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Search For the Higgs Boson at the Fermilab Tevatron at Lower Masses

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On behalf of the CDF & D0 Collaborations

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Outline

- Will present a brief review of CDF and D0 SM Higgs searches at low-mass SM (M_H <135 GeV)
- Will focus on H→bb and show result of combination with other production & decay modes.
- Main goal is to provide complimentary info for related talks :

Tevatron Spin + Couplings (G. Davies)
Tevatron constrains on the Higgs (A. Juste)
Search for SM ZH->llbb at D0 (J. Yu)

- Non-SM Results covered in :

BSM Higgs Tevatron results (J. Hays)

The Tevatron

- proton anti-proton collider @ $\sqrt{s}$ = 1.96 TeV
- Delivered ~12/fb per experiment between 2001 & 2011

- Energy & initial state differ from LHC → unique environment for Higgs searches

Tevatron sensitivity at low mass is driven by **H→bb** searches

Production & Decay

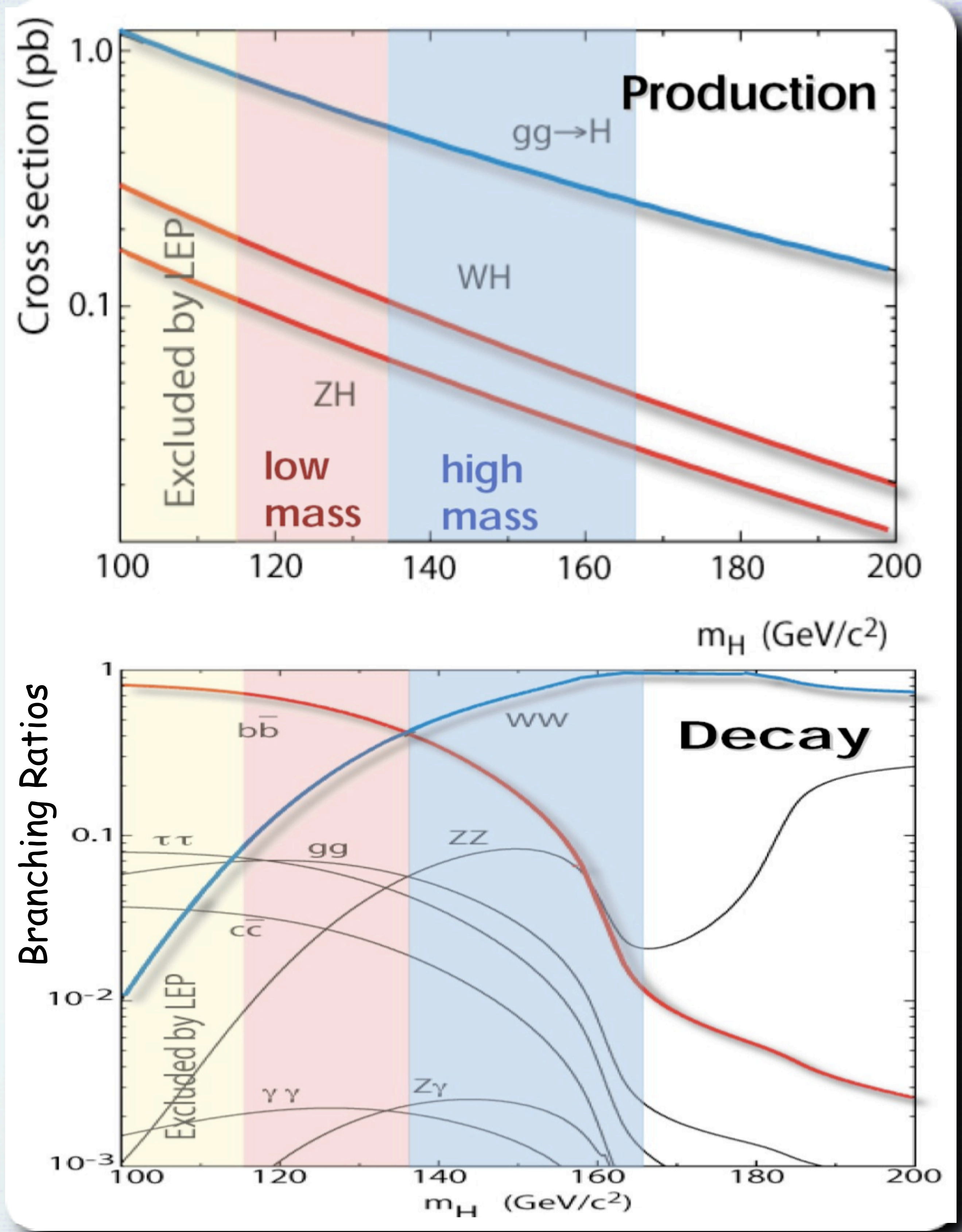
- Main production modes are :

  I. Gluon-gluon fusion (gg→H)
  II. Associated Production (ZH/WH)

- Decays :

