Standard Model Low mass Higgs search at CDF

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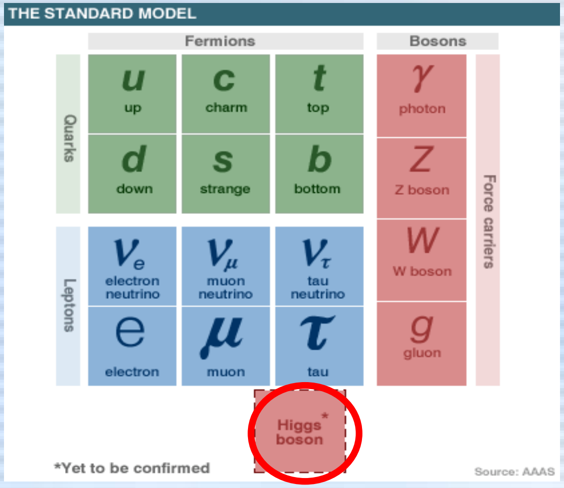
on behalf of the CDF Collaboration

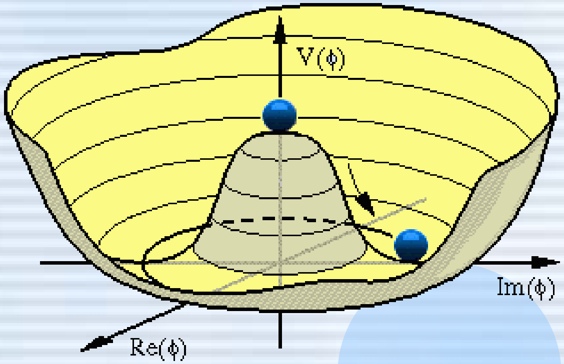
Talk Outline

- Introduction
- Higgs Production and Decay
- Search Strategy
- Results from Low Mass Higgs Boson Searches
- Summary

Motivation

- The Higgs boson is the only undiscovered **"elementary"** particle in the Standard Model
- Its discovery will help answer the questions:
  - How do fermions/weak bosons acquire mass?
  - How EW symmetry is broken?
- The SM can not predict the Higgs boson mass
  - Needs to be determined by experiment !!





Status of SM Higgs Search

- Current constraint on the SM Higgs boson

– Precision electroweak measurements (top mass, W mass, etc)

$M_H = 89^{+35}_{-26}\ GeV/c^2 \quad M_H < 158\ GeV/c^2$

(LEP EWG 2010, http://lepewwg.web.cern.ch/LEPEWWG/

Tevatron covers whole mass region

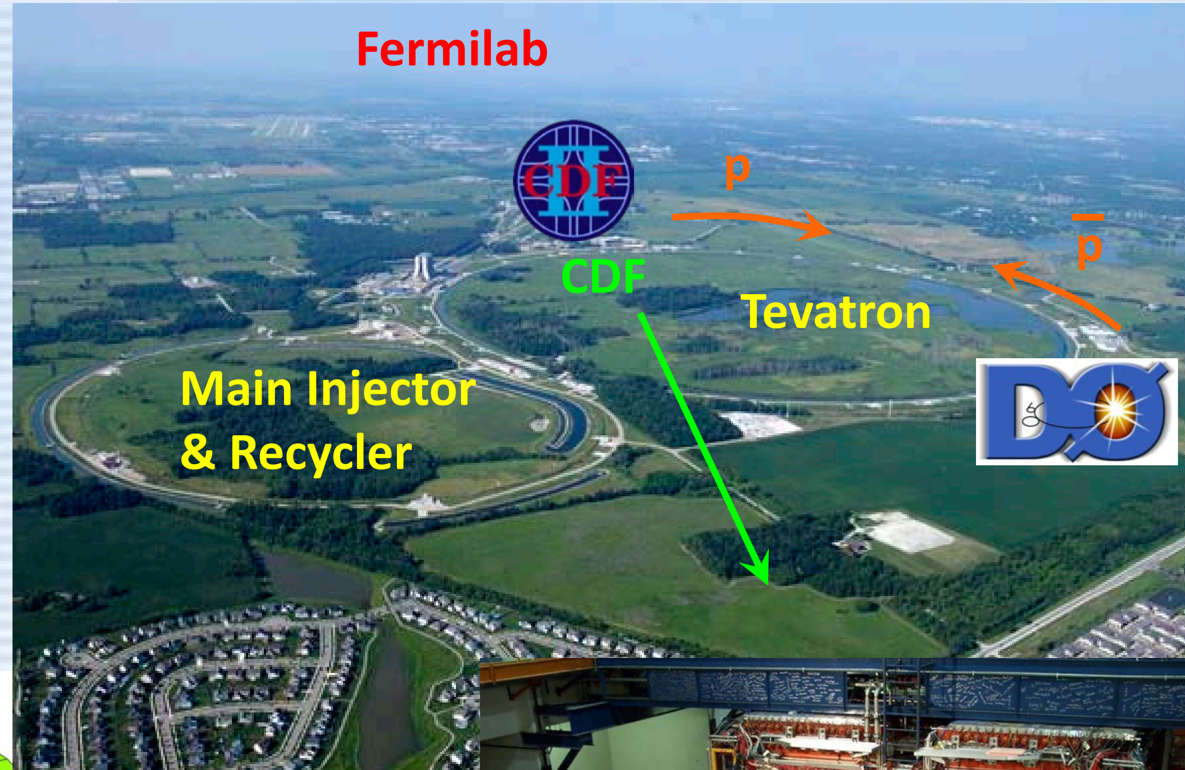
Tevatron and CDF

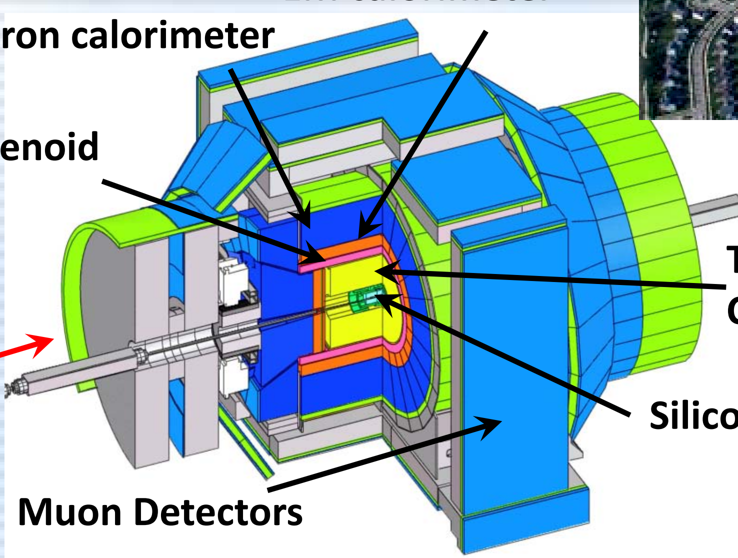
Tevatron

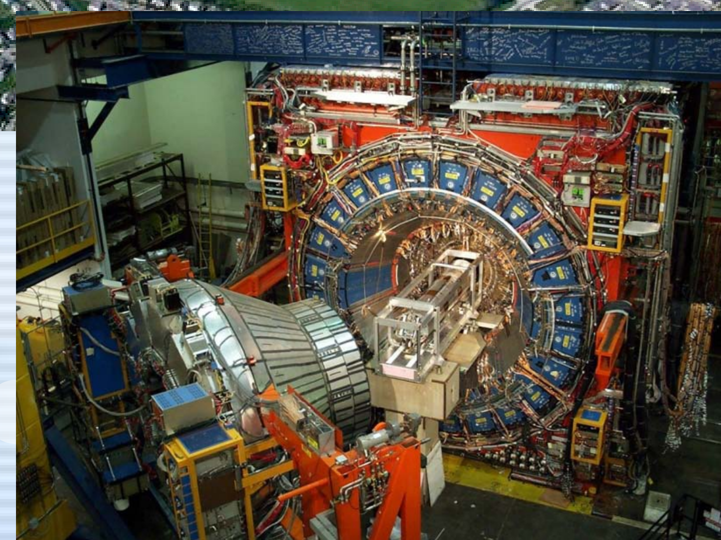
- Proton-antiproton collisions at $\sqrt{S} = 1.96\text{TeV}$
- **> 9.0 fb^{-1} delivered**

