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

Focus:

2 new results for Moriond QCD

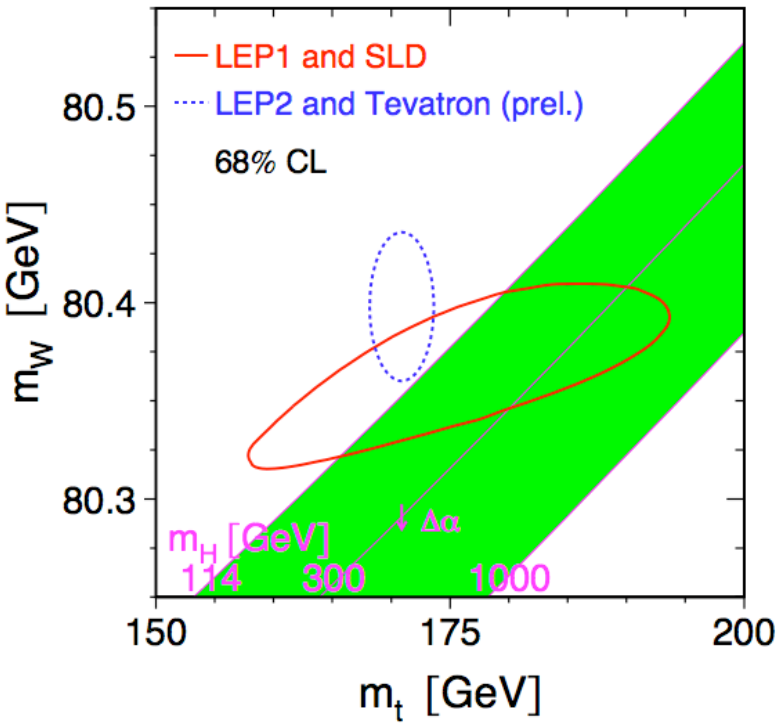
2 results new for Moriond Electroweak

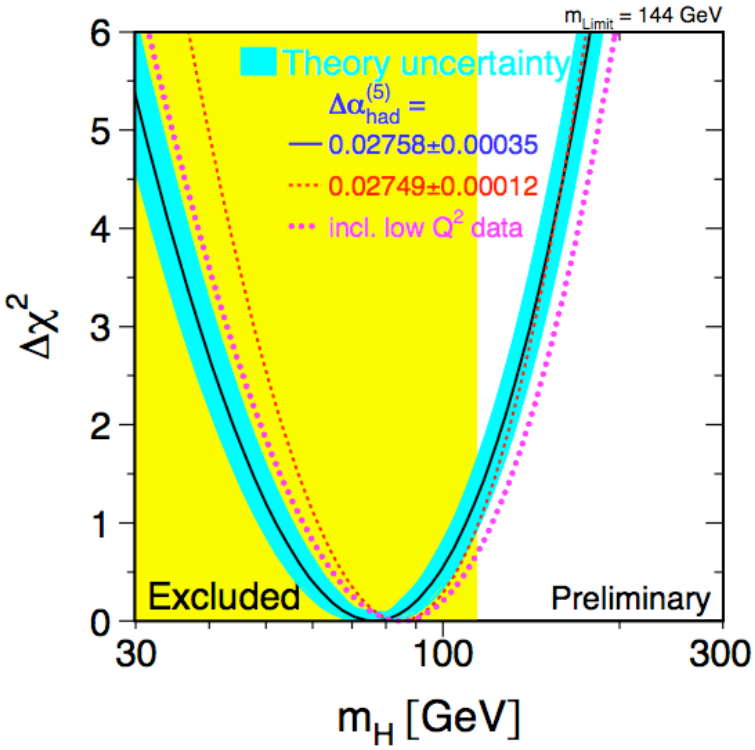
Constraints on the Higgs

- 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 coming up)

