Searches for the Standard Model Higgs at the Tevatron

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on behalf of the CDF and DØ collaborations

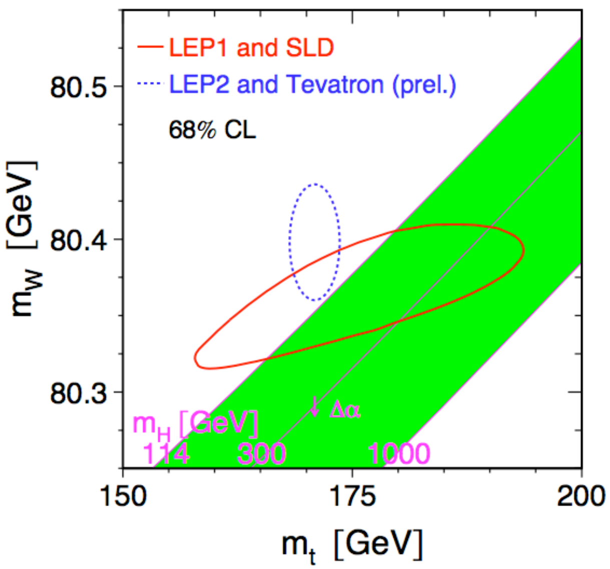
Recontres de Moriond 2007

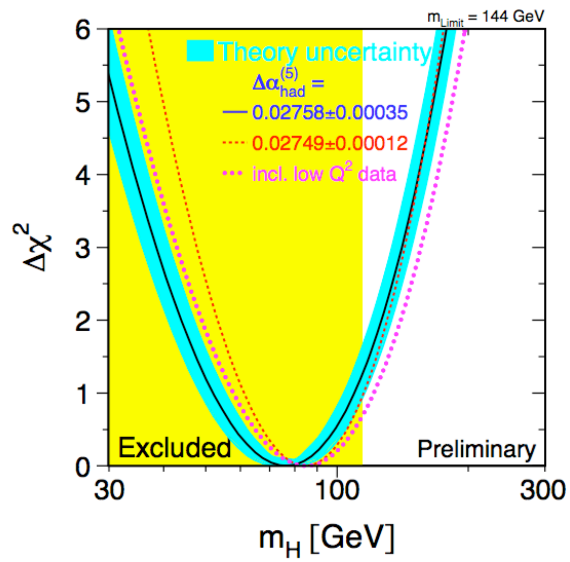
Constraints on the Higgs

- Higgs searches ongoing for last 30 years
- **Direct search at LEP:** M_{Higgs} > 114 GeV @ 95%
- **Indirect searches:** including new Tevatron **M_{top}= 170.9 ± 1.8 GeV** & **M_W=80.398 ± 0.025 GeV** (see M. Wang & E. Nurse's talks tomorrow)

m_H = 77 +XX -XX GeV
m_H < 144 GeV @ 95 % CL

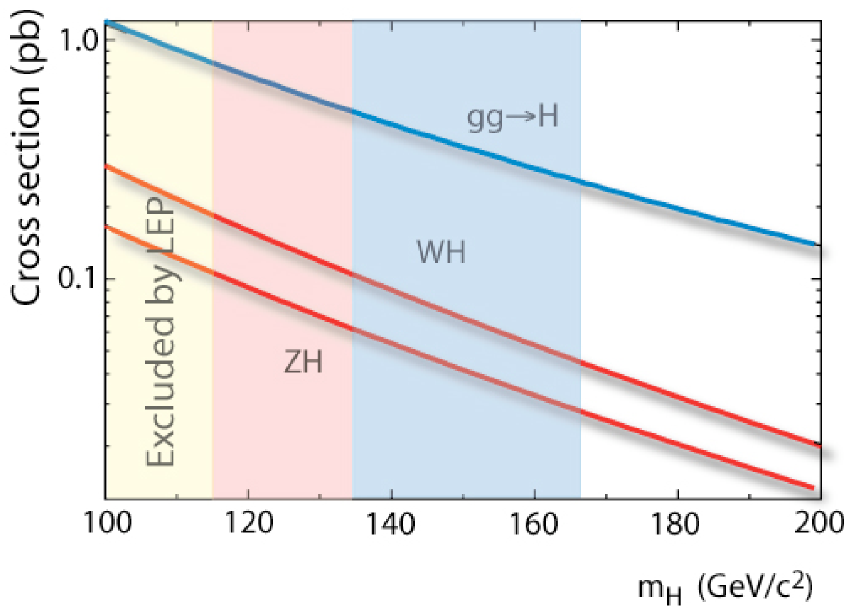
w/ 2007 CDF W mass
2007 D0 top mass



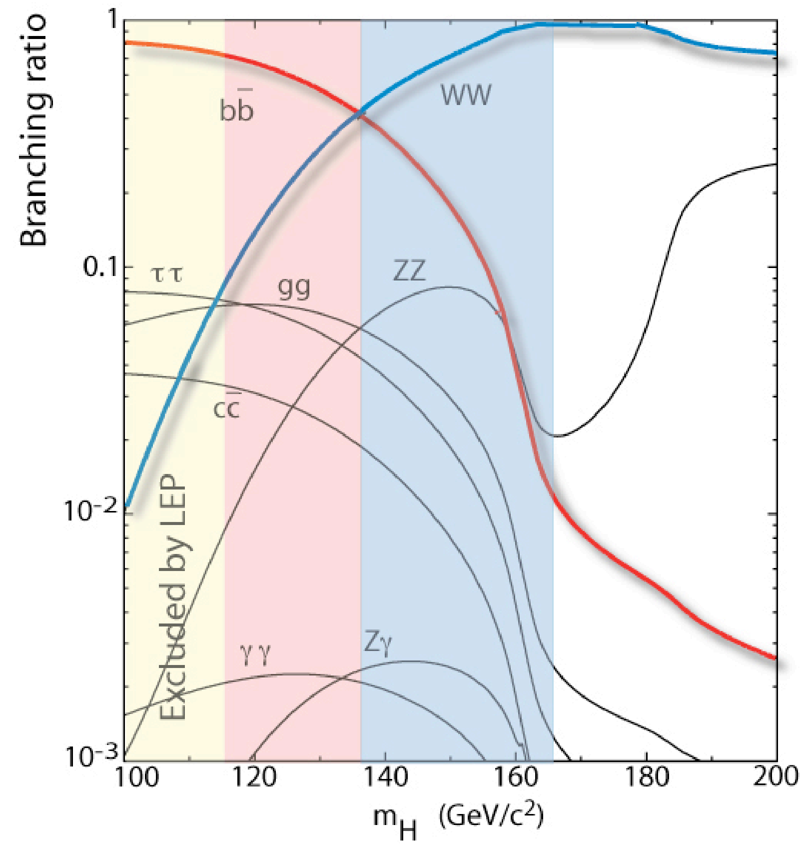


Higgs at the Tevatron

Production



Decay



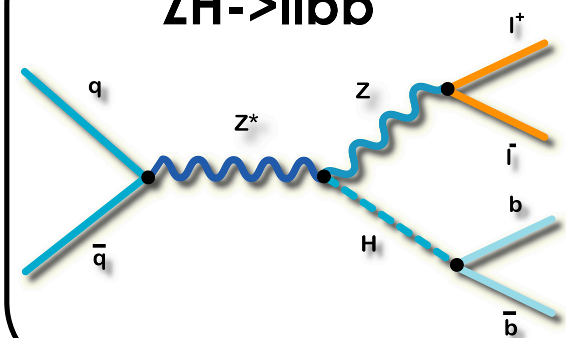
Most sensitive Tevatron searches

- **Low mass region (m_H<135 GeV):** Associated production with decay to a b-quark pair
- **High mass region (m_H>135 GeV):** Direct production with decay to a W-boson pair

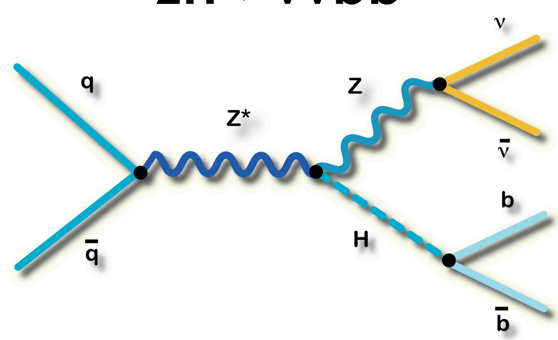
Higgs at the Tevatron

- Low m_H region: 3 main channels

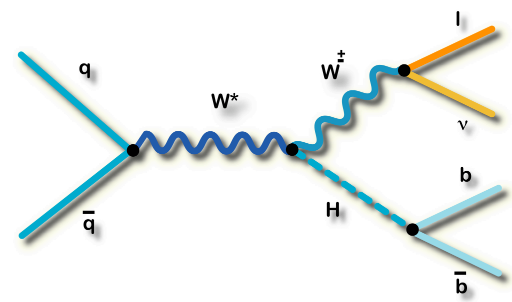
ZH->llbb



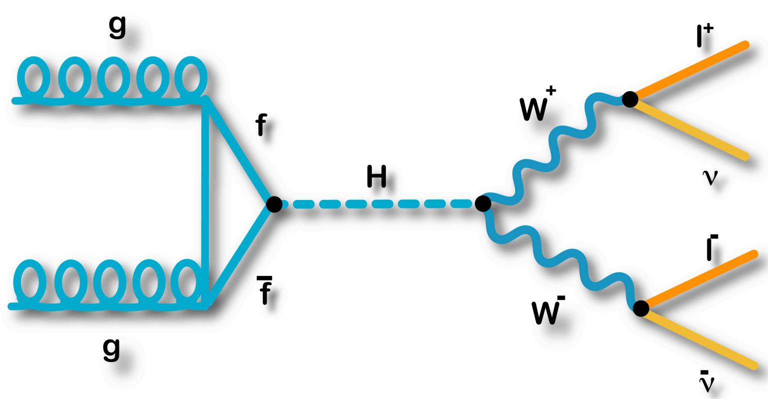
ZH->vvbb



WH->lvbb



- High m_H region: 1 main channel



gg->H->WW->lvlv

Experimental challenges

- Finding (or excluding) Higgs at the Tevatron **possible**
- But very **challenging**
  - Signal yield low and Signal-to-Background small