CDF

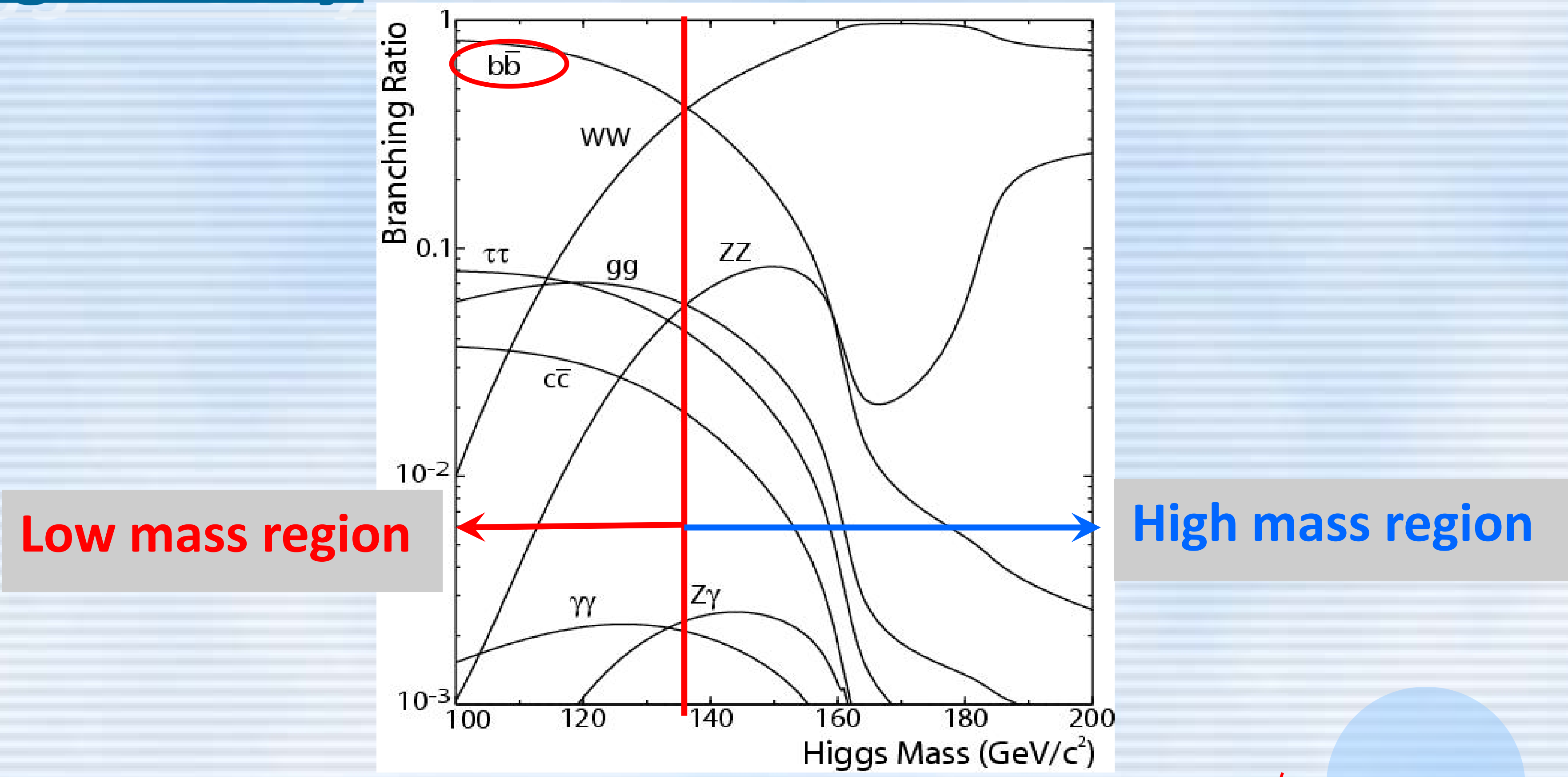
- One of the general purpose detectors
- Currently, CDF has recorded **> 7.5 fb^{-1}** of data.







Higgs Decay



- **Focus on Low mass Higgs boson search** $M_H < 135 GeV/c^2$
  Dominant decay for this region is: $H \to b\bar{b}$

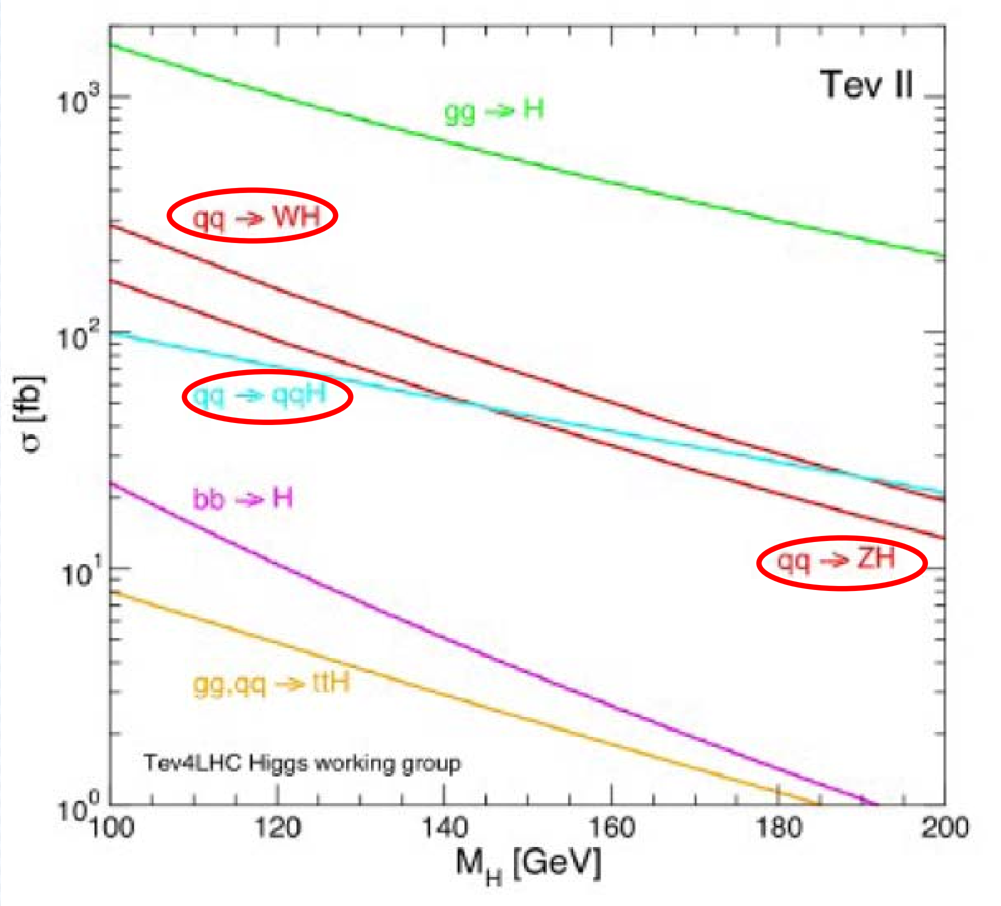
For H->ττ search, see P. Totaro's talk on July 23

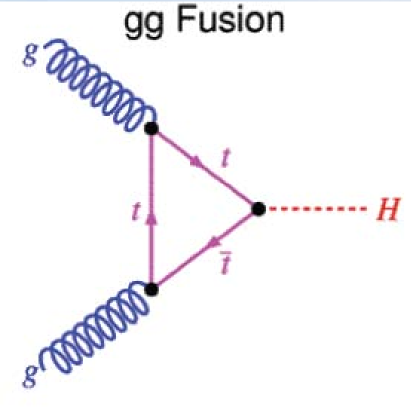
For H->γγ search, see K. Peter's talk on July 23

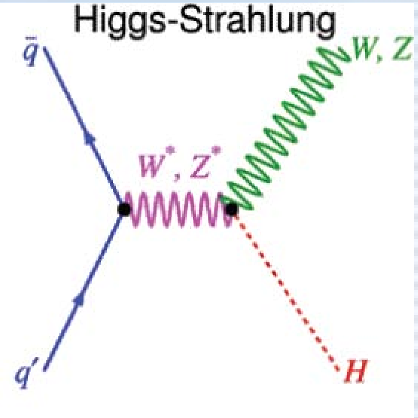
For High mass Higgs search, see D. Lucchesi's talk in this session