  I. mostly H→WW for M_H>135 GeV
  II. mostly H→bb for M_H <135 GeV

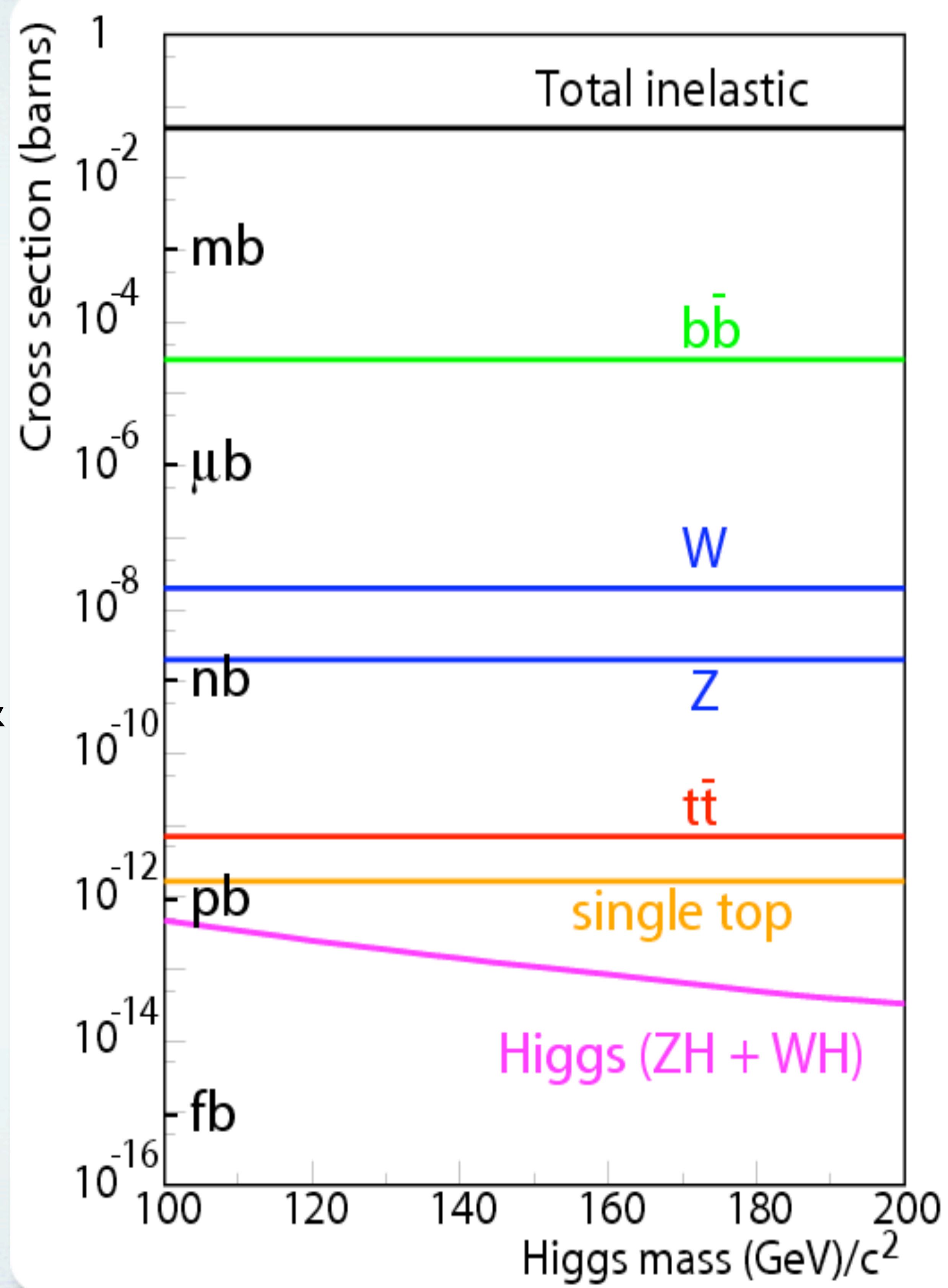
BR(H→bb) ~58% for M_H =125 GeV



The Search Environment

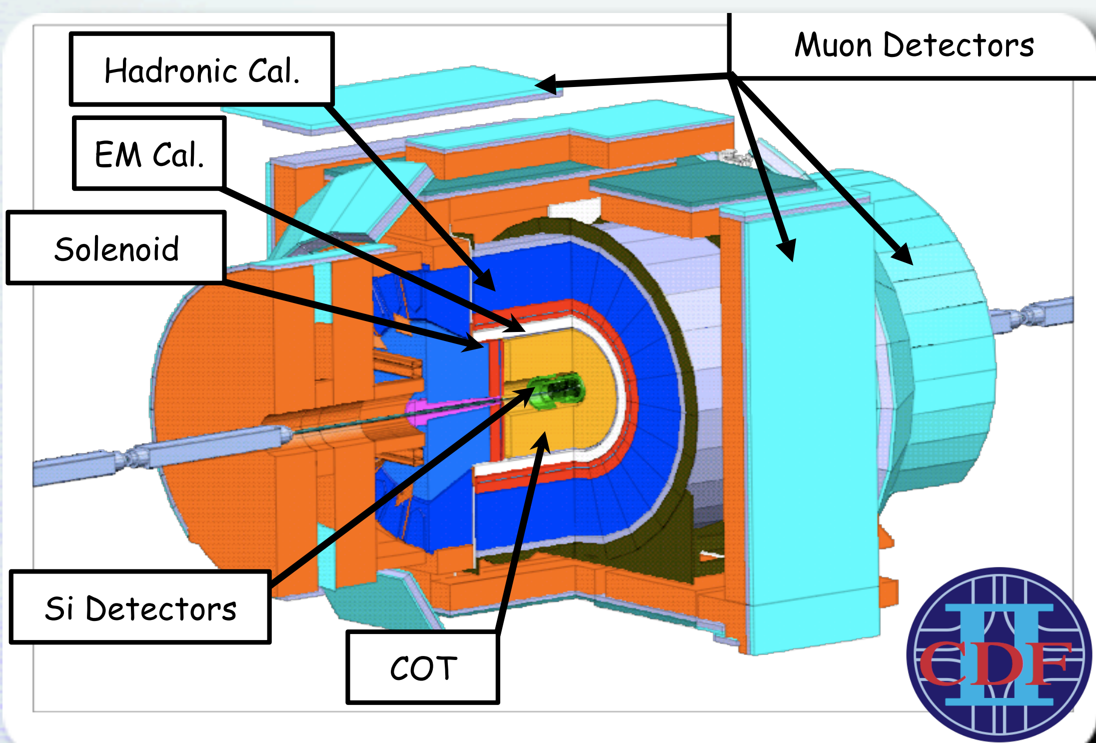
- Background rates many orders of magnitude higher than predicted SM Higgs rates
- The dominant process (gg→H→bb) is overwhelmed by multi-jet production
- Instead, H→bb searches target Higgs production/decay modes with 'distinguishing' final states, relying on Z & W boson decays to differentiate signal from background

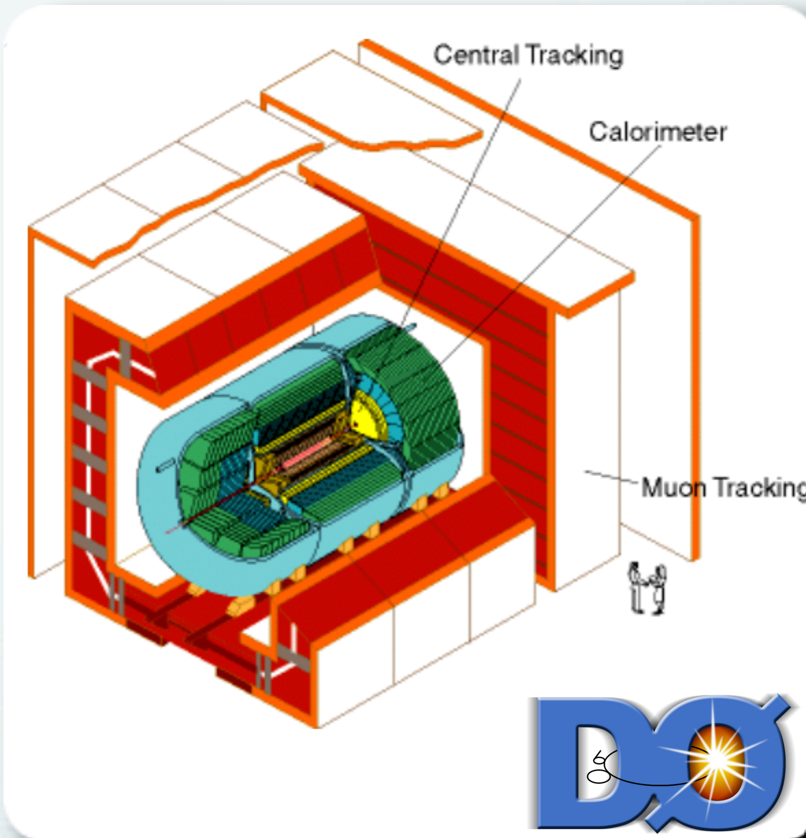
$e^{\pm}/\mu^{\pm} + \nu + bb$
$e^{-}e^{+}/\mu^{-}\mu^{+} + bb$
$\nu\,\nu + bb$



The Experiments : CDF & D0

- CDF II and D0 were general purpose detectors
- Silicon Vertex Detectors, Tracking Chambers, Calorimetry, & Muon Systems
- Multi-level 'trigger systems' to select events with topologies of interest (missing transverse energy, energetic jets/leptons)
- Data taking efficiencies of ~90%, up to 10/fb for Higgs boson searches





Search Overview

- Common features of Tevatron searches :

I. Optimized **selection** (maximize Higgs acceptance, minimize background)

II. **Multivariate** discriminant (Neural Networks, Boosted Decision Trees)

III. Careful treatment of **systematics**, correlated across channels & experiments as appropriate

Typical Systematics	Magnitude (+/- σ)
Luminosity	6%
Signal Production Rate	5-30%
background normalization	6-50%
Jet Energy Scale	~7%

Overall impact ~15-20% degradation in sensitivity

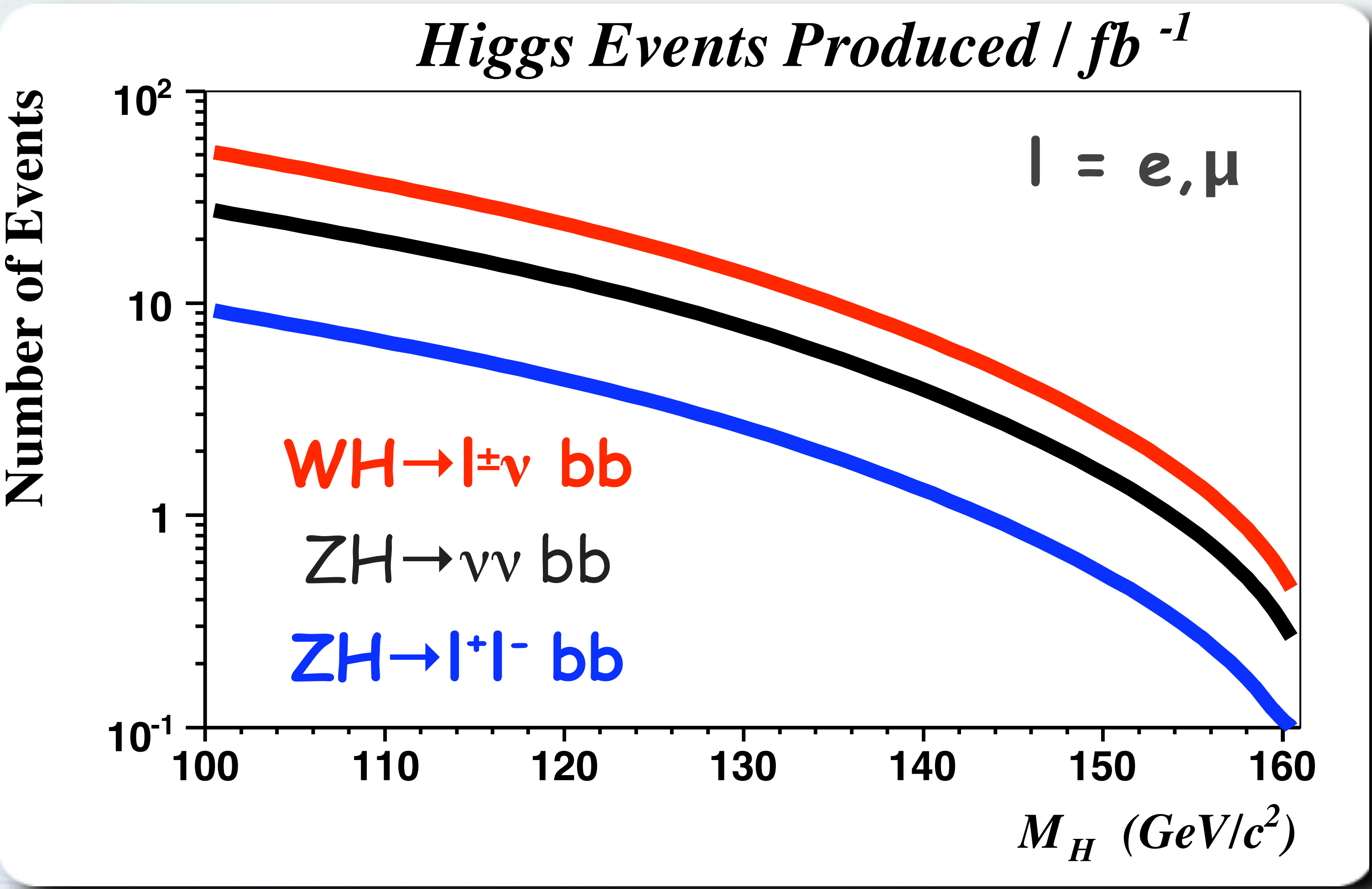
- Extract 95% CL Upper limits on Higgs production rate using both Bayesian & CLs statistical techniques (average ~1% level agreement)