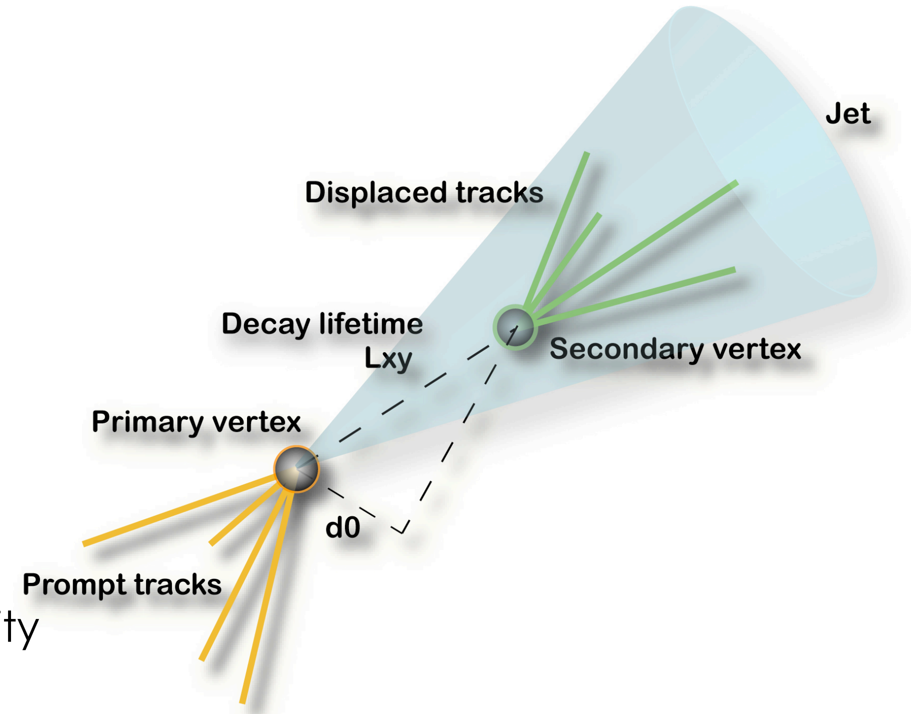
    Typical numbers for main channels in one experiment in 1 fb^{-1}

	ZH → llbb	ZH → ννbb	WH → lνbb	H → WW → lνlν
Signal/Background	**1/100**	**2/300**	**2.5/400**	**2/40**

- To make it happen, need to
  - improve **signal acceptance** for each channel
  - **reduce backgrounds** when possible
  - **combine** all above channels
    - incorporate additional decay modes when feasible
  - **combine** CDF and D0
  - integrate close to **8 fb^{-1}** of data per experiment

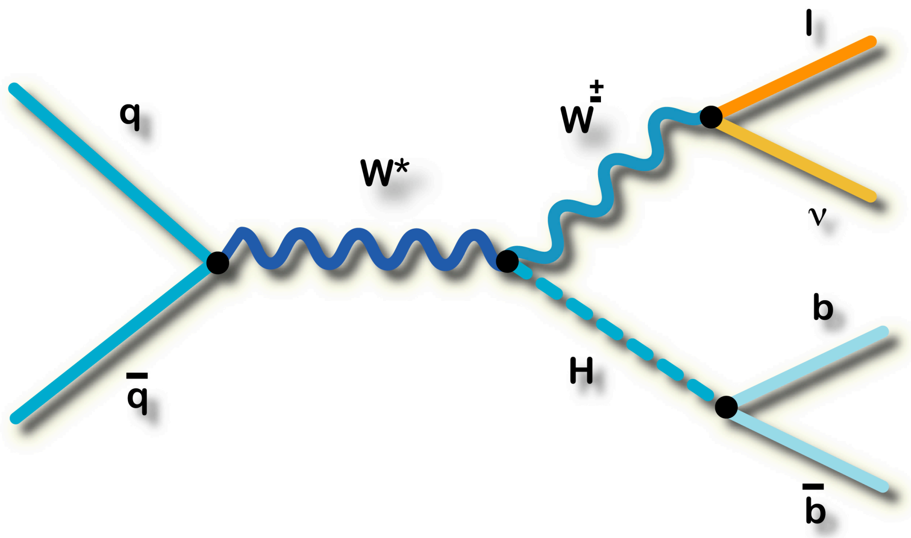
Reducing backgrounds

- For m_H < 135 GeV b-jet "tag" crucial
- **Secondary Vertex Algorithms at CDF**
  - 40 - 50 % efficient (tight, loose)
  - 1 - 2 % fake rate from light jets
  - S/B improves
    - from **1:1000**
    - to **1:100**
  - Events with 2 b-tags
    - S/B is **1:50**
    - Treat as separate channel
  - Advanced methods to improve b purity
- **Neural Network tagger at D0**
  - Used to increase efficiency rather than reduce background
  - Loose tag
    - 70 % efficient, 4.5 % fake rate
  - Tight tag
    - 48 % efficient, 0.5 % fake rate



Secondary vertex tagging

WH → l ν bb



Signature

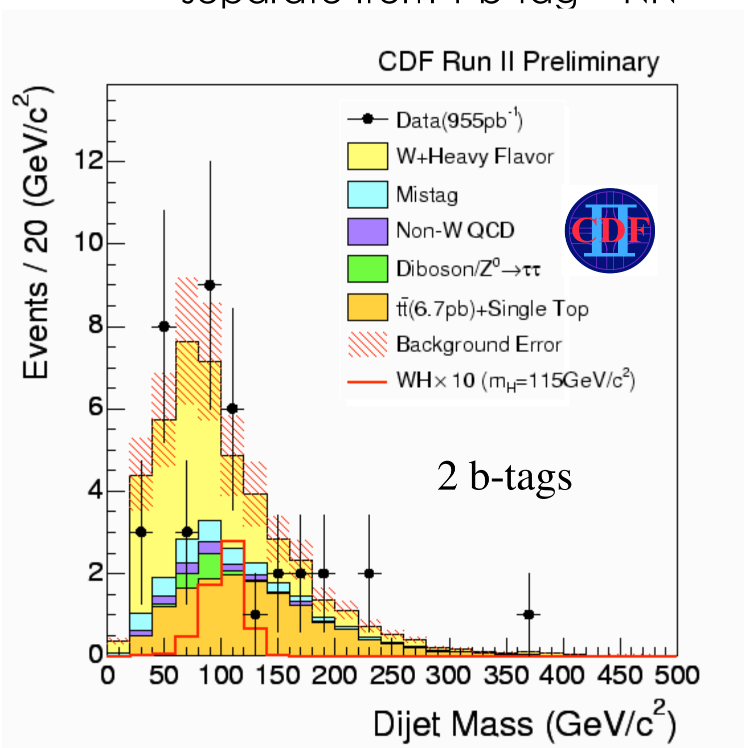
- two high transverse energy jets
- one or two b-tags
- high p_T lepton
- missing transverse energy

