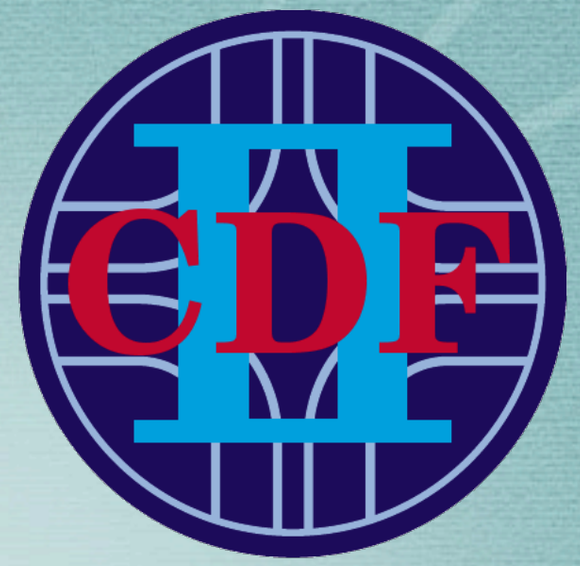


UCDAVIS
UNIVERSITY OF CALIFORNIA

Search For the Standard Model Higgs Boson in H→bb at CDF II

S.Z. Shalhout
on behalf of the CDF collaboration
April 5, 2012 University of Oregon

Outline

- Talk will cover latest CDF SM Higgs searches in H→bb
- Discuss search strategies for WH and ZH
- Present CDF results and Tevatron (H→bb) combination

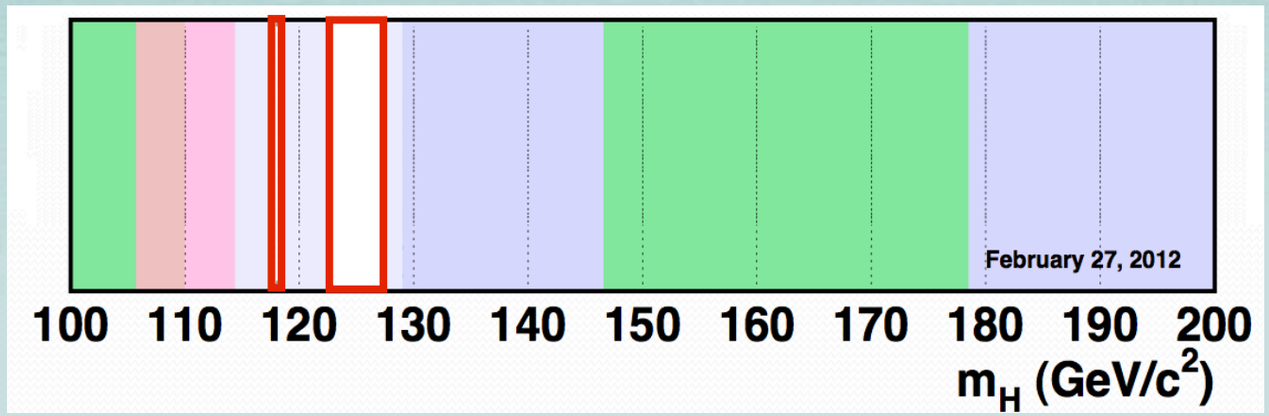
For Additional Details and Latest Results see :

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

http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_12/index.html

Narrowing Search Window

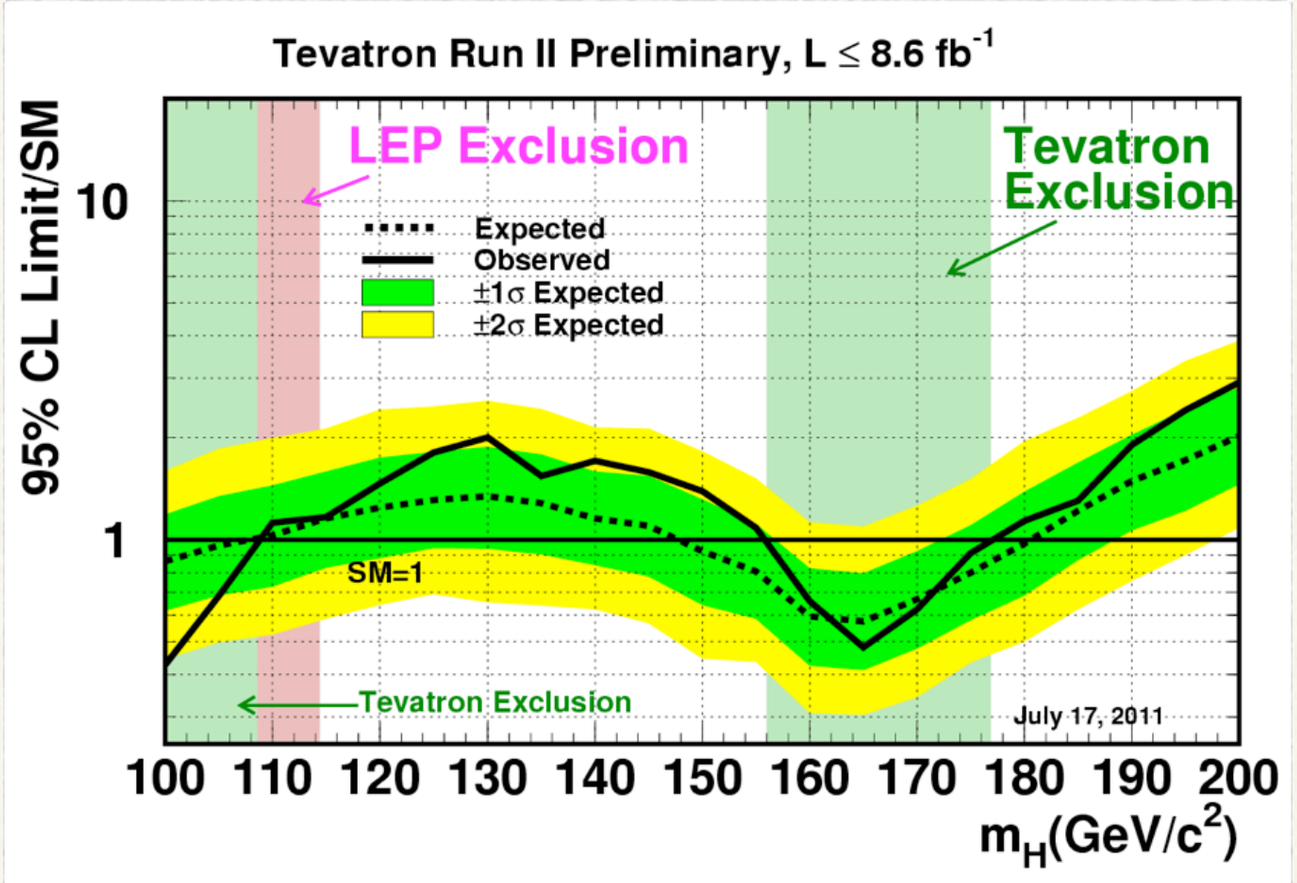
- LHC searches have ruled out a large range of values for M_H



- Remaining regions have interesting excesses, driven mainly by $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ$
- At the LHC searches in $H \rightarrow bb$ (the main decay mode in the open regions of M_H) do not contribute much ($\lesssim$10%) at 125 GeV/c^2
- However this mass range is also accessible at the Tevatron where searches in $H \rightarrow bb$ contribute dominantly at $M_H \lesssim 135$ GeV/c^2

Tevatron Search Status (July, 2011)

- Status of the Tevatron SM Higgs effort as of summer 2011

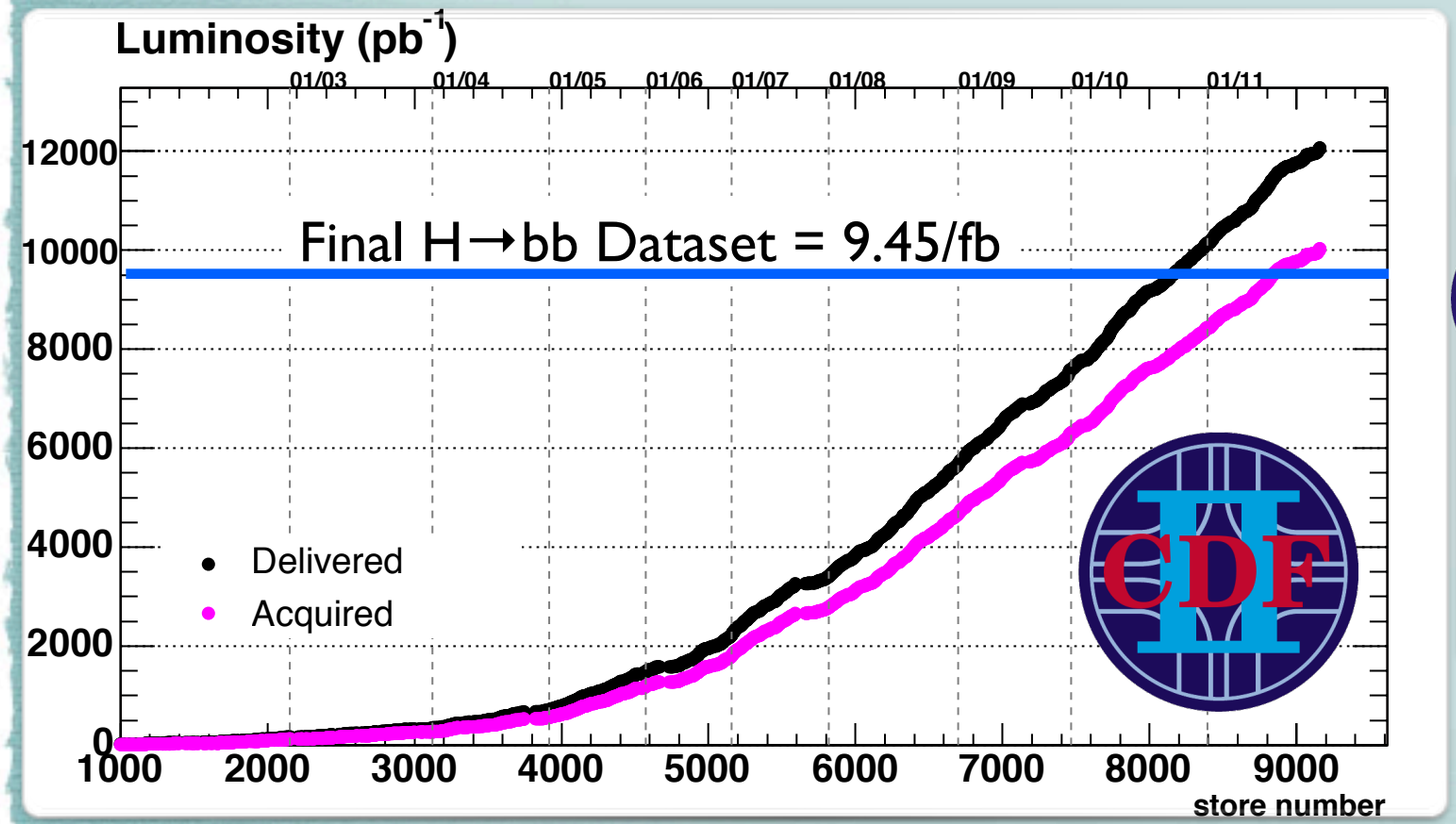


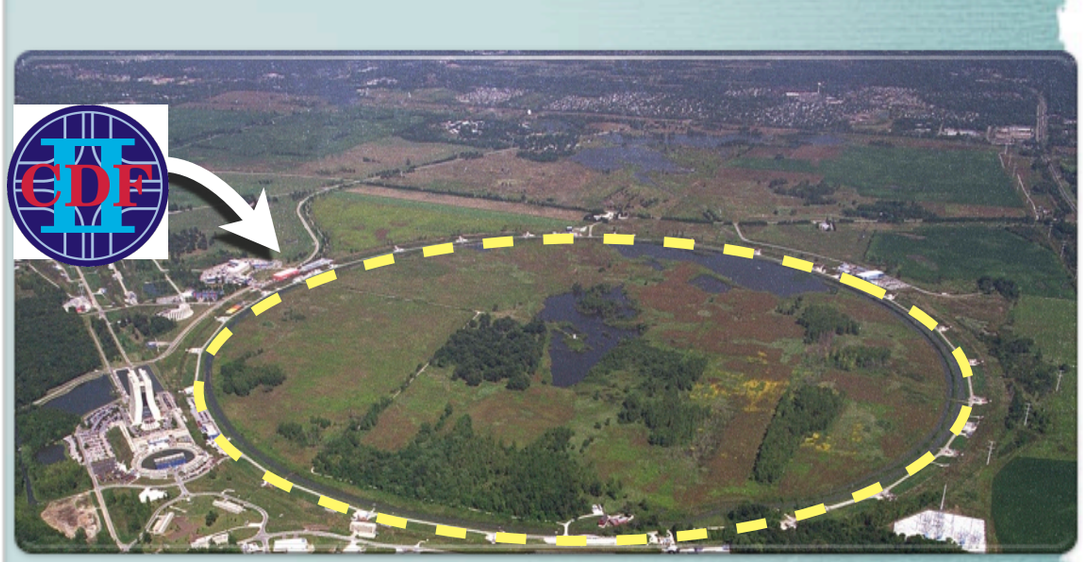
- Searches in H→bb account for ~80-85% of the Tevatron's sensitivity at lower masses
- Major changes to analysis techniques implemented between 2011 and 2012 results

- Expected Sensitivity of 1.3 X SM @ 125 GeV
- Small (~1σ excess at lower mass)

The Tevatron

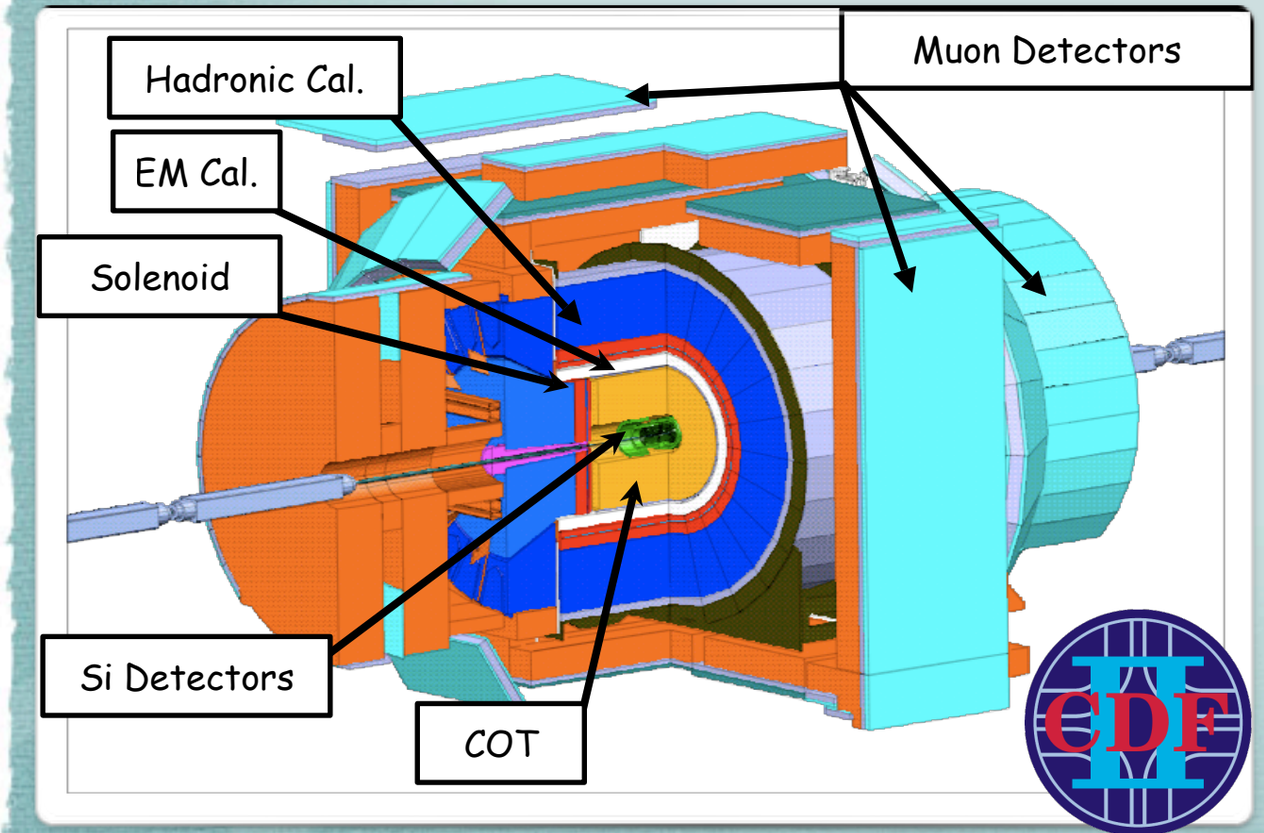
- p pbar collider @ $\sqrt{s}$ = 1.96 TeV
- ~12/fb delivered to each experiment (CDF & D0)
- Beam operations terminated in September 2011
- Final CDF dataset available to H→bb search is 9.45/fb

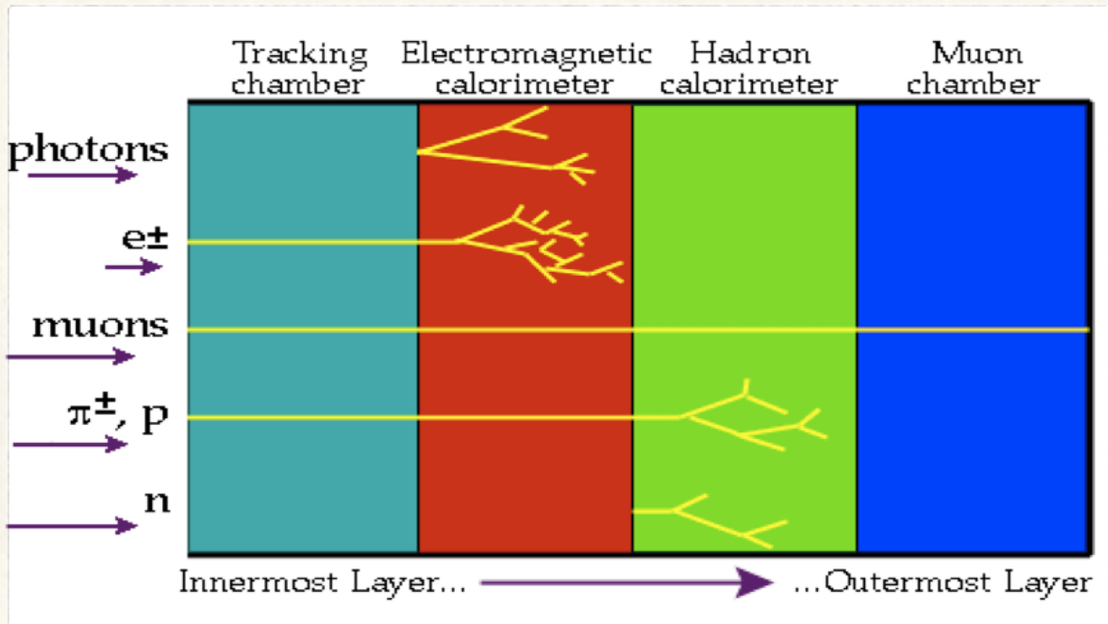




The CDF II Detector

- general purpose detector
- Silicon Vertex Detector (critical for b-jet ID)
- Tracking Chamber
- Calorimeter + Muon Systems (jet, electron, muon ID)
- Combined with muli-level 'trigger systems' to select events with topologies of interest (missing transverse energy, energetic jets/leptons)