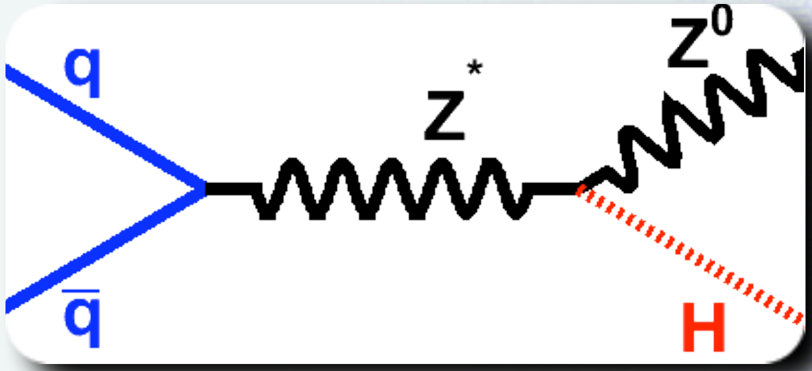
Main Channels for H→bb

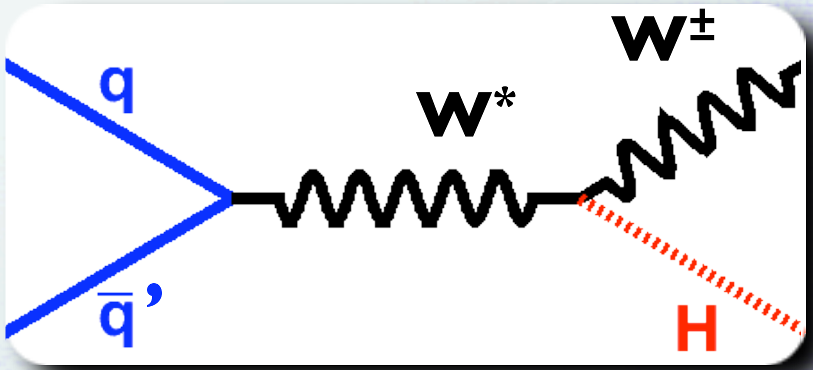
- Searches divided by number of charged leptons in final state

0 leptons	50% ZH→ννbb + 50% WH→$l^{\pm}$ν bb
1 lepton	WH→$l^{\pm}$ν bb + small contributions from ZH→l^+l^-bb
2 leptons	mainly ZH→l^+l^-bb