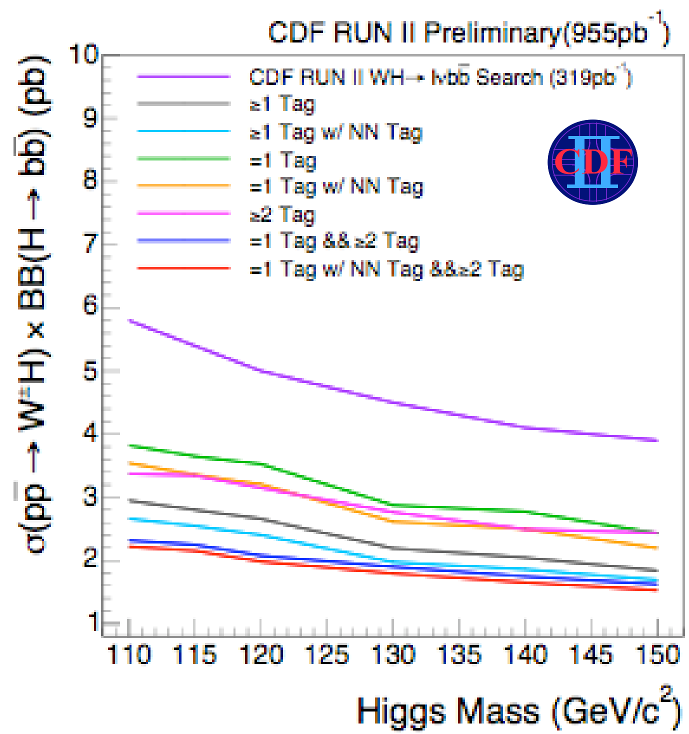
Main backgrounds

- W+jets 60%
- ttbar
  - 10% when 1-tags
  - 20% when 2-tags

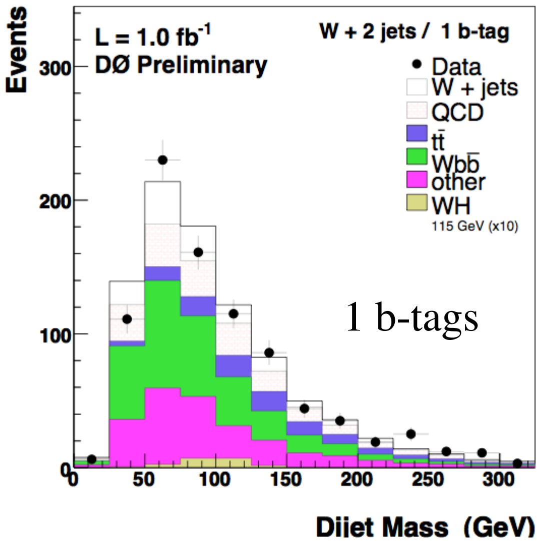
WH → l ν bb

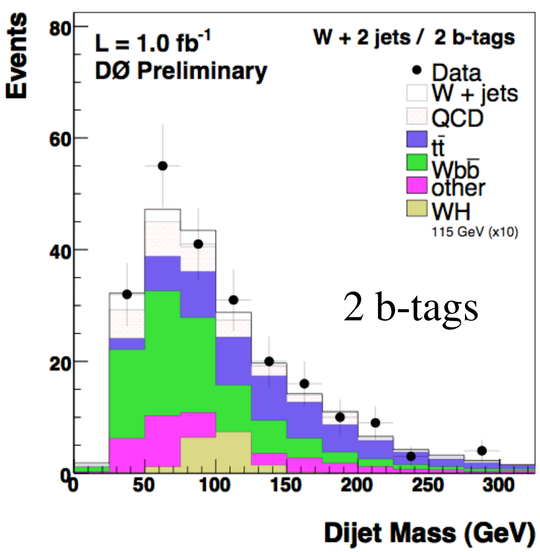
- **CDF 1 fb^{-1} result presented at ICHEP 2006**
  - Neural Network b-tagging used to reduce fake b-jet background
  - Fit done of dijet mass
    - Best expected limit for 2 b-tags fit separate from 1 b-tag + NN
- **Expected limits** (m_H = 110 - 130 GeV)
  - **15 - 23 times SM cross-section**
- **Observed limits**
  - **18 - 23**



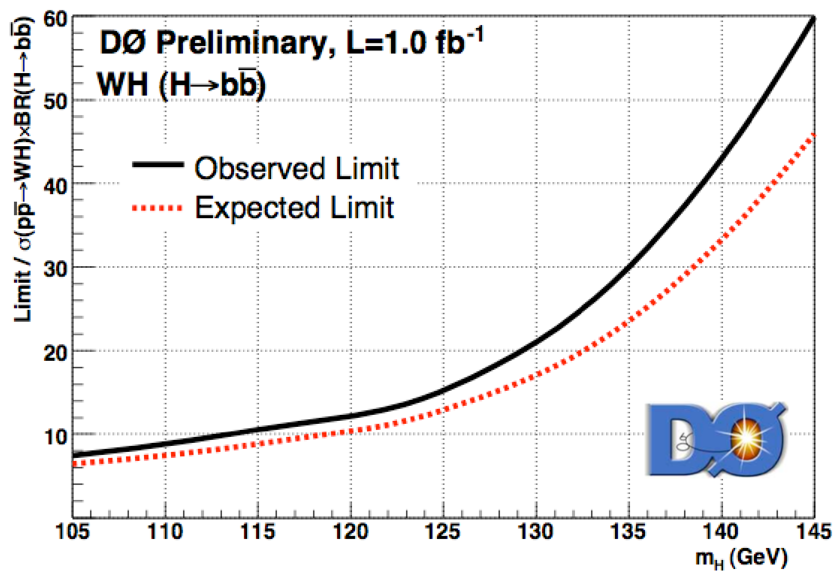


WH → l ν bb





- **New 1 fb^{-1} D0 result presented at Moriond EWK 2007**
- Excellent b-tagging using D0 Neural Network tagger
  - Here NN is used to increase efficiency rather than reduce background (loose and tight)
  - Fit done of dijet mass
    - Best expected limit for 2 loose b-tags, then 1 tight tag
- Expected limit of **9 times SM cross section** at m_H = 115 GeV

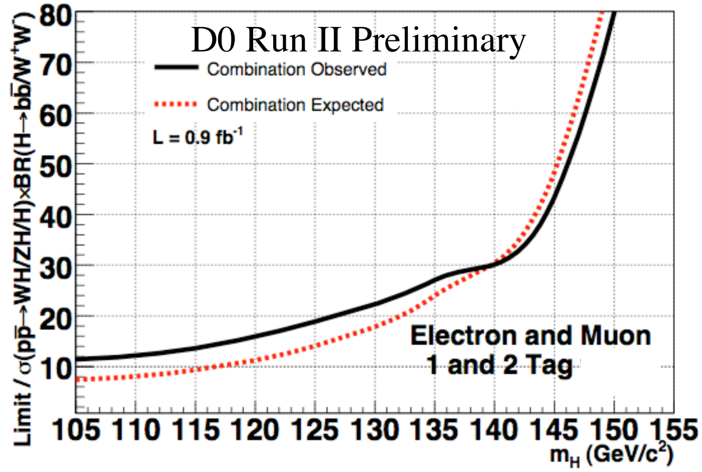


WH → l ν bb

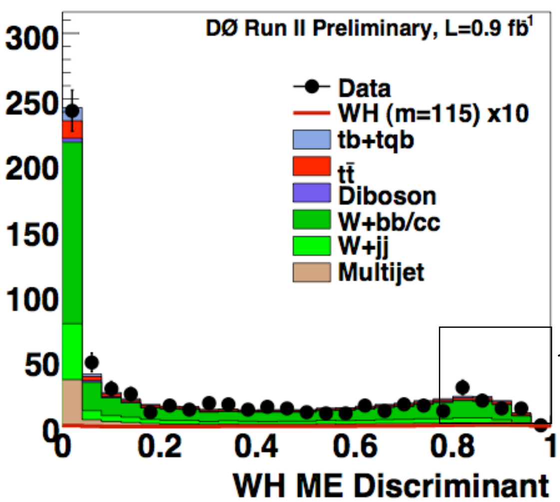
- D0 Matrix Element approach optimized for single top
  - combined for 3 sigma evidence

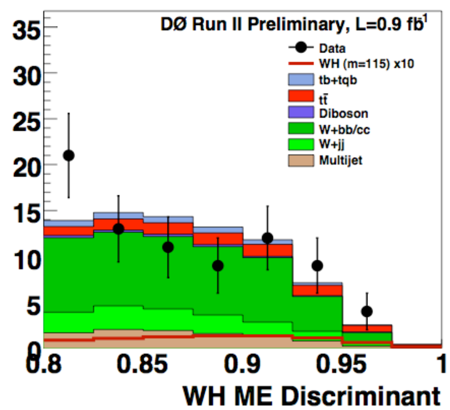
Matrix element technique: use LO ME to compute the event probability densities for signal and background

$$D(\vec{x}) = \frac{P_{WH}(\vec{x})}{P_{WH}(\vec{x}) + \sum c_i P_{Bi}(\vec{x})}$$