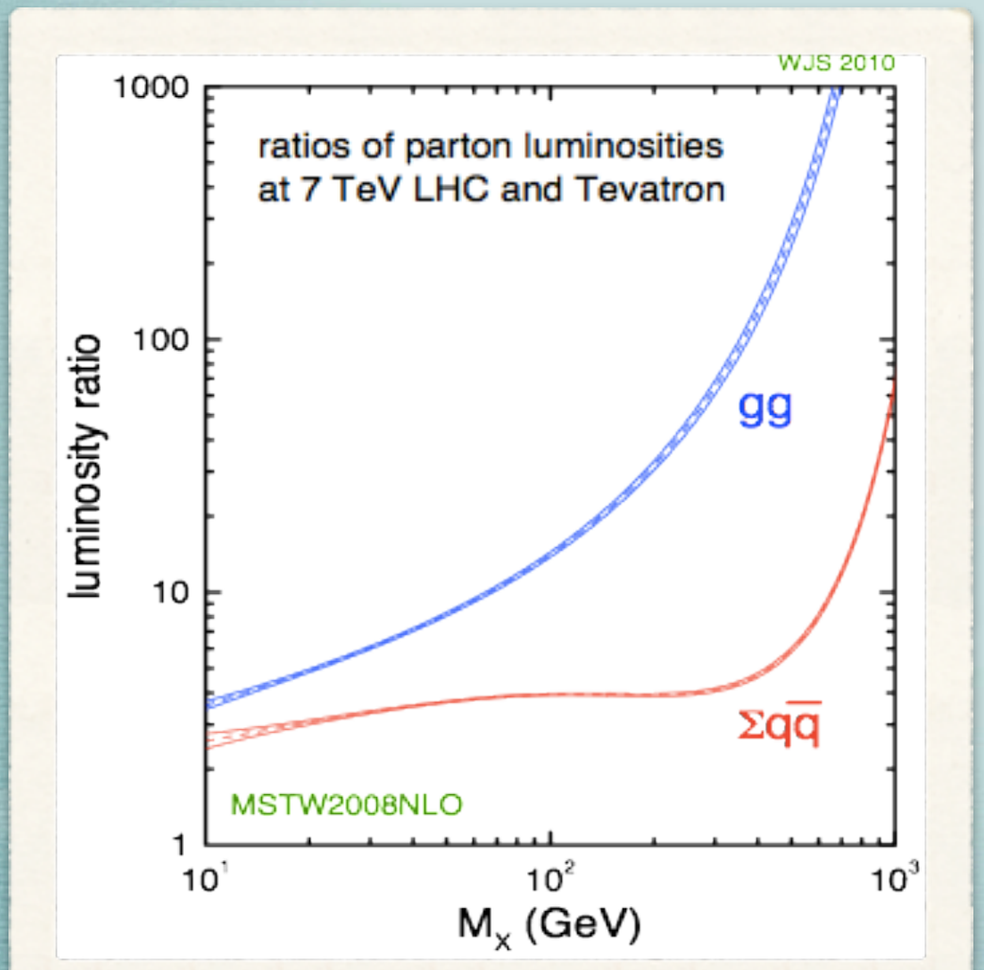


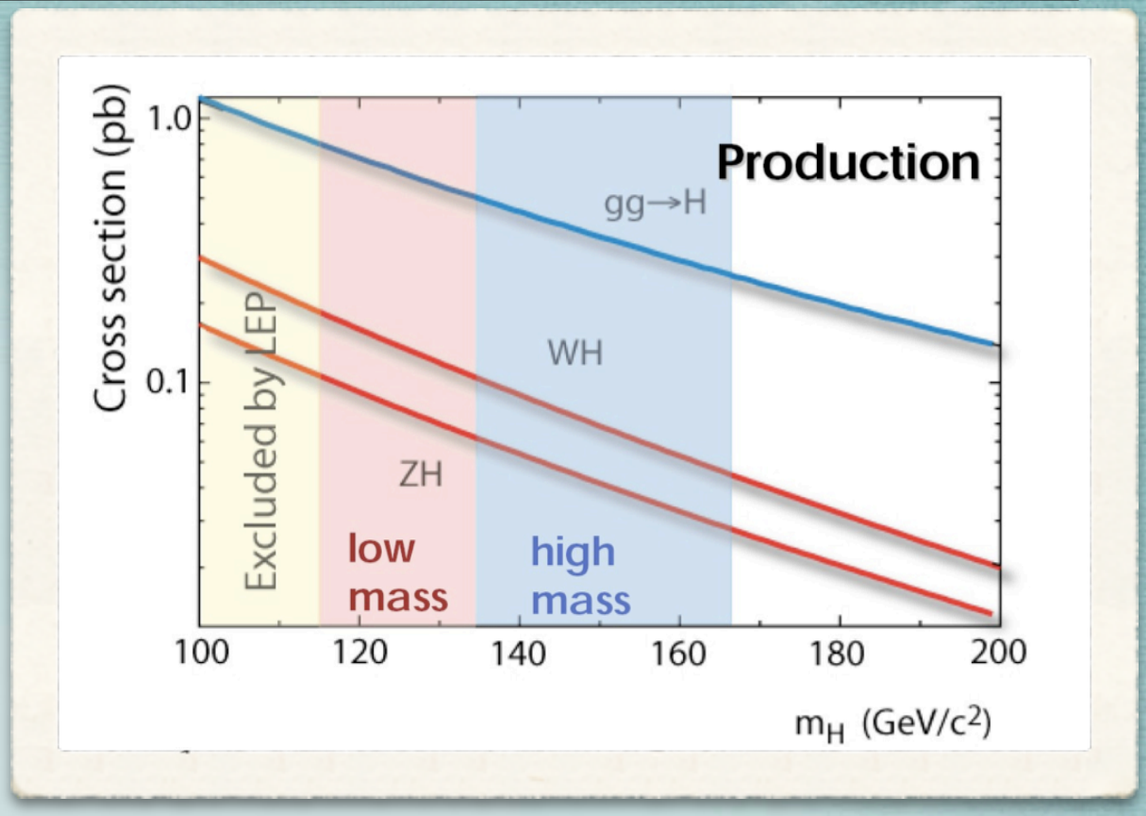


The SM Higgs @ The Tevatron

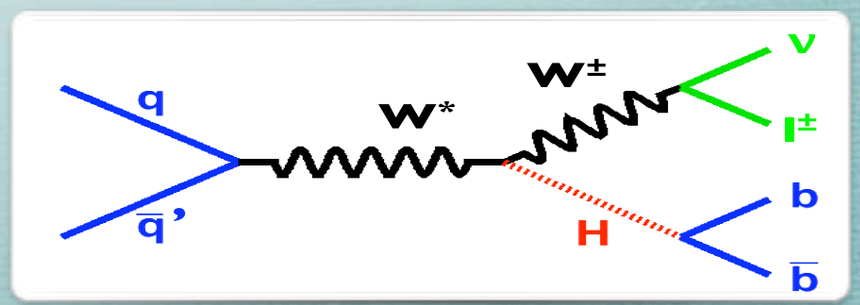
- Main production modes for searches are :
  I. Gluon-gluon fusion (gg→H)
  II. Associated Production (ZH/WH)

- H→bb dominates at low mass





- due to Tevatron's p-pbar initial state LHC gains less in production rate for ZH/WH than other modes



The Search Environment

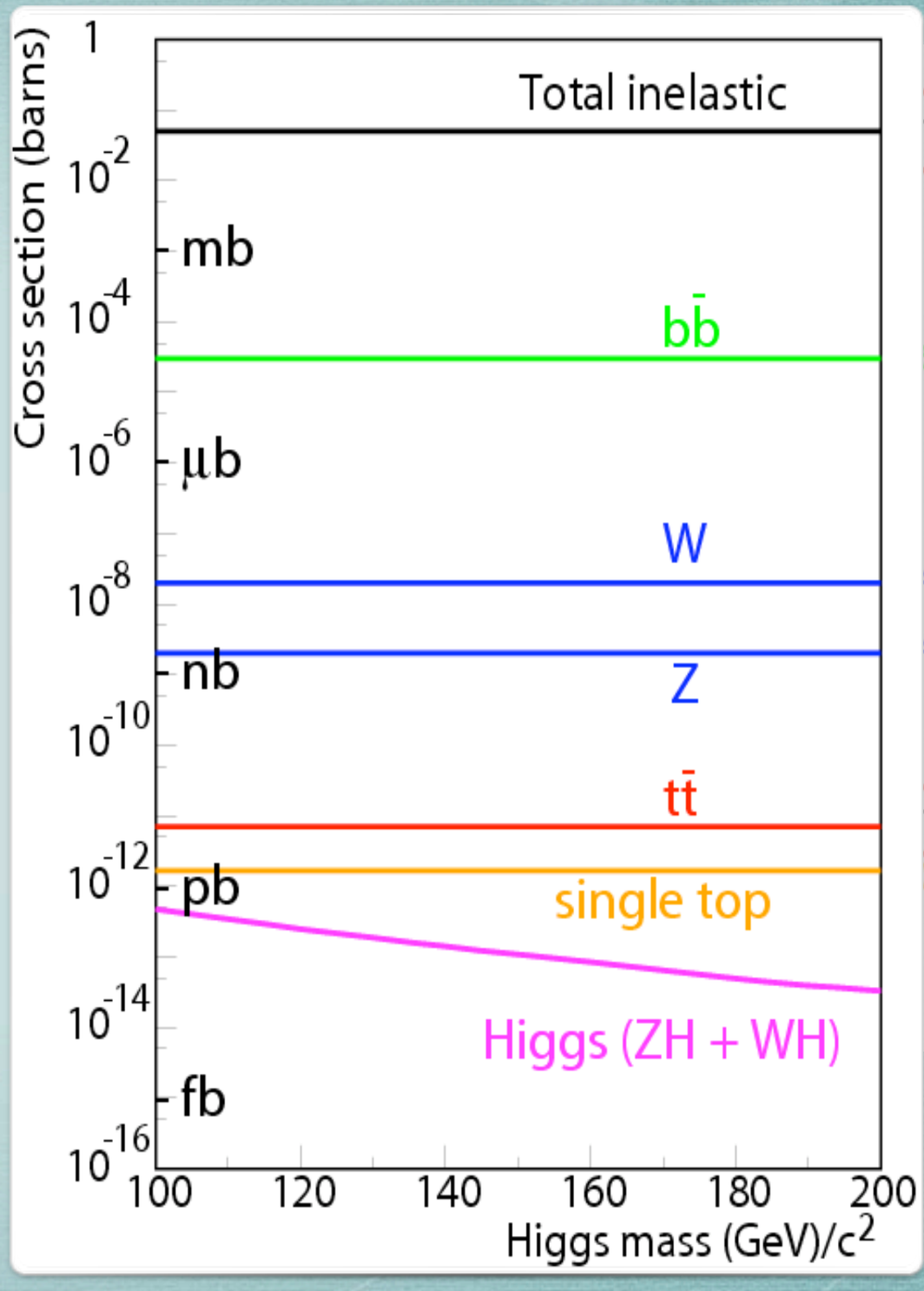
- Background rates many orders of magnitude higher than predicted SM Higgs rates

- The dominant process ($gg \rightarrow H \rightarrow b\bar{b}$) is overwhelmed by multi-jet production

- Searches target Higgs production/decay modes with 'distinguishing' final states :

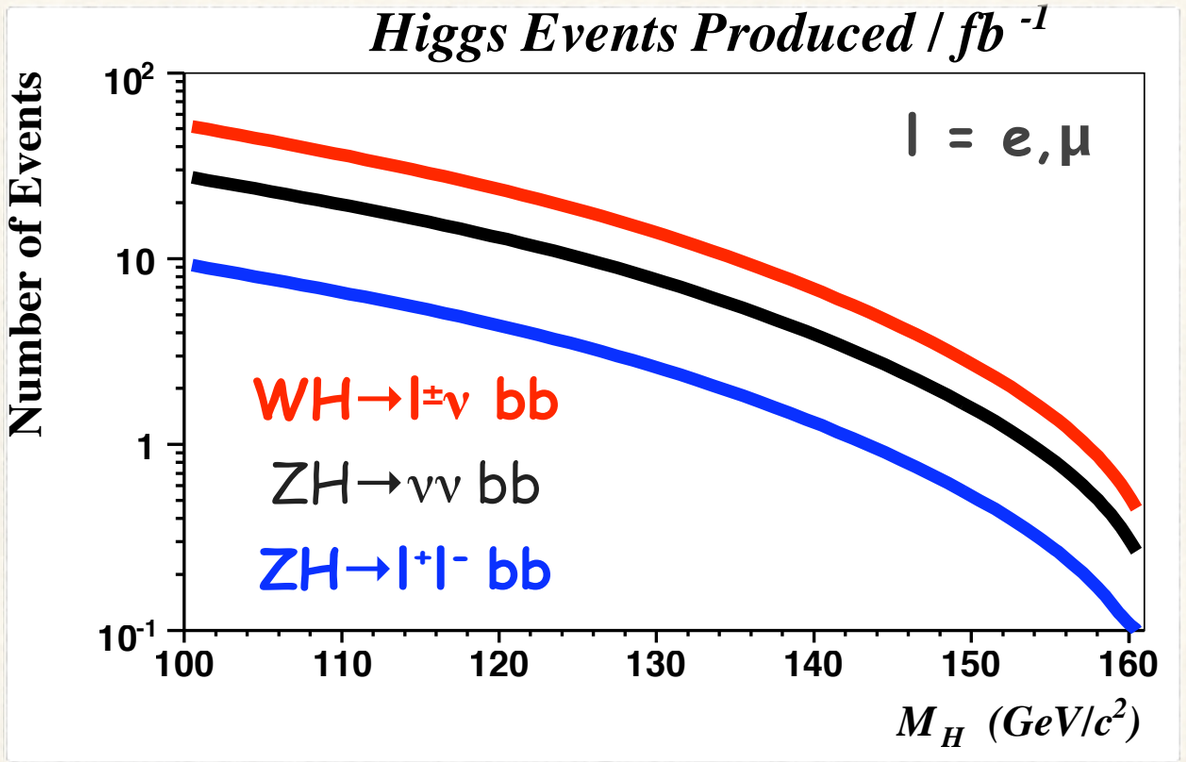
$e^{\pm}/\mu^{\pm} + \nu$
$e^{-}e^{+}$ or $\mu^{-}\mu^{+}$
$\nu\ \nu$

- Analysis methods proven successful in picking out signals as small as single top production (~pb)



bb + 0,1, or 2 charged leptons

- Signal Production Rates :



- Signal rates are low (~100 events/10^{14} collisions)
- Aim for maximum signal/ background
- Have developed several techniques to enhance sensitivity

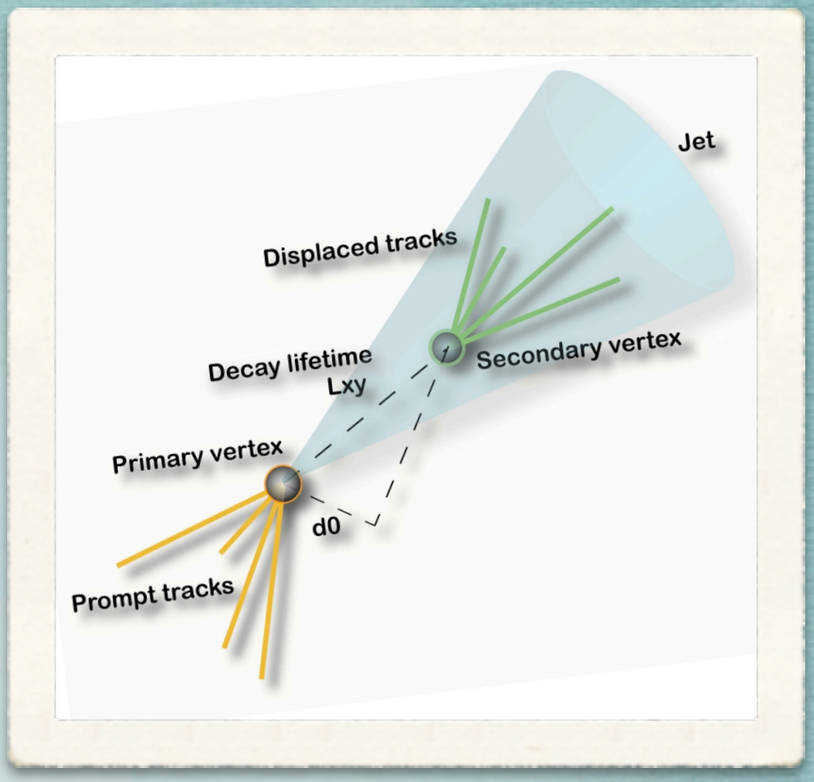
- Expected Backgrounds :

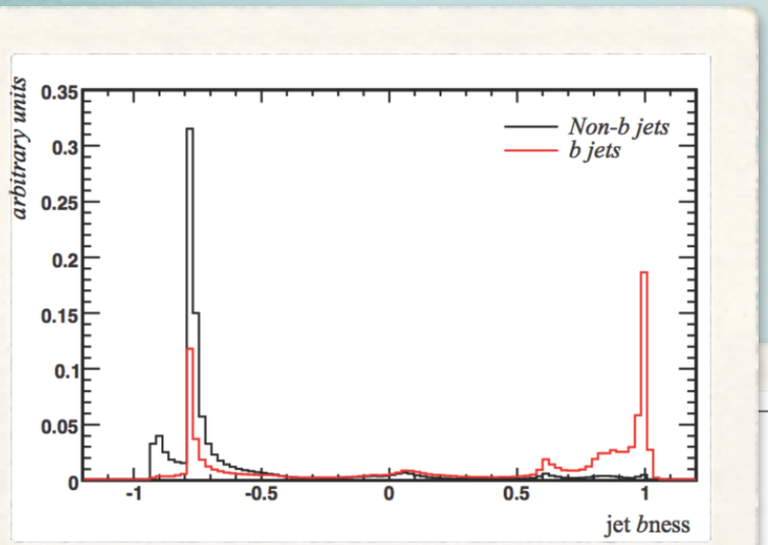
Z+jets
W+jets
Diboson, top

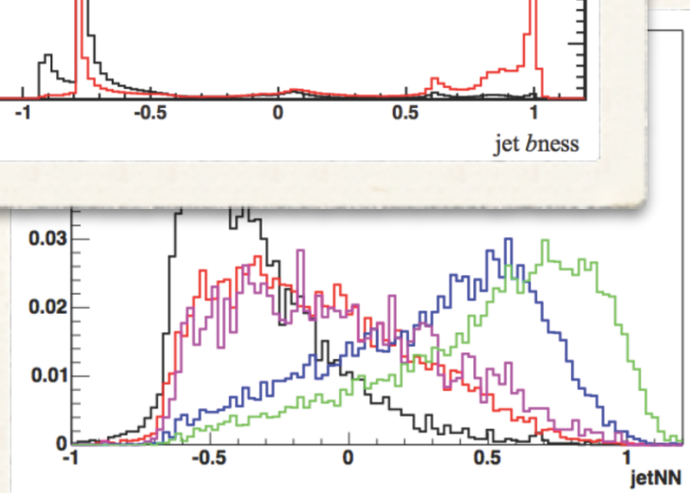
channel	approx. bkg per fb^{-1} (after all selections)
WH→l±ν bb	~3000 events
VH→ννbb	~2000 events
ZH→l⁺l⁻bb	~100 events

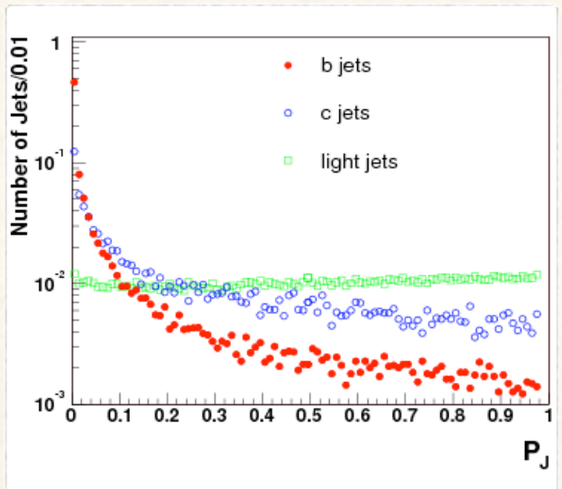
b-jet Identification

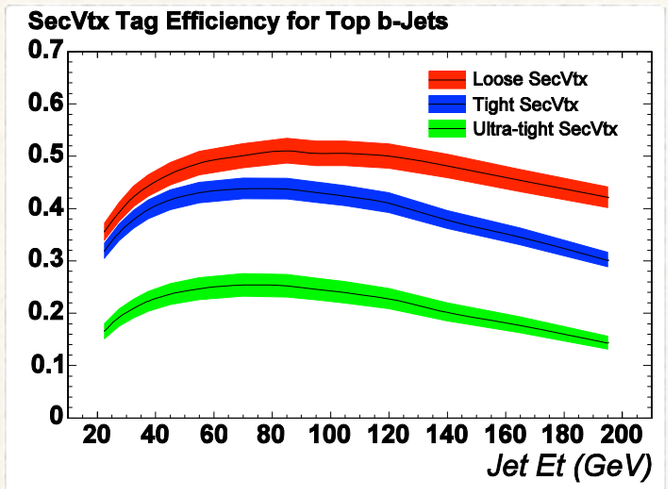
- Distinguish b-jets from c/light jets
- Most important analysis tool for low mass searches
- Various algorithms available @ CDF
- Typically tag ~50% of b-jets with 1%≲ If "mis-"tag rate







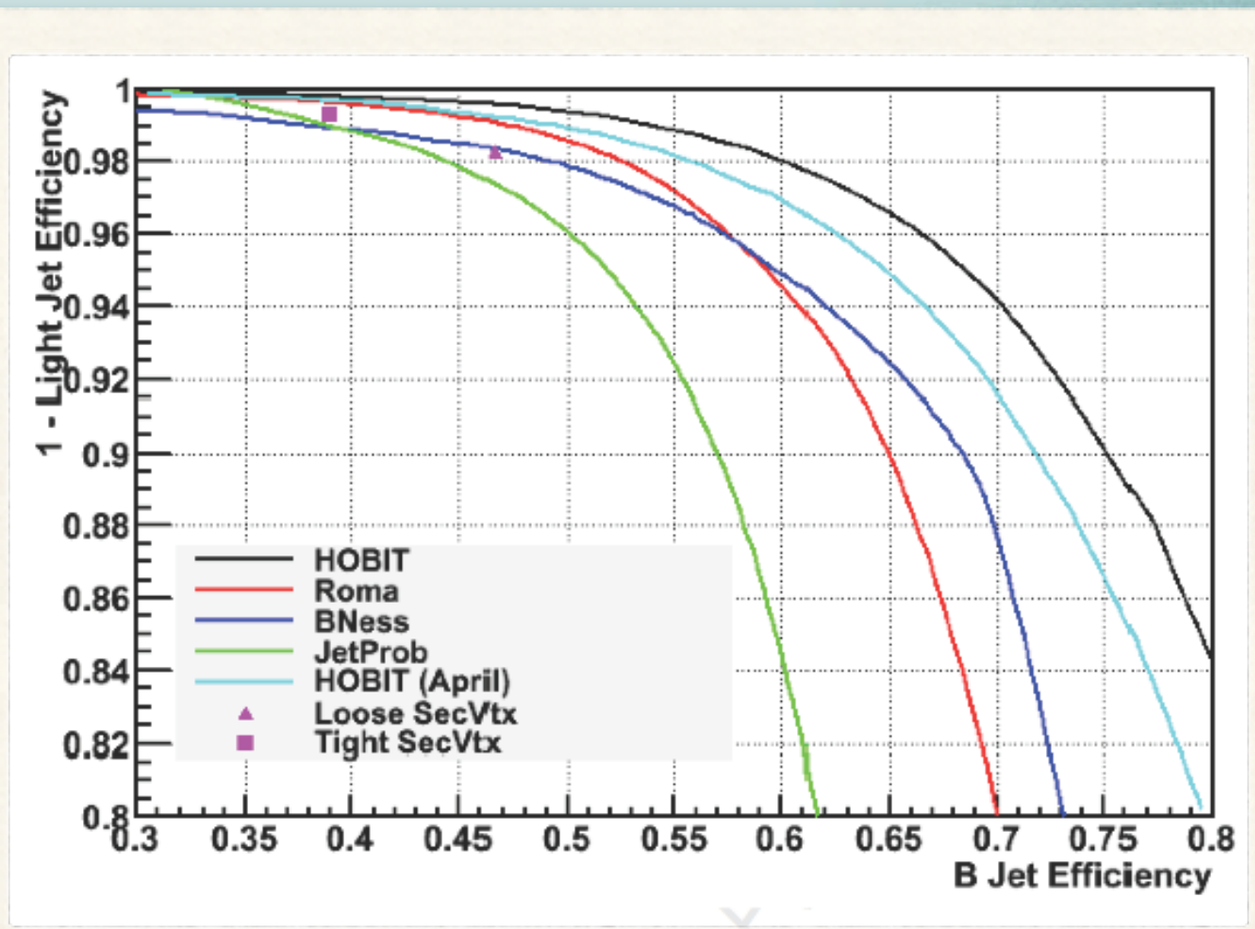




New For Winter 2012 :