- Challenging due to low signal rates (~100 events/fb) & large Z/W backgrounds

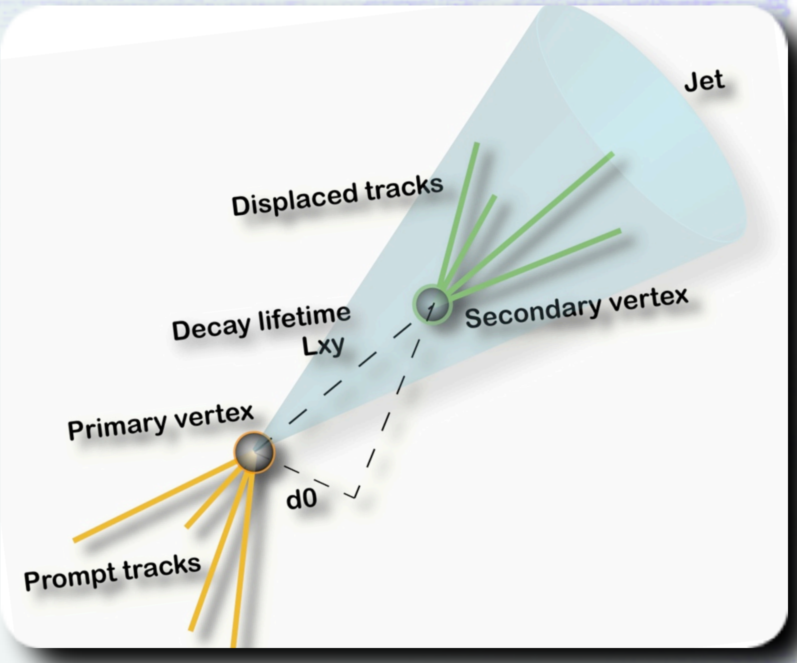




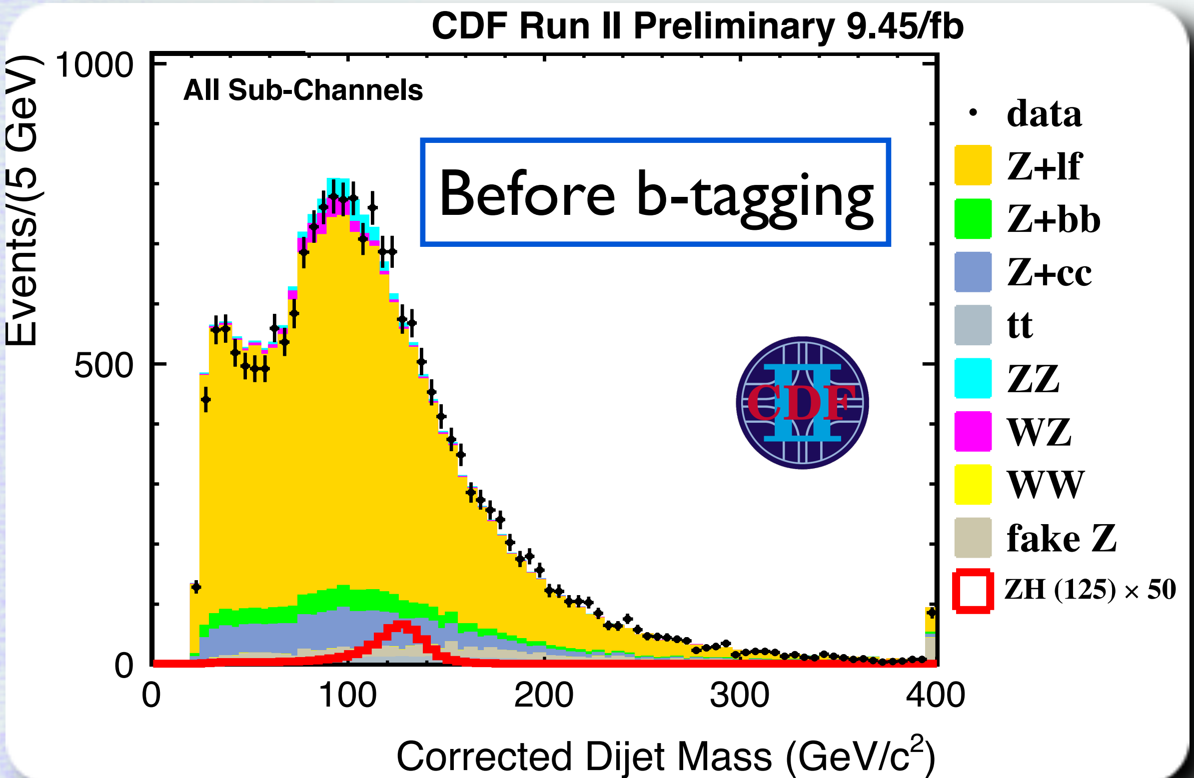


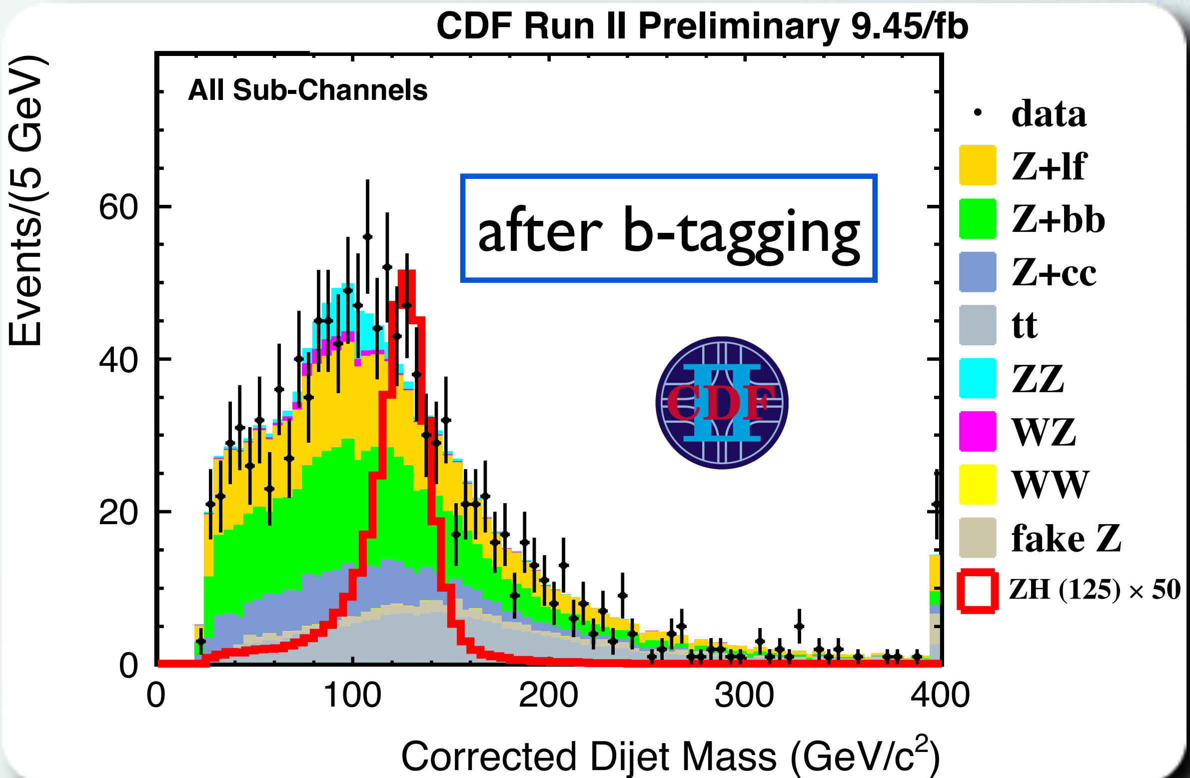
b-jet Tagging is Key

- Little sensitivity to H→bb without efficient b-jet identification capabilities
- CDF & D0 employ advanced ID algorithms (NN/BDT) with b-jet efficiencies of up to 60-80% with low u,d,s,g - jet mis-ID rates (≲1-10%)