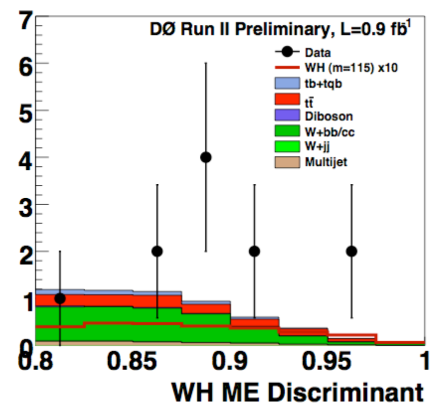


- Expected limit of **10 times SM cross section** at m_H = 115 GeV



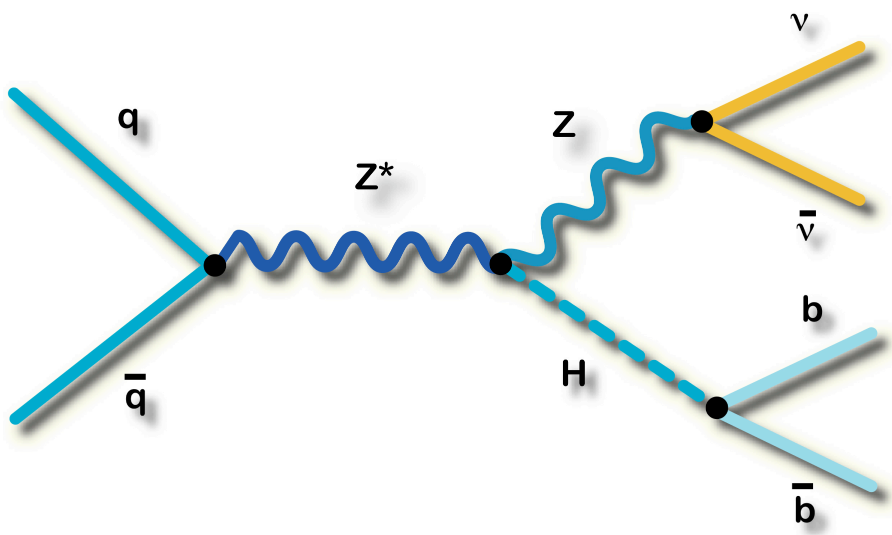


1-tag close-up



2-tag close-up

ZH → ν ν bb

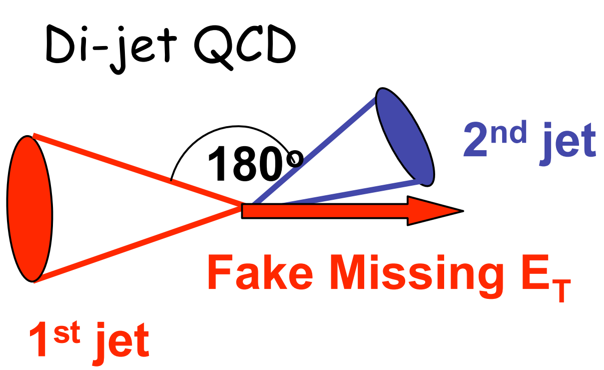


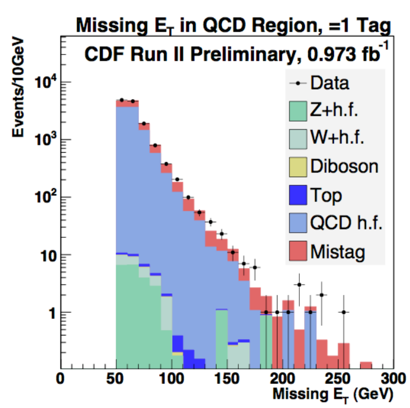
- **Signature**
  - two high transverse energy jets
  - one or two b-tags
  - recoil against large missing transverse energy
  - no leptons or isolated tracks
- **Main backgrounds**
  - 50% W/Z + jets
  - 1 tag
    - 10% ttbar, 30% QCD
  - 2 tags
    - 30% ttbar, 20% QCD
- **Bonus:** event selection also captures WH → lνbb where lepton is not reconstructed

ZH → ν ν bb

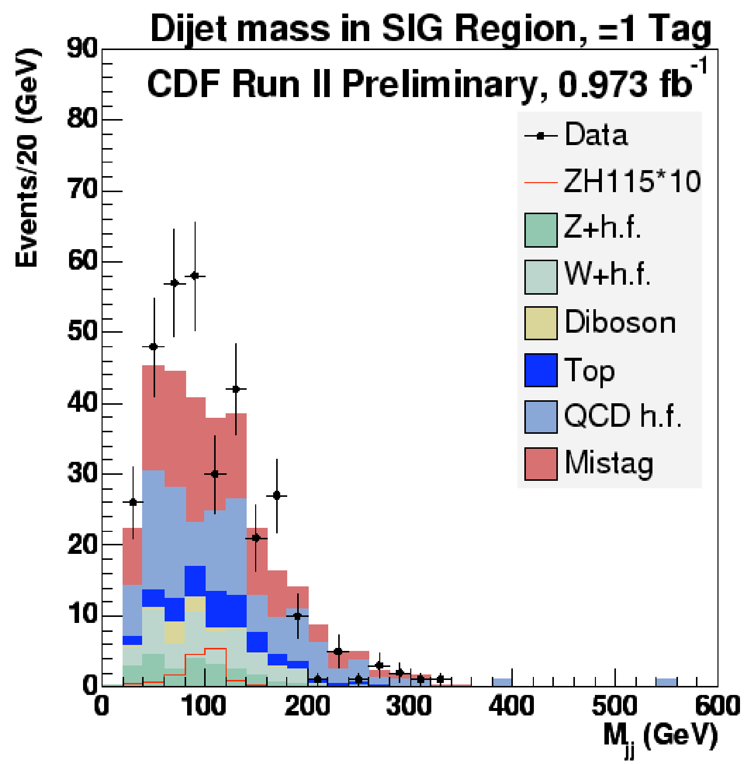
- CDF 1 fb^{-1} results presented at ICHEP 2006
- Fit done of dijet mass
- 1 b-tag and 2 b-tags separated

- Challenge
  - –modeling QCD heavy flavor background
  - –results from jet energy misreconstruction



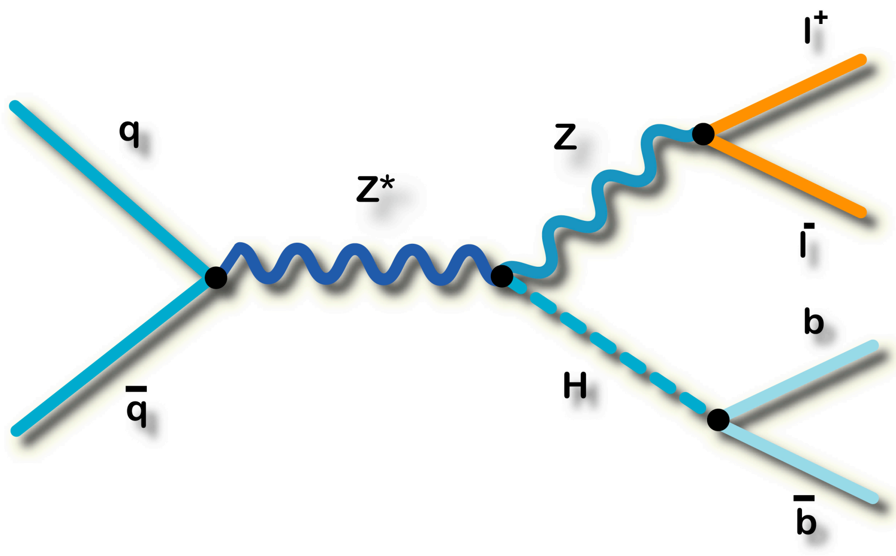


MET in QCD control region:
- no leptons
- met close to second jet



- CDF Expected limits (m_H = 110 - 130 GeV)
  - 15 -> 23 times SM cross section
- CDF Observed limits
  - 18 -> 23

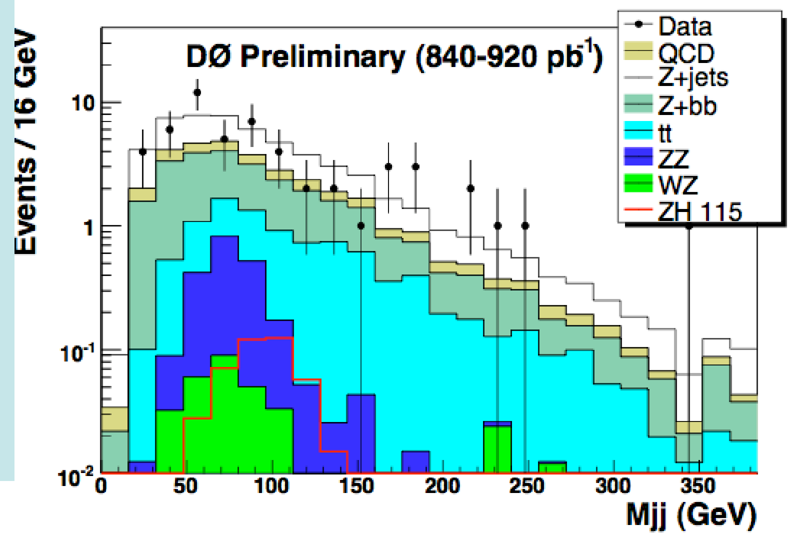
ZH → llbb



- **Signature**
  - two high transverse energy jets
  - one or two b-tags
  - two high Pt leptons consistent with Z invariant mass
- **Main background**
  - 85% Z+jets
  - 8% ttbar

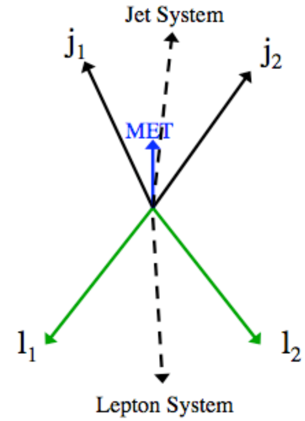
ZH → l^+l^- bb

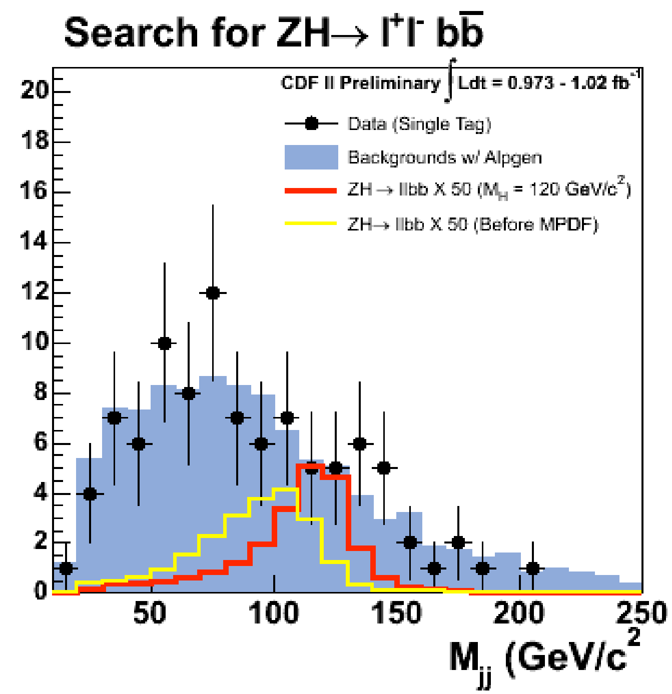
- CDF 1 fb^{-1} ICHEP 2006 analysis
  - uses 2-D Neural Network discriminant
    - for m_H = 115 GeV,
      - $\sigma \cdot$ BR(H->bb) < 2.2 pb
      - 27 times SM (23 expected)
- D0 1 fb^{-1} November 2006 analysis
  - fits dijet mass in 1-tag & 2-tag samples
      - $\sigma \cdot$ BR(H->bb) < 2.7 pb
      - 33 times SM