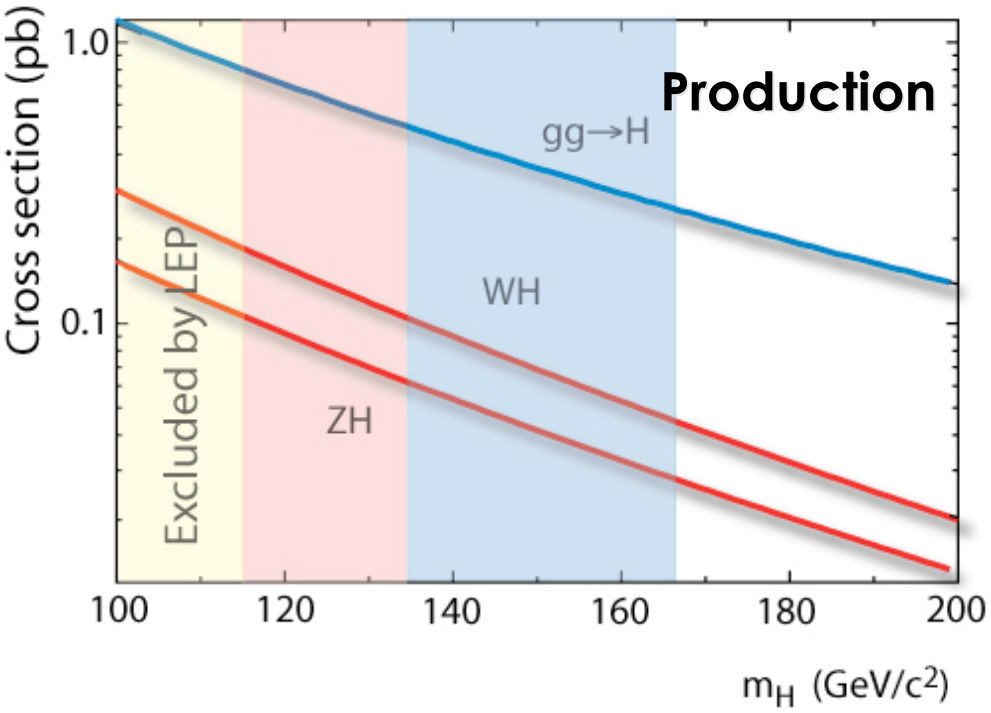
m_H = 76 +33 -24 GeV

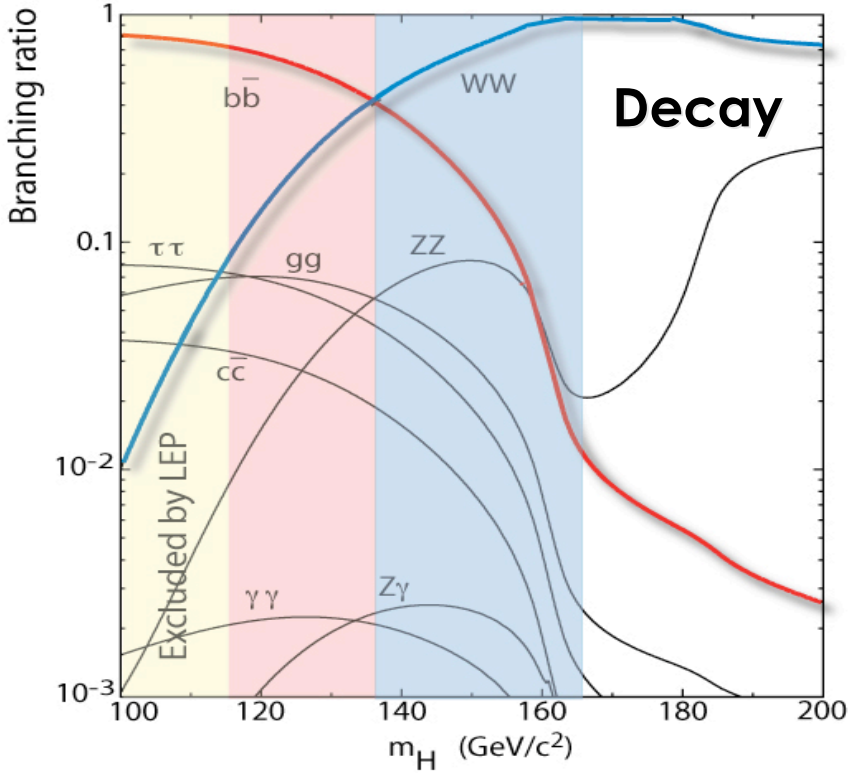
m_H < 144 GeV @ 95 % CL





Higgs at the Tevatron





Higgs Production

- < 1 pb

Compare to

- 12 pb WW
- 7 pb top pair
- 3 pb top single
- 2 pb ZZ

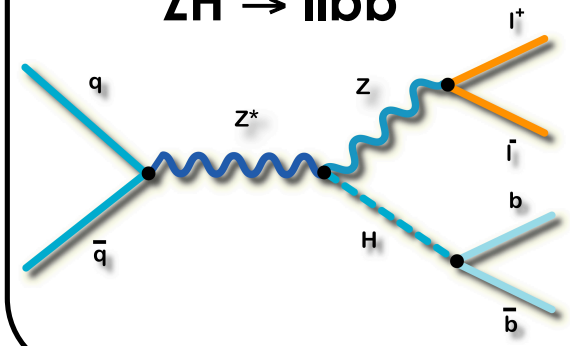
Most sensitive Tevatron searches

- If low mass (m_H<135 GeV):
  - Production with W or Z
  - Decay to a b-quark pair
- If high mass (m_H>135 GeV):
  - Direct production
  - Decay to a W-boson pair