Demonstration of b-tagging in ZH→llbb

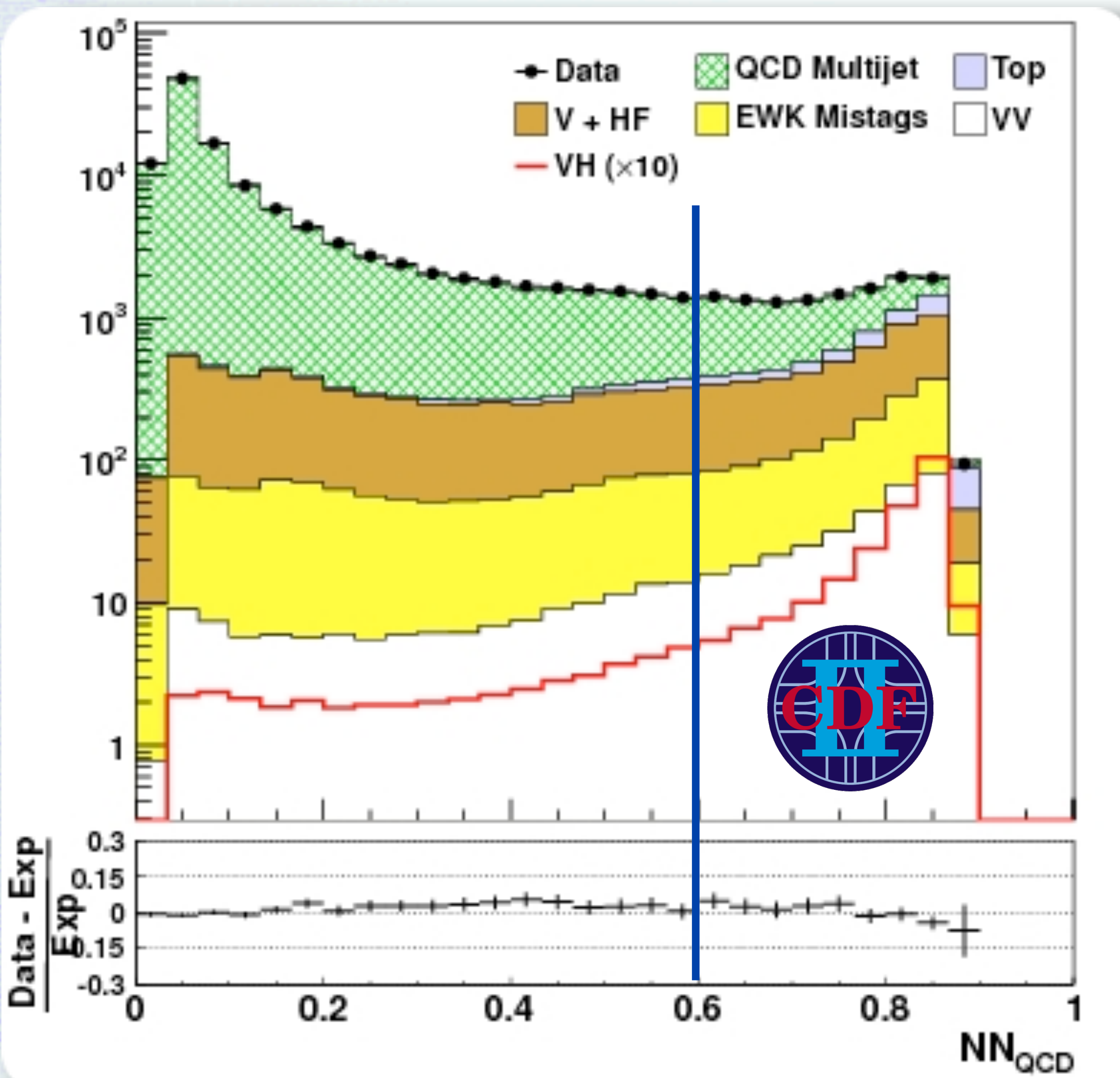


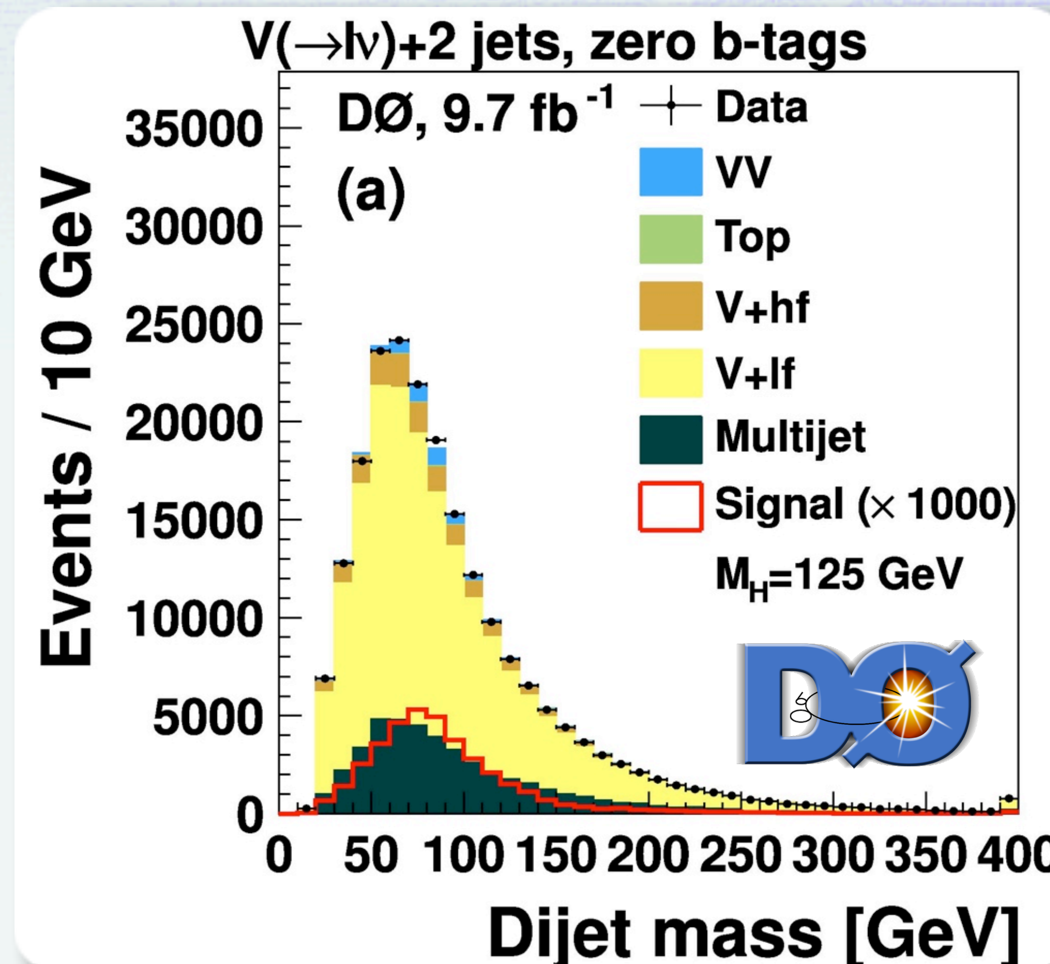


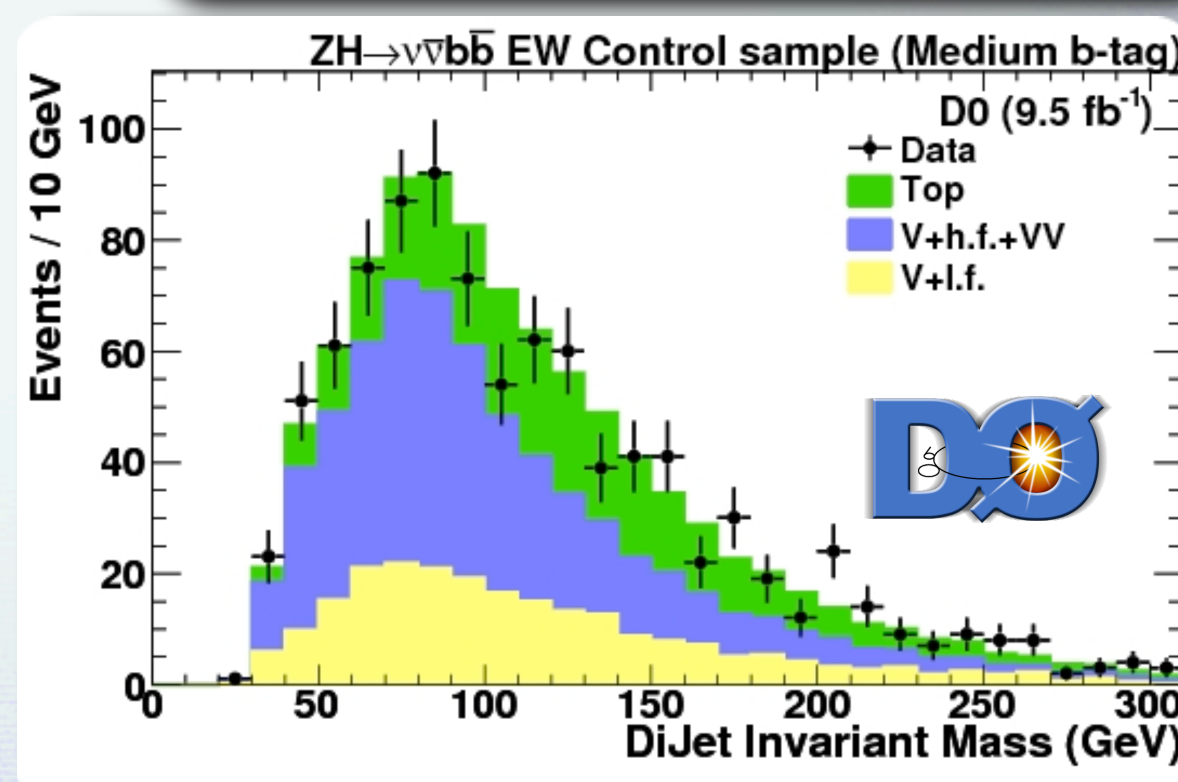
- S/B enhanced by up to a factor of 30

Search Validation

- Understanding of SM backgrounds demonstrated in control regions



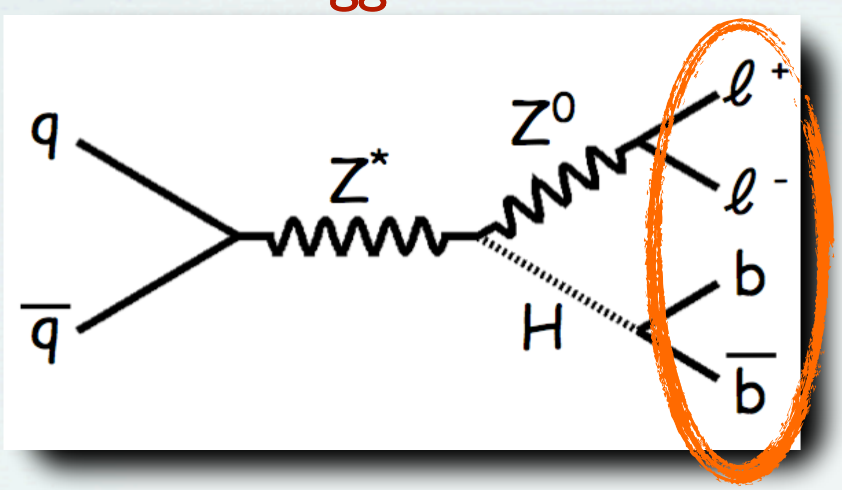




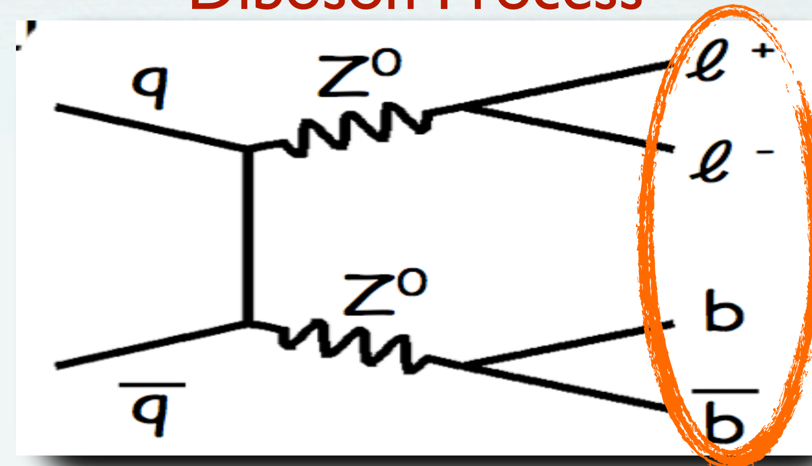