Improving ZH → l^+l^- bb

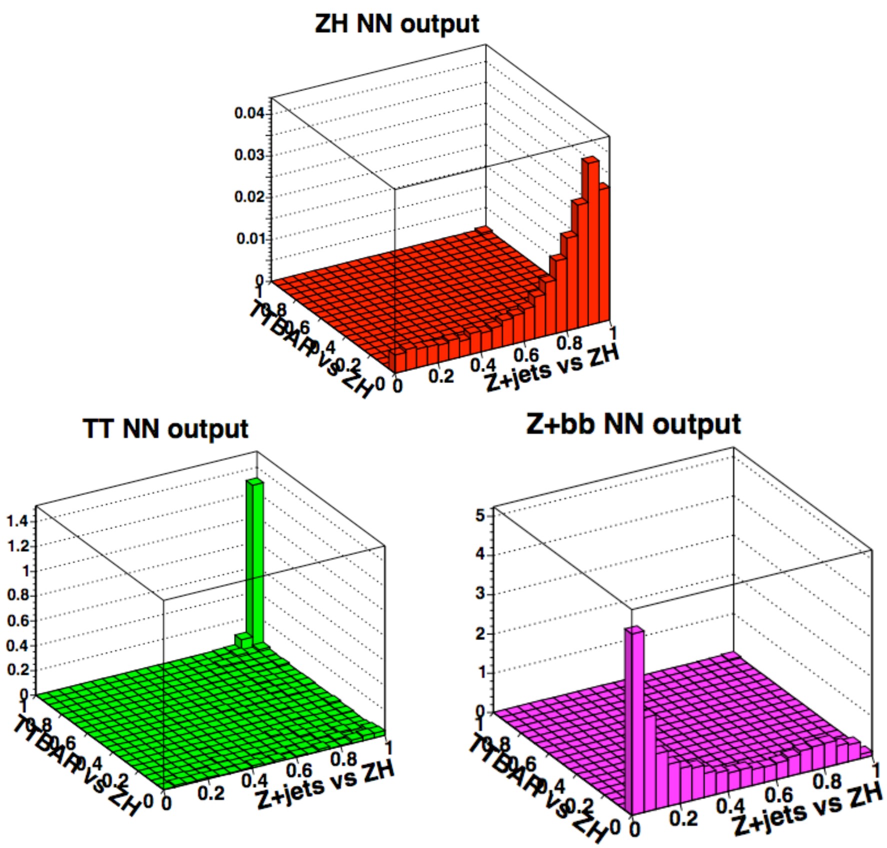
- New CDF result for this conference using the same 1 fb^{-1} dataset
- Improvements
  - split data into 2 loose b-tags and 1 tight single tag
  - now use a Met Projection Dijet Fitter (MPDF)
    - Missing energy in Z+jets events results from mismeasured jets
    - MPDF corrects jets based on their projection onto the MET direction
    - Improves dijet mass resolution
      - from 17% to 10%
    - Previous 2D Neural Network is reoptimized to make use of improved dijet mass resolution
    - Results in effective luminosity increase of 30%



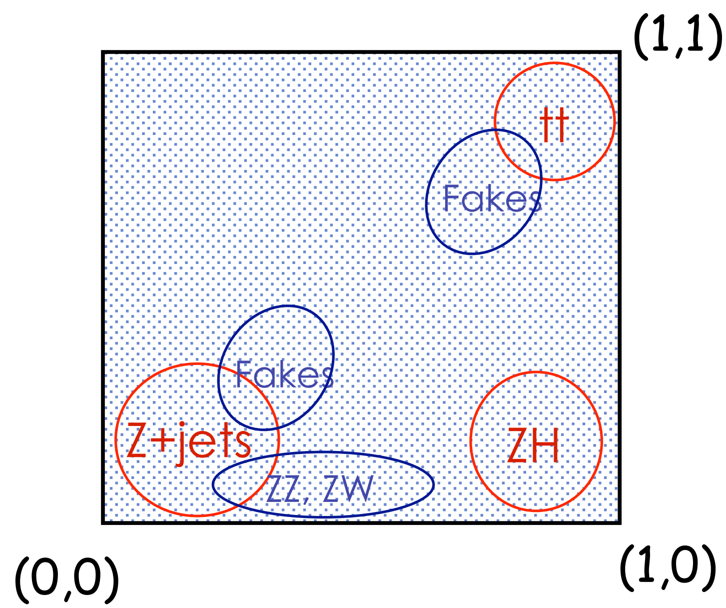


ZH → ll bb

- 2D Neural Network
  - Trained on main backgrounds
  - Z+jets (85% BKG)
  - ttbar (8% BKG)



2D Neural Network Discriminant

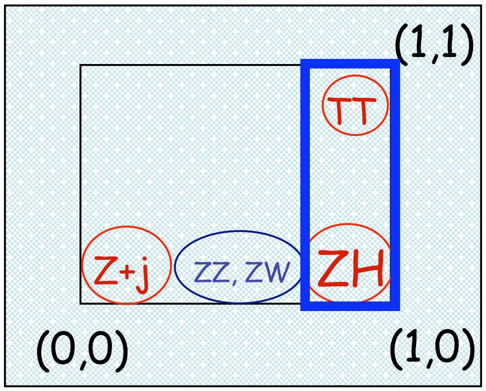


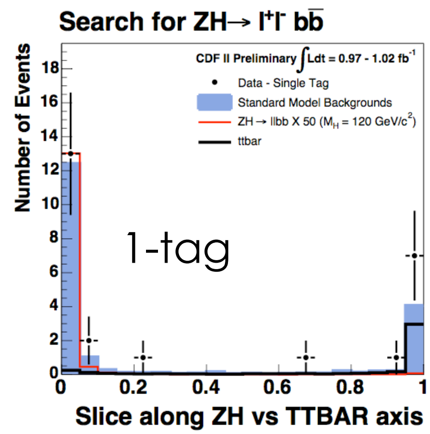
Allow other backgrounds to fall in place