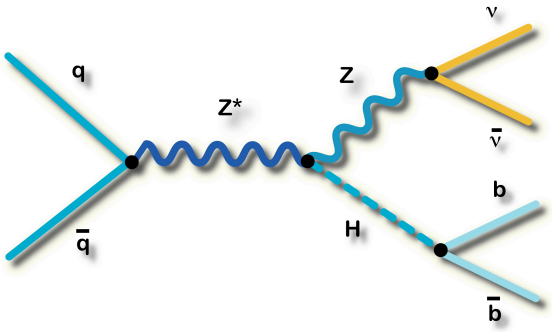
Higgs at the Tevatron

- For low mass Higgs : 3 main channels

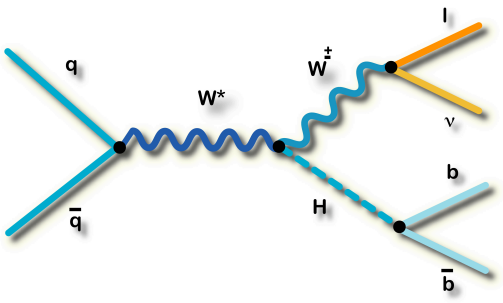
ZH → llbb



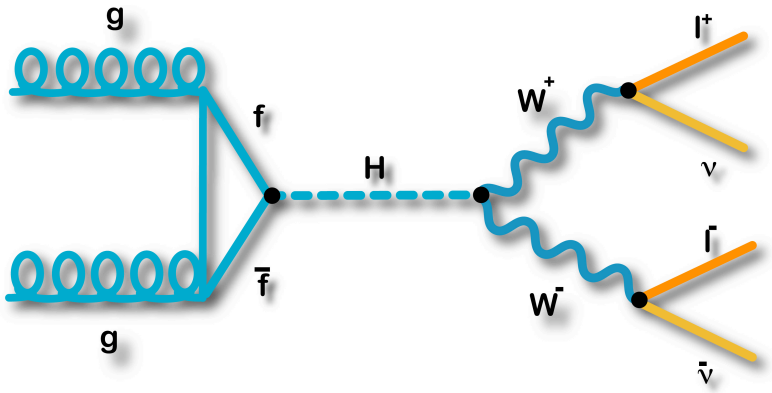
ZH → ννbb



WH → lνbb



- For high mass Higgs : 1 main channel

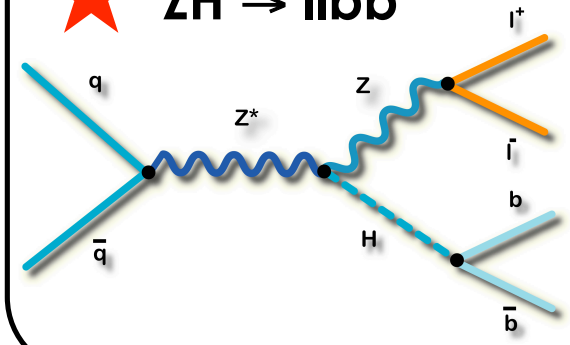


gg → H → WW → lνlν

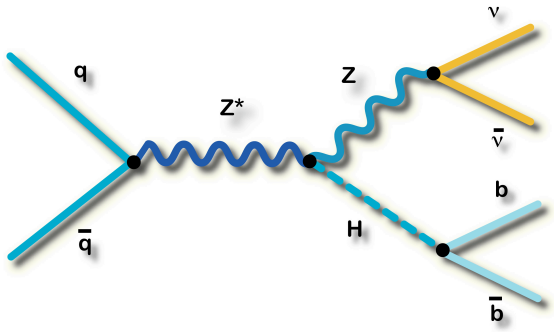
Higgs at the Tevatron

- For low mass Higgs : 3 main channels

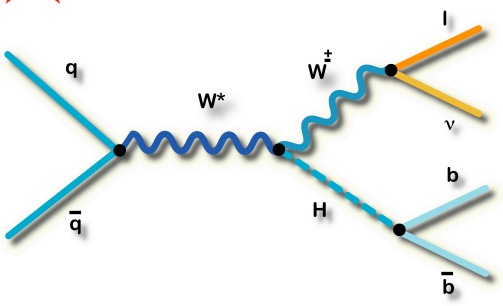
★ ZH → llbb



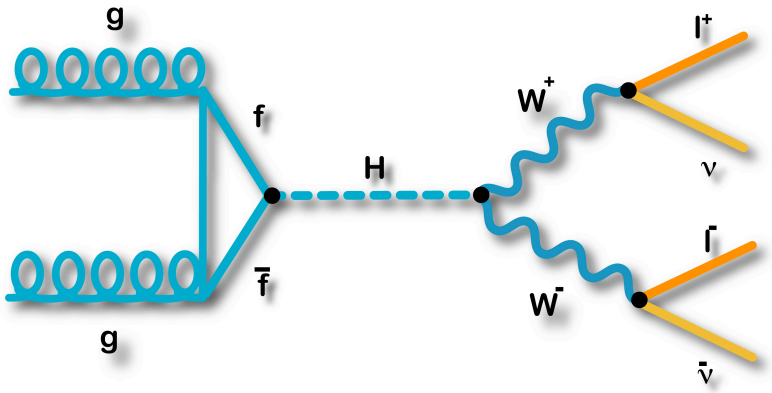
ZH → νν̄bb



★ WH → lνbb



- For high mass Higgs : 1 main channel



★ gg → H → WW → lνlν

★ New Results: Now all channels done with 1fb-1 of data!

Experimental challenges

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

Typical events in 1 fb^{-1} (l = e,μ)	ZH → llbb	ZH → ννbb	WH → lνbb	H → WW → lνlν
Signal Produced	**5**	**15**	**30**	**20**
Signal Accepted	**1**	**2**	**3**	**4**
Background	**100**	**300**	**500**	**300**

Typical numbers above, but :