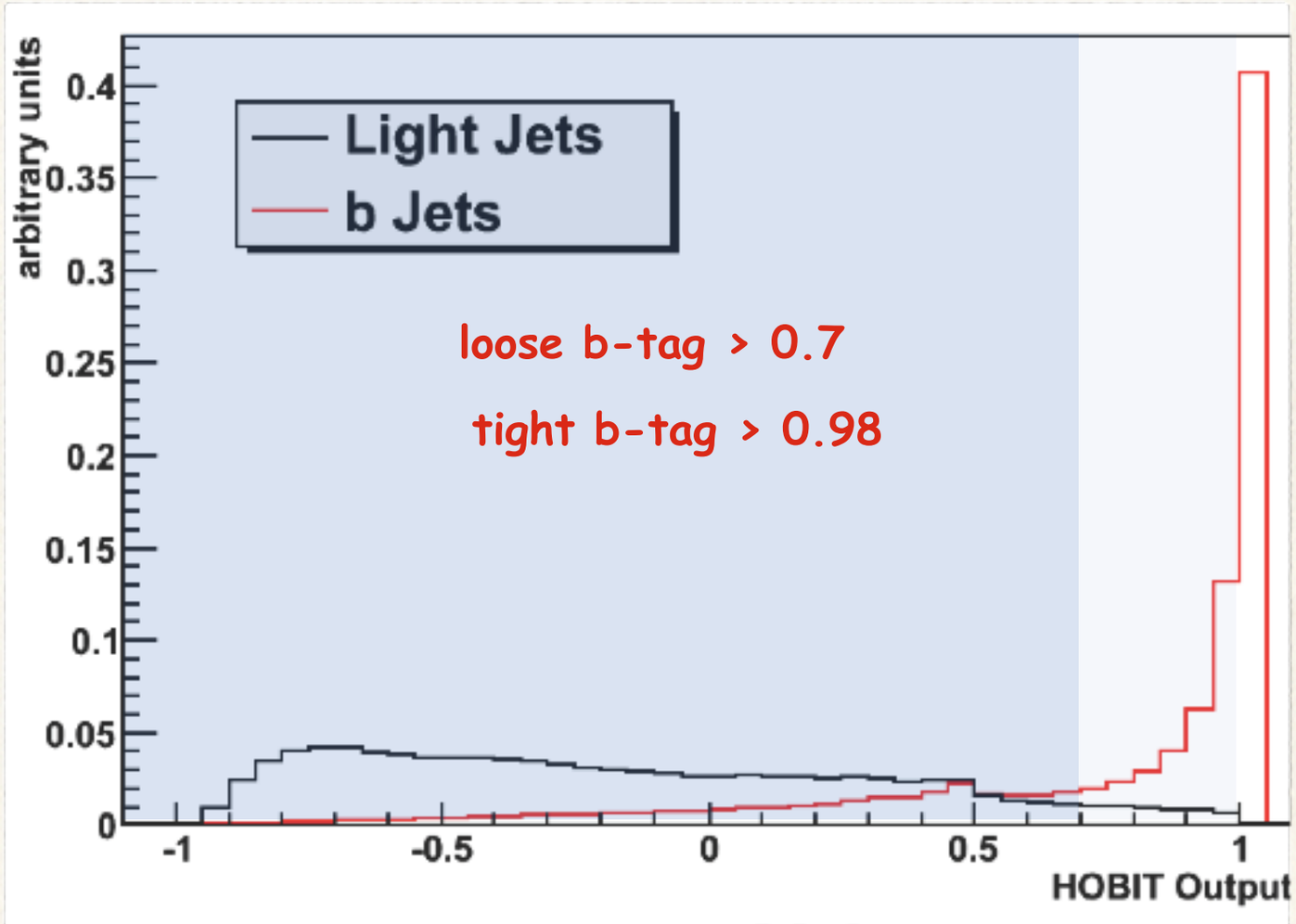
- Higgs Optimized b Identification Tagger
- Neural Network b-jet tagger
- Optimized for identification of b-jets from H→bb
- uses top 25 inputs used by previous algorithms

- Continuous output allows for S/B optimized choice of operating points
- better b-efficiency and light flavor rejection than all previous methods
- Direct ~10-15% sensitivity gain for H→bb searches



New For Winter 2012 :

- Performance in MC matched to data in control samples
- S/B optimization of operating points

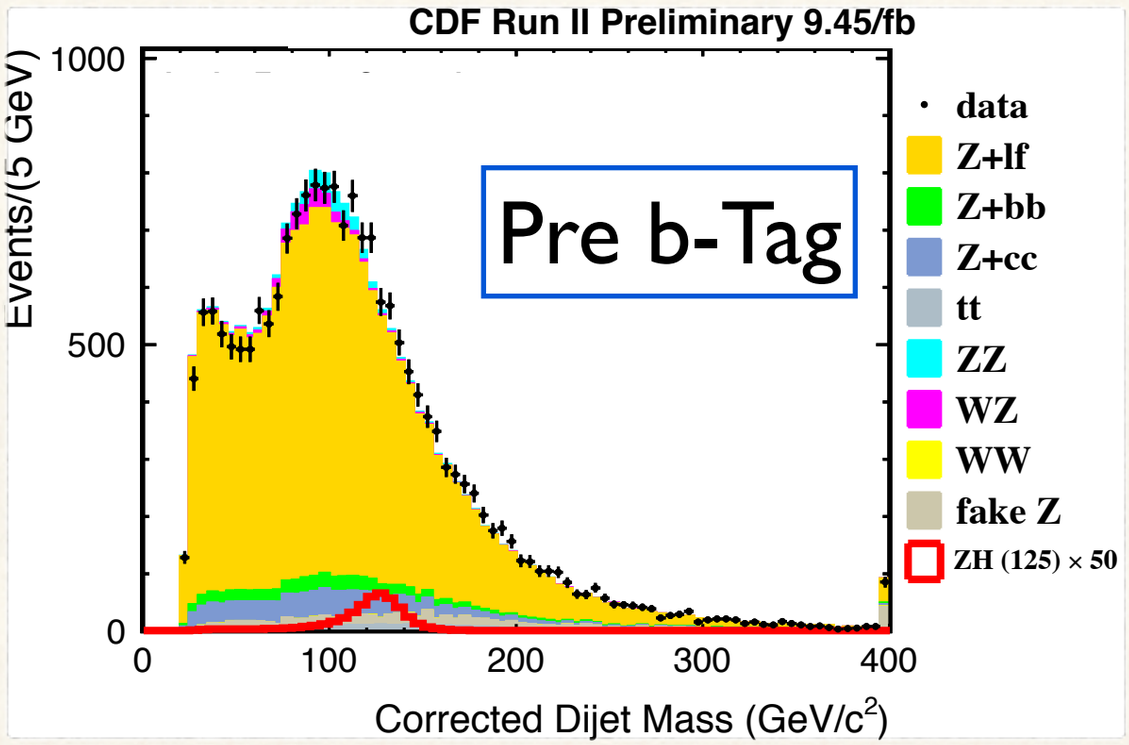


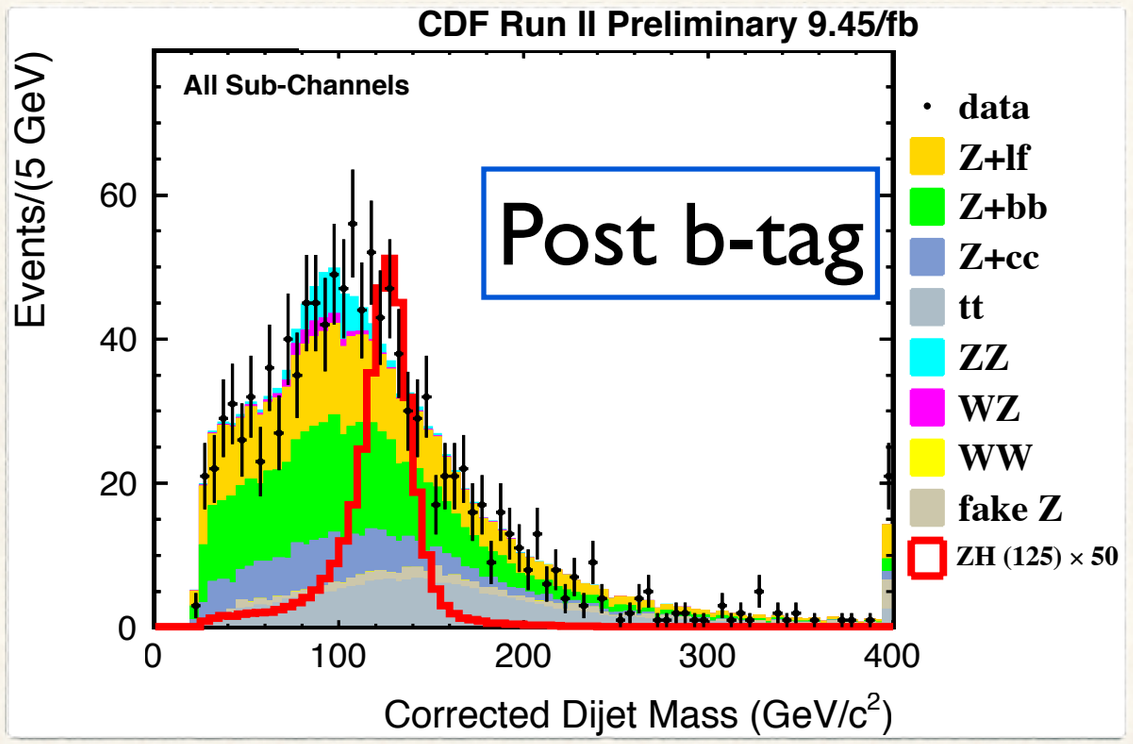
For the WH search :

Combination	~S/B (115 GeV)
Tight + Tight	0.017
Tight + Loose	0.009
Single Tight	0.003
Loose + Loose	0.003
Single Loose	0.001

b-jet Identification

- Demonstration of b-tagging in ZH→llbb:

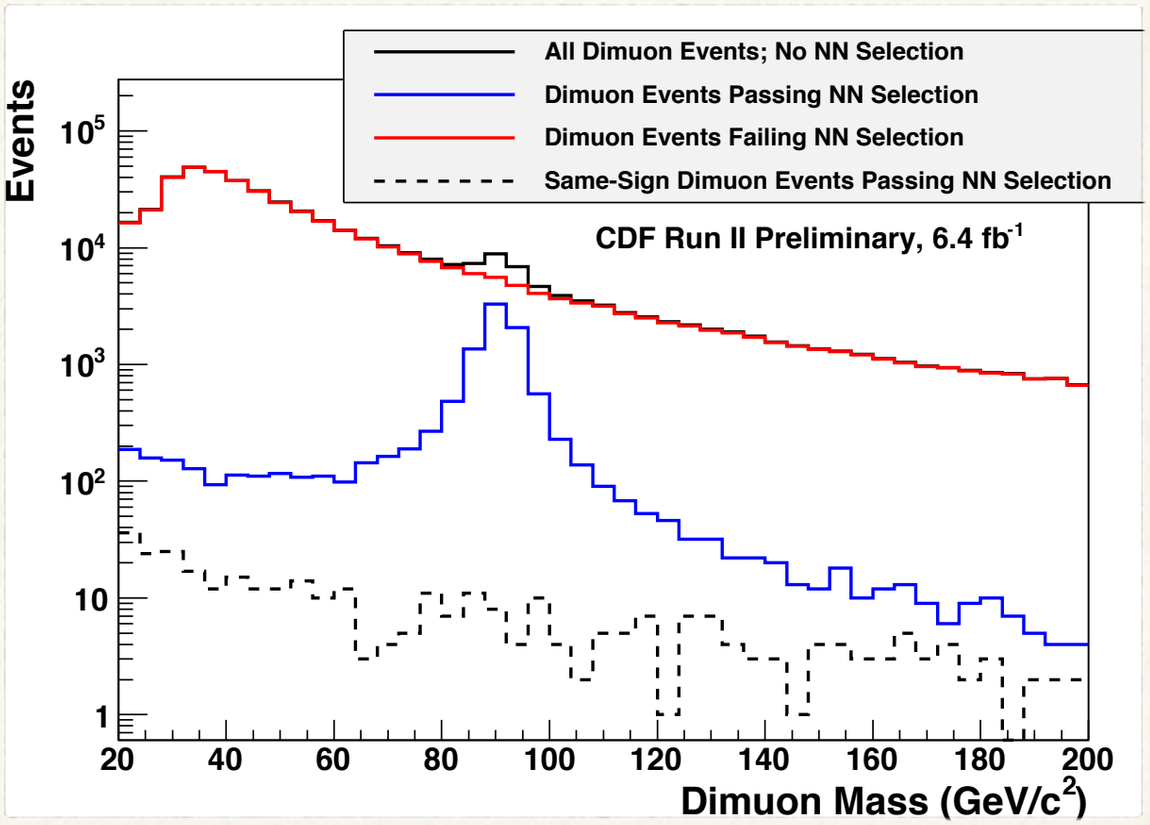


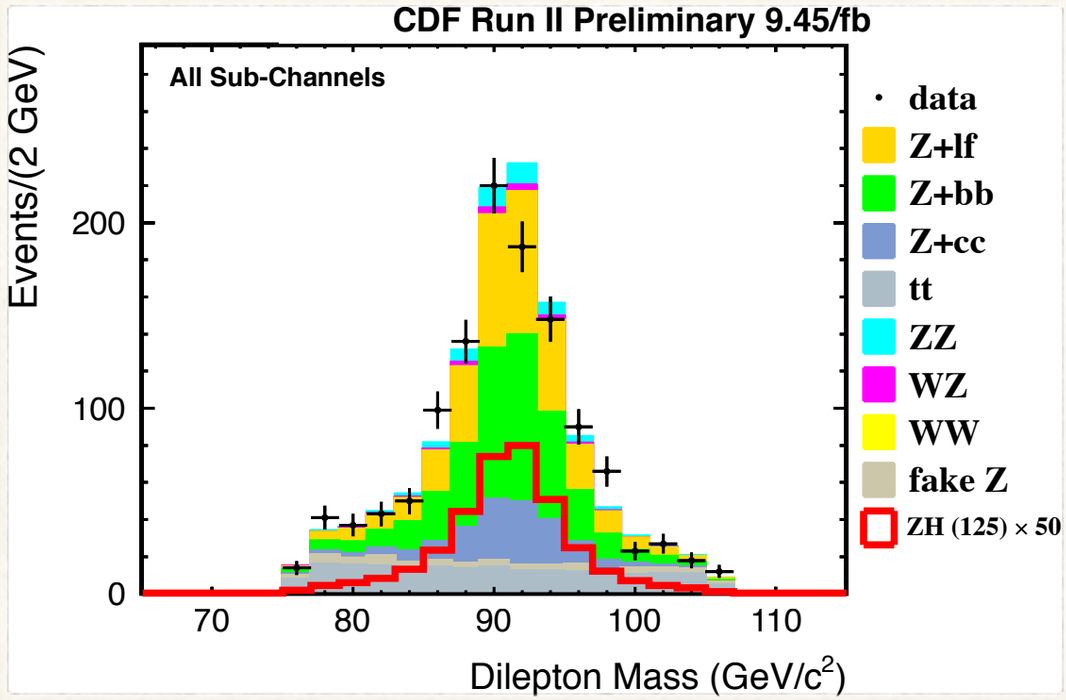


MultiVariate Lepton ID

- Have replaced 'cut' based lepton identification with multivariate algorithms for certain classes of electron and muon (~95% multivariate ID in ZH→llbb)

- Neural Networks achieve ~10-20% lepton acceptance gains, and reduce misidentification rates by a factor of 5



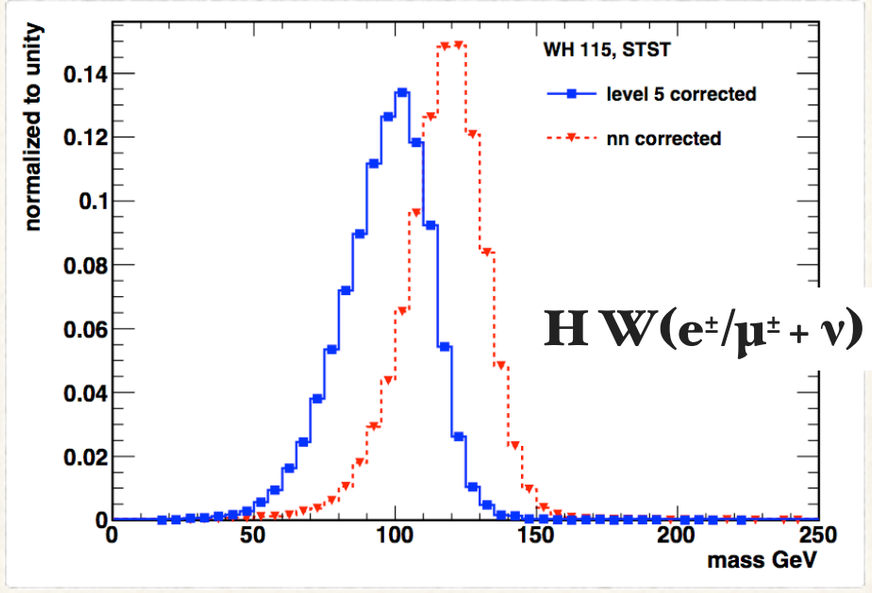


Neural Network Jet Energy Corrections

- Dijet mass is typically among the most discriminating distributions for H→bb
- Improved jet energy resolution = improved sensitivity
- Default resolution of 15 to 20%

Analysis	NN Corrects Jet Energy Based On …
H W($e^{\pm}/\mu^{\pm}$ + ν)	secondary vertex info (b-specific)
H Z(e^-e_+ or $\mu^-\mu_+$)	topological event properties ($\Delta\Phi$[jet,met])
H Z(ν ν)	tracks and neutral particles within the jet cone *

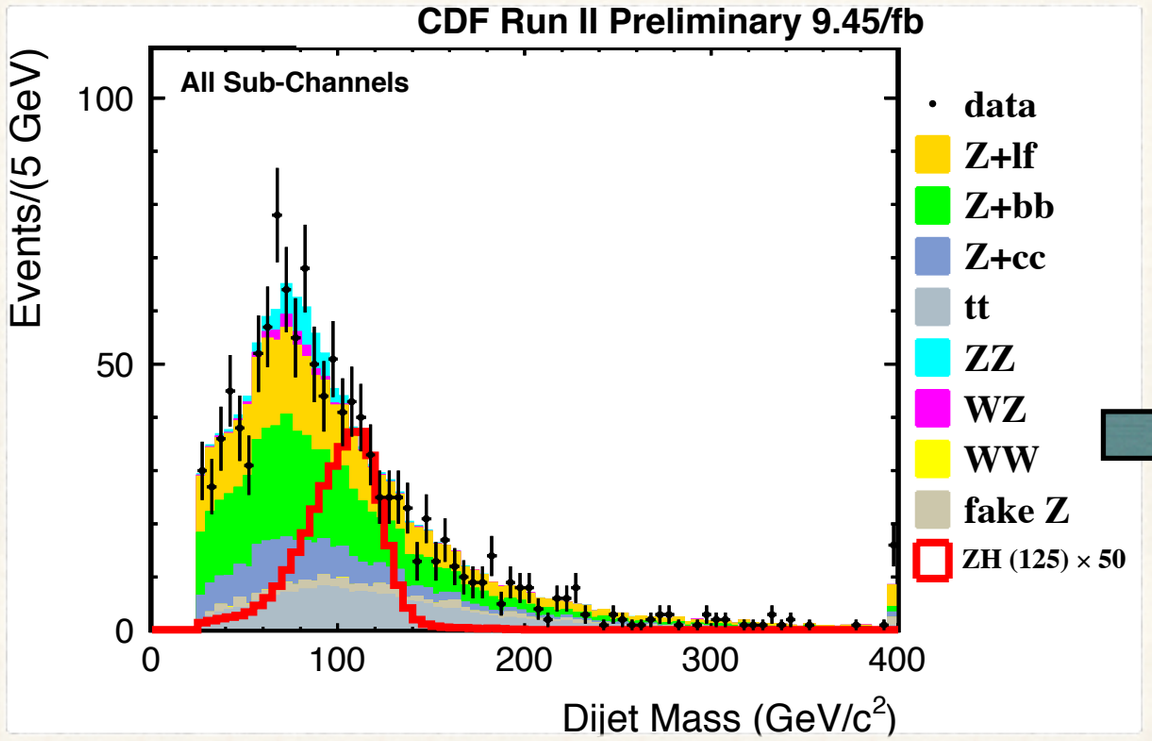
- Multiple approaches with similar performance
- Dijet mass resolution improved to 10-12%