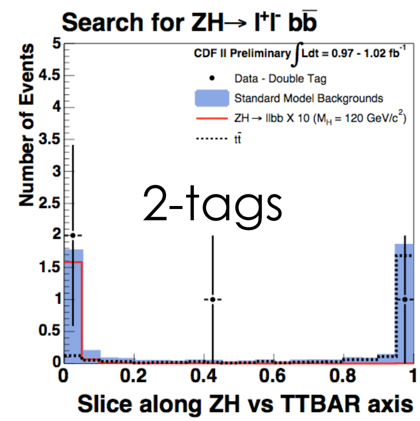
New ZH → l l bb CDF results

Shown are projections of "slices" along axes

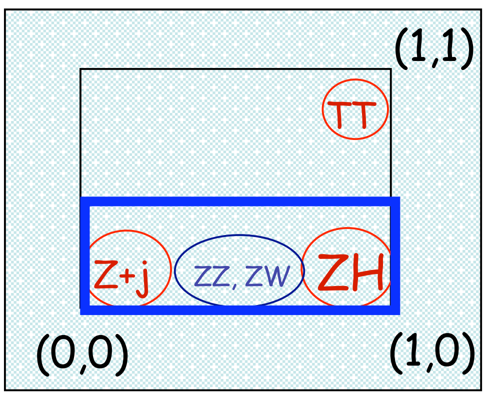
tt slice

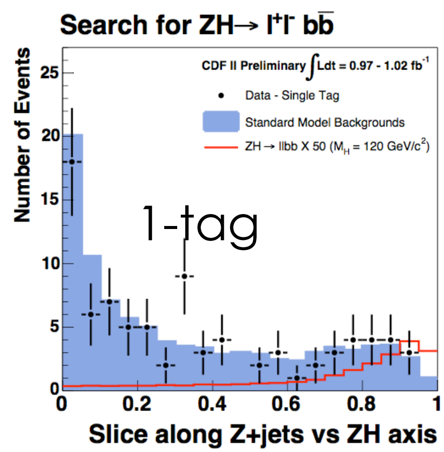


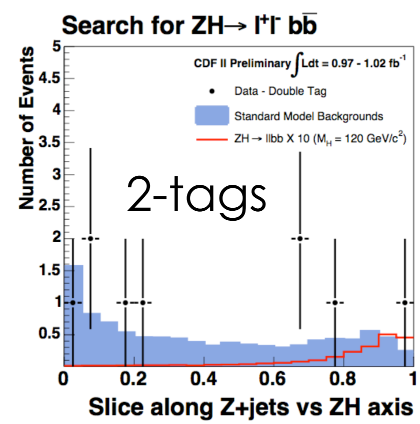




Z+jets slice



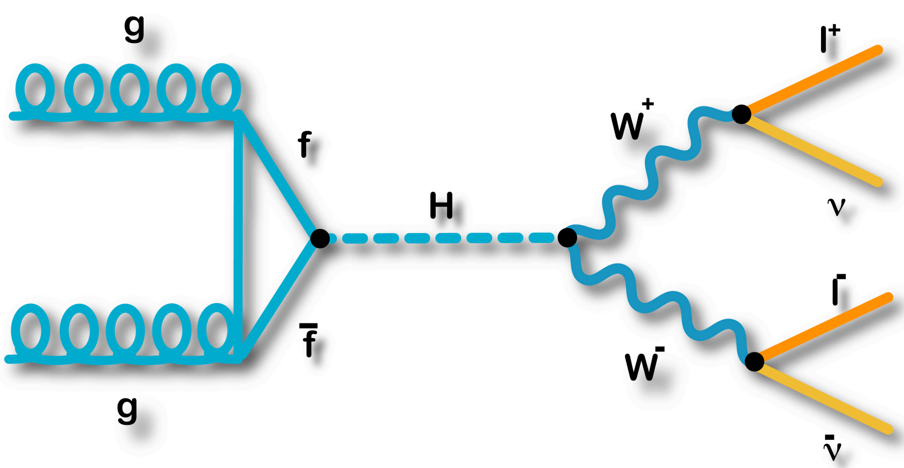




New 1 fb^{-1} CDF result : 16.3 Observed, 16.2 Expected (was 23)

Equivalent to twice as much data !

gg → H → WW



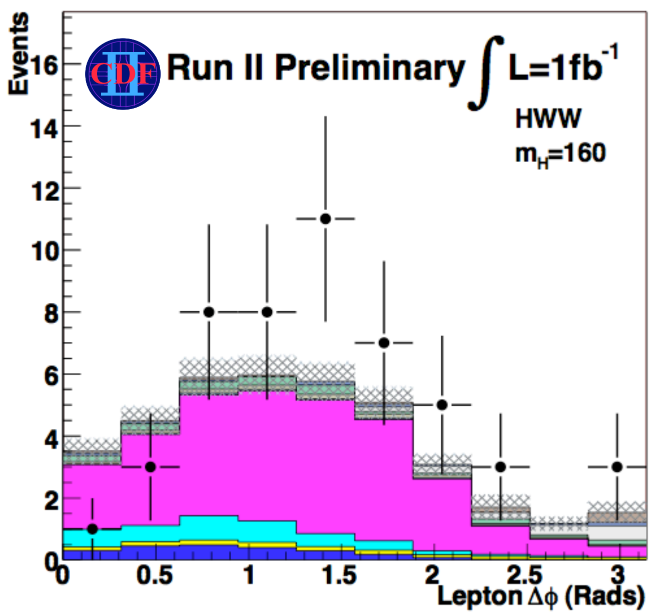
- **Signature**
  - two high Pt leptons (e, or μ)
  - large missing transverse energy
- **Main backgrounds**
  - 45% WW
  - 33 % Drell Yan

gg → H → WW

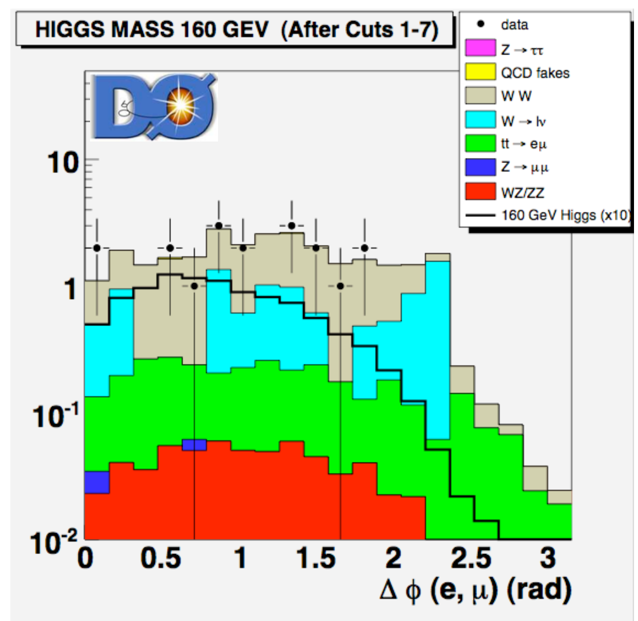
- **g -> WW vs. H-> WW**
  - spin-0 higgs results in different angular correlations of leptons
  - $\Delta\Phi$(lepton,lepton) good discriminant
- Both CDF and D0 have 1 fb^{-1} results with fit of $\Delta\Phi$(lepton,lepton)

For m_H = 160 GeV,
Expected (observed)

Aspen 2007:
σ*H(WW) < 3.6 (2.3) pb



ICHEP 2006:
σ *H(WW) < 2.2 (3.0) pb



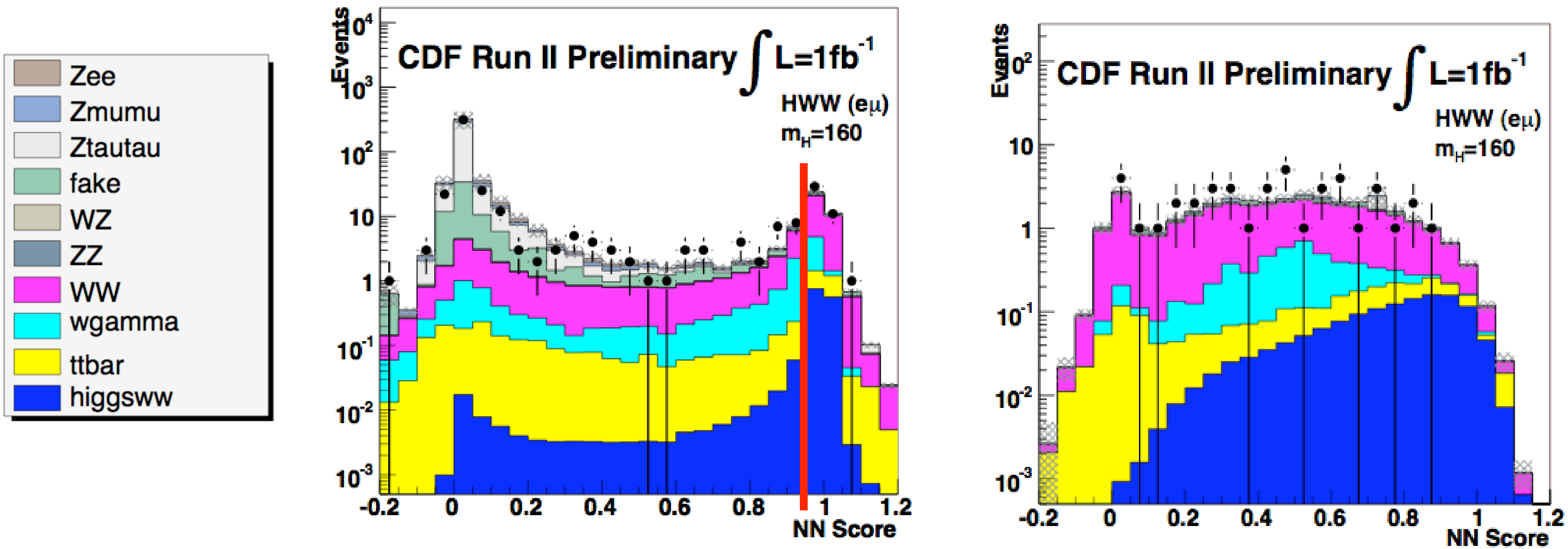
gg → H → WW

- Now, **new improvements** to H->WW sensitivity at CDF
  - Improved lepton acceptance
  - Advanced analysis techniques
    - Neural Network
    - Matrix Element

gg → H → WW: neural networks

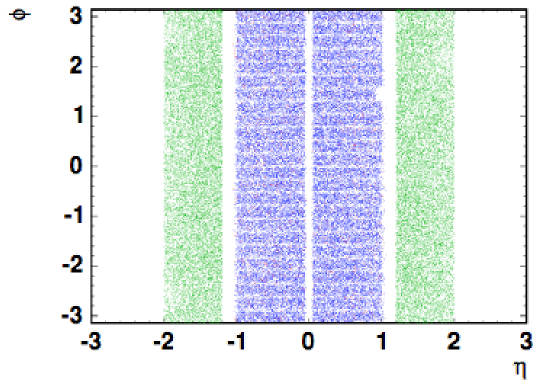
- Neural Network analysis applied to previous 1 fb^{-1} result
  - Expected 2.5 events signal, 108 events background
  - Two neural networks are used to distinguish Drell Yan & W^+W^-
  - Cut is made on Drell Yan Neural Net output
  - Likelihood fit done on W^+W^- Neural Network output
    - Separate cuts and fit in e^+e^-, μ^+e^-, $\mu^+\mu^-$