… **Increasing signal a little can greatly increase background**

… Can **separate into categories** or add cuts for better Signal/Background

Experimental challenges

- Finding (or excluding) Higgs at the Tevatron **possible**
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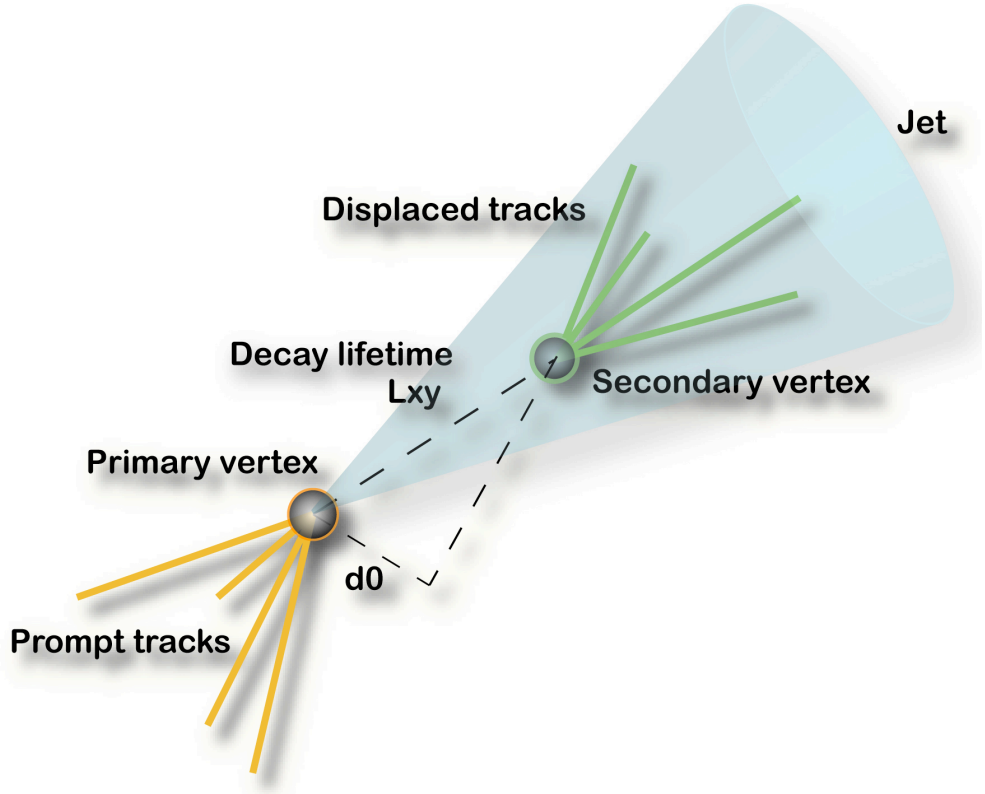
Typical events in 1 fb^{-1} (l = e,μ)	ZH → llbb	ZH → ννbb	WH → lνbb	H → WW → lνlν
Signal Produced	**5**	**15**	**30**	**20**
Signal Accepted	**1**	**2**	**3**	**4**
Background	**100**	**300**	**500**	**300**

- **For discovery / exclusion, need to**
  - improve **signal acceptance** for each channel
  - **reduce backgrounds** when possible
  - **combine** all above channels
  - **combine** CDF and D0
  - integrate close to **8 fb^{-1}** of data per experiment