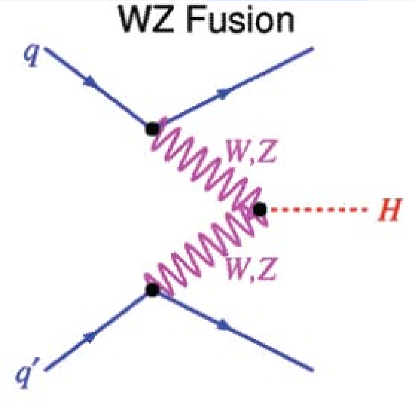
Higgs Production @ Tevatron

- Dominant SM Higgs production channels at the Tevatron



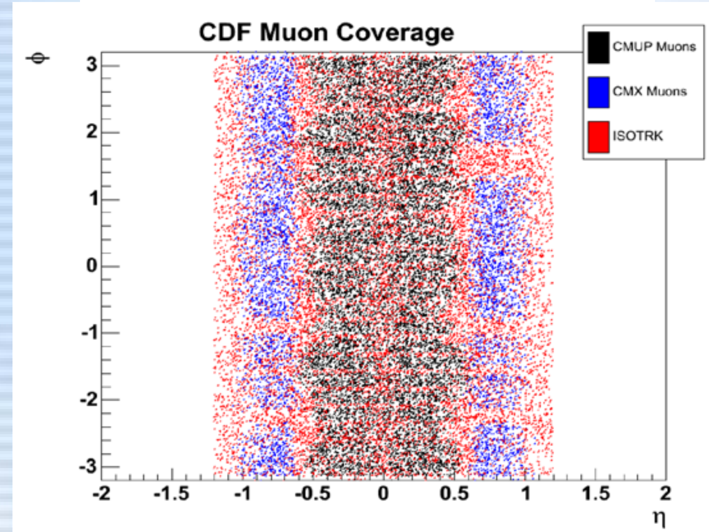






Event Reconstruction

CDF Muon ID



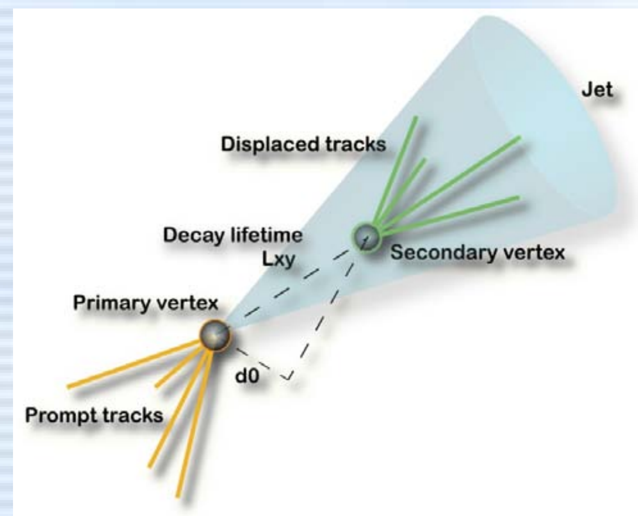
High p_T Lepton

- Existence of lepton(s) greatly suppresses QCD multi-jet background.
- Extended lepton coverage helps to maximize signal acceptance
- *ZH -> llbb, WH -> lνbb*

Large Missing Transverse Energy (MET)

- Requiring large MET also greatly suppresses QCD multi-jet background.
- *ZH -> ννbb, WH -> lνbb*

b-flavor jets



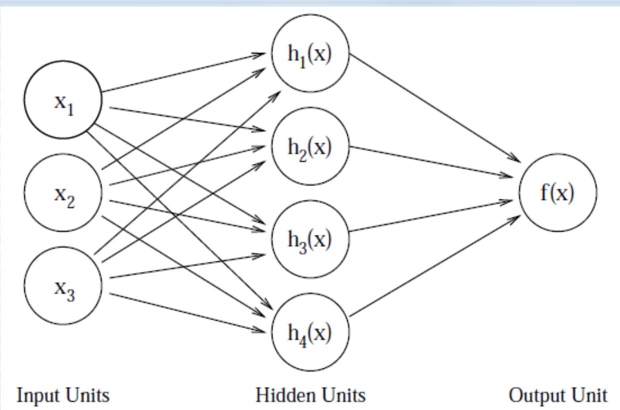
- B-hadrons have relatively long life time.
- Identifying b-jets greatly enhance S/B.
- Three main algorithms used in CDF:
  - **SECVTX**: Find secondary vertices displaced from the interaction point.
  - **JETPROB**: Identify b-jets using impact parameter of tracks in jets.
  - **NN**: Combine multiple jet variables to exploit b-jet properties.

Multivariate Analysis (NN,ME)

- Employ advanced multivariate techniques to further improve signal vs background separation

Neural Network

Combine multiple kinematic variables



Matrix Element

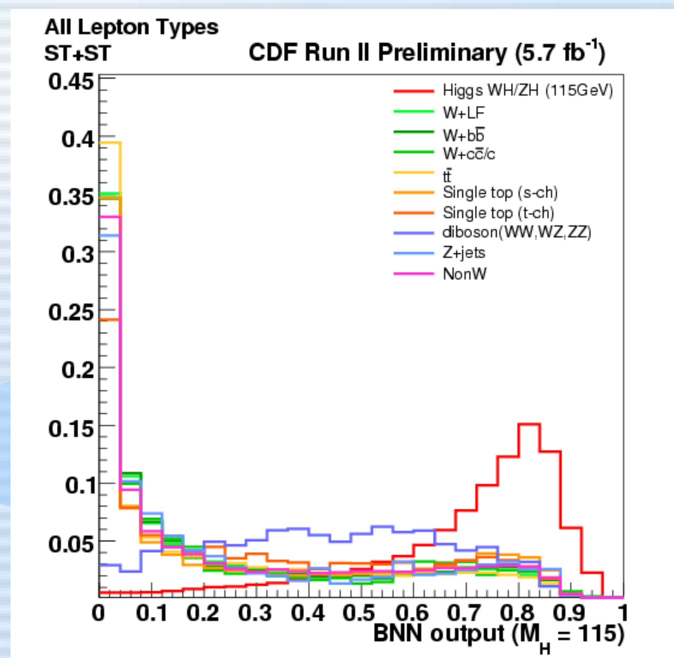
Calculate event probability using the LO matrix elements

ME

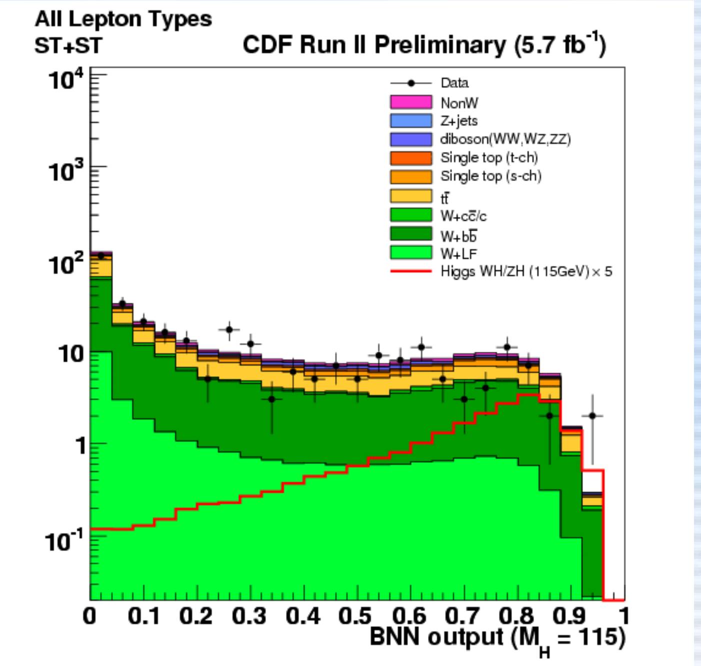
PDF

Transfer Function (detector response)

$$P(p_l, p_{jet}) = \frac{1}{\sigma}\int d\rho_{jet}\, dp_\nu \sum \phi_4 |M(p_i)|^2 \frac{f(q_1)\, f(q_2)}{|q_1||q_2|} W_{jet}(E_{parton}, E_{jet})$$



WH->lνbb (NN)



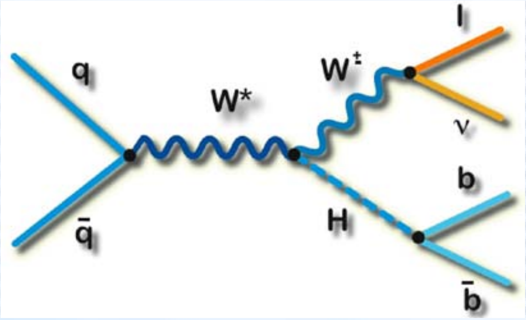
Event Selection

One high-p_T lepton (e,μ, isolated track) + large MET + 2 high-E_T jets

- Isolated tracks recover lost acceptance from limited muon detector coverage and e/τ reconstruction inefficiencies

Analysis techniques

- NN b-jet energy correction to improve $\sigma(m_{jj})$
- **Four b-tagging categories using SECVTX, JETPROB, NN to maximize sensitivity**
- Bayesian Neural Network as discriminant

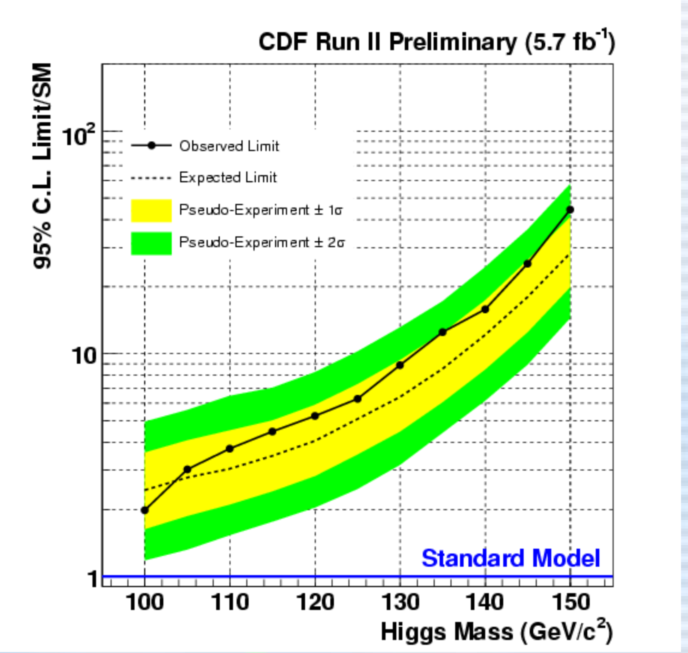


Expected upper limit

3.5 x σ(SM) (@115 GeV)

Observed upper limit

4.5 x σ(SM) (@115 GeV)



WH->lνbb (ME)