Search Validation

- $H\to bb$ search techniques validated with ZZ/WZ diboson extraction

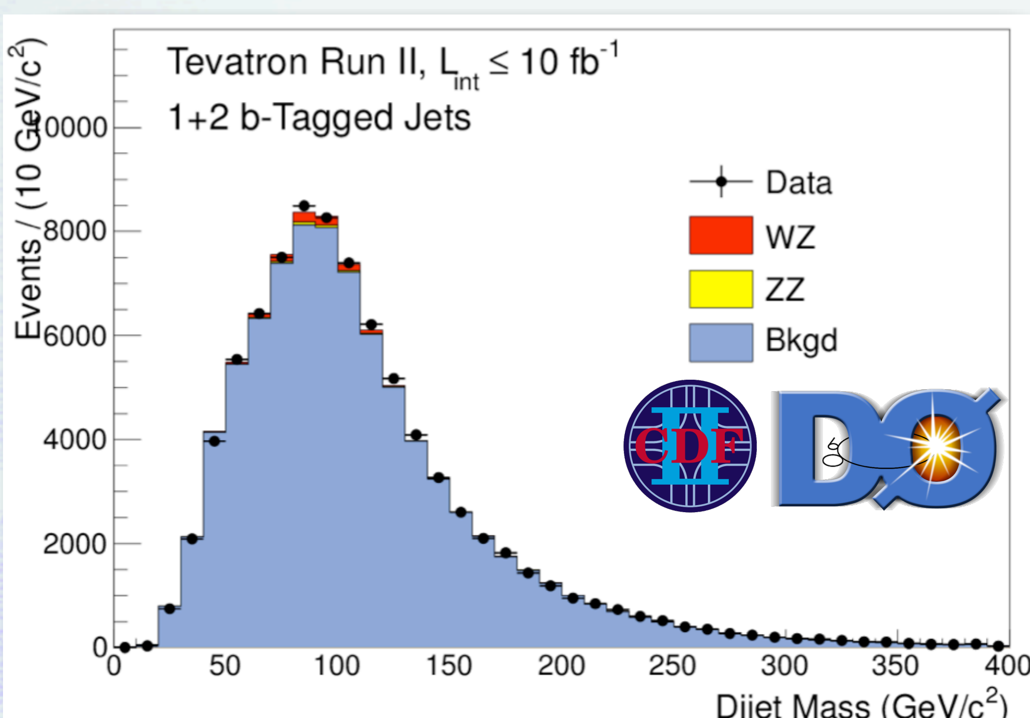
Higgs Process

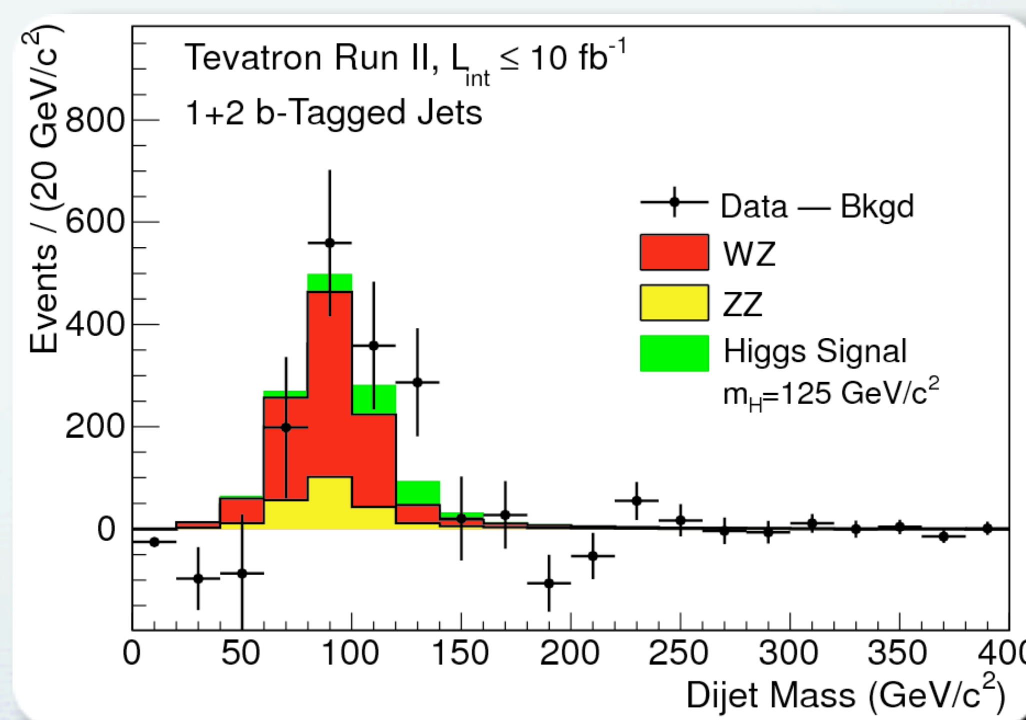


Diboson Process



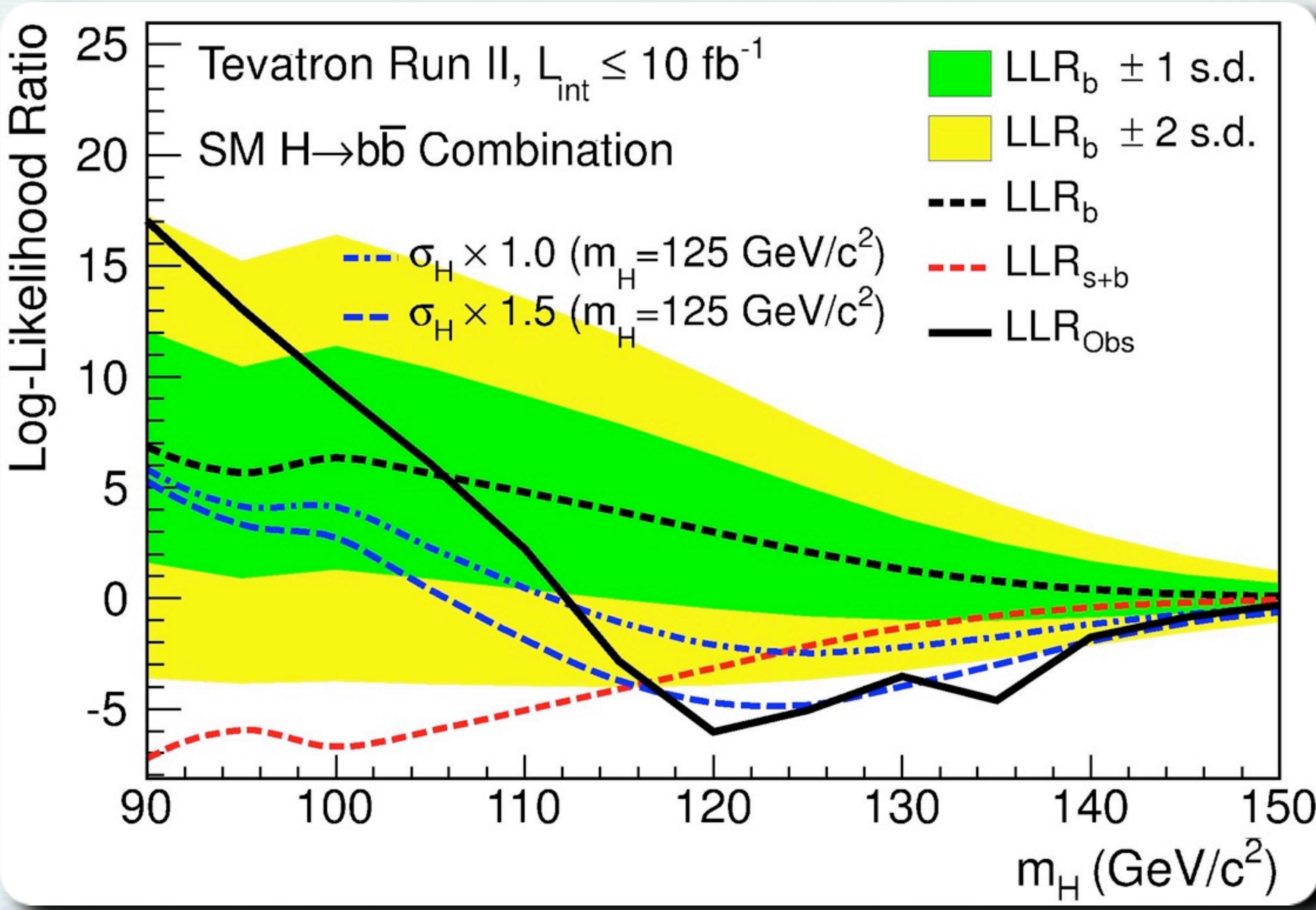
- Validates modeling and ability to extract a $Z\to bb$ signal with a production rate ~1 order of magnitude greater than $H\to bb$