Reducing backgrounds

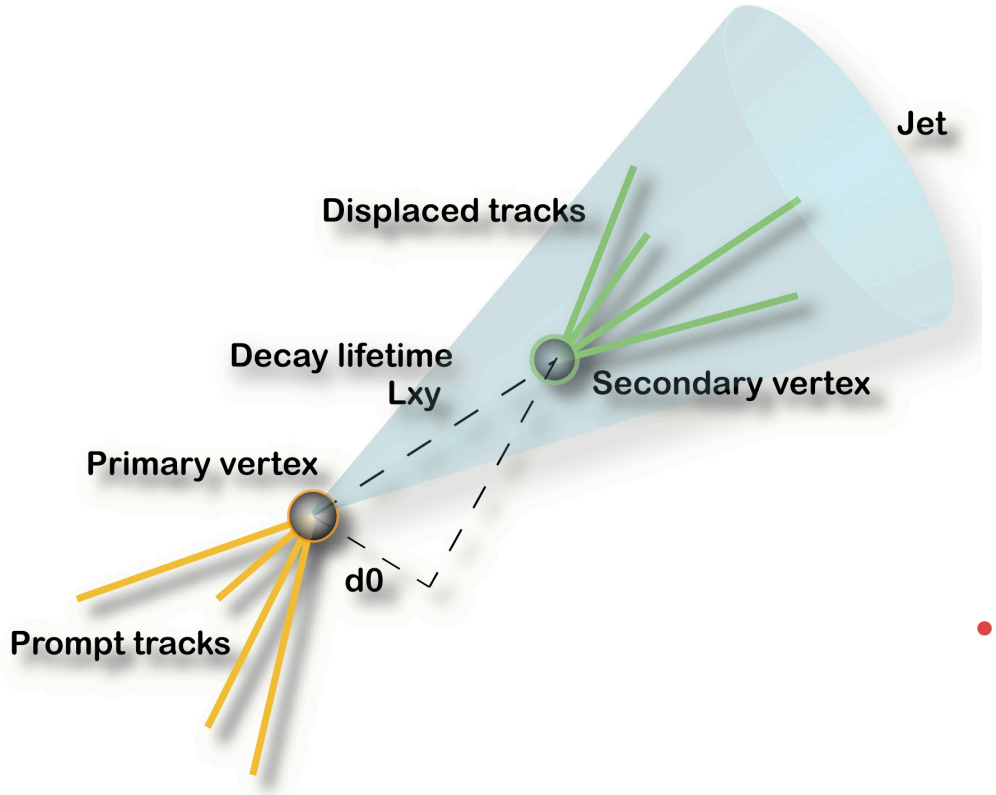
For m_H < 135 GeV "b-jet tag" crucial



b-jet tag = Identify 2nd vertex

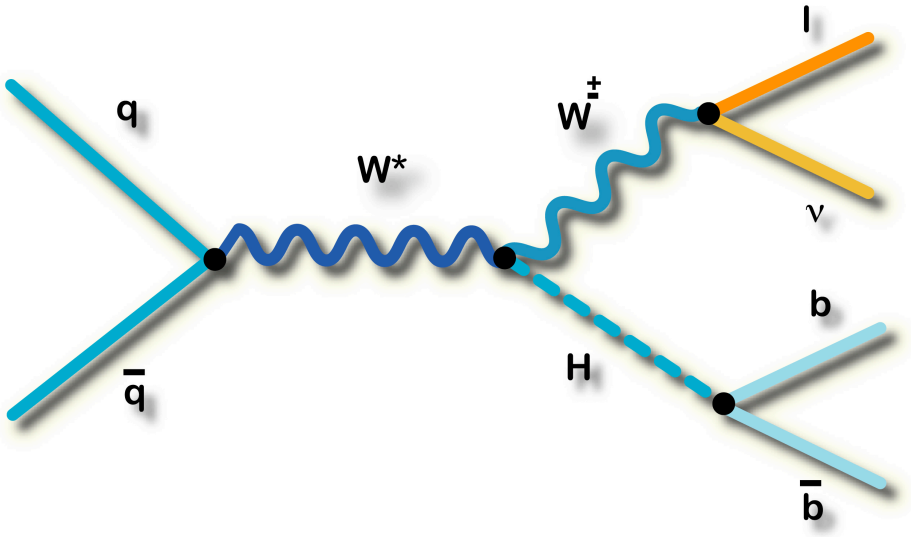
Reducing backgrounds

For m_H < 135 GeV "b-jet tag" crucial



- **Secondary Vertex Algorithms at CDF**
  - 40 - 50 % efficient (tight, loose)
  - 0.5 - 1.5 % fake rate from light jets
  - S/B improves
    - from **1:1000**
    - to **1:100**
  - Events with 2 b-tags
    - Fake b-jets removed
    - S/B is **1:50**
    - Treat as separate channel
  - Neural Net to improve b purity
- **Neural Network tagger at D0**
  - Used to increase efficiency
  - 50 - 70% efficient (tight, loose)
  - 0.5 - 4.5% fake rate

$WH \rightarrow l \nu\, bb$



Signature

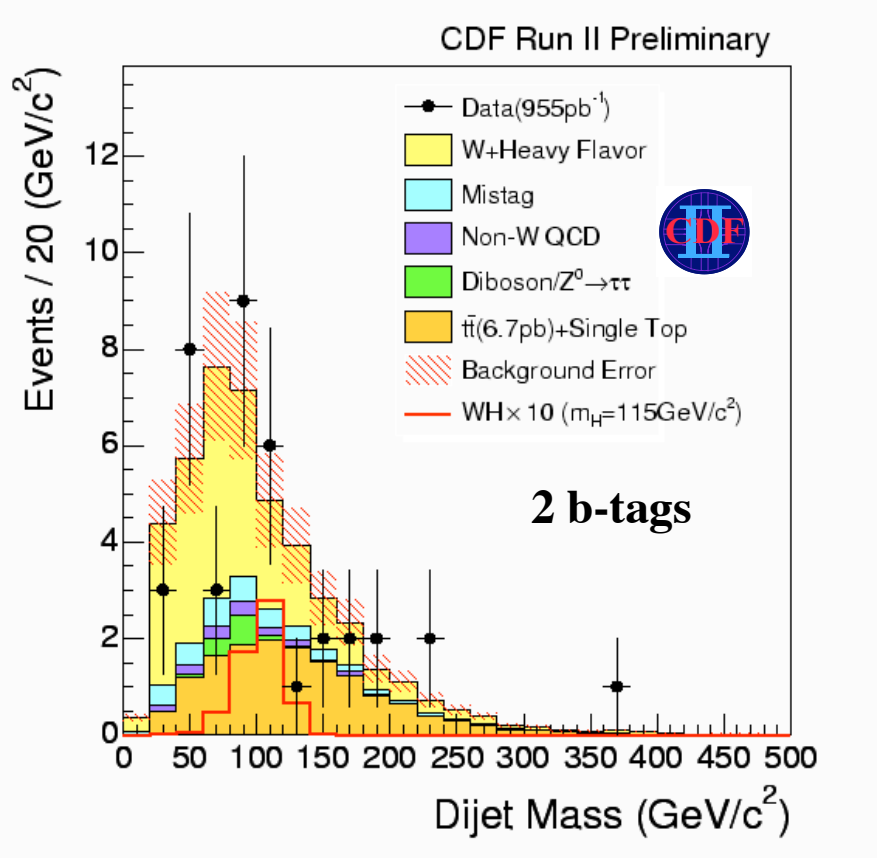
- high p_T lepton
- missing transverse energy
- two high transverse energy jets
- one or two b-tags

Main backgrounds

- W+jets 60%
- ttbar & single top

WH → l ν bb

- **CDF result presented at ICHEP 2006**
  - Neural Network b-tagger reduces c & light jets
    - uses number of tracks, pt of tracks, vertex mass, decay length, …
  - Fit done of dijet mass
    - Separately for 2 b-tags & (1 b-tag + NN)