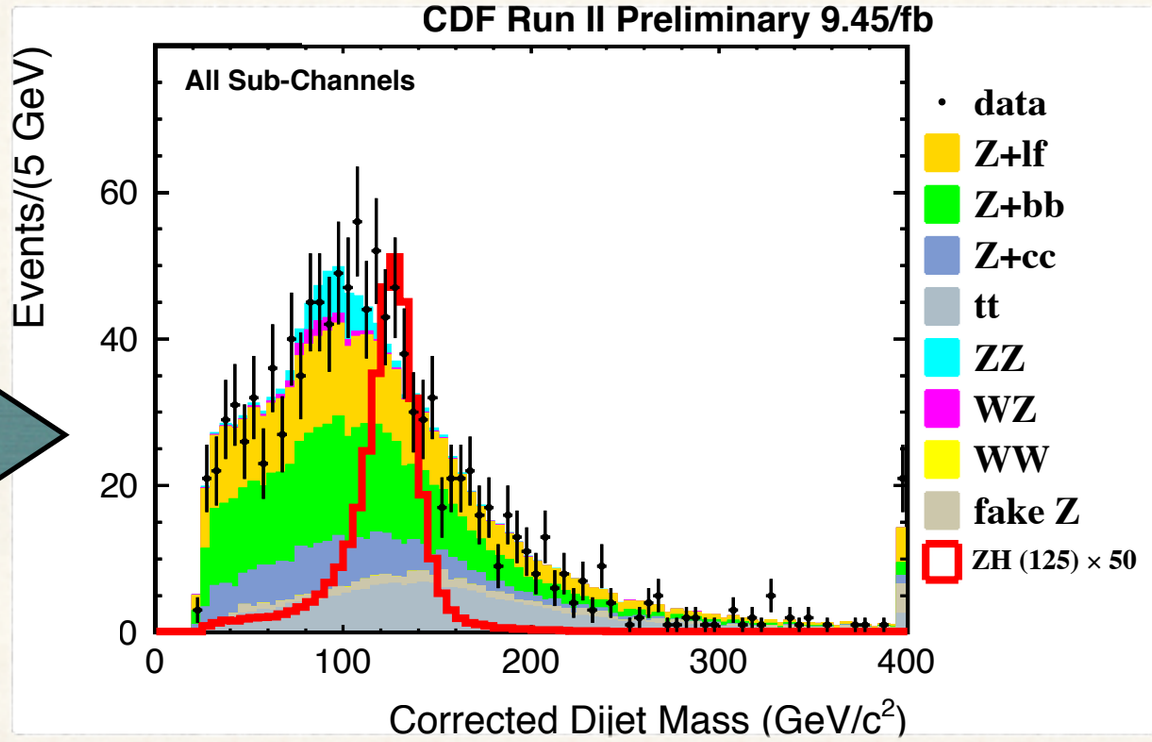


* work in progress

Neural Network Jet Energy Corrections

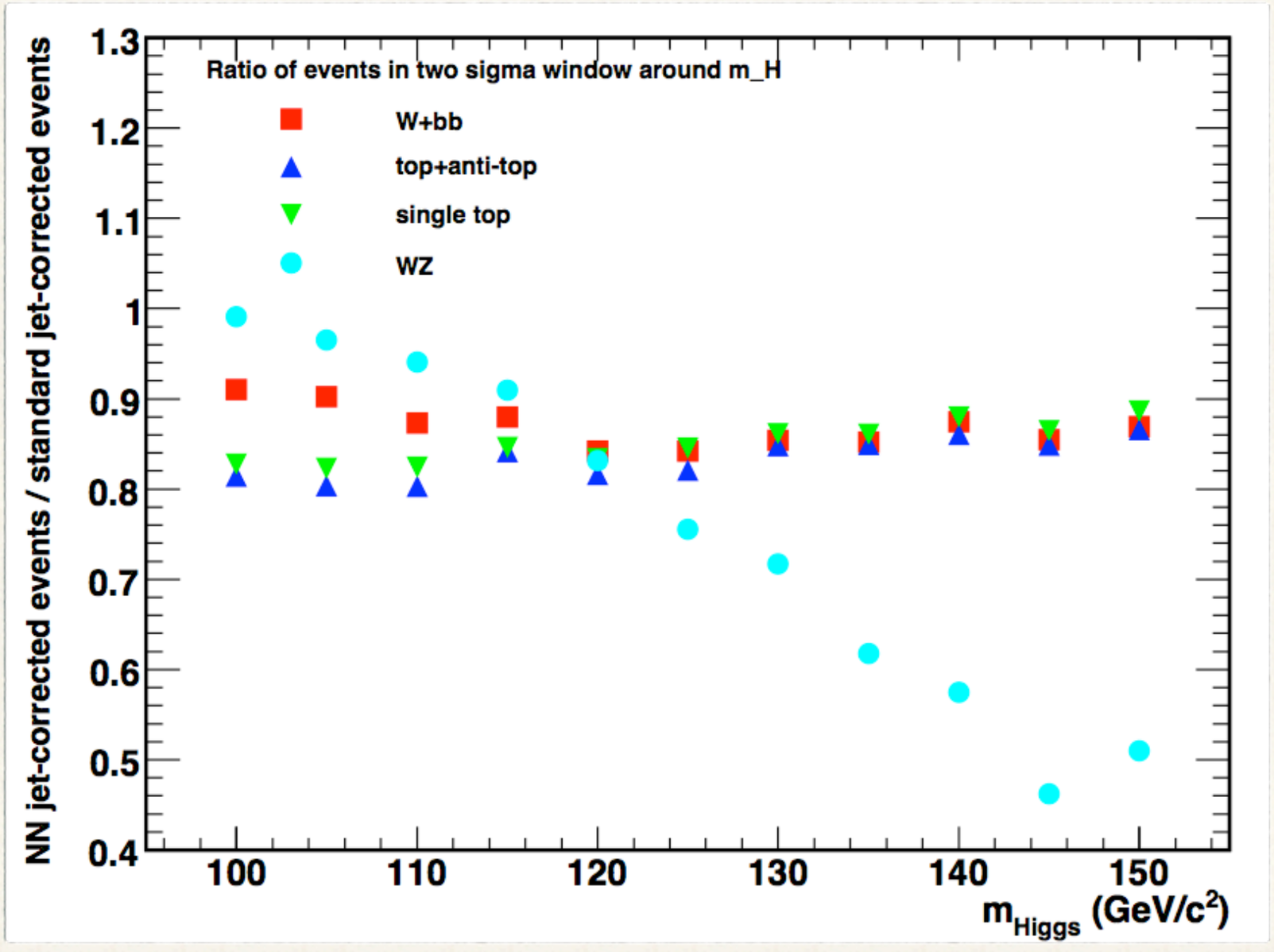
- Effect on the background shape [H Z(e⁻e⁺ or μ⁻μ⁺)]





Neural Network Jet Energy Corrections

- Effect on the background [$H\,W(e^{\pm}/\mu^{\pm} + \nu)$]



- In a 2 σ window around mean M_H :

-10% diboson
-11% W+bb
-15% top

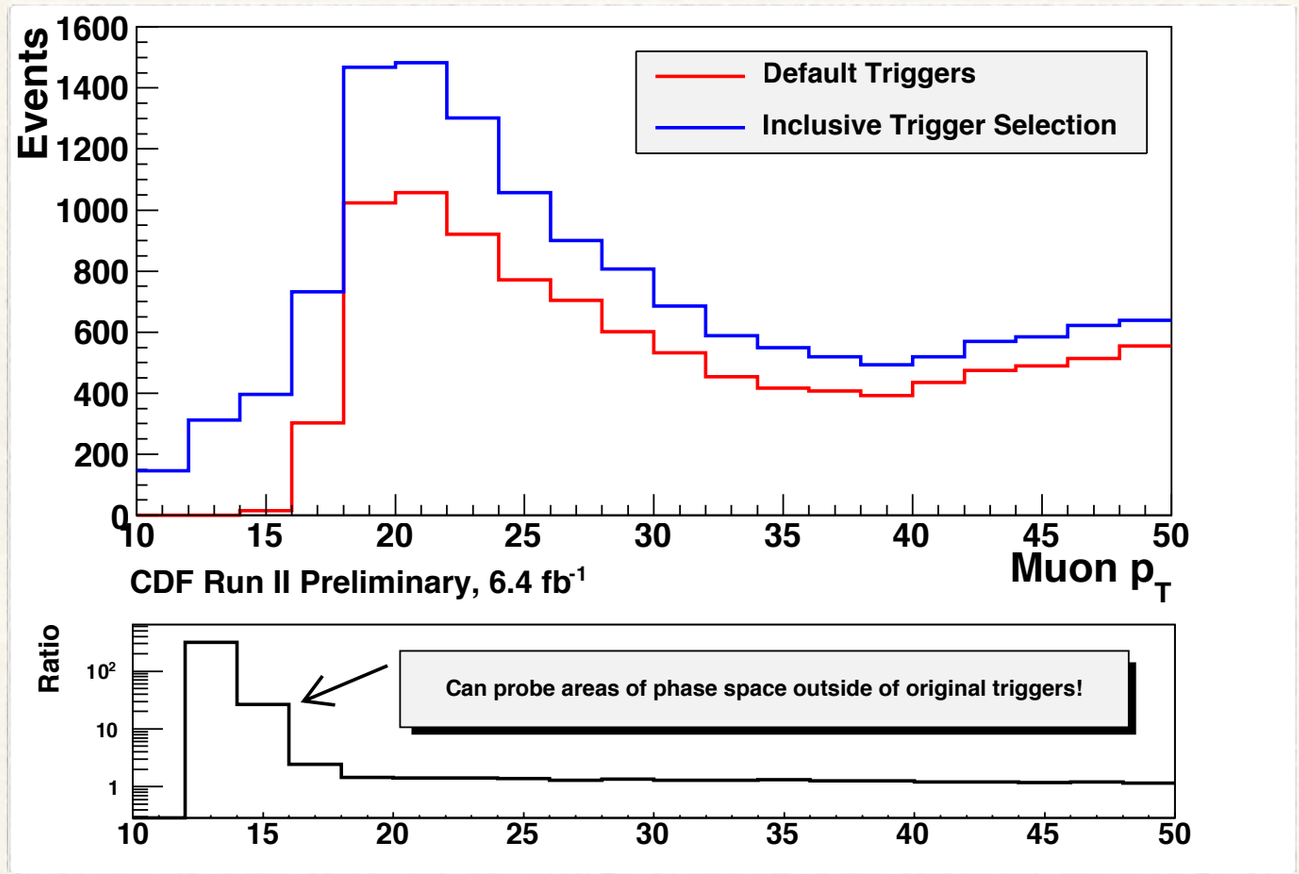
MultiVariate Trigger Emulation

- By utilizing NN's for trigger response emulation, we are able effectively incorporate the combined response of multiple trigger selections in our data model

- Allows searches to combine several trigger selections

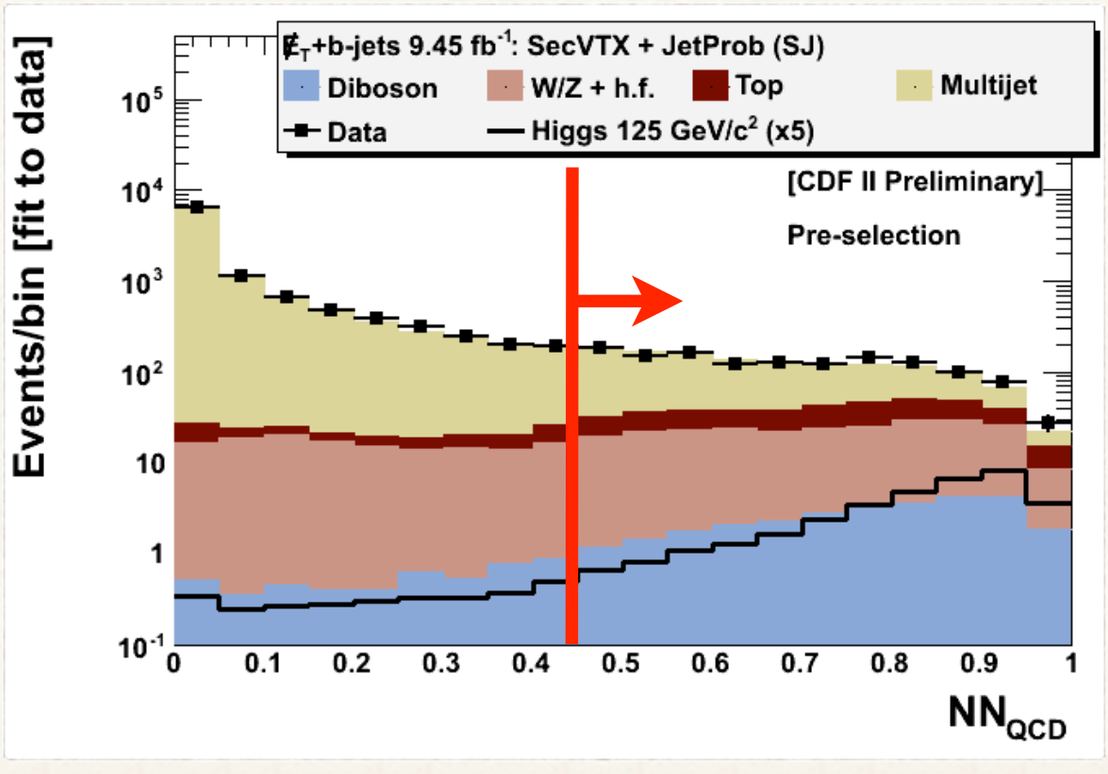
- Allows analysis-level cuts to be closer to the cuts at trigger level

- Gain signal acceptance including lower P_T leptons and events with less Missing E_T



0 leptons: VH→νν̄bb̄

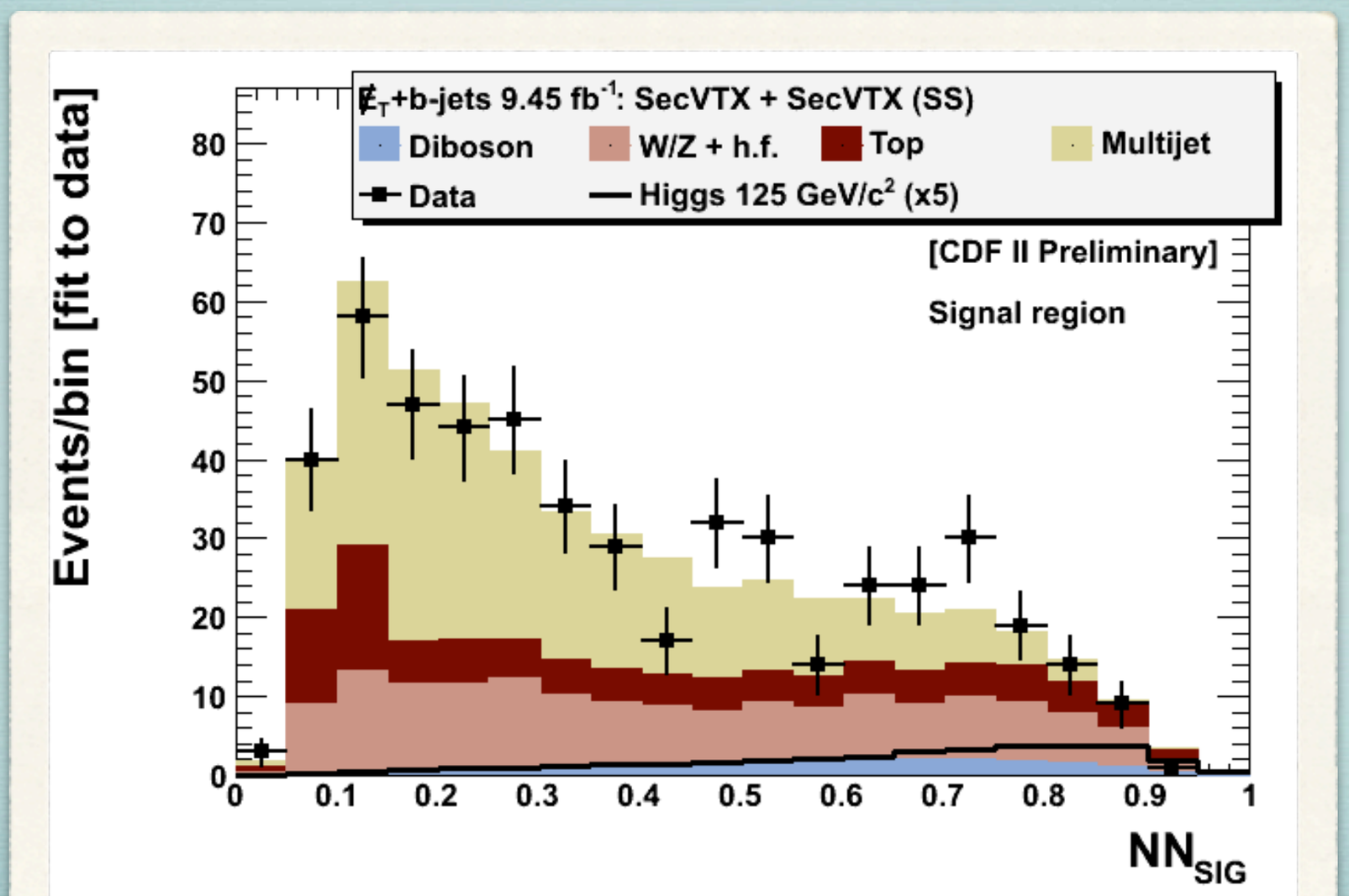
- Signal from Z→νν̄ and W with a missed lepton
- Require energetic jets, significant missing transverse energy, and good separation between jets and missing E_T
- Multivariate technique to reduce multijet background :



- Multijet background is largely instrumental with large systematic uncertainties (limits search sensitivity)
- NN cut rejects ~90% of multijet background
- Retains ~84% of Higgs Signal

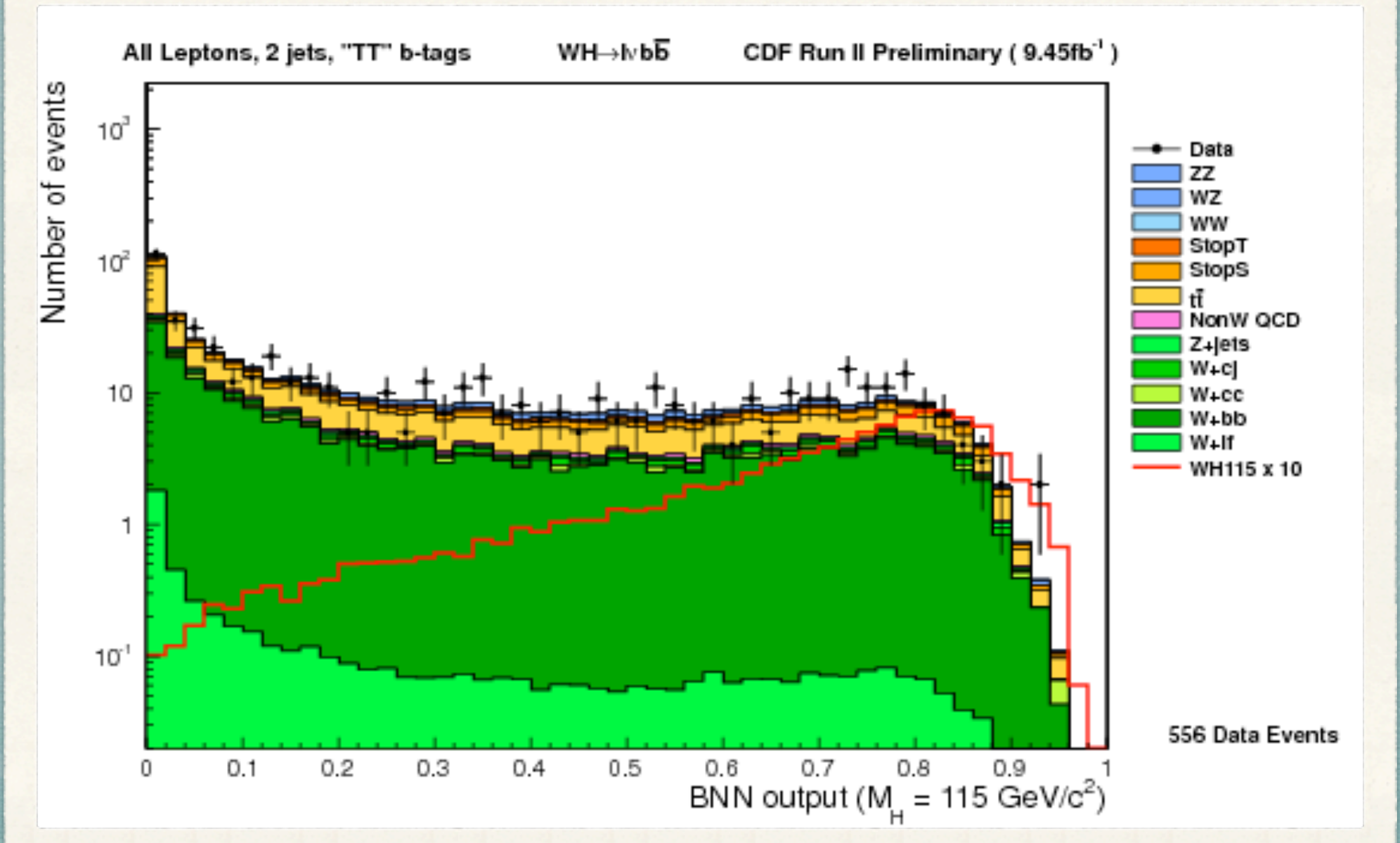
0 leptons: VH→ννbb

- Events surviving multijet rejection are processed by a second multivariate algorithm which aims to increase signal isolation



l lepton: WH→ ℓ νbb

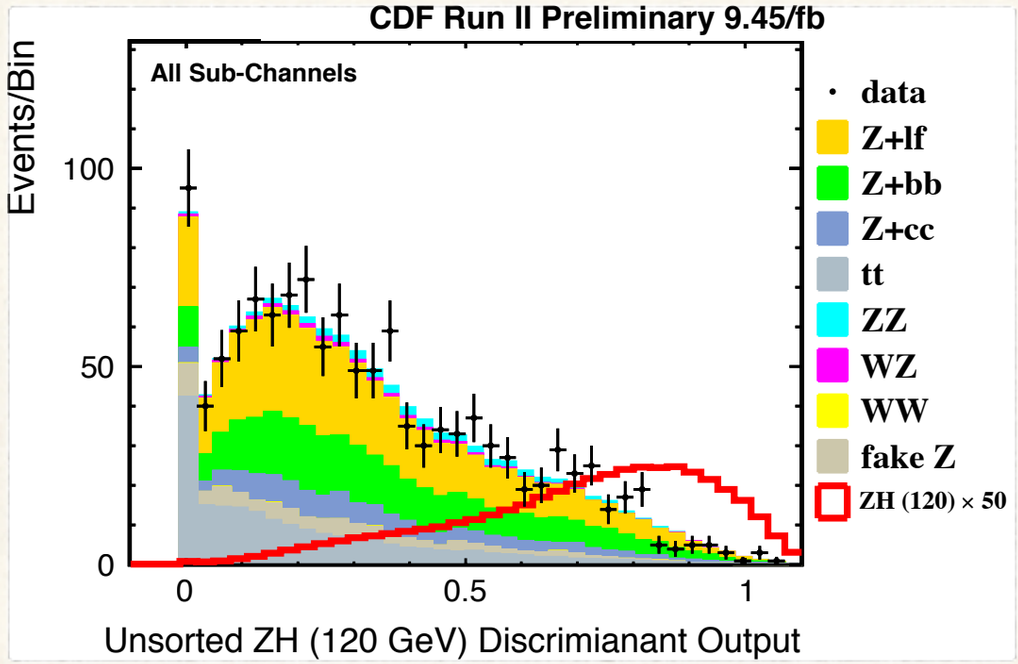
- Events contain exactly one lepton & significant missing E_T