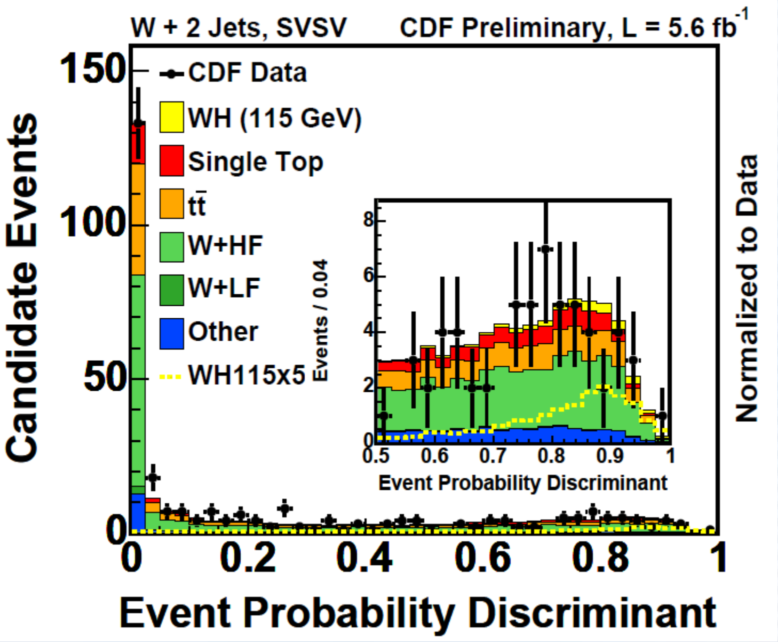
Event Selection

One high-p_T lepton (e,μ) + large MET + 2 or 3 high-E_T jets

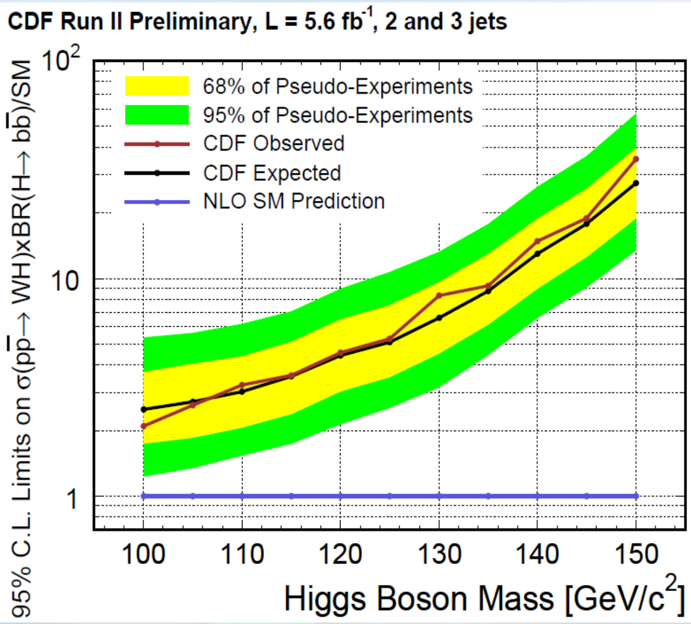
- Muon is recovered by additional loose muon categories.

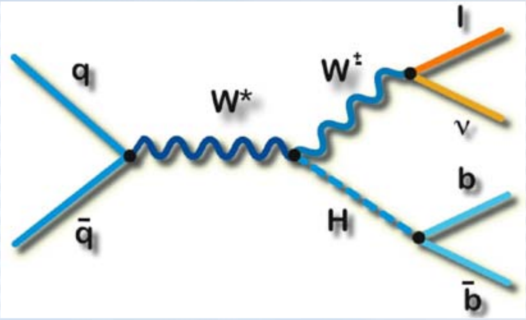
Analysis techniques

- Three b-tagging categories (SECVTX and JETPROB)
- **Add 3-jet bin signal**
- Matrix element probability as discriminant
- **NN flavor separator outputs designed to separate flavor content of tagged jets to calculate EPD**



$$EPD = \frac{P_{signal}}{P_{signal} + \sum P_{background}}$$





Expected upper limit

3.5 x σ(SM) (@115 GeV)

Observed upper limit

3.6 x σ(SM) (@115 GeV)

ZH->ννbb & WH->lνbb

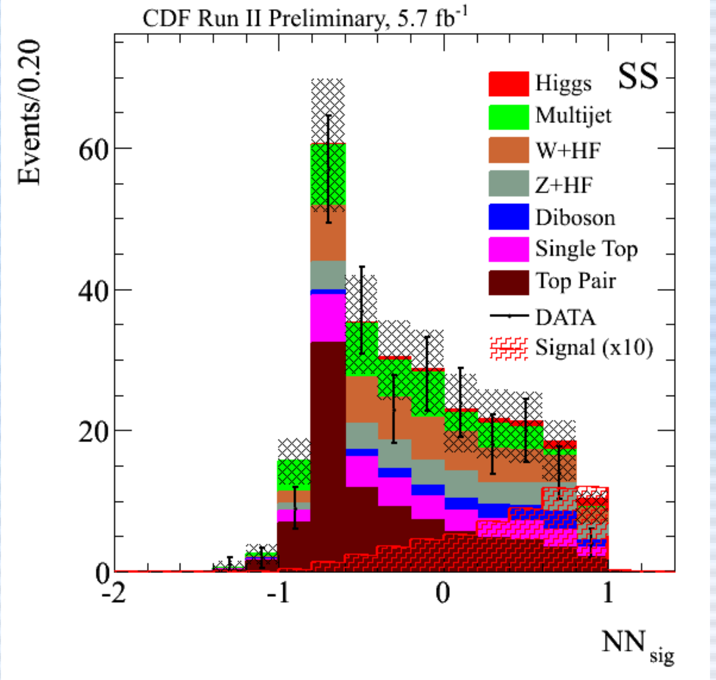
Event Selection

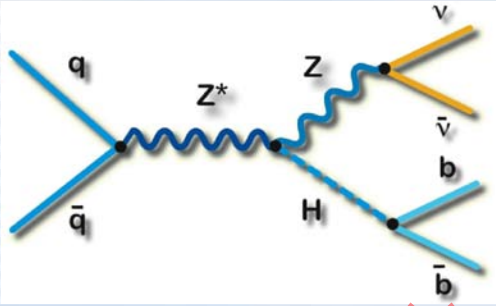
large MET + 2 high-E_T jets

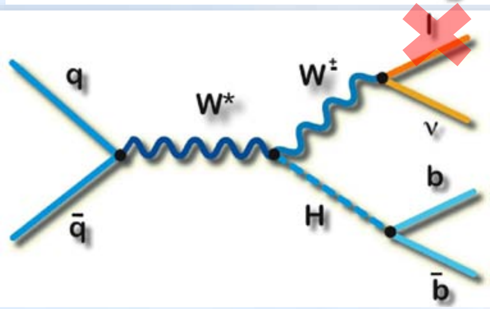
Include WH->(l)νbb and ZH->(ll)bb

Analysis techniques

- **First NN to remove huge QCD multijet background**
- Three b-tagging categories (SECVTX and JETPROB)
- **Jet energy resolution improvement by combining tracking and calorimeter information**
- Second Neural Network for final discriminant





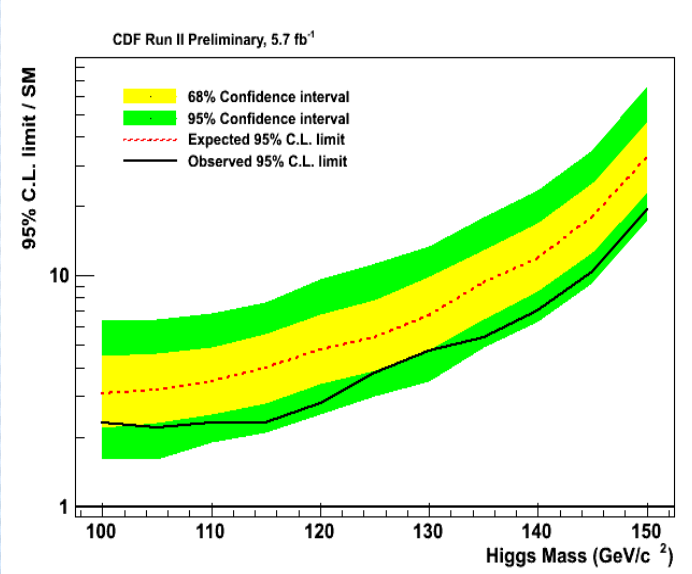


Expected upper limit

4.0 x σ(SM) (@115 GeV)

Observed upper limit

2.3 x σ(SM) (@115 GeV)