- **Expect. 95% CL limit (m_H = 115 GeV)**
  - **< 2.2 pb**
  - **< 17 times SM cross-section**
- **Observed limits**
  - **< 3.4 pb**
  - **< 26 times SM cross-section**

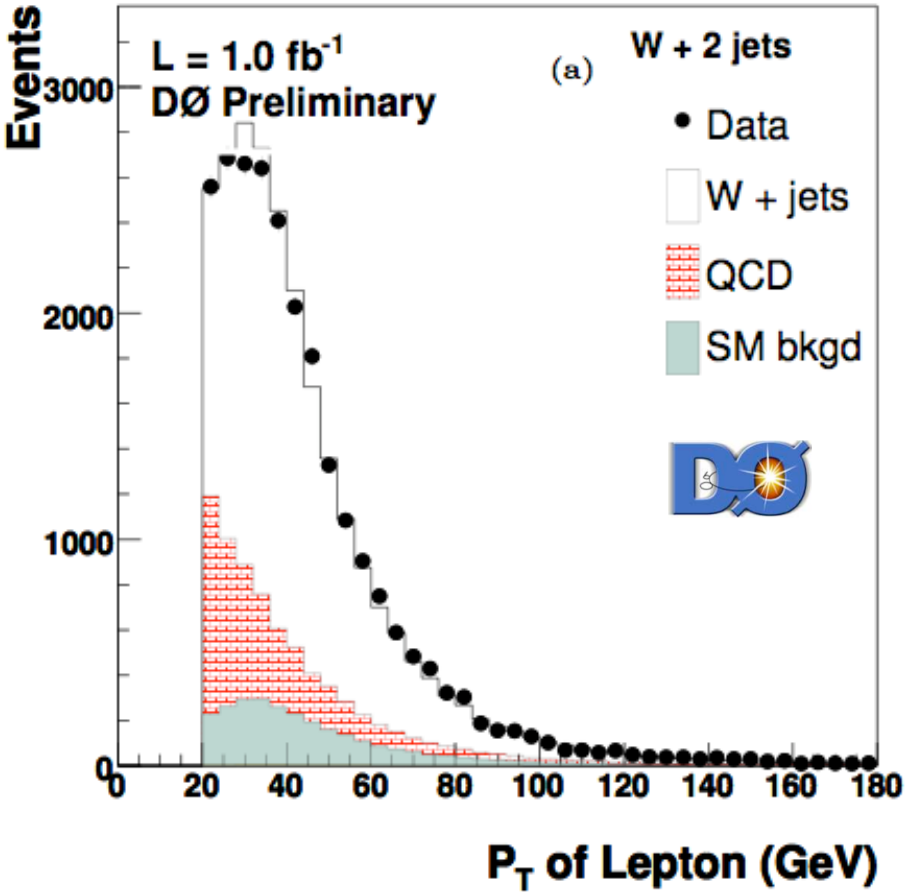
WH → l ν bb

- **D0 result presented at Moriond EWK 2007**

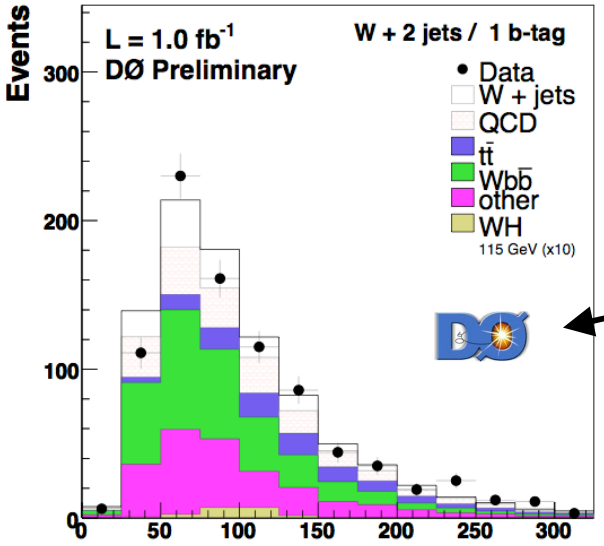
- Excellent b-tagging using D0 Neural Network tagger
  - Here NN increases efficiency for b-tag

- Fit done of dijet mass
  - Search for 2 loose b-tags, else 1 tight tag

- Improvements : Multiple muon triggers
  - get ~100% muon acceptance
  - single muon, muon+jets, …
  - ~ 50% more signal