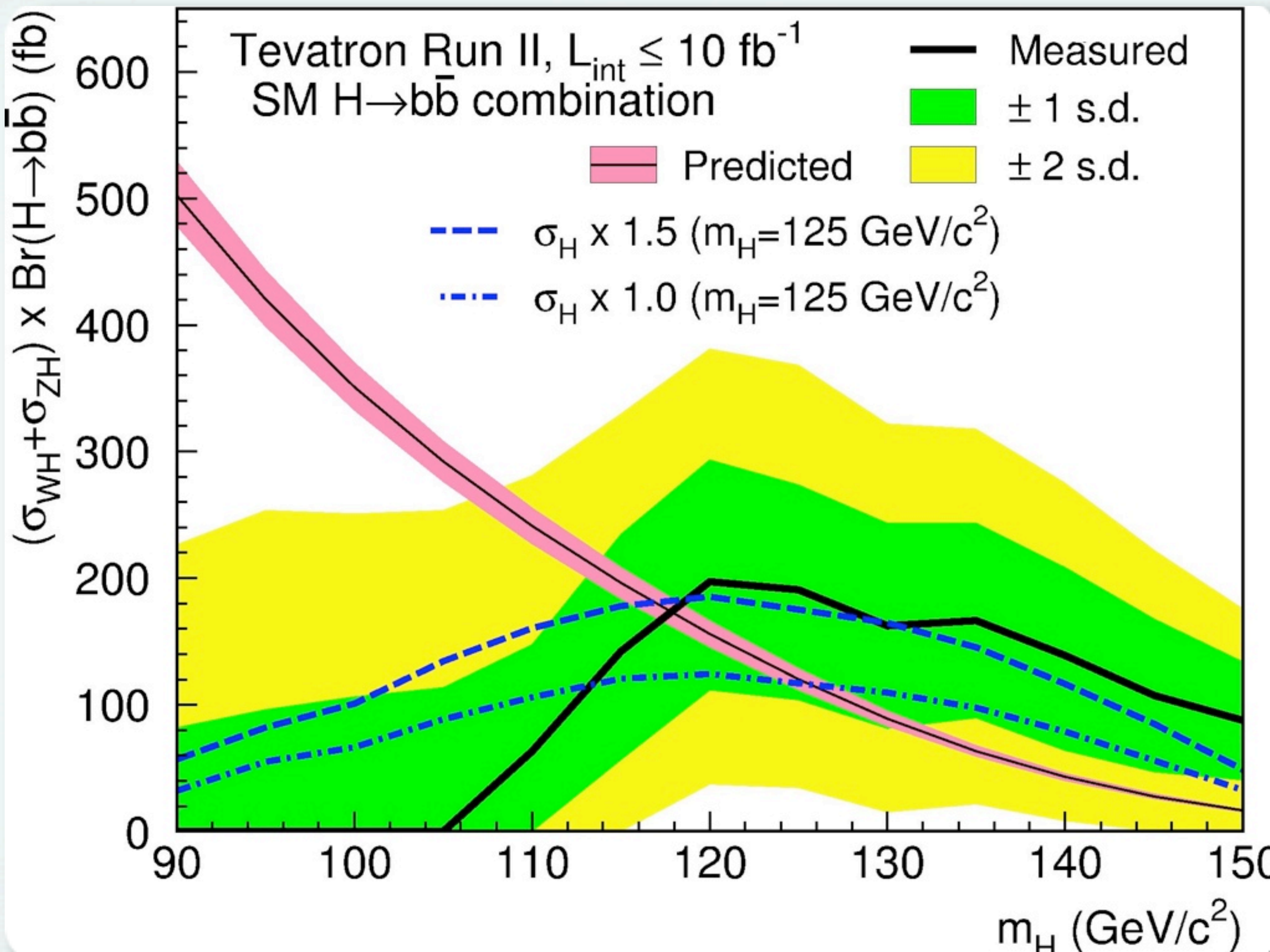
H→bb Combination

- Broad deviation from background-only between 115 and 150 GeV/c^2



Fitted H→bb Cross Sections

- Best fit for $(\sigma_{WH} + \sigma_{ZH}) \times B(H \rightarrow bb)$



- At M_H = 125 GeV : $(\sigma \times B)/ SM = 1.59^{+0.69}_{-0.72}$

Tevatron Search Channels

- Many additional channels combined with H → bb searches

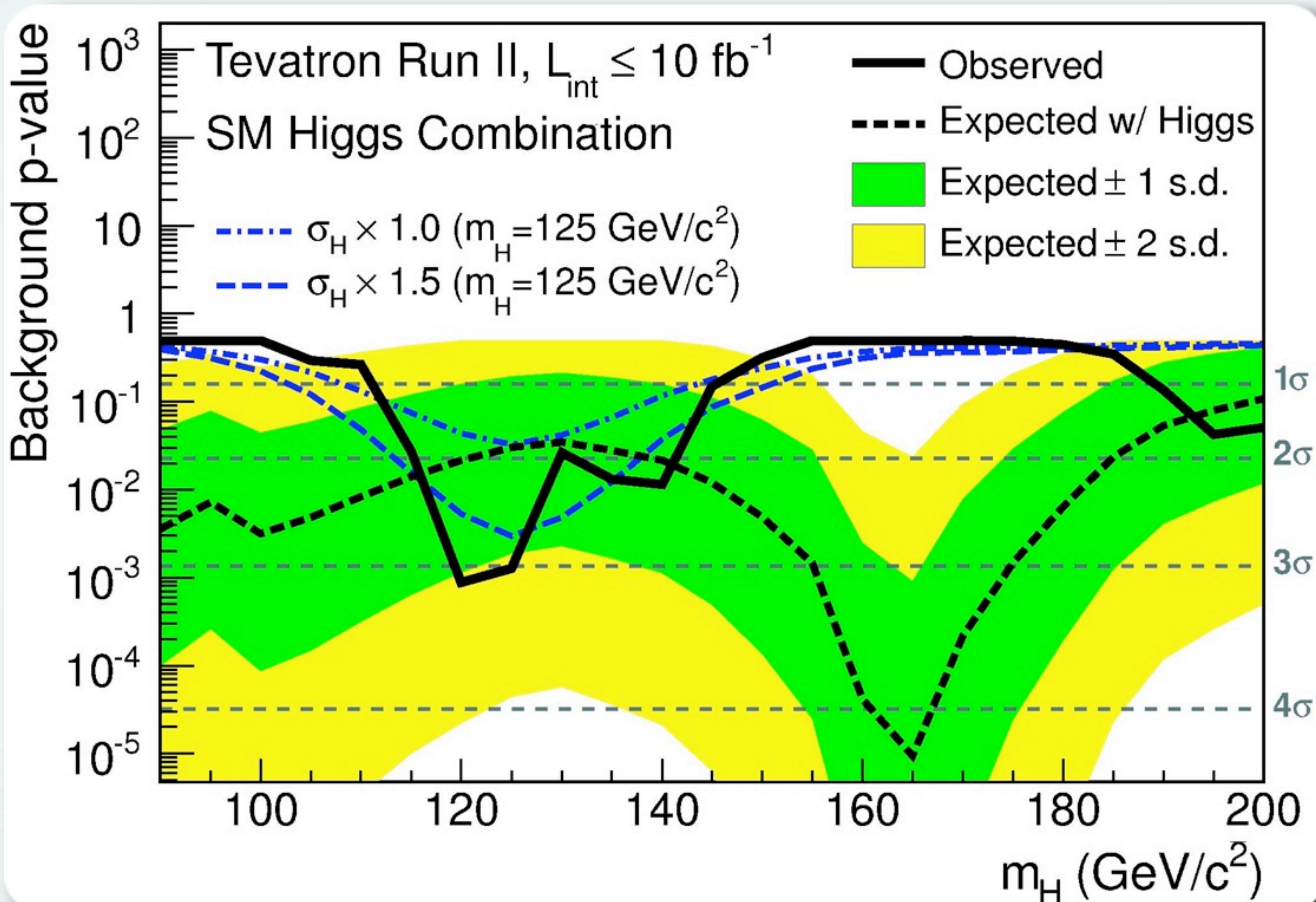
Channel	Luminosity (fb^{-1})	m_H range (GeV/c^2)	Reference
$WH \to \ell\nu bb$ 2-jet channels 4×(5 b-tag categories)	9.45	90–150	[48]
$WH \to \ell\nu b\bar{b}$ 3-jet channels 3×(2 b-tag categories)	9.45	90–150	[48]
$ZH \to \nu\bar{\nu}b\bar{b}$			
$ZH \to \ell^+\ell^- b$			
$ZH \to \ell^+\ell^- b$			
$WH + ZH \to$			
$t\bar{t}H \to W^+bW$			
$H \to W^+W^-$			
$H \to W^+W^-$			
$WH \to WW$			
$WH \to WW$			
$ZH \to ZW^+$			
$H \to \tau^+\tau^-$			
$H \to \gamma\gamma$ 1×			
$H \to ZZ$ (			

Channel		Luminosity (fb^{-1})	m_H range (GeV/c^2)	Reference
$WH \to \ell\nu bb$ 2-jet channels 2×(4 b-tag categories)	$H \to b\bar{b}$	9.7	90–150	[57, 58]
$WH \to \ell\nu b\bar{b}$ 3-jet channels 2×(4 b-tag categories)		9.7	90–150	[57, 58]
$ZH \to \nu\bar{\nu}b\bar{b}$ (2 b-tag categories)		9.5	100–150	[45]
$ZH \to \ell^+\ell^- b\bar{b}$ 2×(2 b-tag)×(4 lepton categories)		9.7	90–150	[59, 60]
$H \to W^+W^- \to \ell^\pm\nu\ell^\mp\nu$ 2×(0 jets,1 jet,≥2 jets)	$H \to W^+W^-$	9.7	115–200	[61]
$H + X \to W^+W^- \to \mu^\mp\nu\tau^\pm_{\rm had}\nu$ (3 τ categories)		7.3	115–200	[62]
$H \to W^+W^- \to \ell\bar{\nu}jj$ 2×(2 b-tag categories)×(2 jets, 3 jets)		9.7	100–200	[58]
$VH \to e^\pm\mu^\pm + X$		9.7	100–200	[63]
$VH \to \ell\ell\ell + X$ ($\mu\mu e$, 3 × $e\mu\mu$)		9.7	100–200	[63]
$VH \to \ell\bar{\nu}jjjj$ 2×(≥4 jets)		9.7	100-200	[58]
$VH \to \tau_{\rm had}\tau_{\rm had}\mu + X$ (3 τ categories)	$H \to \tau^+\tau^-$	8.6	100-150	[63]
$H+X \to \ell^\pm\tau^\mp_{\rm had}jj$ 2×(3 τ categories)		9.7	105–150	[64]
$H \to \gamma\gamma$ (4 categories)	$H \to \gamma\gamma$	9.6	100-150	[65]