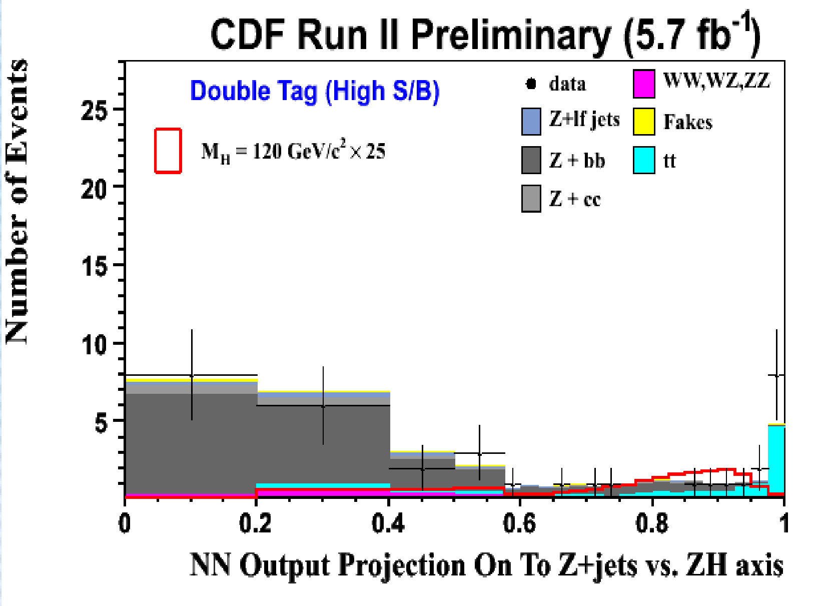
ZH->llbb

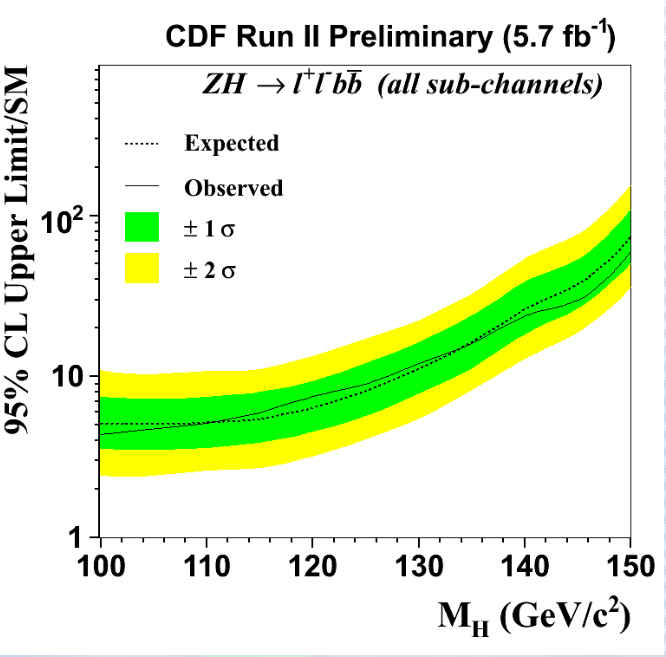
Event Selection

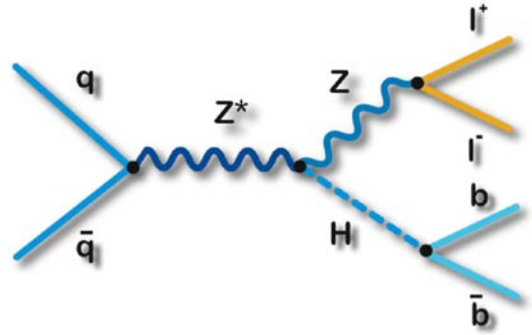
Two high-p_T leptons (ee,μμ), m(ll) within Z boson mass window + 2 high-E_T jets

Analysis techniques

- NN to correct jet energies based on observed missing E_T
- Three b-tagging categories (SECVTX and JETPROB)
- Recover loose muon pairs using NN selection (first use of multivariate lepton ID in a low-mass analysis)
- 2-D Neural Network as discriminant (ZH vs top-pair, ZH vs Z+jets)







Expected upper limit

5.5 x σ(SM) (@115 GeV)

Observed upper limit

6.0 x σ(SM) (@115 GeV)

VH->jjbb & VBF H->bb

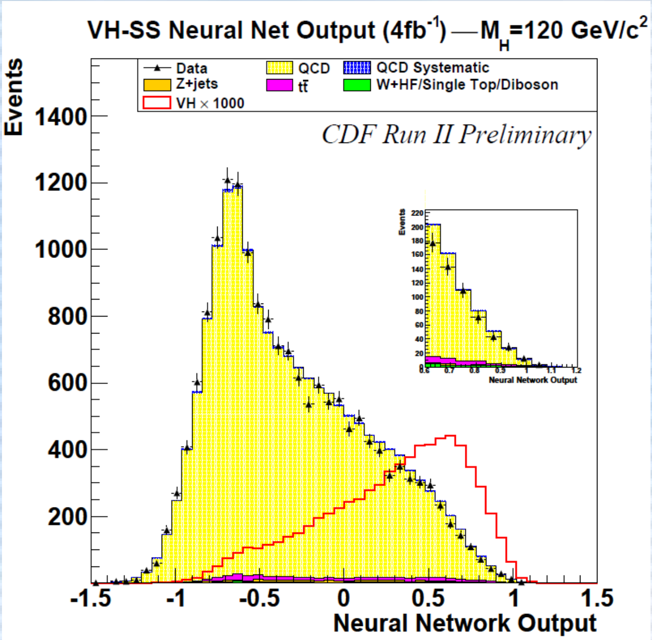
Event Selection

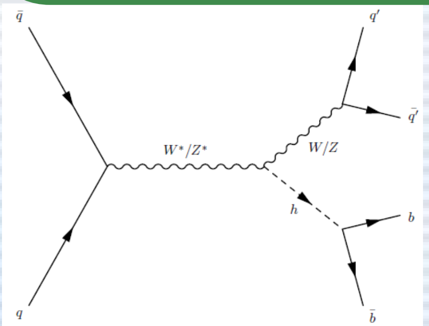
4 or 5 high-E_T jets

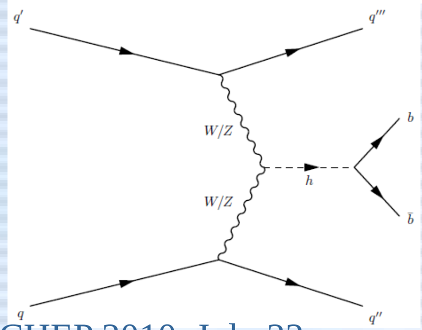
Signal from WH/ZH and VBF processes.

Analysis techniques

- Two b-tagging categories (SECVTX and JETPROB)
- **Data-driven QCD background estimation**
- **Use jet shape of quarks/gluons to remove gluon background**
- Neural Network as discriminant





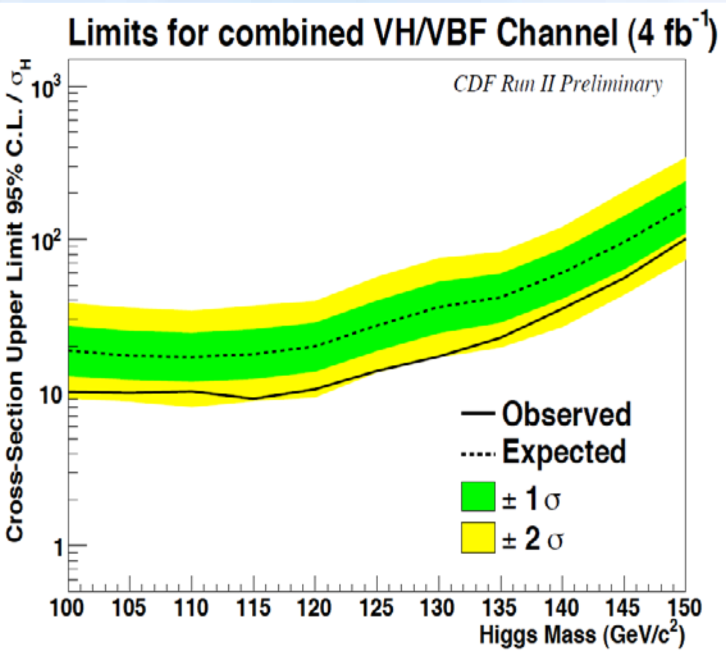


Expected upper limit

17.8 x σ(SM) (@115 GeV)

Observed upper limit

9.1 x σ(SM) (@115 GeV)



Summary

- We have performed searches for the low mass SM Higgs boson at CDF using multiple channels
- Each channel employs sophisticated multivariate techniques to maximize search sensitivity.
- CDF Higgs search sensitivity is now close to the SM prediction, we have a chance to find evidence of the Higgs in the low mass region if it exists there.
- We have achieved **3.5 x σ(SM) @ 115 GeV/c^2** sensitivity in the best single low mass channel (***WH -> $l\nu bb$***)