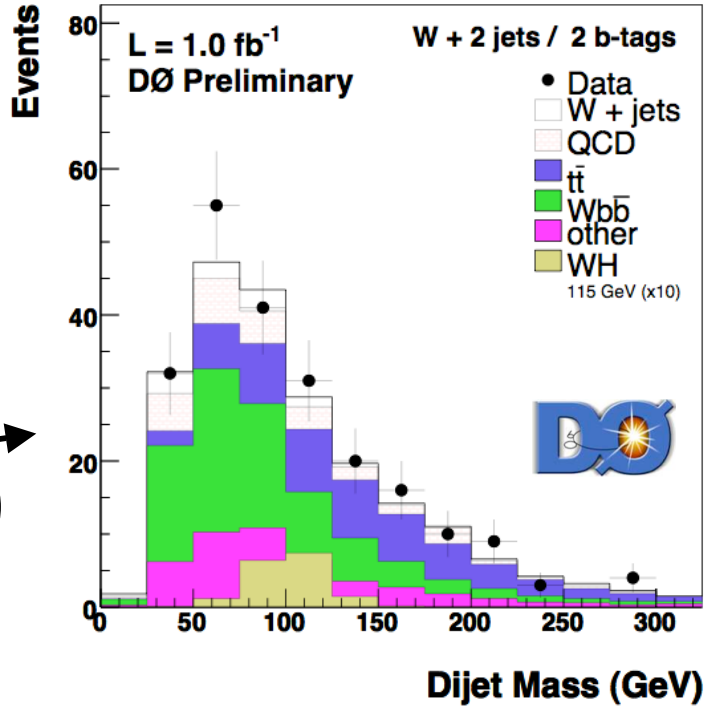


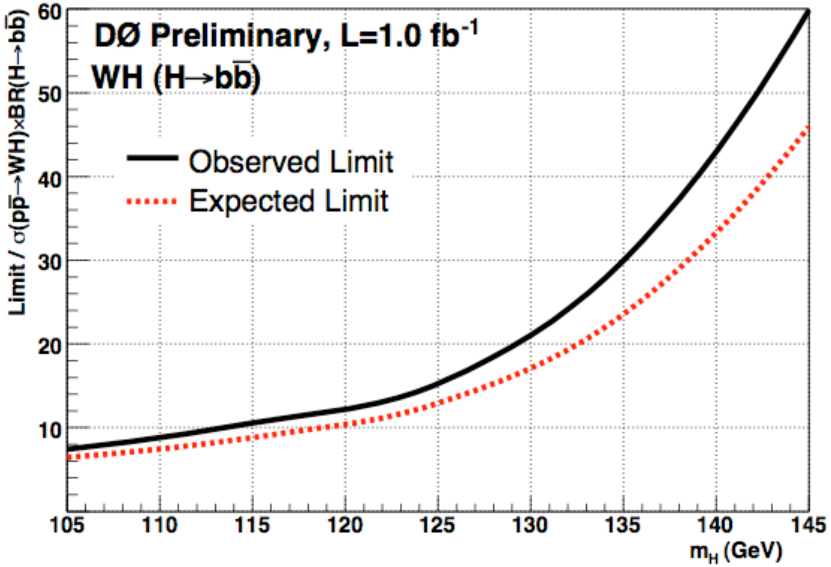
WH → l ν bb



Dijet mass
1 b-tag

2 b-tags
(most sensitive)





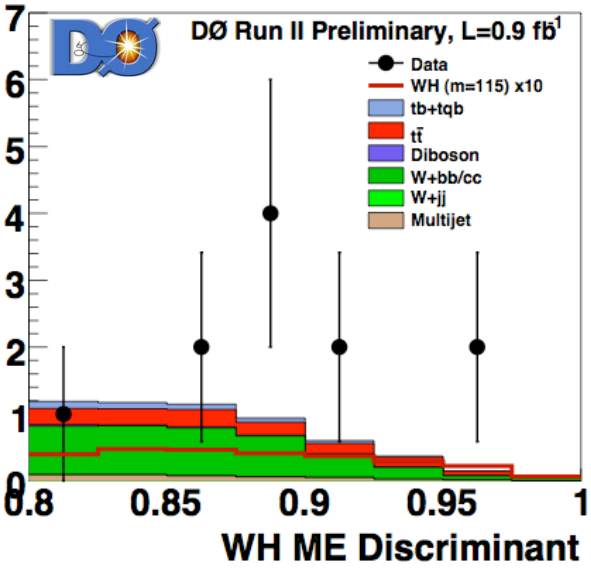
D0 new result

- **Expect. 95% CL limit (m_H=115 GeV)**
  - **< 1.1 pb**
  - **< 9 times SM cross-section**
- **Observed limit**
  - **< 1.3 pb**
  - **< 10 times SM cross-section**

