

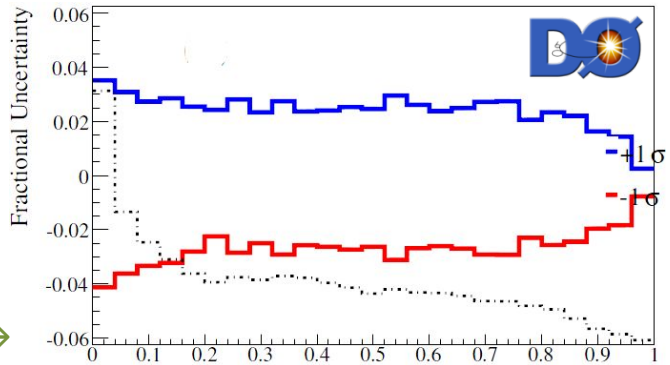


WH→ℓνjj

2 jet, 1 *b*-tag

← *e*-channel:
tt electron ID

μ-channel:
single-*t* *b*-jet ID →



Setting a Limit: Generating Pseudo-data

- Each final output bin is treated independently
  - Adding analysis channels is as easy as adding bins!
- Two ensembles are created: B only and S+B
  - Poisson seeded by nominal S and B expectation
  - Systematic uncertainties are used to vary the nominal S and B predictions for each "experiment"
    - Correlated systematics share the same shift in all bins
- Every pseudo-experiment contributes to the expected distribution of our test statistic

The Profiled Likelihood Test Statistic

- Start with a "normal" Log Likelihood Ratio
  - Can integrate over systematics as nuisance pars...

$$\Gamma = -2 \cdot \log\left(\frac{P(x|H_{\mathrm{S+B}})}{P(x|H_{\mathrm{B}})}\right)$$

- Instead of integrating over nuisance pars., perform a fit to maximize each $P(x|H_\alpha)$
  - θ_α are best fit nuisance parameter values

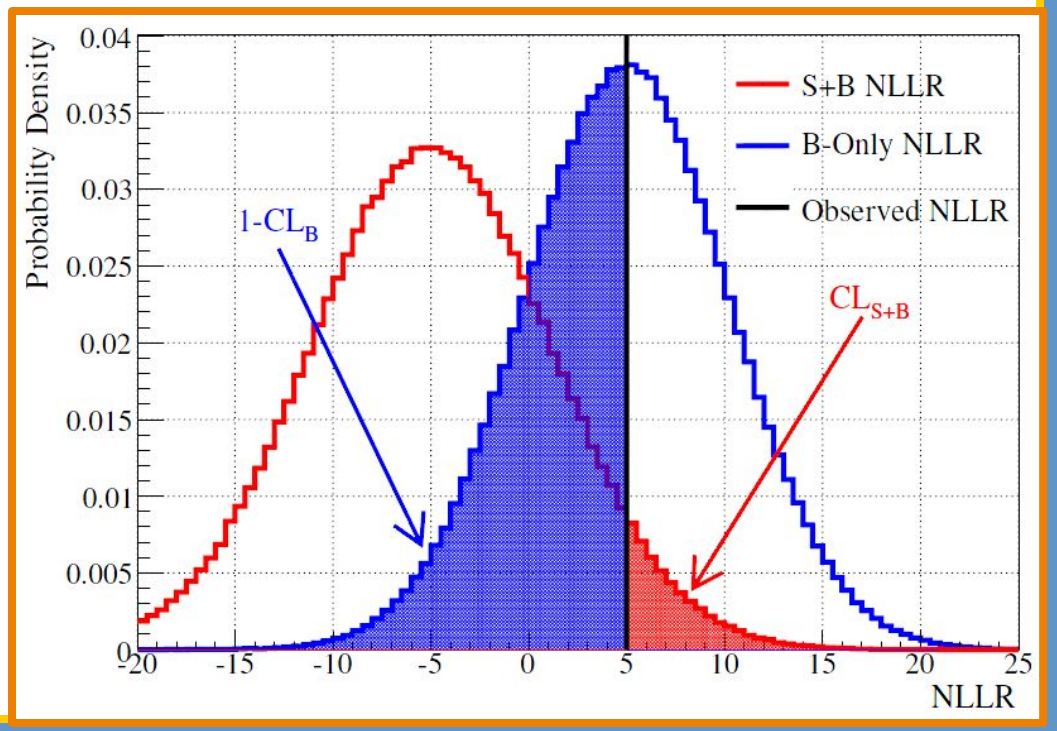
$$\Gamma = -2 \cdot \log\left(\frac{P(x|H_{\mathrm{S+B}}, \theta_{\mathrm{S+B}})}{P(x|H_{\mathrm{B}}, \theta_{\mathrm{B}})}\right)$$