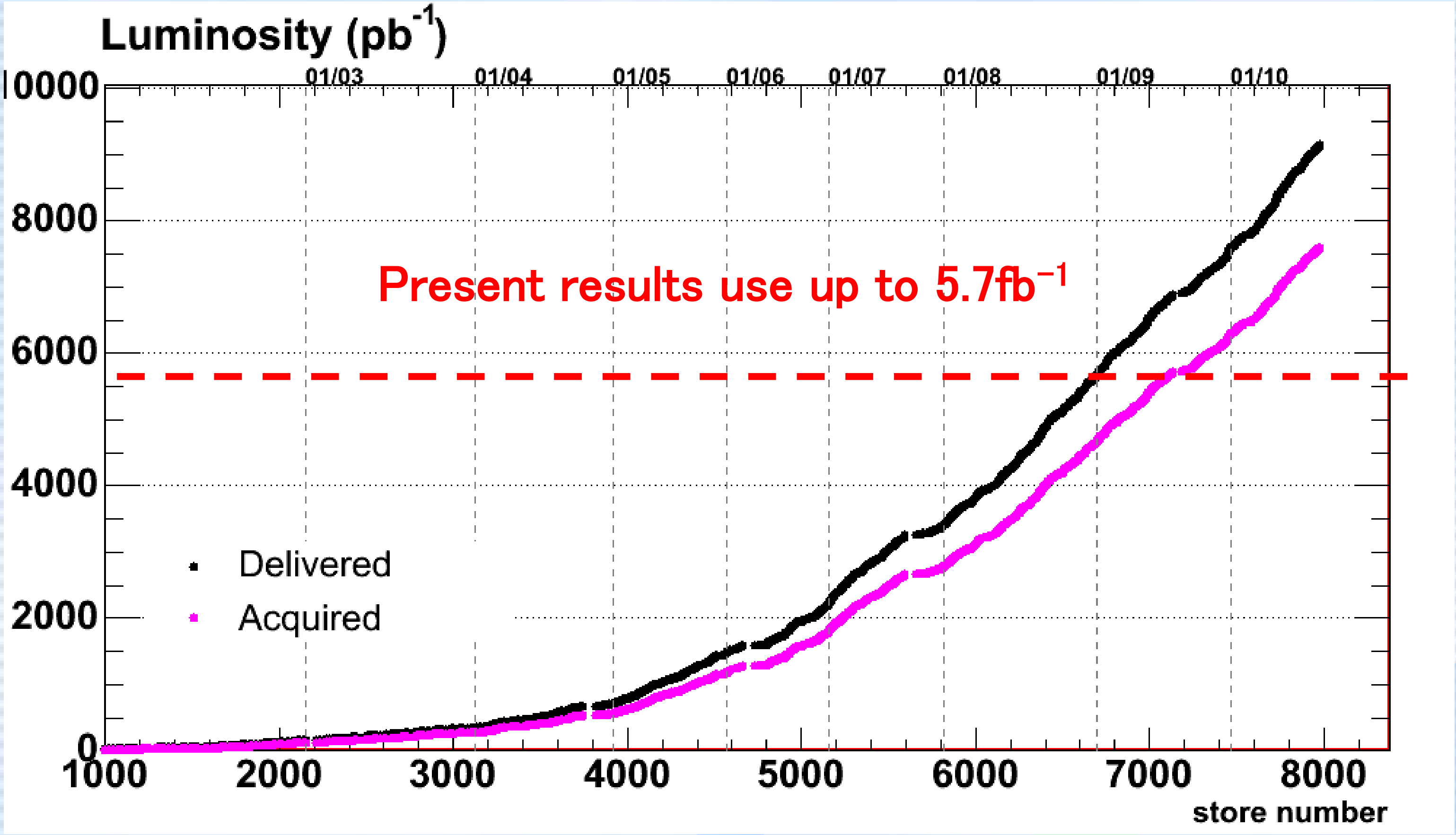
For CDF combined SM Higgs limit, see K. Potamianos's talk on July 23
For Tevatron combined limit, see B. Kilminster's talk on July 26

Stay tuned!!


Thank you!!

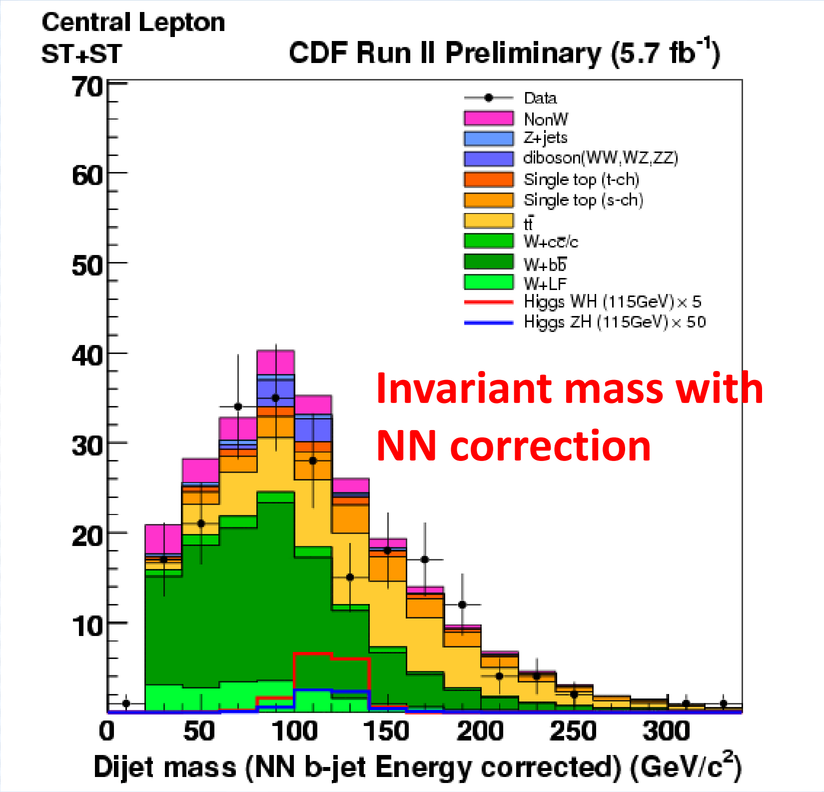
Backup

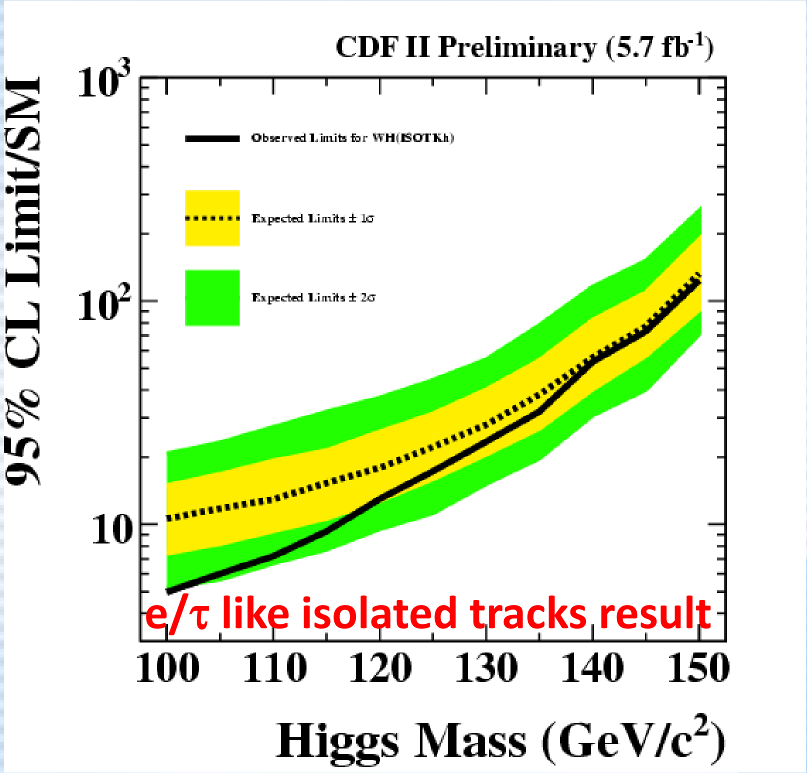
Luminosity



Luminosity (pb^{-1})
10000
8000
6000
4000
2000
0
01/03
01/04
01/05
01/06
01/07
01/08
01/09
01/10
Present results use up to 5.7fb^{-1}
Delivered
Acquired
1000
2000
3000
4000
5000
6000
7000
8000
store number