Drell Yan NN W^+W^- NN

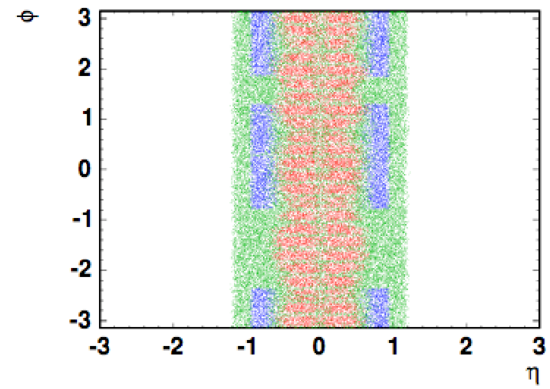


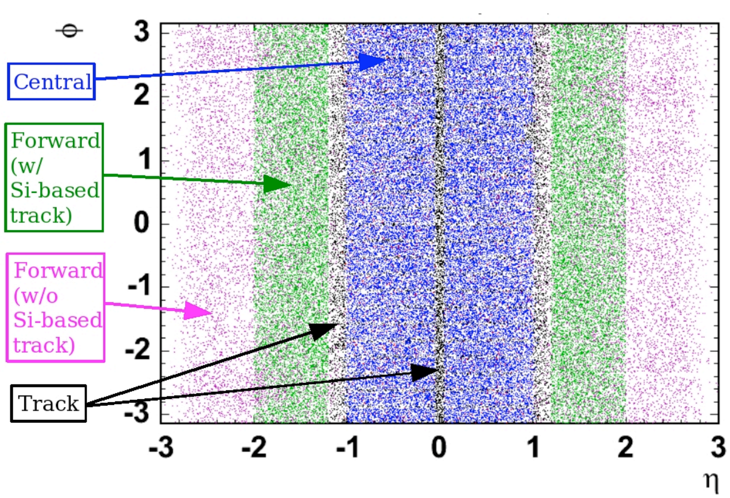
gg → H → WW: lepton acceptance

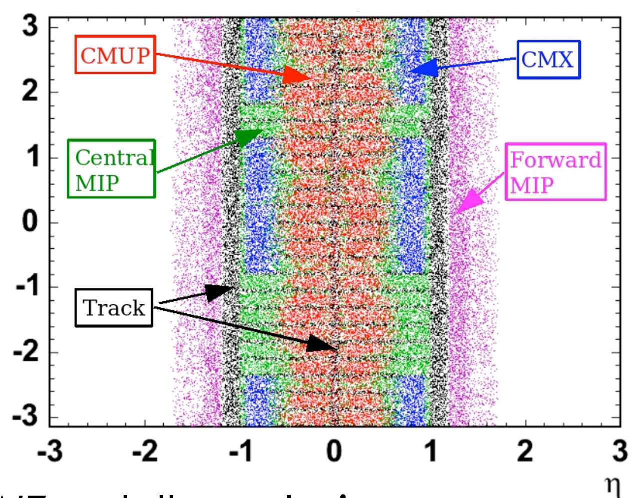
Adding electron categories



Adding muon categories





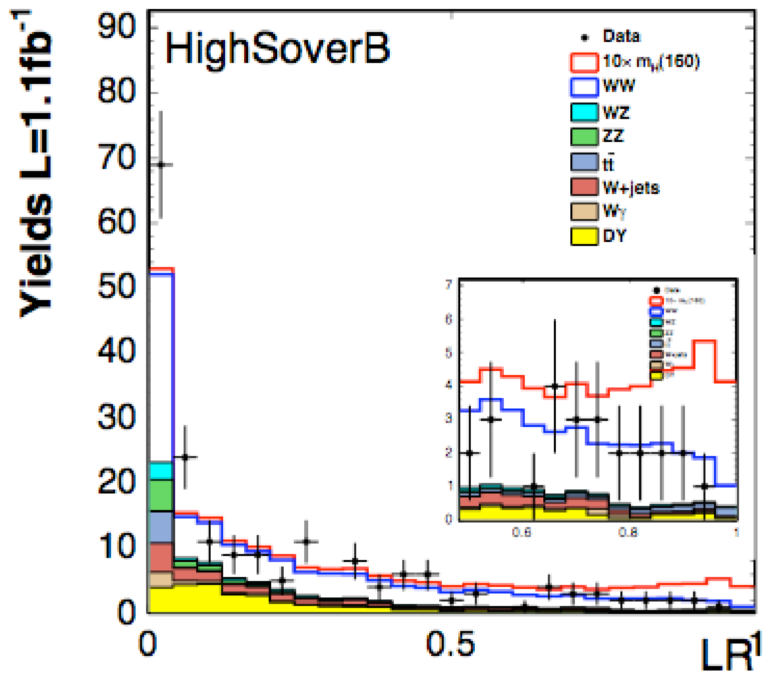


Categories developed for the WZ -> lvll analysis

- WZ signal doubled - proportional background increase
- led from evidence to 5.9 sigma discovery in WZ -> lvll analysis

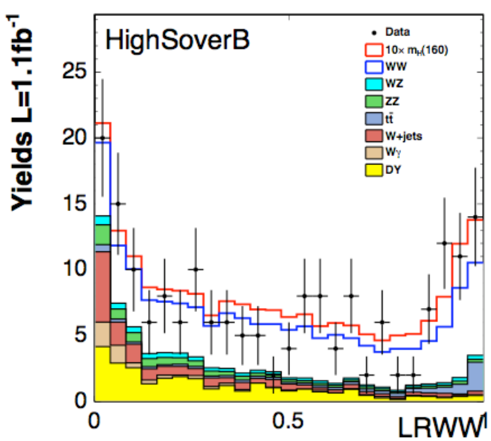
gg → H → WW: matrix element

- Matrix Element analysis
  - Probability used for H->WW, WW, ZZ, W+fake, W+conversion electron
  - ADD DISCRIMINANT EQN.
  - Uses additional lepton categories
    - 4 events signal, 323 events background
    - **60% increase** in signal