Evaluating a Limit: The CL_S Method

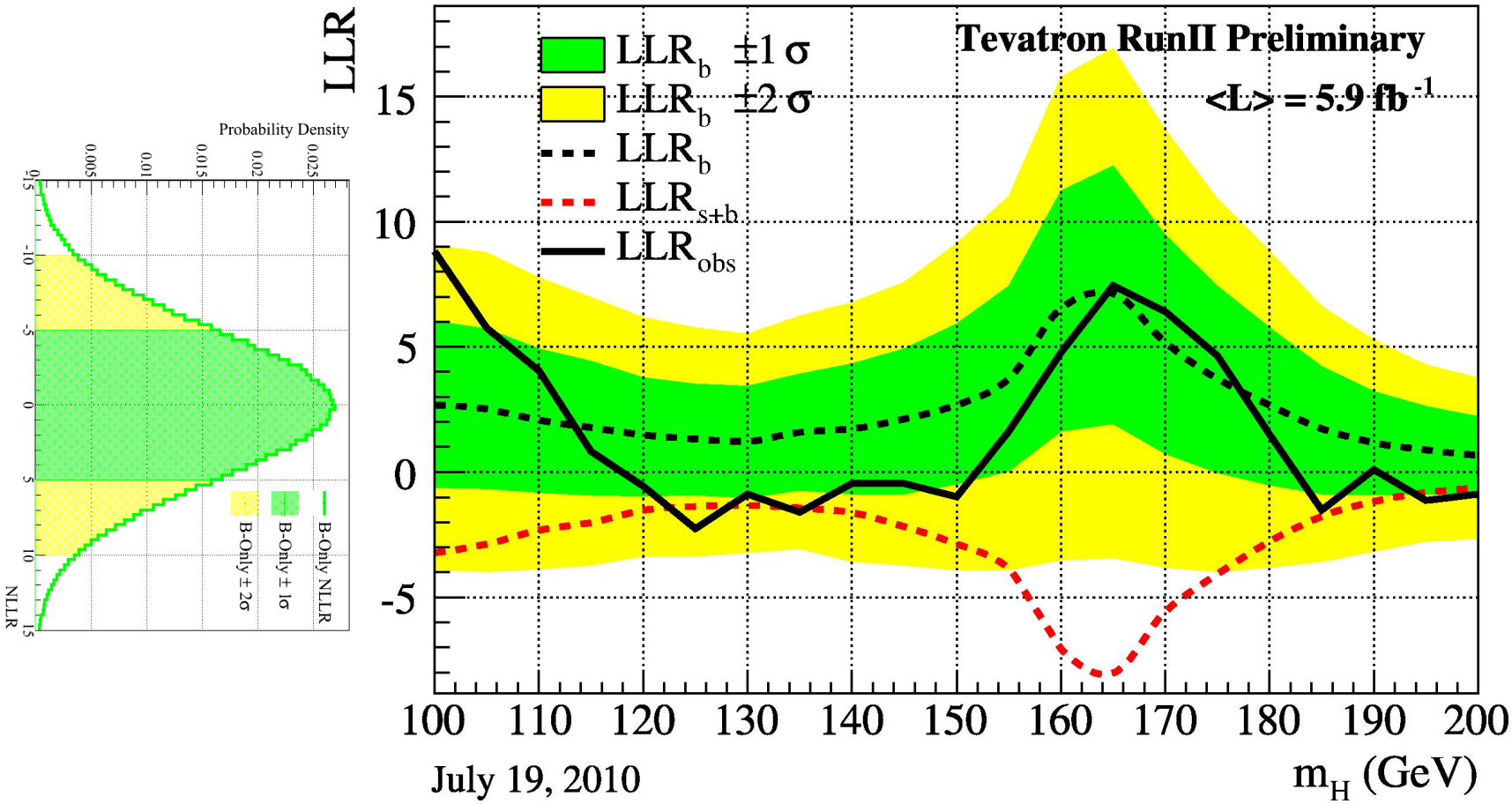
- Knowing the expected test statistic distribution for H_{S+B} could let us set limits
  - Poor B modeling not accounted for

$$CL_S = \frac{CL_{S+B}}{CL_B}$$

  - As CL_B approaches 1, reduces to CL_{S+B}



The Tevatron Combined LLR Distribution



How Would a Higgs Appear Today?

- If a 125 GeV mass Higgs is injected into our current Tevatron combination, the result is consistent with our current observations