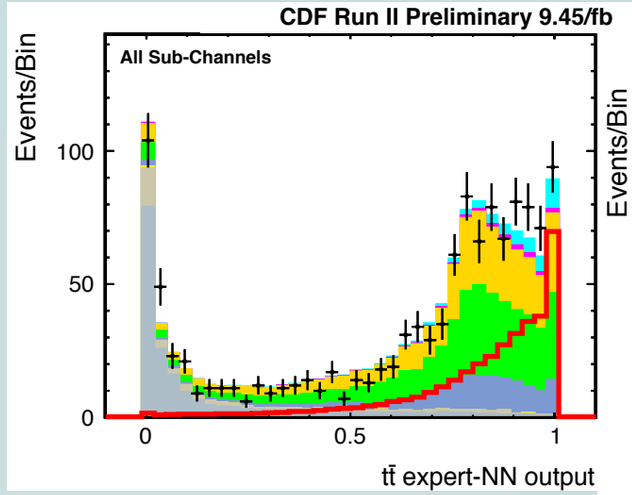
2 leptons: ZH→ $\ell^+\ell^-$ bb

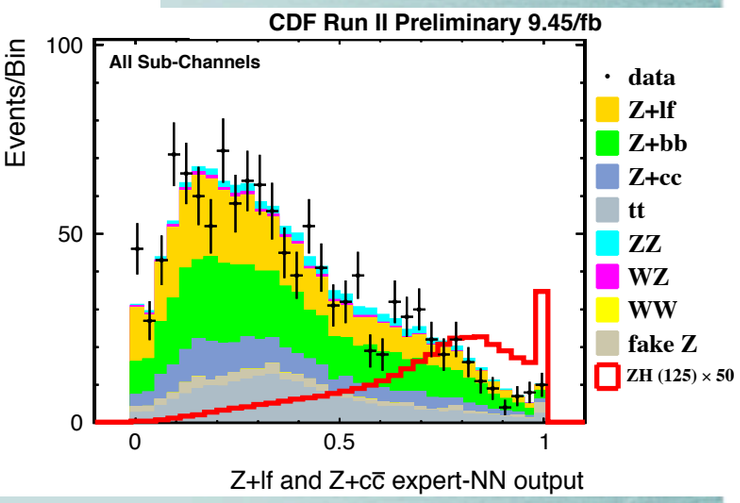
- Utilizes series of Neural Nets targeting tt, Z+lf/ charm, and diboson backgrounds separately

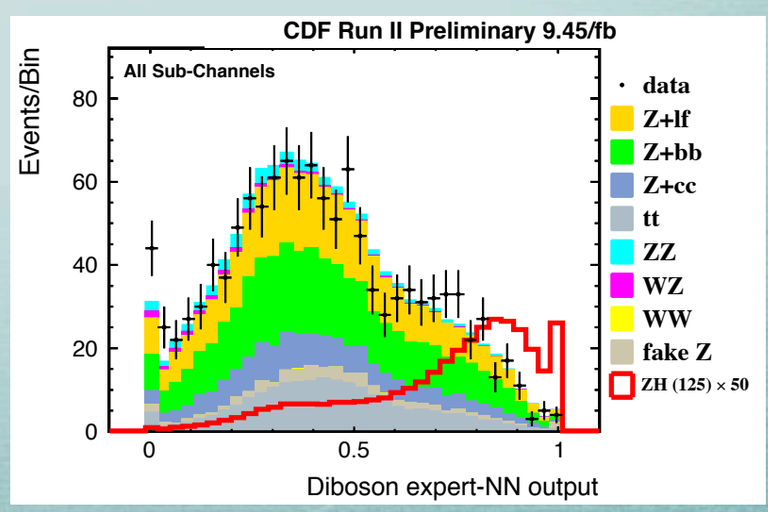
ZH vs Mix of Backgrounds



Combined with Specialized "Expert" Discriminants

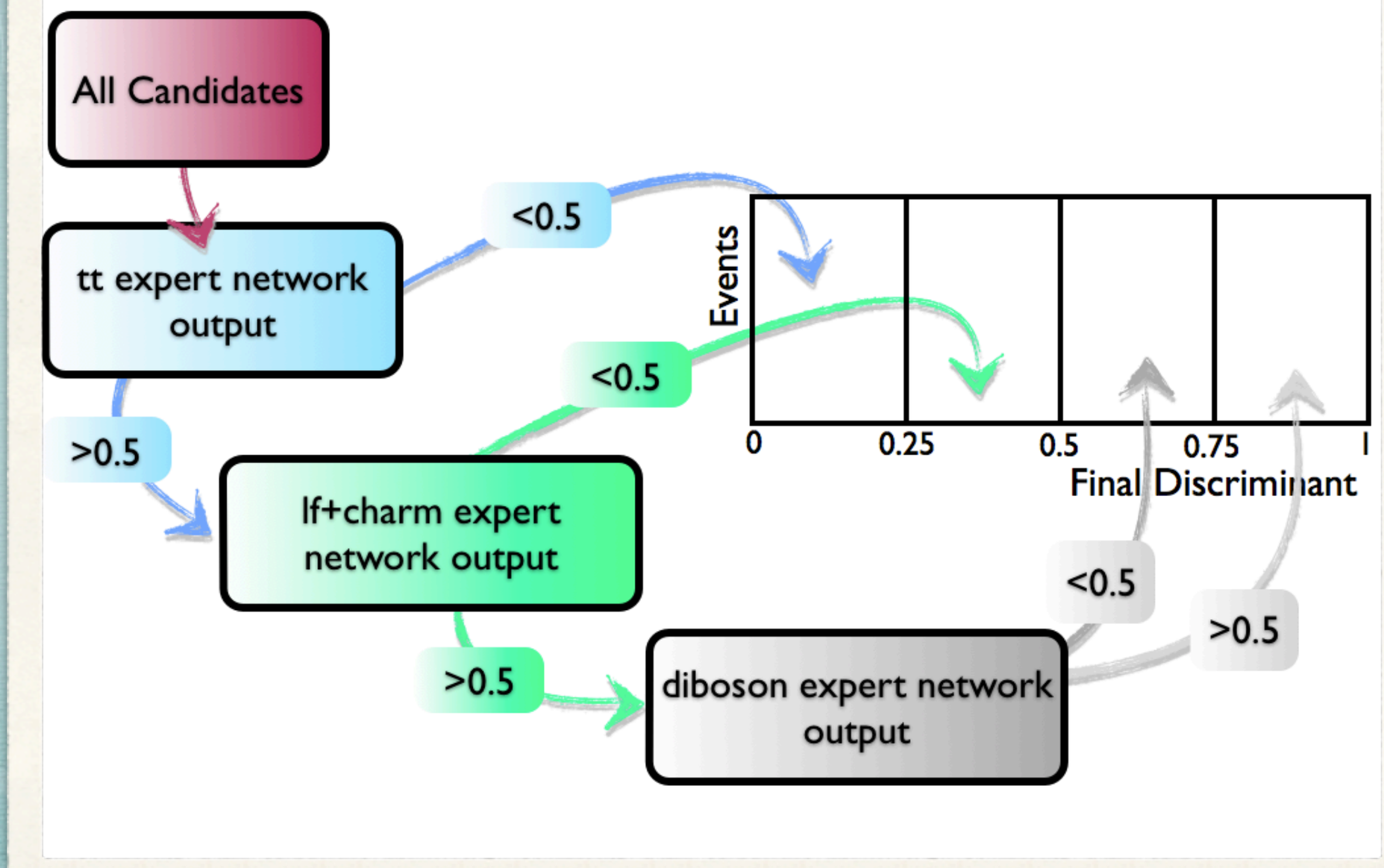






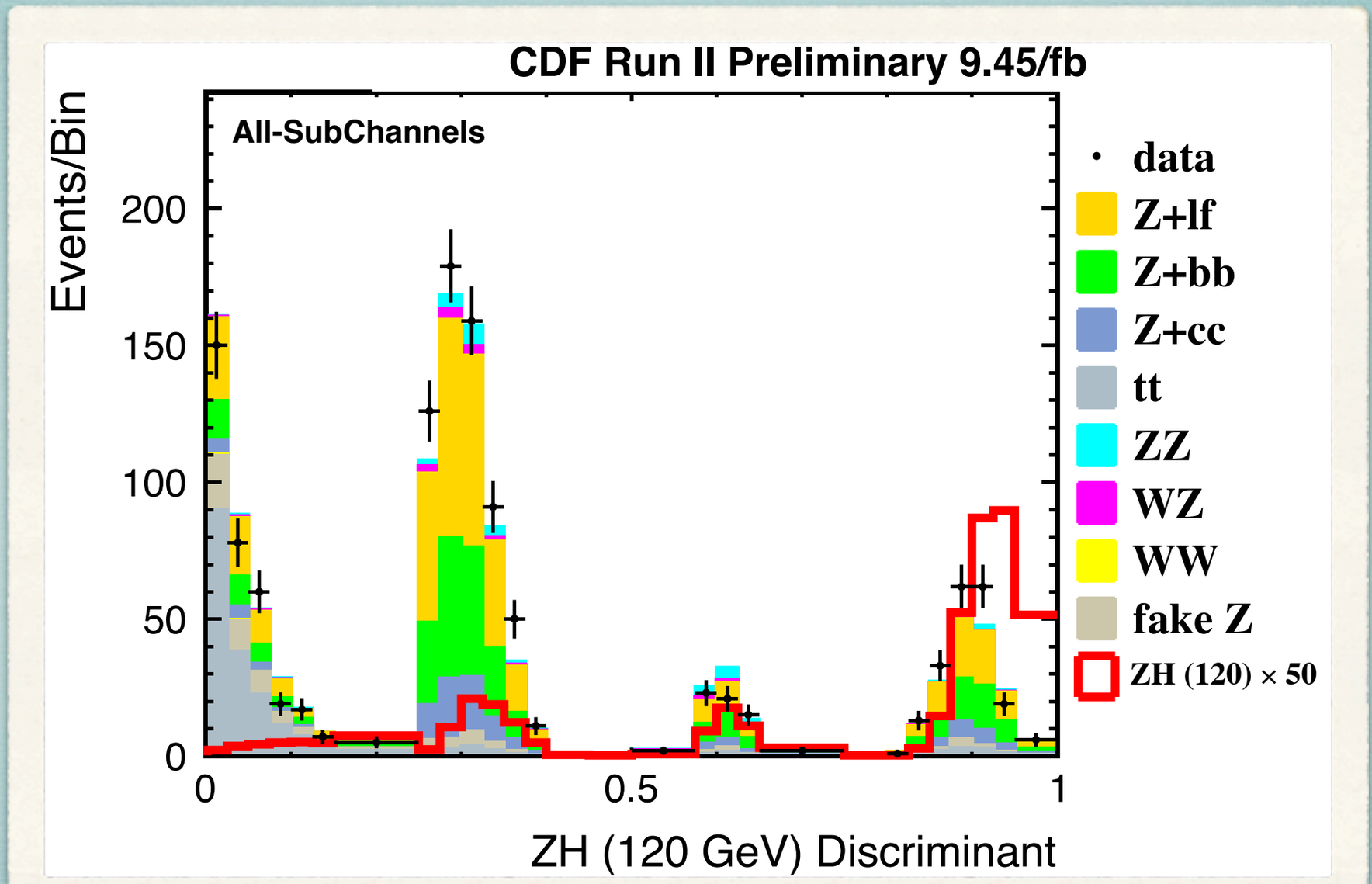
2 leptons: ZH→ $\ell^+\ell^-$ bb

- Sort events based on expert discriminant outputs



2 leptons: $ZH \rightarrow \ell^+ \ell^- bb$

- Final sorted discriminant :



- Expert sorting improves sensitivity by ~10%

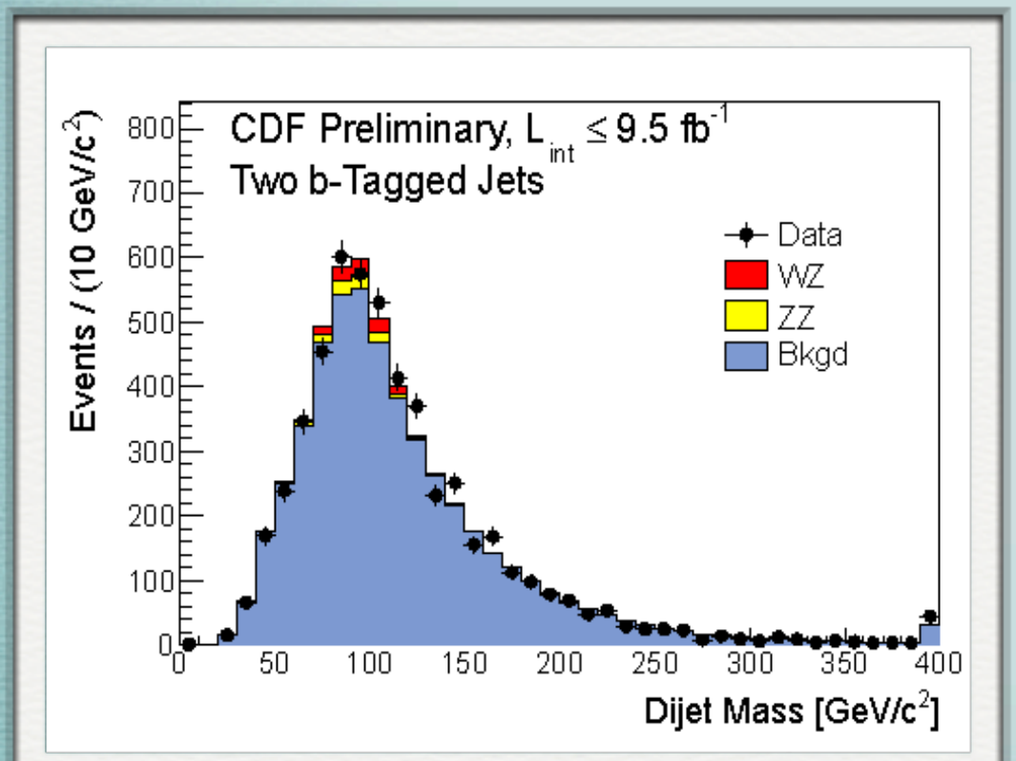
Validation in Dibosons

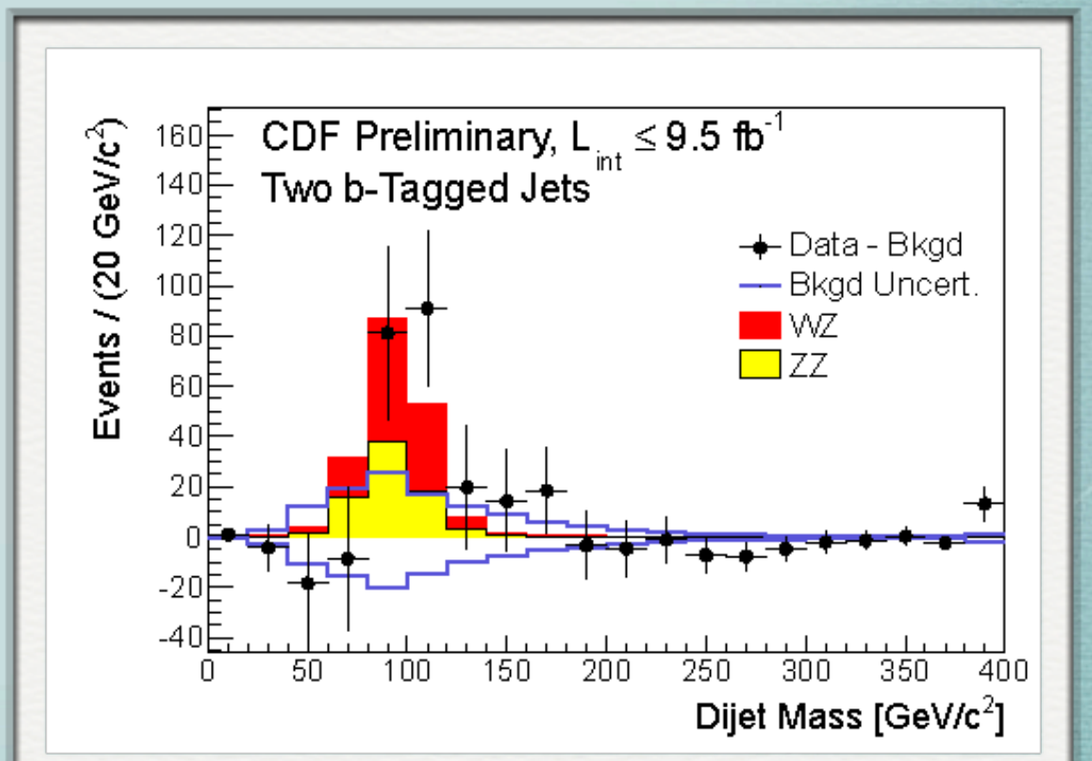
- CDF H→bb searches have grown in complexity over the years

  (~40 neural networks in ZH→llbb analysis alone!)

- Important to validate analysis methods

- With sensitivity approaching SM Higgs rate we should be able to see WZ and ZZ (Z→bb)



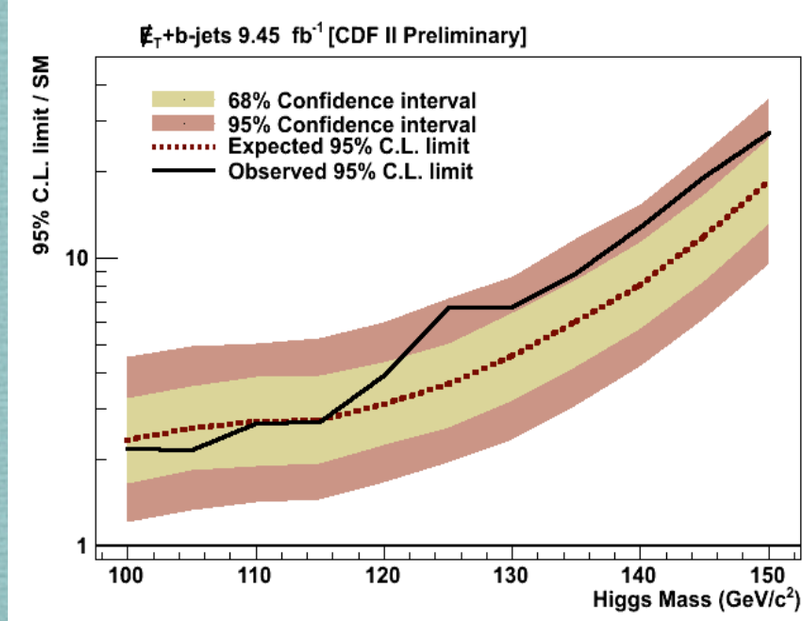


- Measured cross section (ZZ+WZ) in close agreement with SM

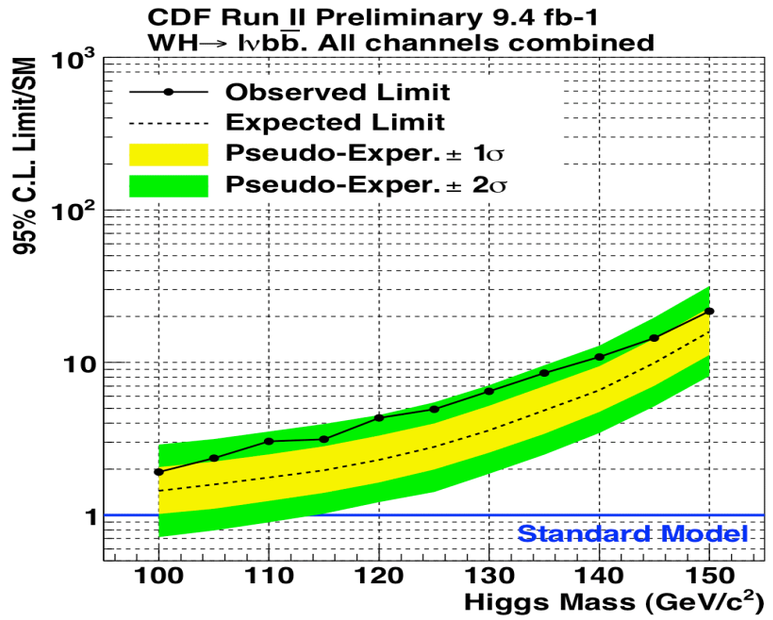
Results From Individual Channels

- Extract 95% CL upper limits on Higgs production rate using a Bayesian technique
- Systematics reduce sensitivity by ~15-20%

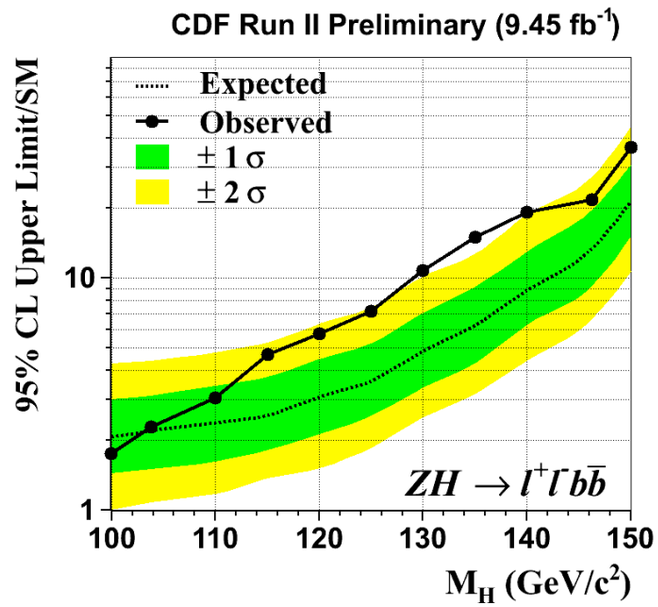
H Z(ν ν)



H W(e±/μ± + ν)



H Z(e-e+ & μ-μ+)



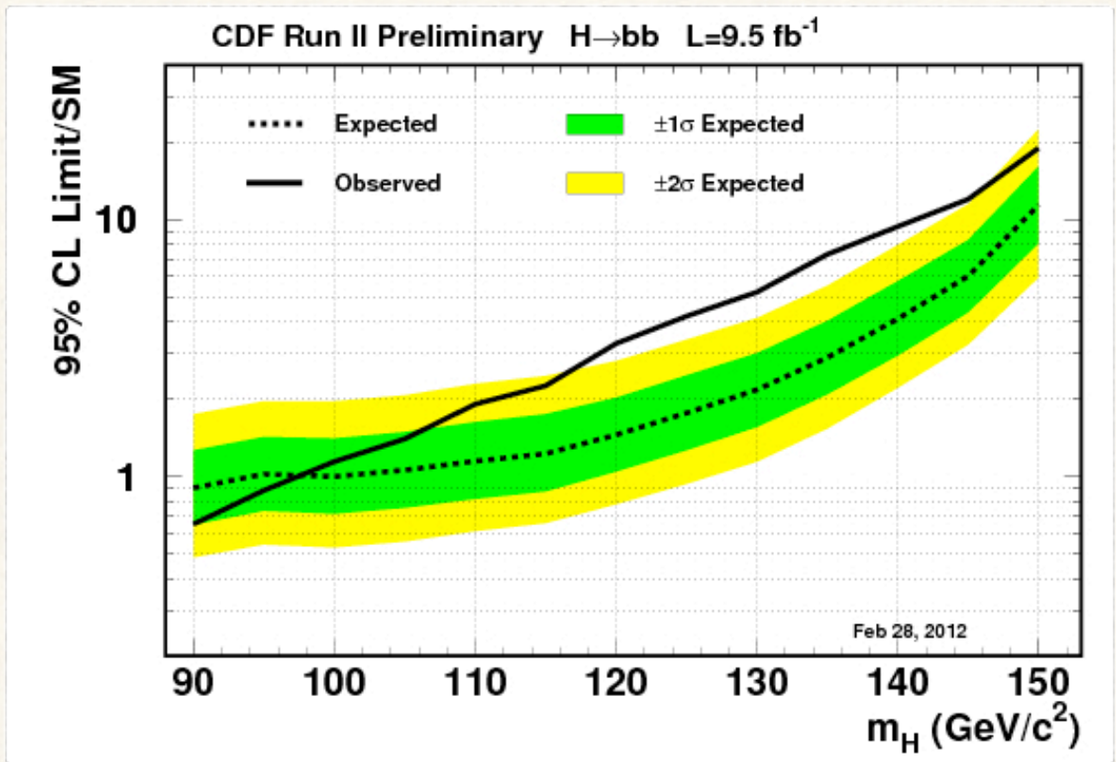
- Expected sensitivity @ 115 GeV :