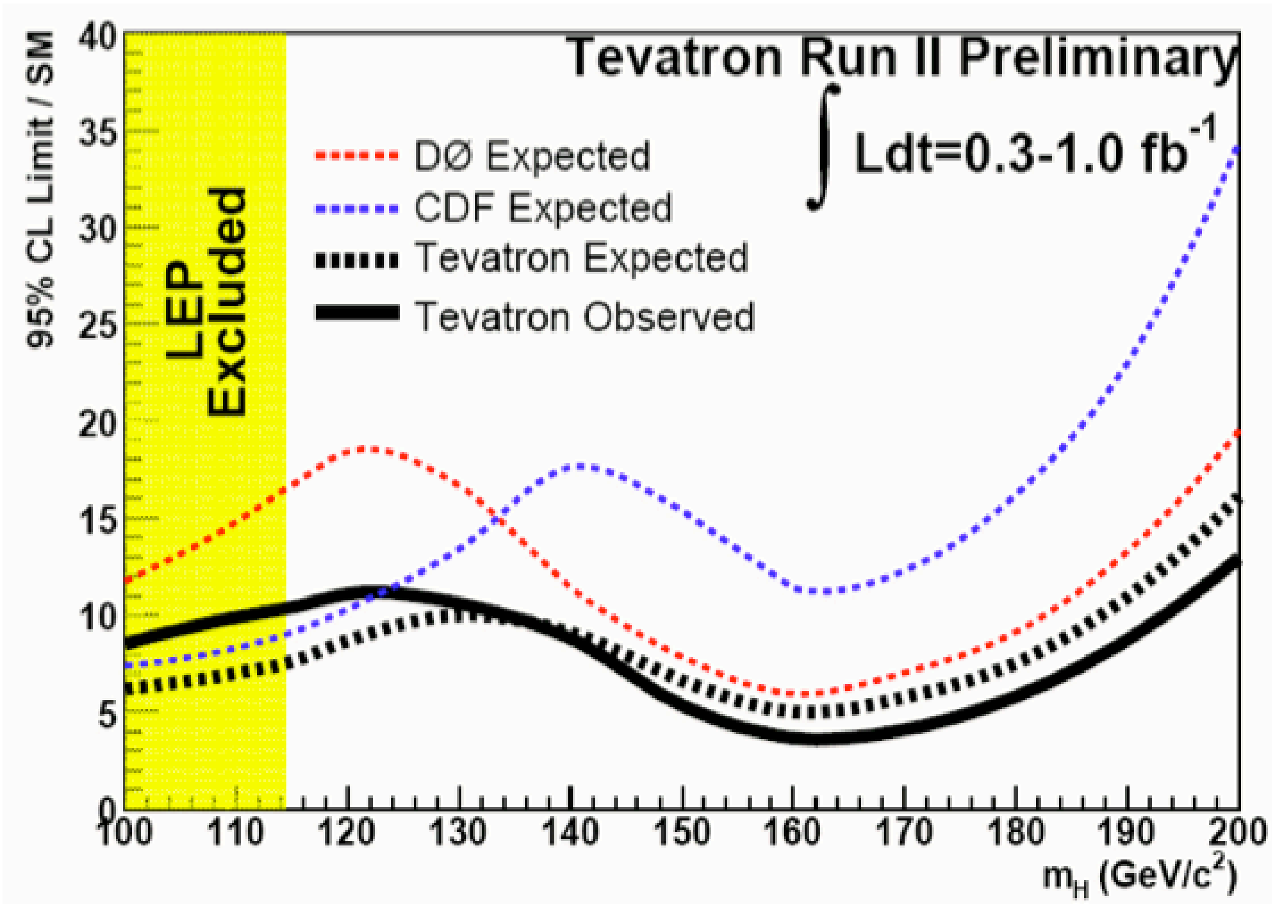


Result of discriminant in the signal region

Validation for leading WW background



Combinations



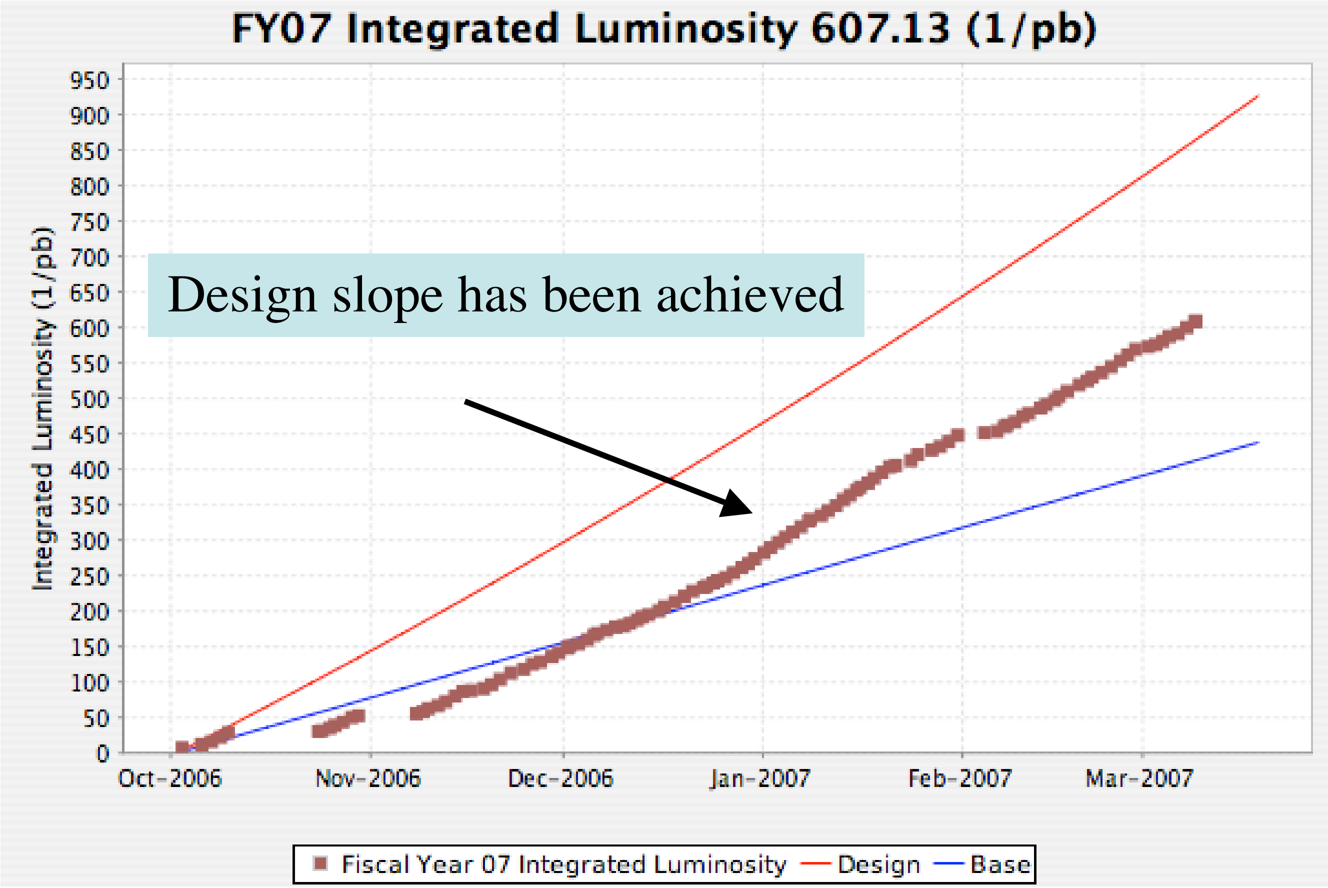
- The above limits do not include
  - new CDF ZH->llbb
  - new CDF H->WW results
  - new D0 WH results

Summary of Tevatron Results

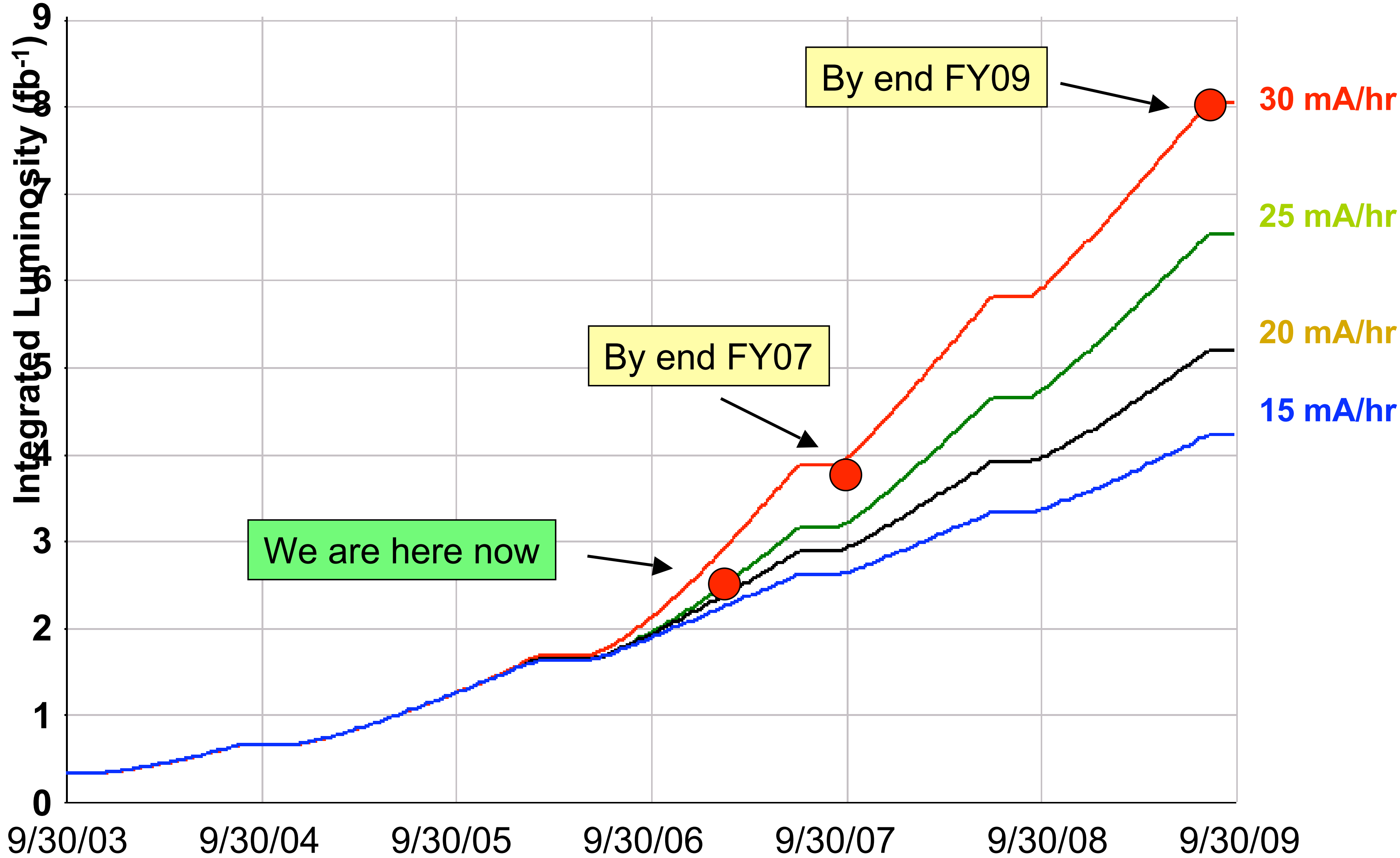
Analysis	CDF limit @ M_H = 115 GeV factor above SM observed (expected)	D0 limit factor above SM observed (expected)
ZH -> νν bb @ 115	($1fb^{-1}$) 16 (15.4)	($0.25 fb^{-1}$) (41)
WH -> lν bb @ 115	($1fb^{-1}$)	($1fb^{-1}$)
M_{jj}	XX (23)	10 (9)
ME		13 (10)
ZH -> llbb @ 115	($1fb^{-1}$) 16.3 (16.2)	($1fb^{-1}$) XX (33)
H -> WW -> lνlν @ 160 ΔΦ (l,l)	9.2 (6.0)	5.8 (7.8)
NN	5.7 (4.8)	
ME	3.5 (4.8)	

Luminosity this year so far ...

- Red indicates optimal design goal
- Blue is baseline goal



Luminosity projections



Conclusions

- First time Higgs searches shown
  - CDF ZH -> llbb Improved 1 fb^{-1} Neural Net
  - CDF H -> WW 1 fb^{-1} Neural Net
  - CDF H -> WW1 fb^{-1} Matrix Element
- New from last week
  - D0 WH 1 fb^{-1} Matrix Element
  - D0 WH 1 fb^{-1} Dijet mass

- CDF and D0 are not just talking about it …
- They are working hard to improve existing analyses
  - Improving b-tagging
  - Improving lepton acceptance
  - Improving jet resolution
  - Improving analyses techniques
- Luminosity extrapolations are looking good

- This one's going to be close !