WH->lνbb (NN) Key plots





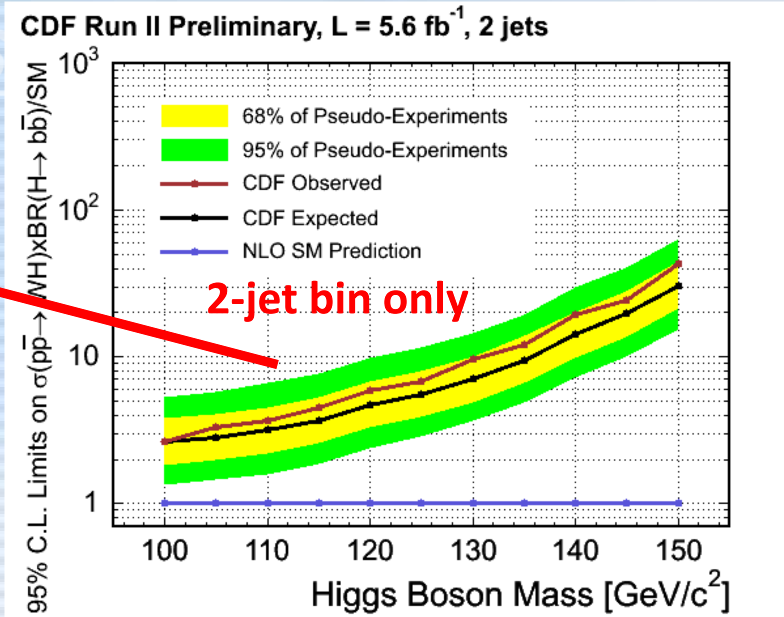
<u>Observed (Expected) upper limit</u>

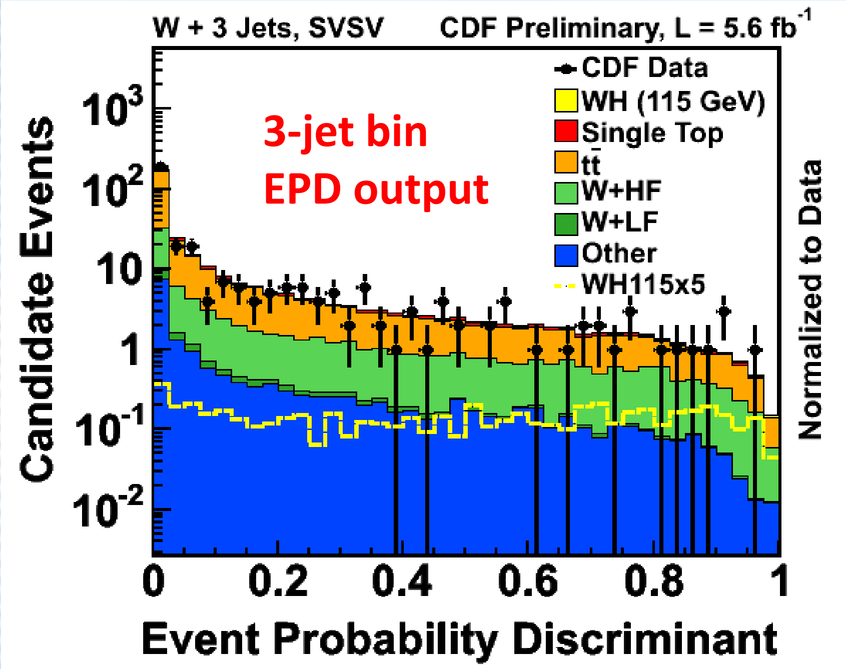
9.3 (15.3) x σ(SM) (@115 GeV)

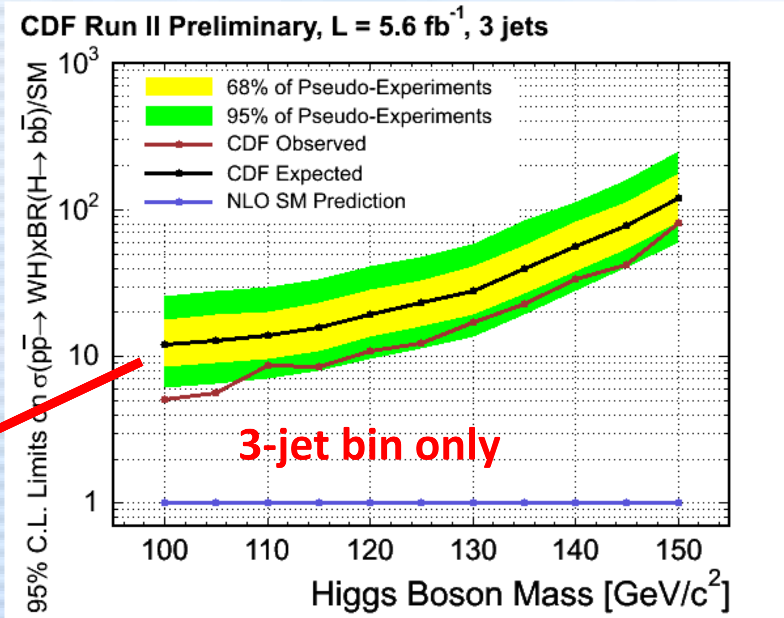
WH->lνbb (ME) Key plots

Observed (Expected) upper limit

4.5 (3.7) x σ(SM)   (@115 GeV)



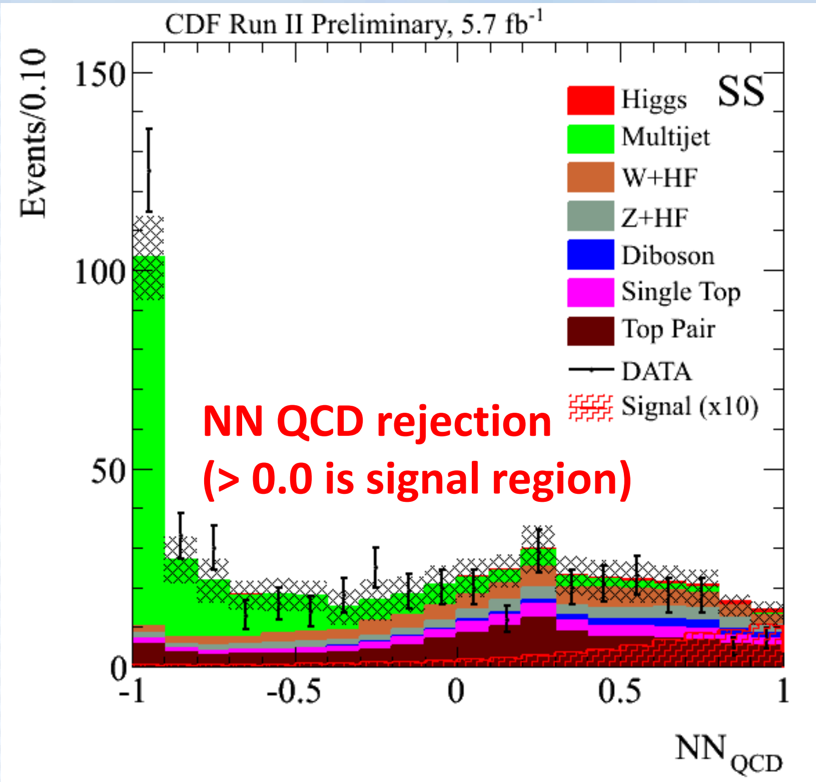


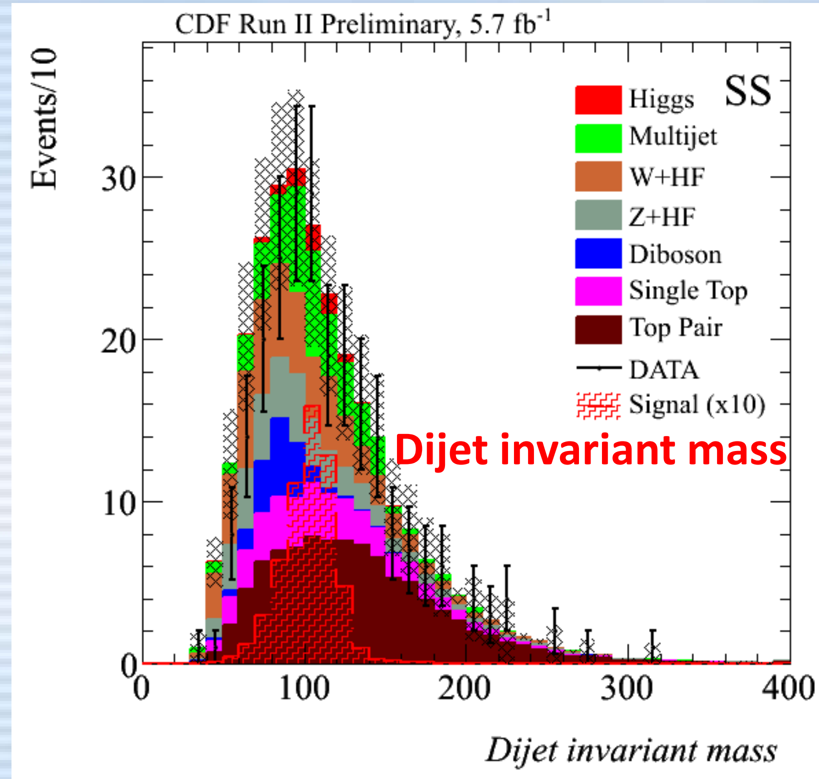


Observed (Expected) upper limit

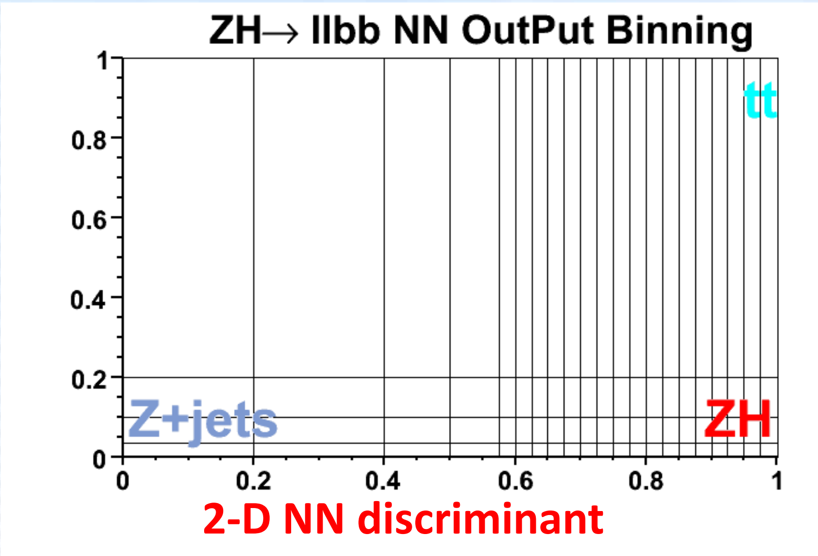
8.5 (15.8) x σ(SM)   (@115 GeV)