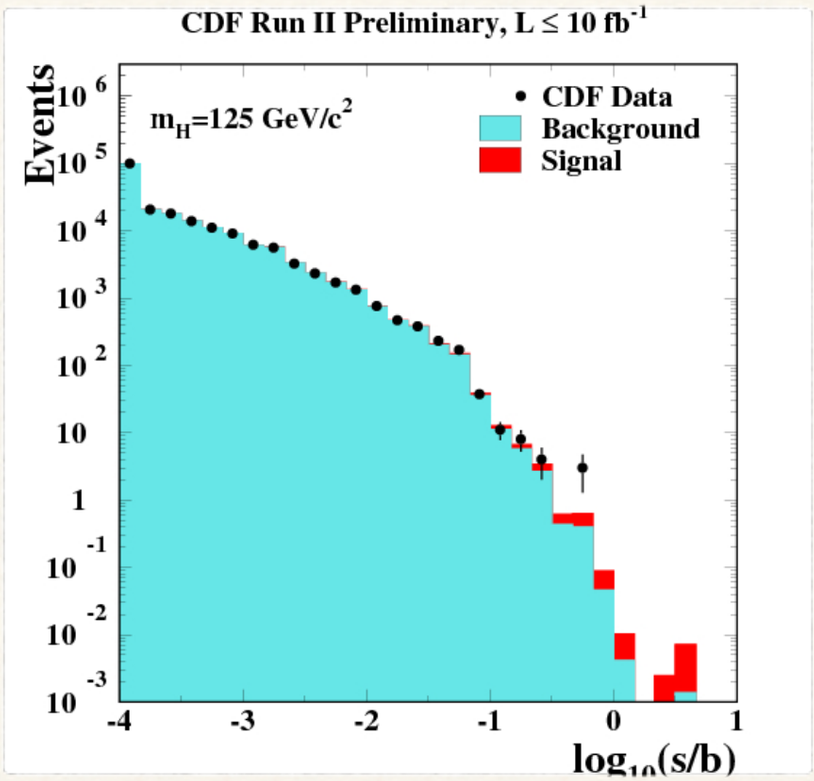
H W(e±/μ± + ν)	H Z(e-e+ & μ-μ+)	H Z(ν ν)
2.0 x SM	2.6 x SM	2.7 x SM

- Excesses ~1-2σ in each of the individual channels

CDF Combination

- 95% CL Upper limits on σ_{VH} X BR(H→bb)
- Includes proper correlation of systematics between sub-channels

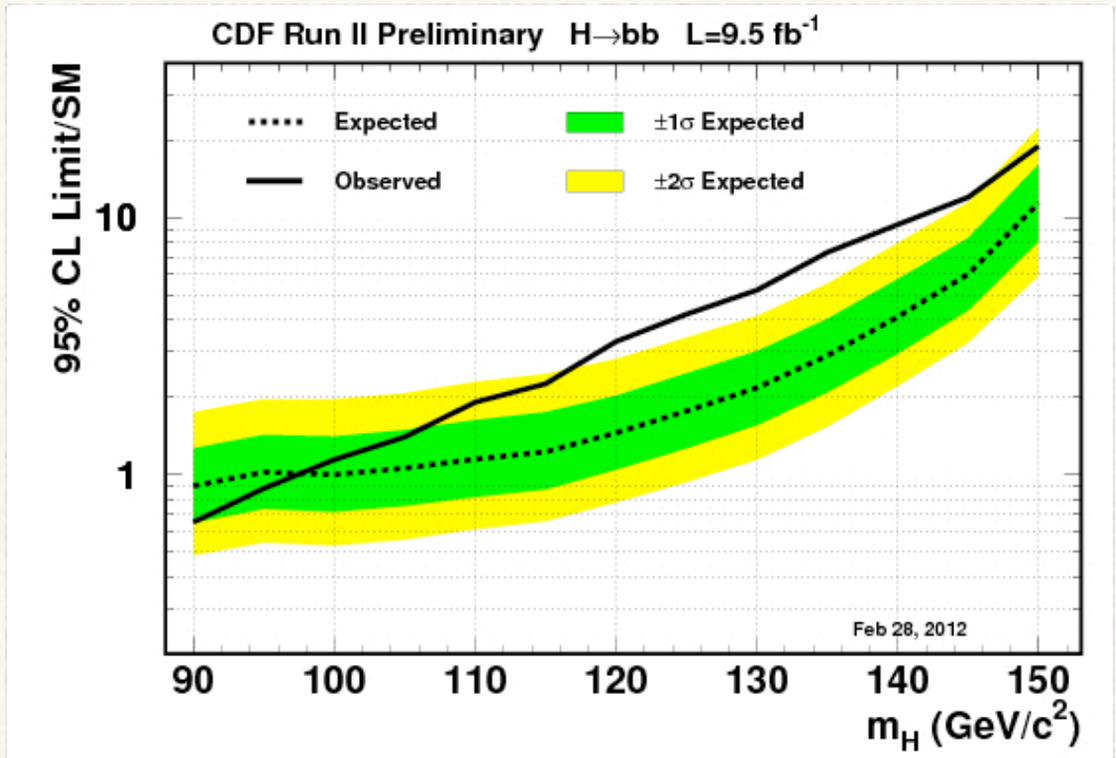




	115 GeV	125 GeV	135 GeV
Observed	2.25 x SM	2.89 x SM	2.58 x SM
Expected	1.16 x SM	1.39 x SM	1.45 x SM

CDF Combination

- 95% CL Upper limits on σ_{VH} X BR(H→bb)
- Includes proper correlation of systematics between sub-channels

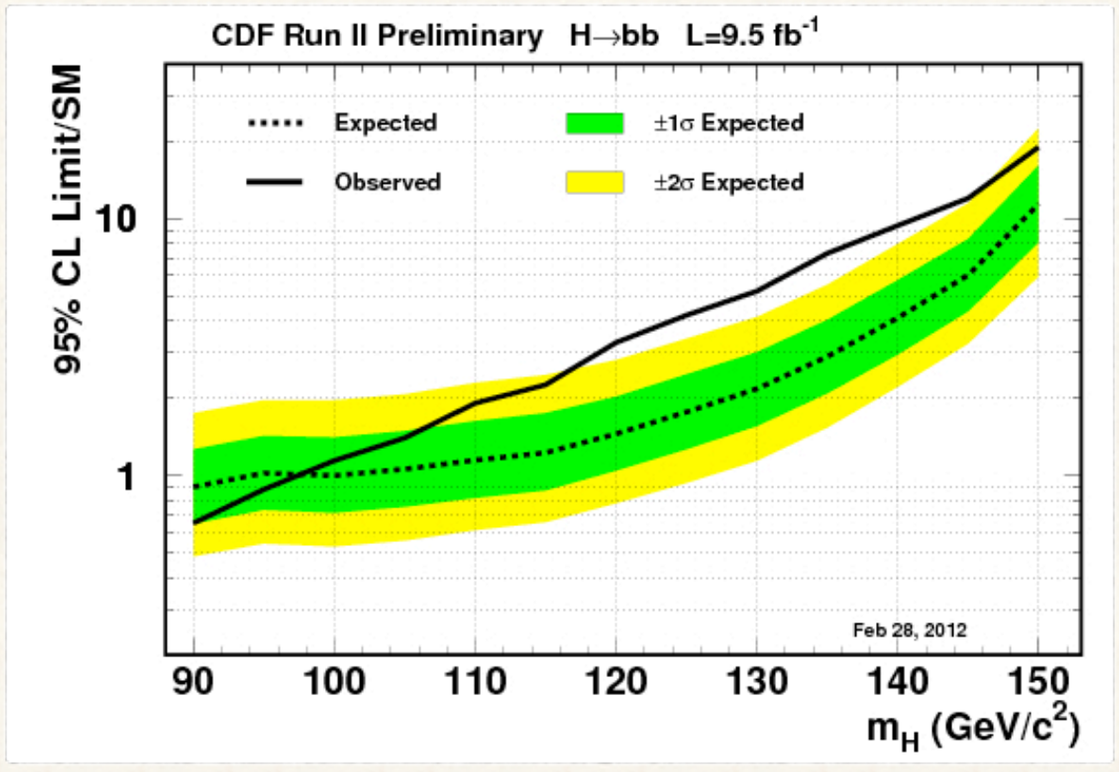


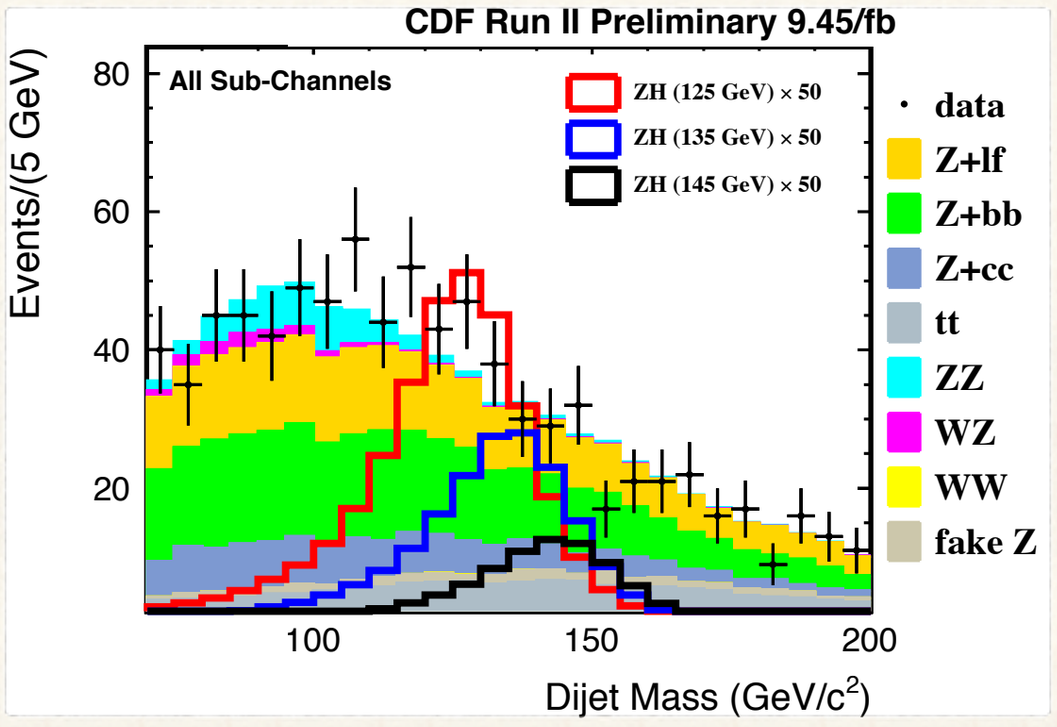
- 2.9 σ max local p-value at 135 GeV
- 2.7 σ max global p-value at 135 GeV after estimated LEE of 2

	115 GeV	125 GeV	135 GeV
Observed	**2.25 x SM**	**2.89 x SM**	**2.58 x SM**
Expected	**1.16 x SM**	**1.39 x SM**	**1.45 x SM**

CDF Combination

- 95% CL Upper limits on σ_{VH} X BR(H→bb)
- Includes proper correlation of systematics between sub-channels

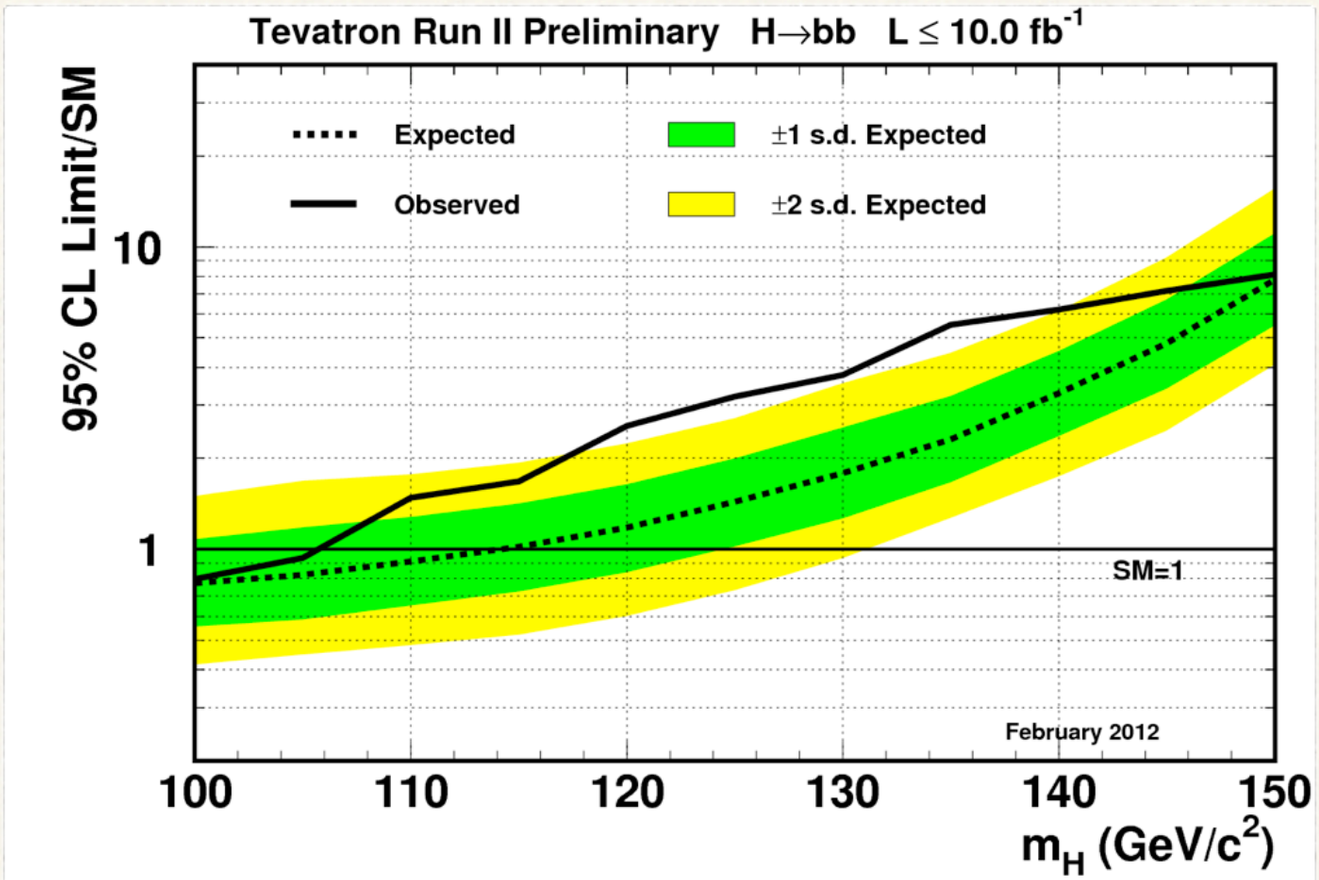




	115 GeV	125 GeV	135 GeV
Observed	2.25 x SM	2.89 x SM	2.58 x SM
Expected	1.16 x SM	1.39 x SM	1.45 x SM

Tevatron Combination

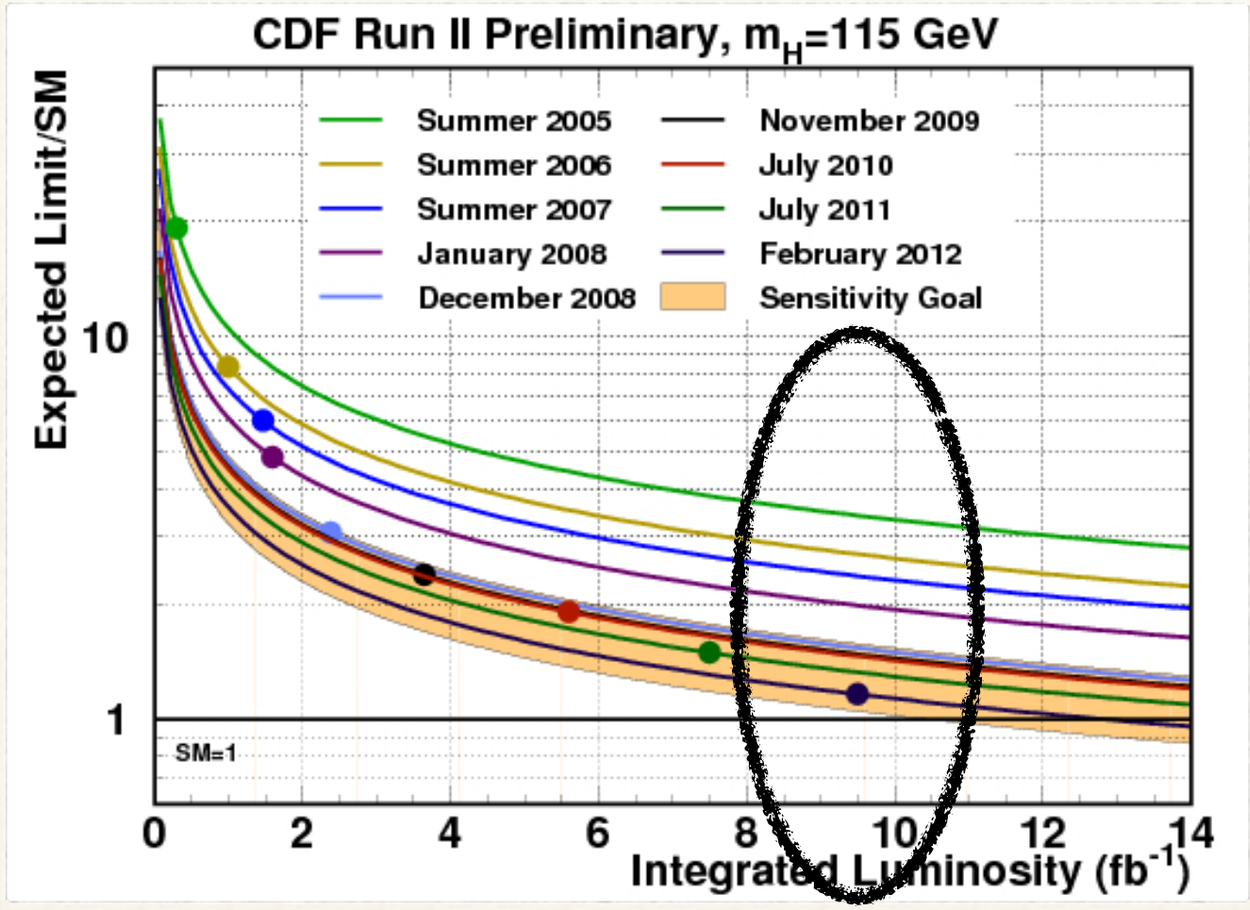
- Combined Results from CDF and D0



- 2.8 σ max local p-value
- 2.6 σ max global p-value

Conclusions

- Major effort by CDF collaboration to maximize sensitivity
- Gains from 'planned improvements' have materialized as advertised



channel	plans for summer 2012
$WH \to l^{\pm}\nu\, bb$	minor tweaks
$ZH \to l^{+}l^{-}bb$	minor tweaks
$VH \to \nu\nu bb$	improved M_{jj} resolution incorporation of new b-tagger

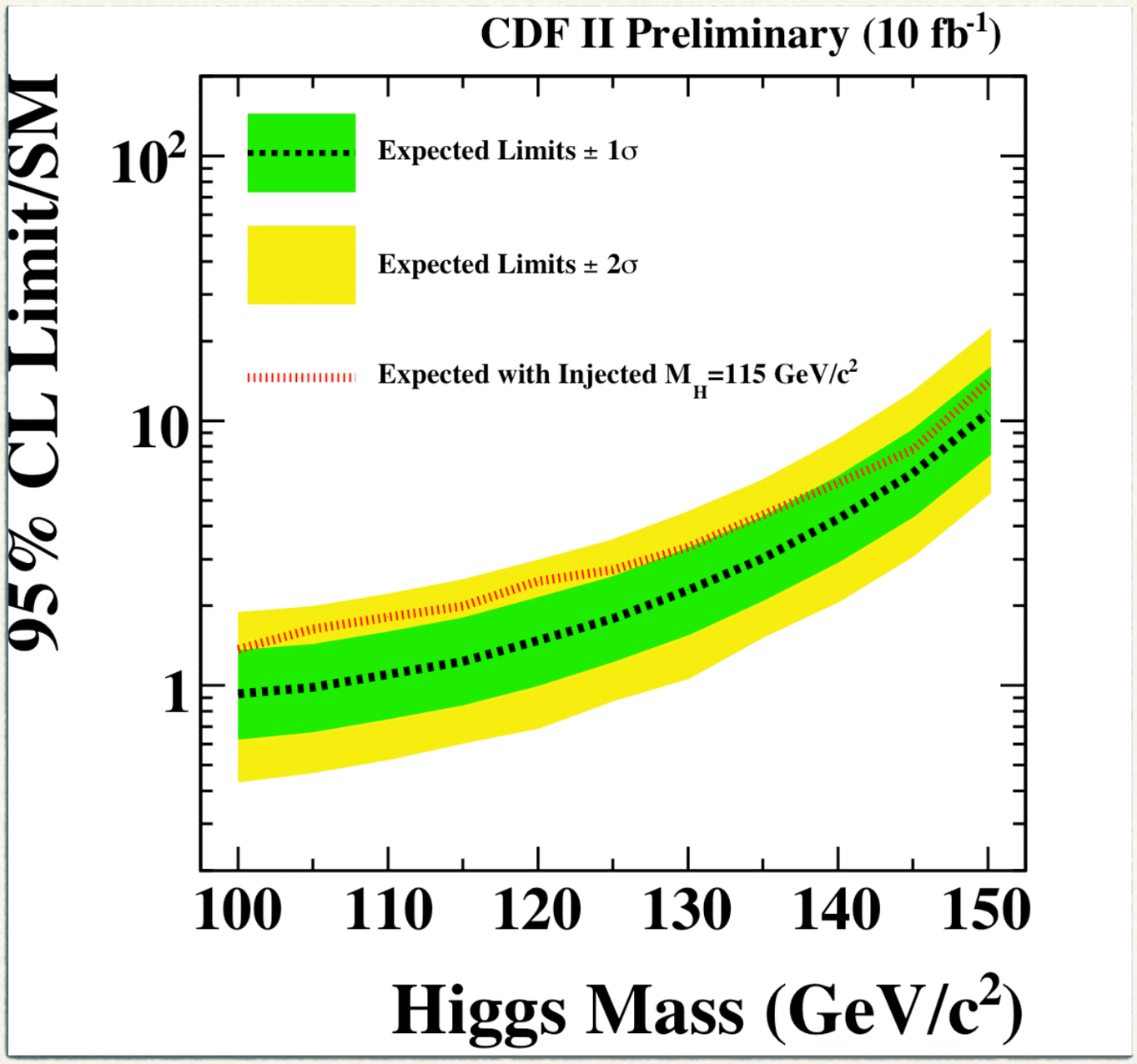
- Tevatron (CDF+D0) update planned for summer 2012
- Thanks!