Combined Tevatron Result

- Adding searches for H→WW, H→γγ + other modes

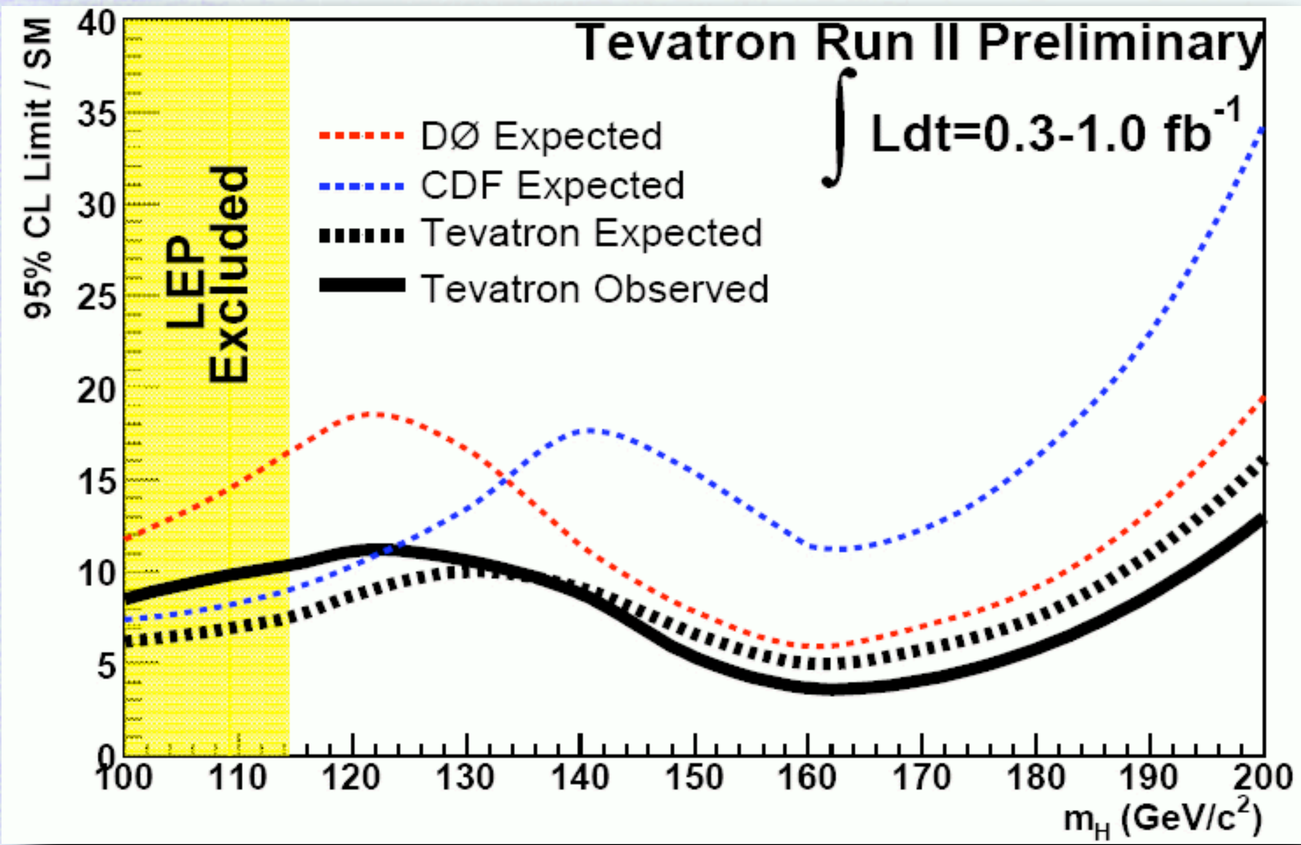
Background p-values



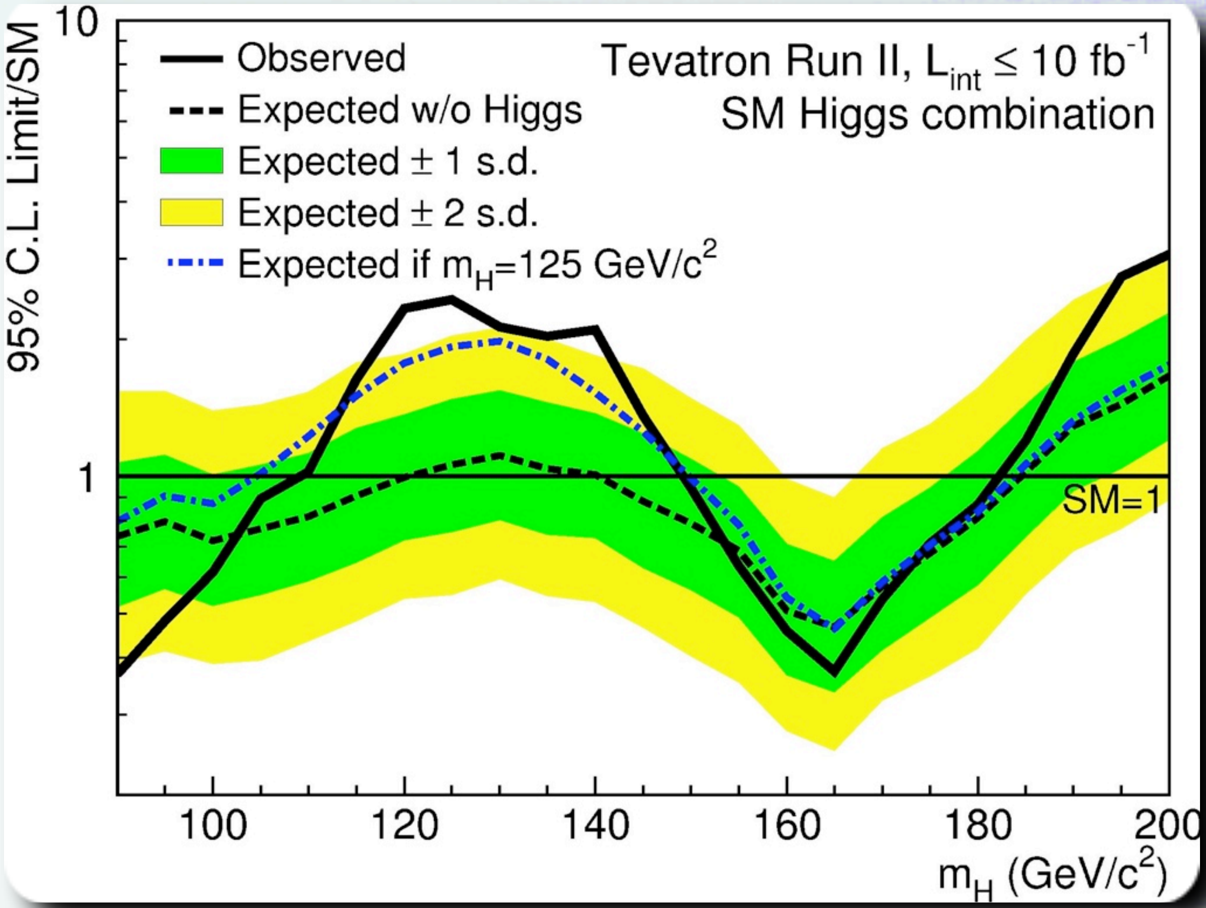
- 3.1 σ 120 GeV (3.0 σ at 125 GeV)

Tevatron Higgs Search Status : 2006 vs. 2013

2006



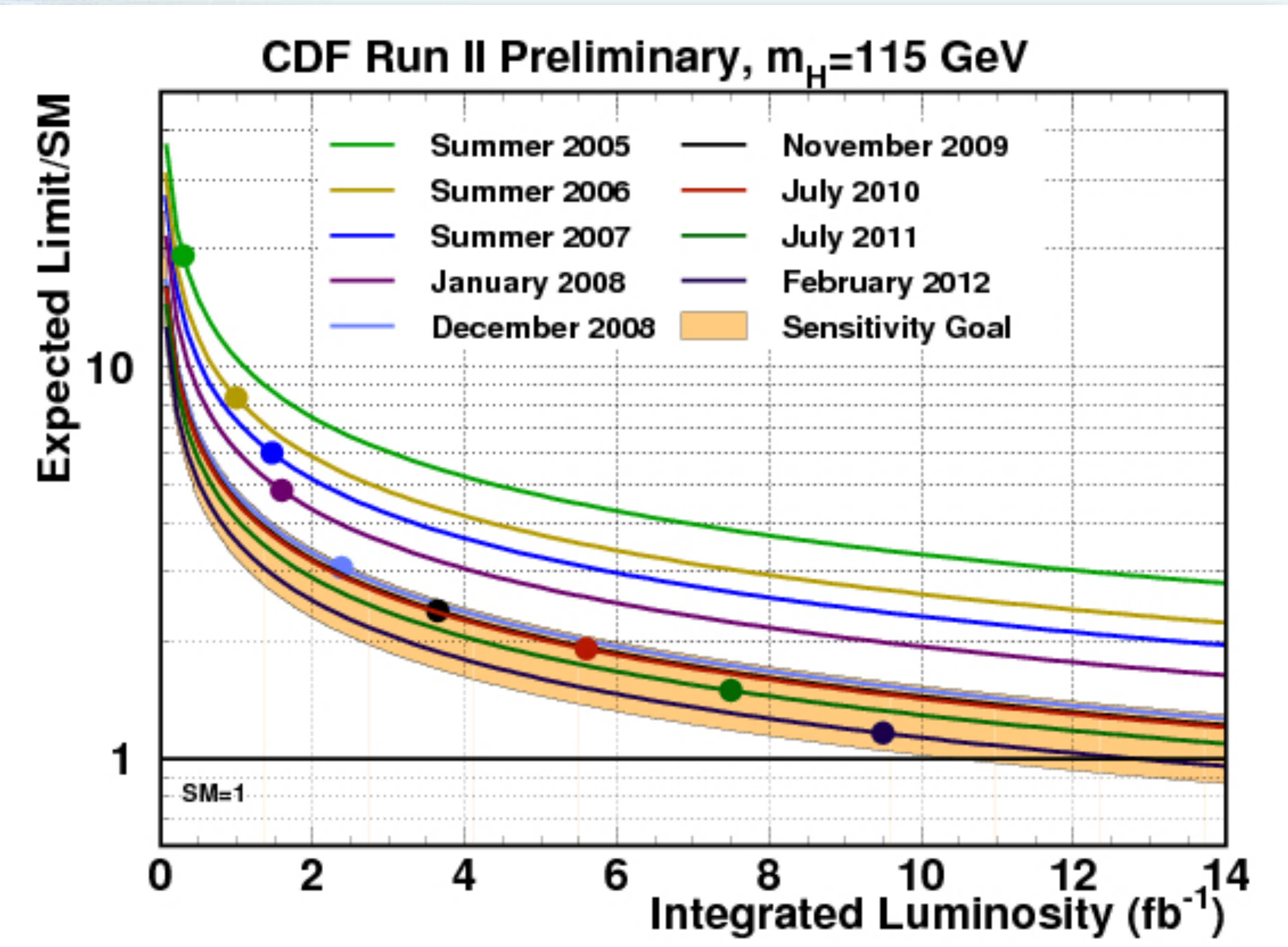
2013



- Early Tevatron combination in 2006 achieved expected sensitivity of ~10xSM rate
- The 2013 combination achieved an expected sensitivity of ~1.1xSM rate for MH ~125 GeV

Track Record of Sensitivity Improvements

- In each successive combination have introduced analysis techniques that boost sensitivity beyond expectation from increased data sample alone



- increased lepton acceptance
- better b-tagging
- improved signal discrimination & background rejection

Hard work over many years!

Conclusions

- Presented overview of low-mass SM Higgs results in full Tevatron dataset
- Broad excess in observed data compared with background-only hypothesis for masses between 115 and 150 GeV/c^2, consistent with LHC observation
- For more details see :

  http://tevnphwg.fnal.gov

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

  http://www-cdf.fnal.gov/physics/new/hdg/Results.html

Thanks!