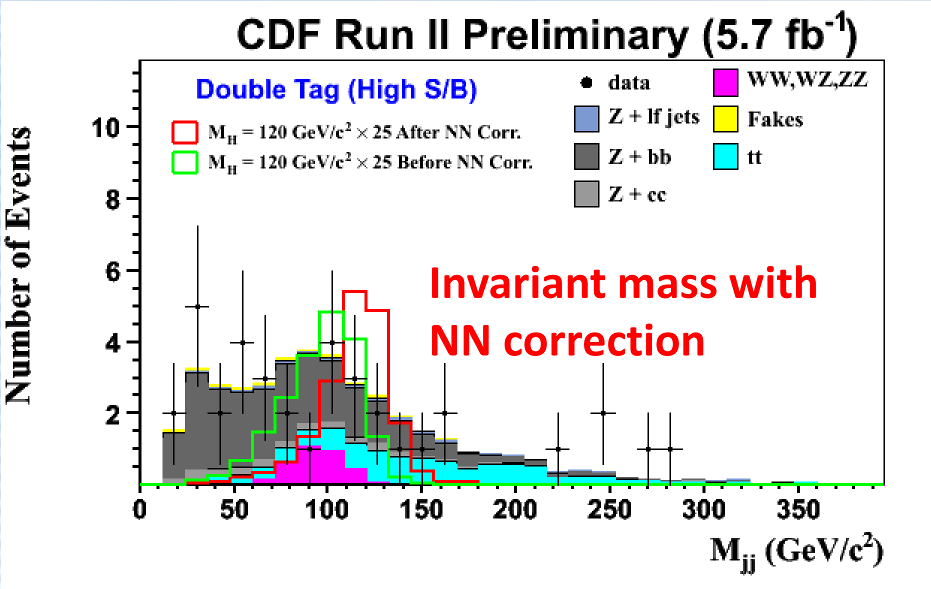
ZH->$\nu\nu$bb & WH->$l\nu$bb Key plots

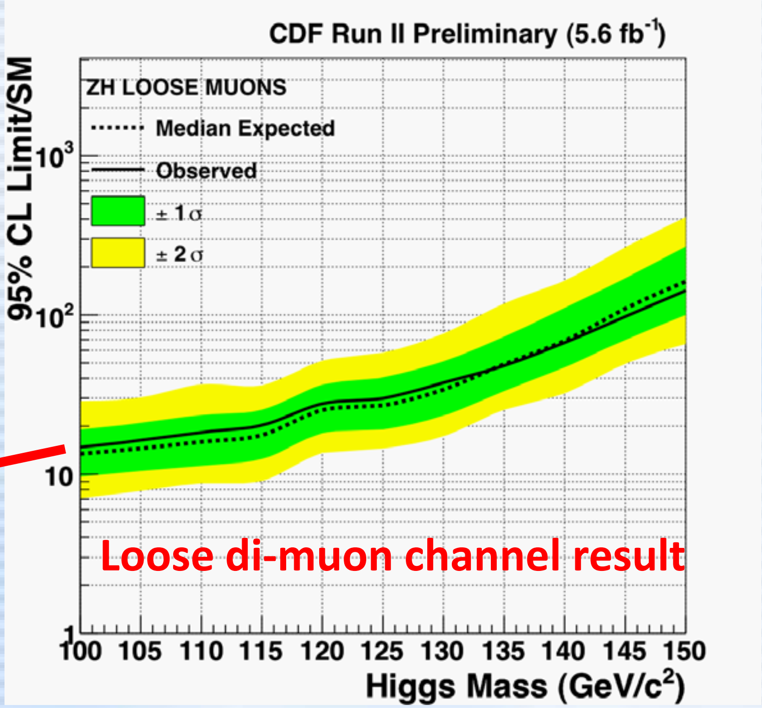




ZH->llbb Key plots



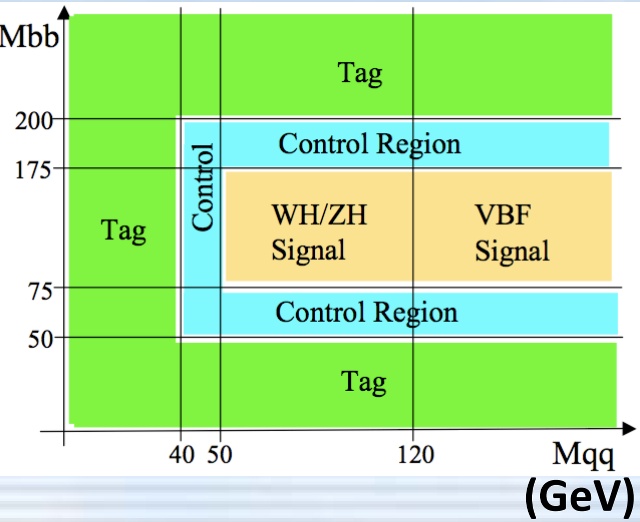




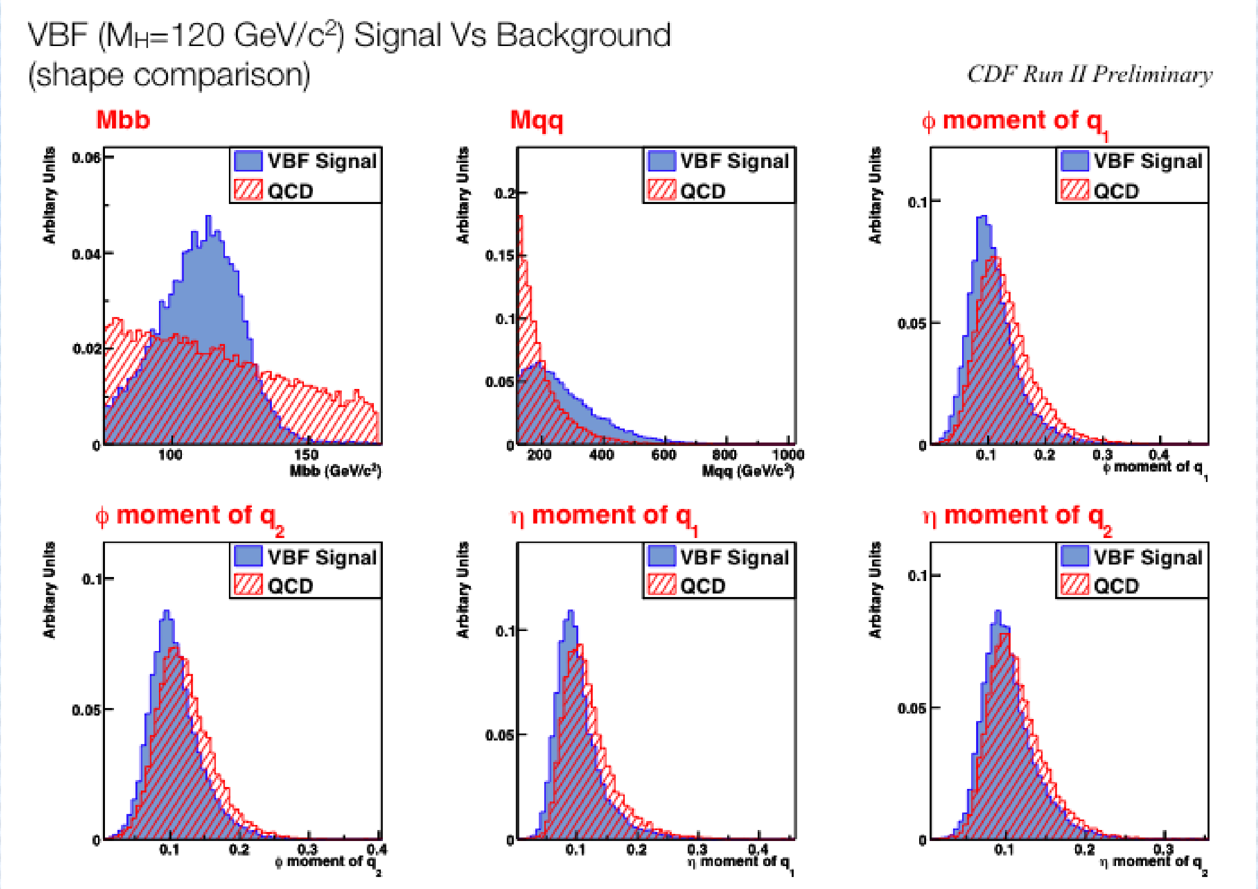
Observed (Expected) upper limit

20.3 (17.6) x σ(SM)   (@115 GeV)

VH->jjbb & VBF H->bb Key Plots



Signal/Control region definition



$$\phi\text{-moment}(\langle\phi\rangle) = \sqrt{\sum_{\text{towers}} \left(\left(\frac{E_t^{\text{tower}} \phi_{\text{tower}}}{E_t^{\text{jet}}} \right)^2 - \phi_{\text{jet}}^2 \right)}$$

$$\eta\text{-moment}(\langle\eta\rangle) = \sqrt{\sum_{\text{towers}} \left(\left(\frac{E_t^{\text{tower}} \eta_{\text{tower}}}{E_t^{\text{jet}}} \right)^2 - \eta_{\text{jet}}^2 \right)}$$