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

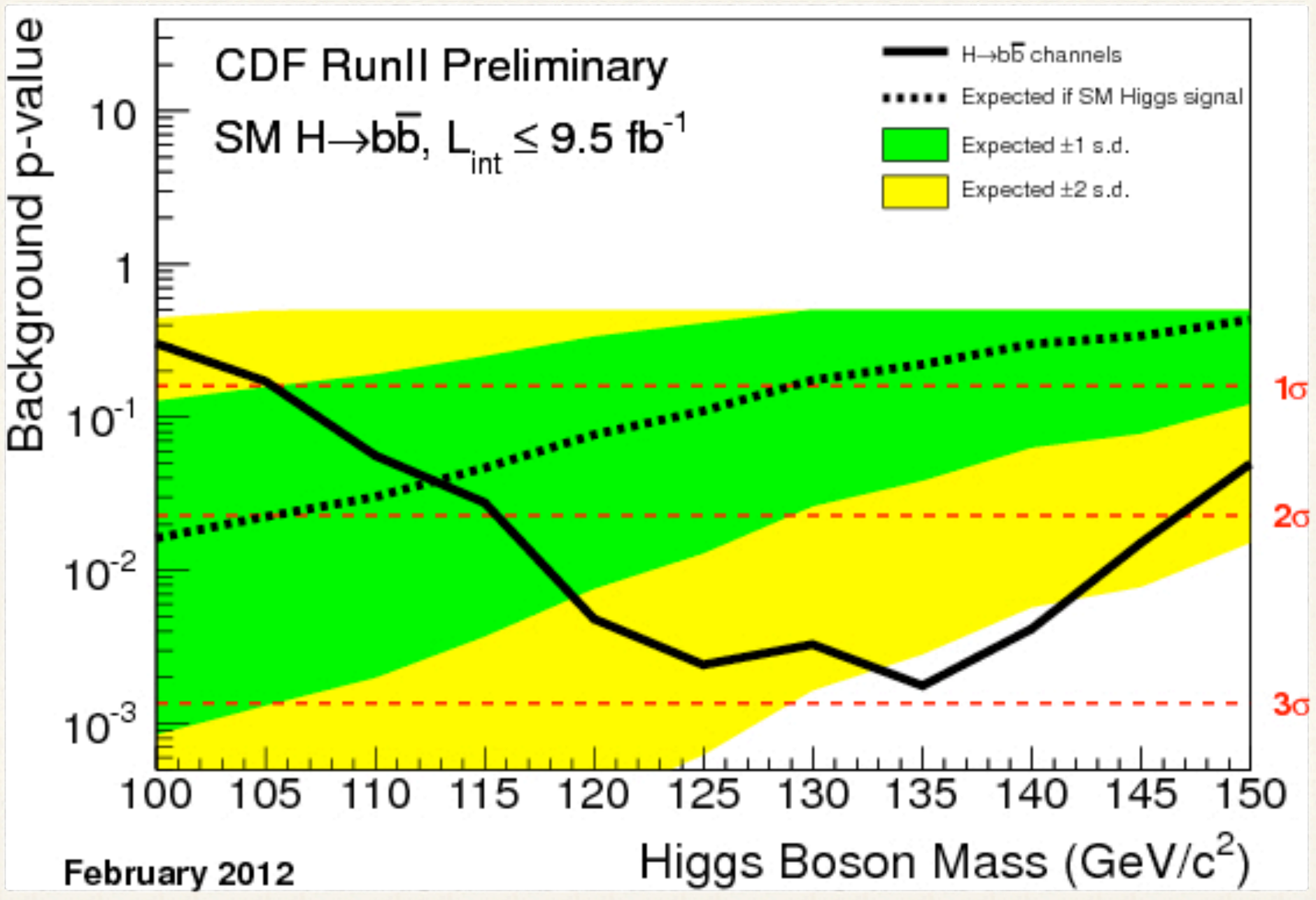
http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_12/index.html

Backup

Signal Injection Test

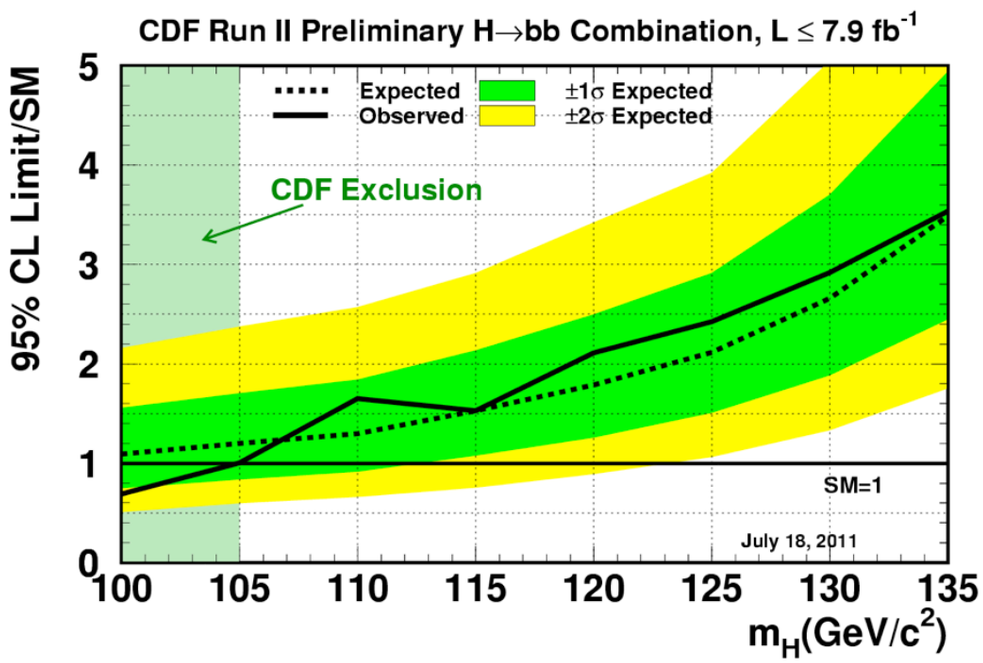


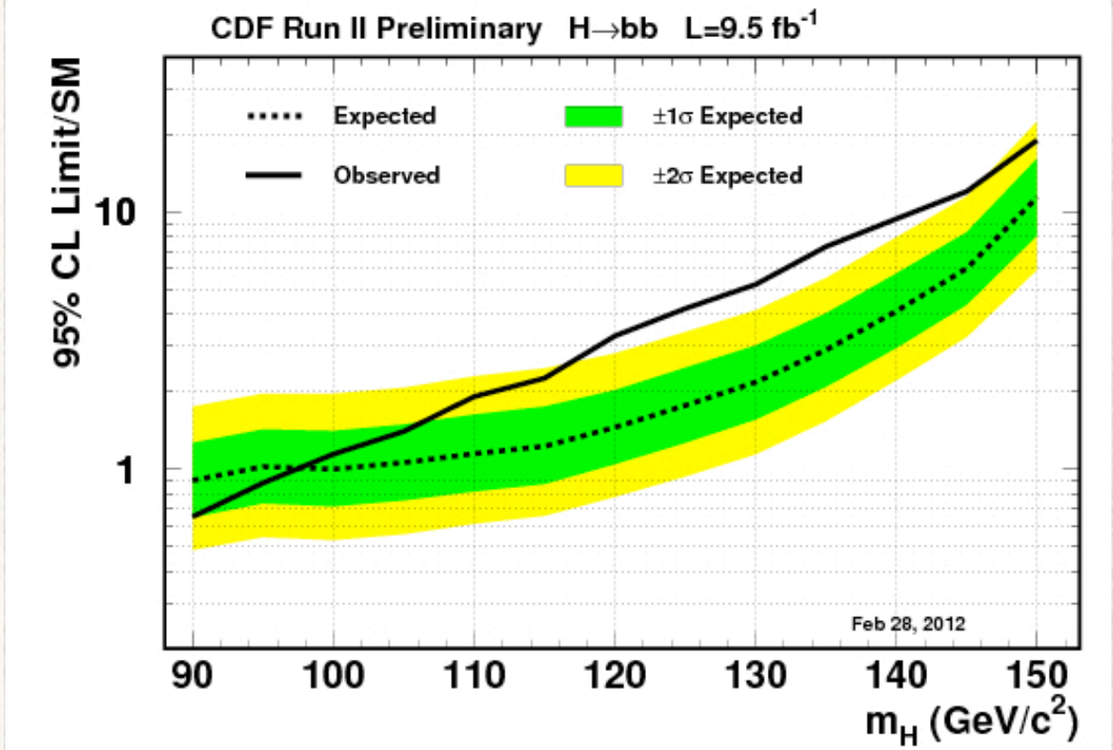
- limits from a pseudo-dataset generated which includes background + a 115 GeV Higgs at SM rate


CDF RunII Preliminary
SM H→bb̄, L_int ≤ 9.5 fb^-1
H→bb̄ channels
Expected if SM Higgs signal
Expected ±1 s.d.
Expected ±2 s.d.
Background p-value
10
1
10^-1
10^-2
10^-3
1σ
2σ
3σ
100 105 110 115 120 125 130 135 140 145 150
Higgs Boson Mass (GeV/c^2)
February 2012

Comparison to Summer 2011

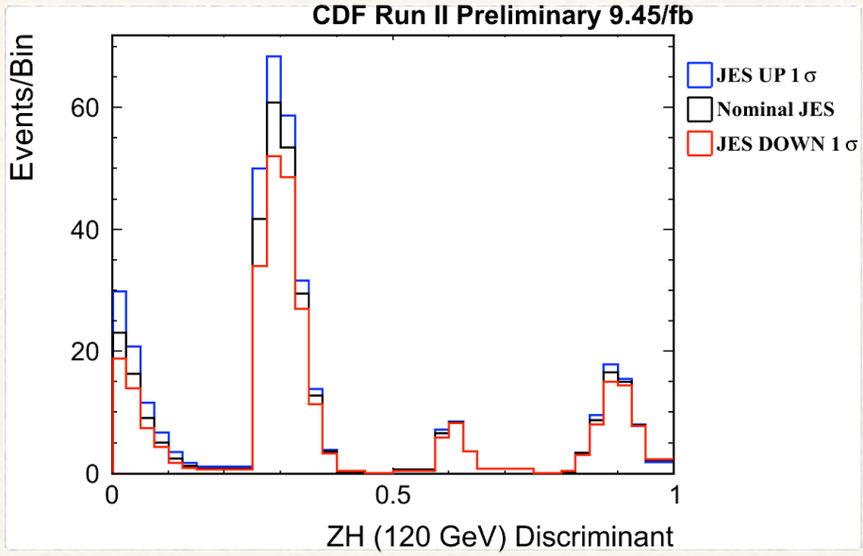
- Major changes to search techniques between July 2011 and February 2012





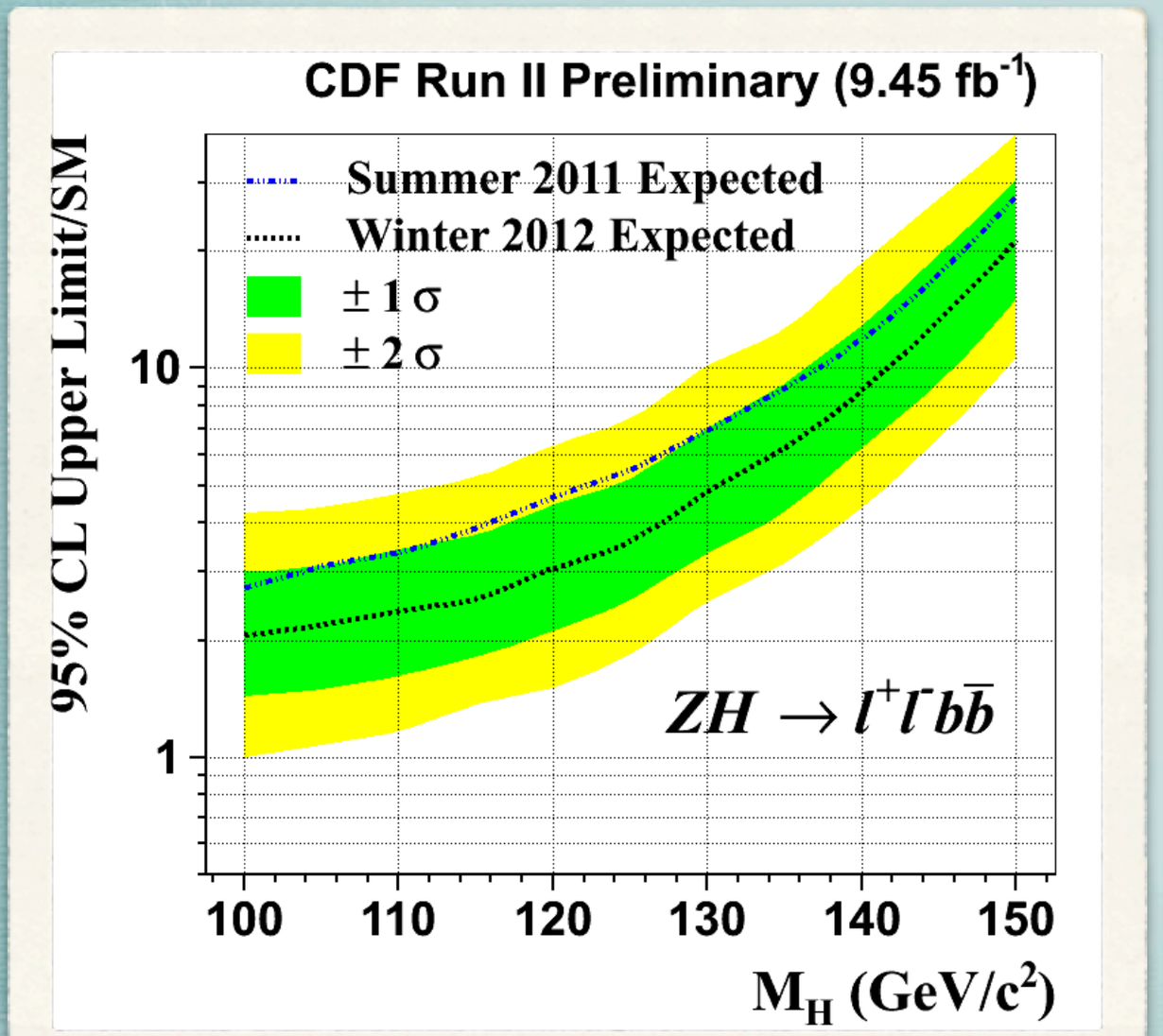
Systematics

Systematic	Effect	Affected Samples
Luminosity $\sigma_{inel}(p\bar{p})$	± 3.8%	all simulated
Luminosity Monitor	± 4.4%	all simulated
Lepton ID Efficiency	± 1%	all simulated
Lepton Energy Scale	± 1.5%	all simulated
Mis-reconstructed $Z \to l^+l^-$ Rate	± 50% (electrons) ± 5% (muons)	Mis-reconstructed Z Model
udsg-jet tight mistag rate	± 19 to 40%	Z+lf samples
udsg-jet loose mistag rate	± 10 to 20%	Z+lf samples
Jet Energy Scale (JES)	on the order of ± 10% includes variation in shape as seen here.	Z+lf samples
tight b-tag rate	± 3.9 to 7.8%	$Z+c\bar{c}$,$Z+b\bar{b}$ $t\bar{t}$, diboson, ZH
loose b-tag rate	± 3.2 to 6.3%	$Z+c\bar{c}$, $Z+b\bar{b}$ $t\bar{t}$, diboson, ZH
$t\bar{t}$ cross section	± 10%	$t\bar{t}$
diboson cross section	± 6%	WW,WZ,ZZ
$Z+c\bar{c}$ and $Z+b\bar{b}$ cross section	± 40%	$Z+c\bar{c}$, $Z+b\bar{b}$
ZH cross section	± 5%	ZH
Amount of initial or final state radiation	± 1 to 15%	ZH
Trigger Efficiency	± 5% (muons) ± 1% (electrons)	all simulated



Comparison to Summer 2011

- Major changes to search techniques between July 2011 and February 2012

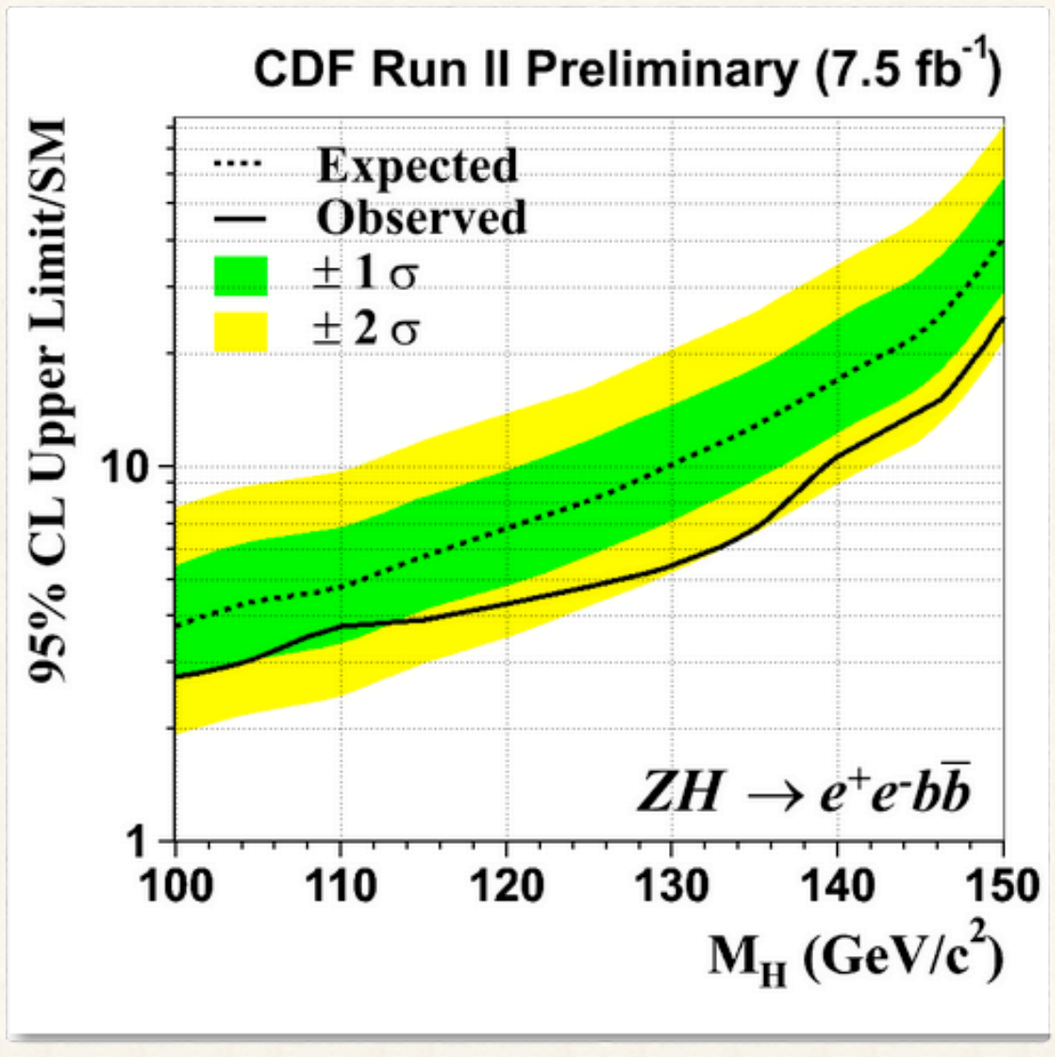


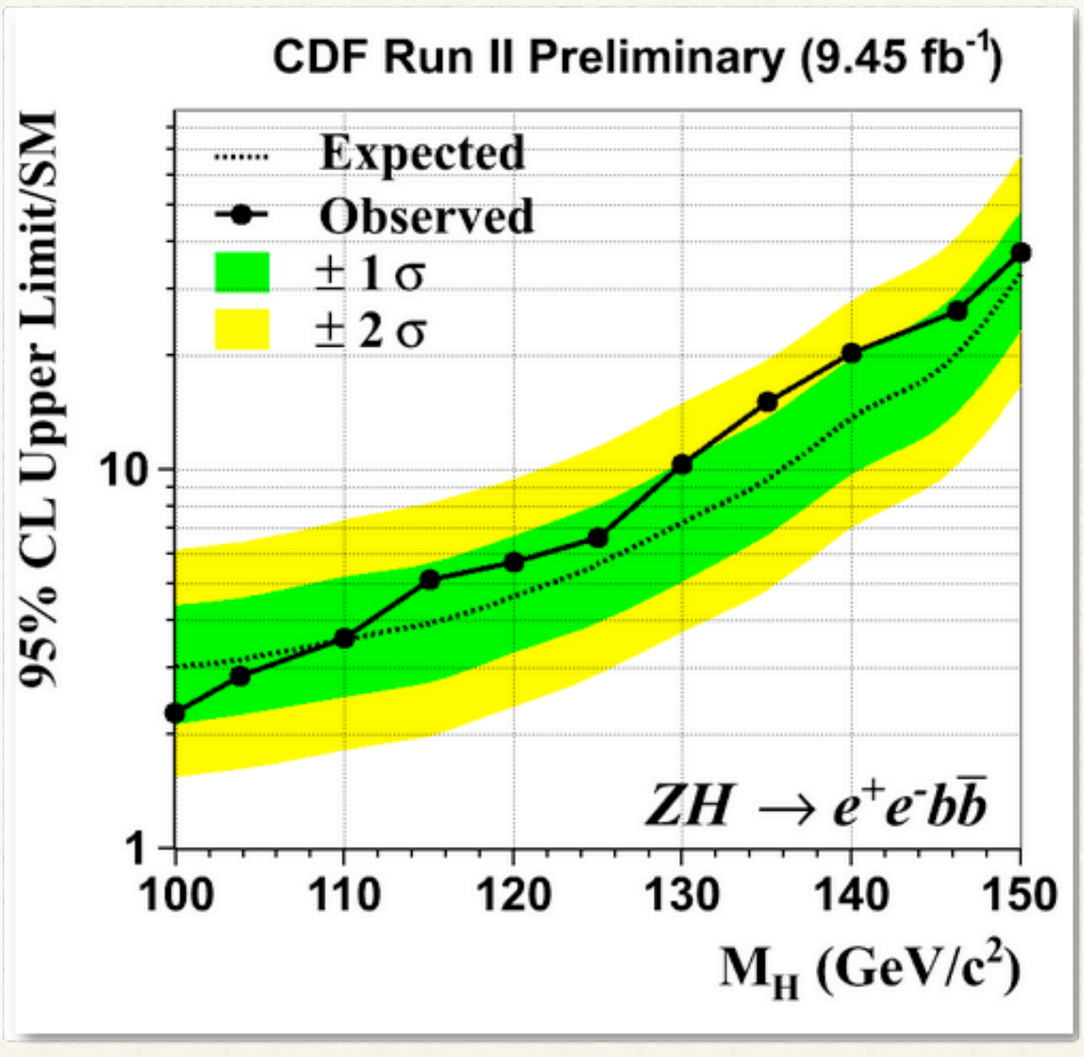
- Modified cuts
- New b-tagging
- New discriminants

- 53% of candidates new for winter 2012

Comparison to Summer 2011

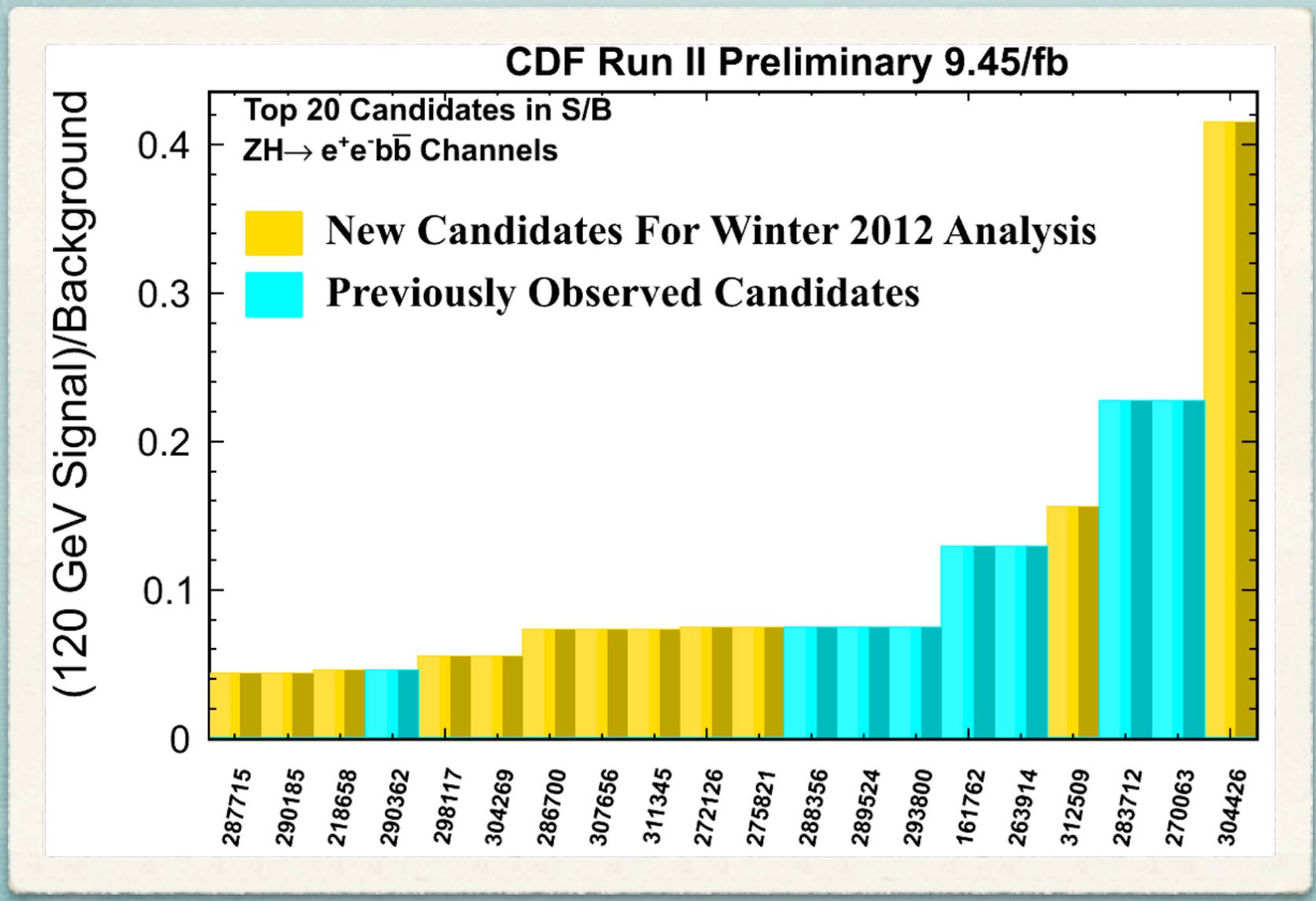
- Most channels showed enhancement of 0.5-1 sigma excesses
- Most dramatic change in ZH(ee)bb



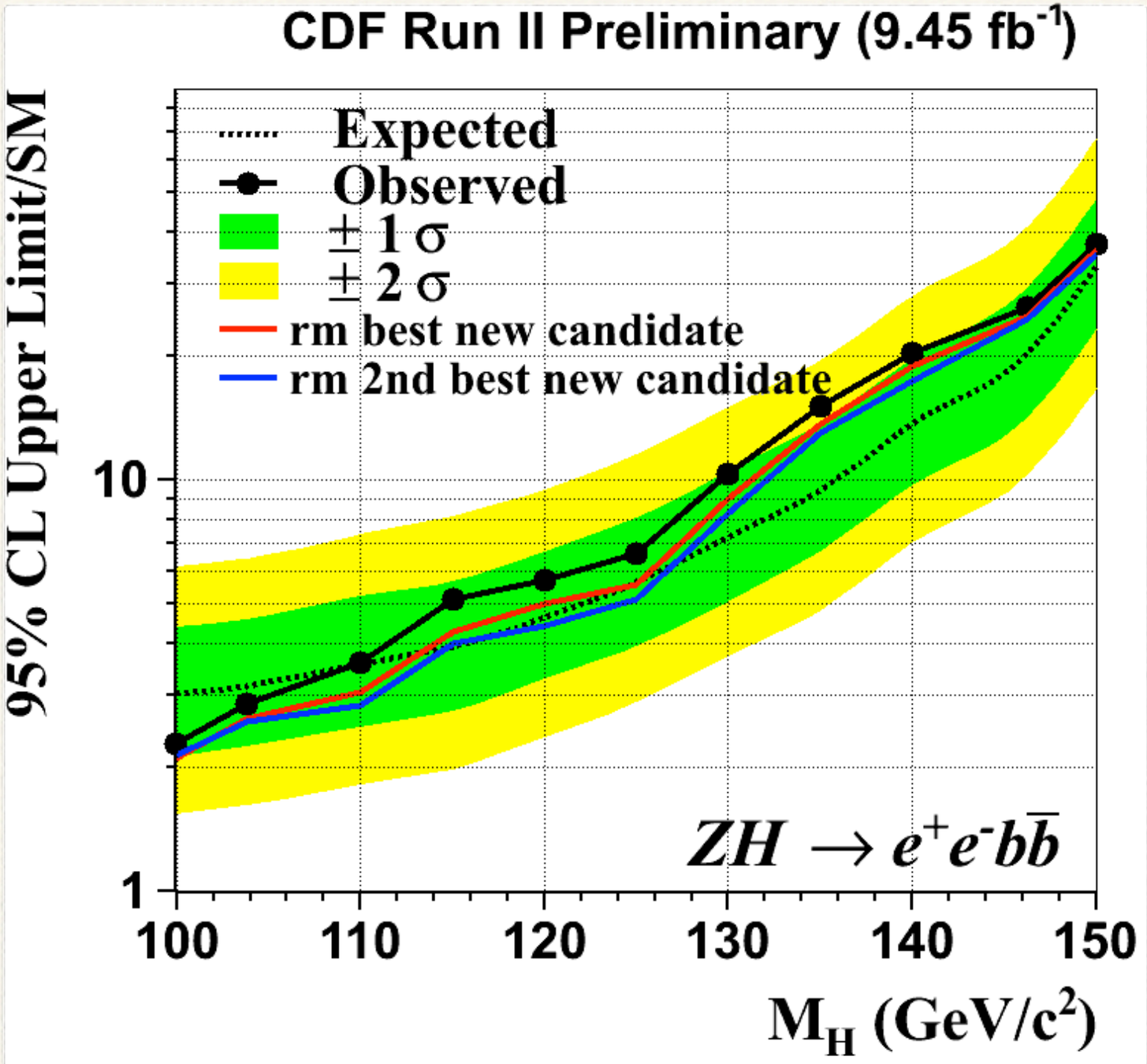


Comparison to Summer 2011

- Most channels showed enhancement of 0.5-1 sigma excesses
- Most dramatic change in ZH(ee)bb

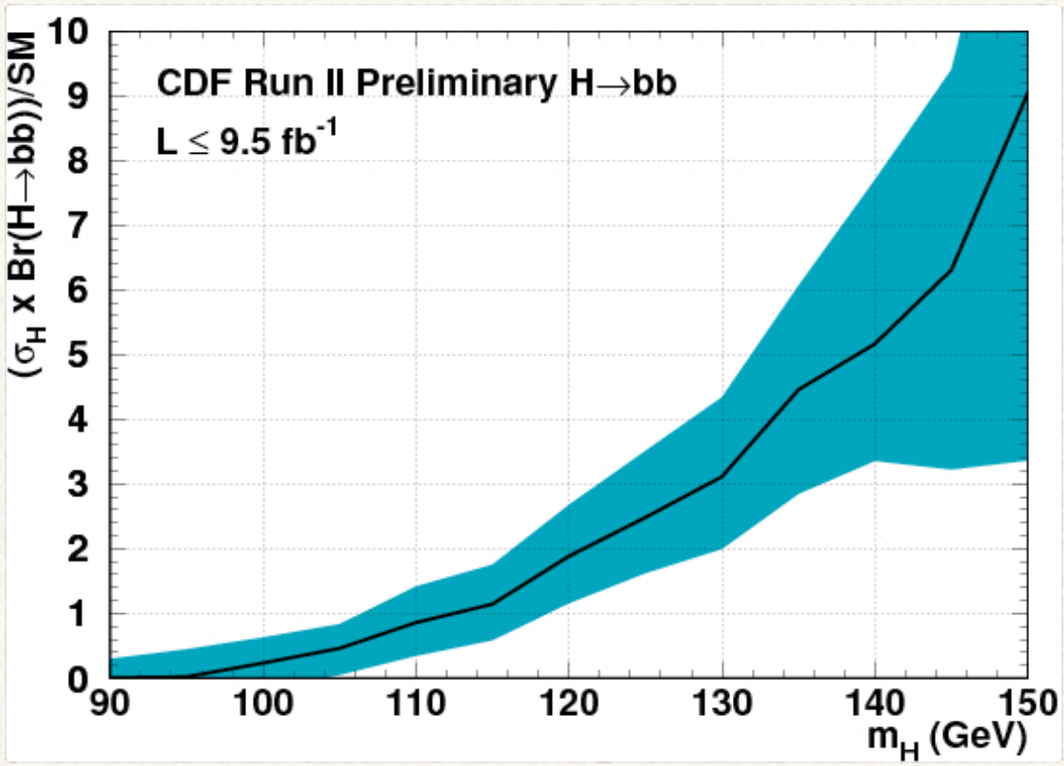


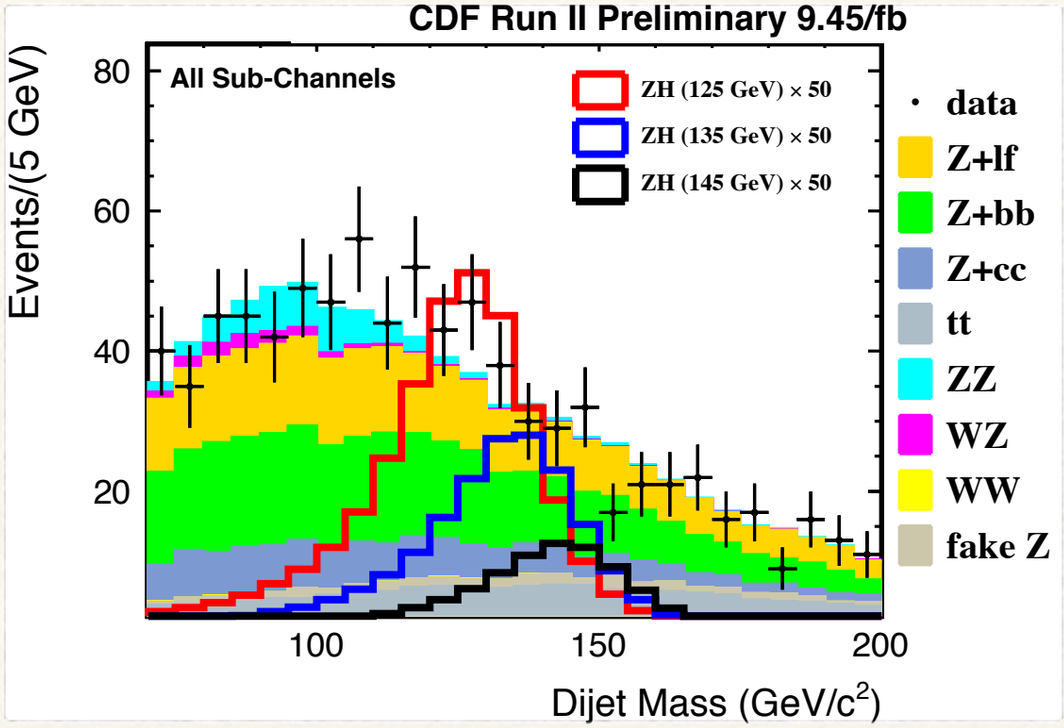
Comparison to Summer 2011



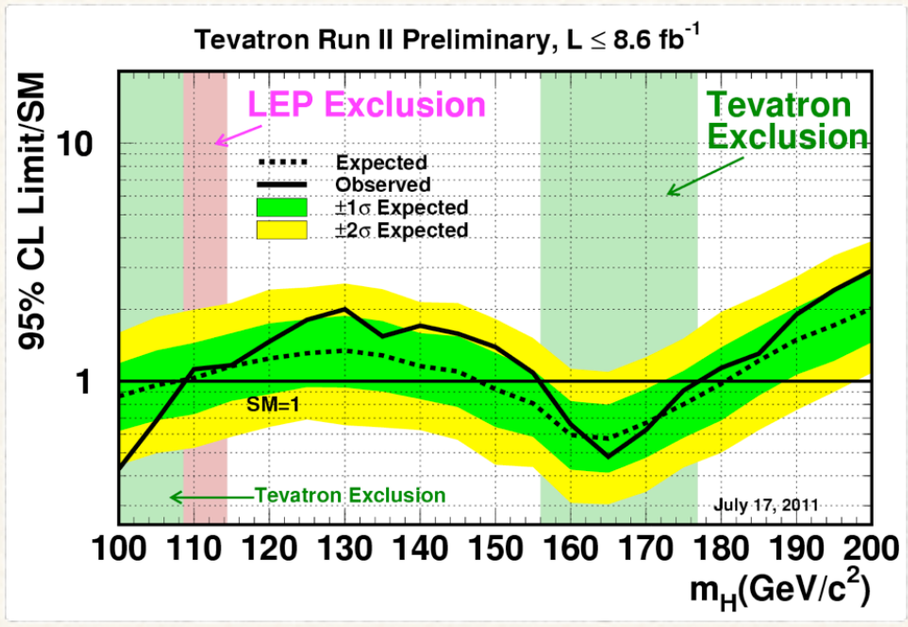
CDF Combination

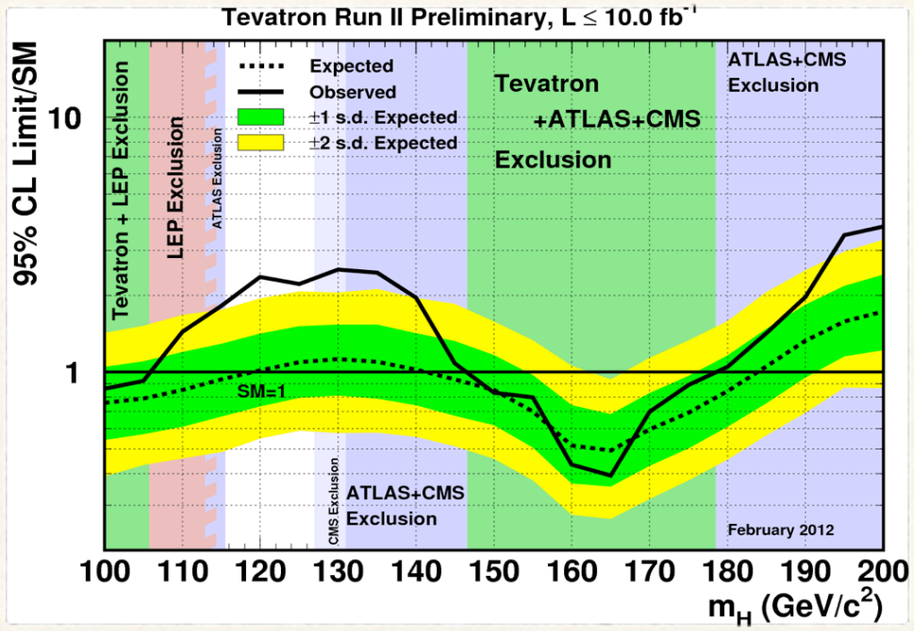
- Fitted higgs cross sections

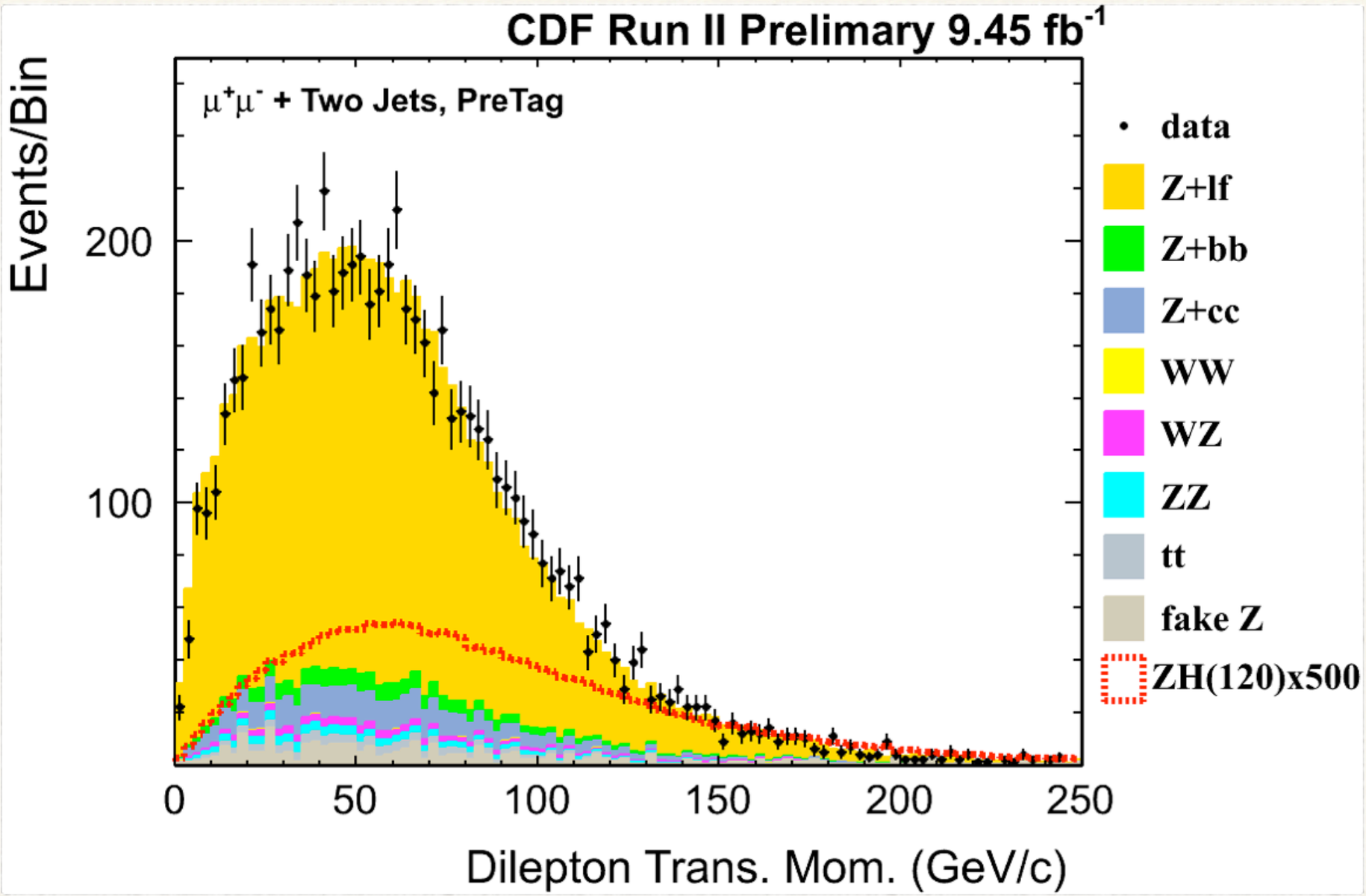




Tevatron Search Status :






CDF Run II Prelimary 9.45 fb-1
μ+μ- + Two Jets, PreTag
Events/Bin
200
100
0
50
100
150
200
250
Dilepton Trans. Mom. (GeV/c)
data
Z+lf
Z+bb
Z+cc
WW
WZ
ZZ
tt
fake Z
ZH(120)x500