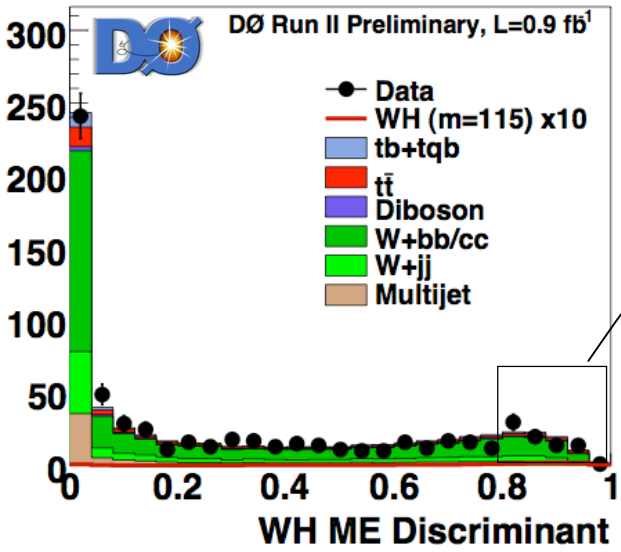
WH → l ν bb

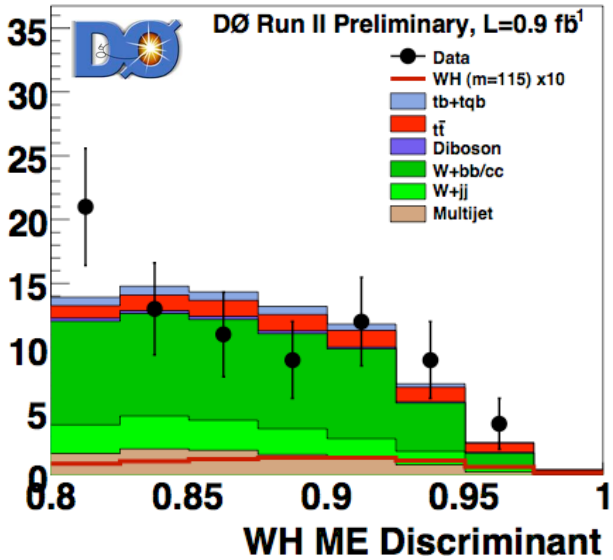
- **D0 result presented at Moriond EWK 2007**
- Matrix Element approach carried over from single top
  - combined for 3 sigma evidence
  - see L. Christofek's talk later today

$$\text{Discriminant} = \frac{P_{WH}}{P_{WH} + \sum_i c_i P_{\text{background}i}}$$



2-tags close-up

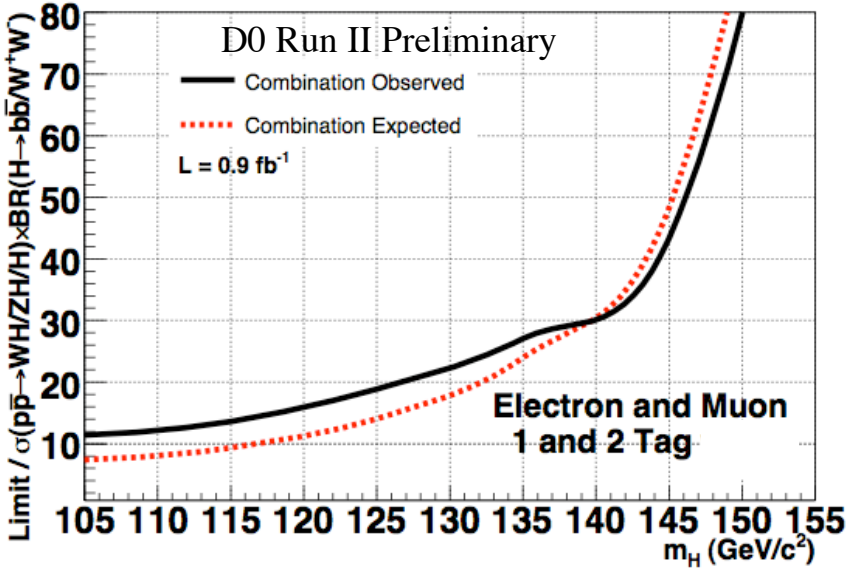




1-tag close-up

WH → l ν bb

- D0 WH Matrix Element approach

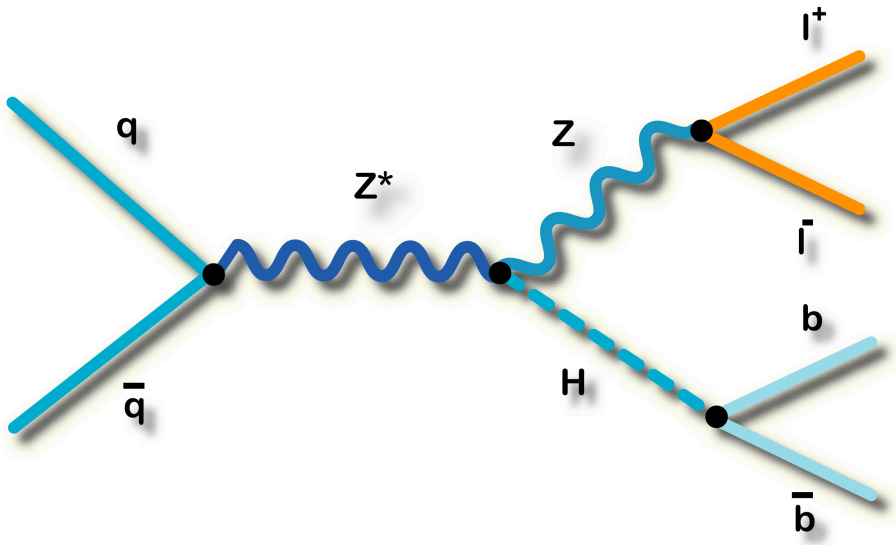


D0 new result

- **Expect 95% CL limit (m_H=115 GeV)**
  - **< 1.2 pb**
  - **< 9 times SM cross-section**
- **Observed limit**
  - **< 1.7 pb**
  - **< 13 times SM cross-section**

- M.E. approach compared to dijet mass fit
  - Currently 10% worse expected limit
  - Reasons :
    - M.E. not yet using full muon acceptance
      - 50% less WH signal
      - 2.4 WH events instead of 3.6
    - M.E. b-tagging optimized for single-top
- With improvements used in dijet mass analysis
  - **Expect 30% better limit**

$ZH \rightarrow llbb$



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

ZH → llbb

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CDF ICHEP 2006 analysis

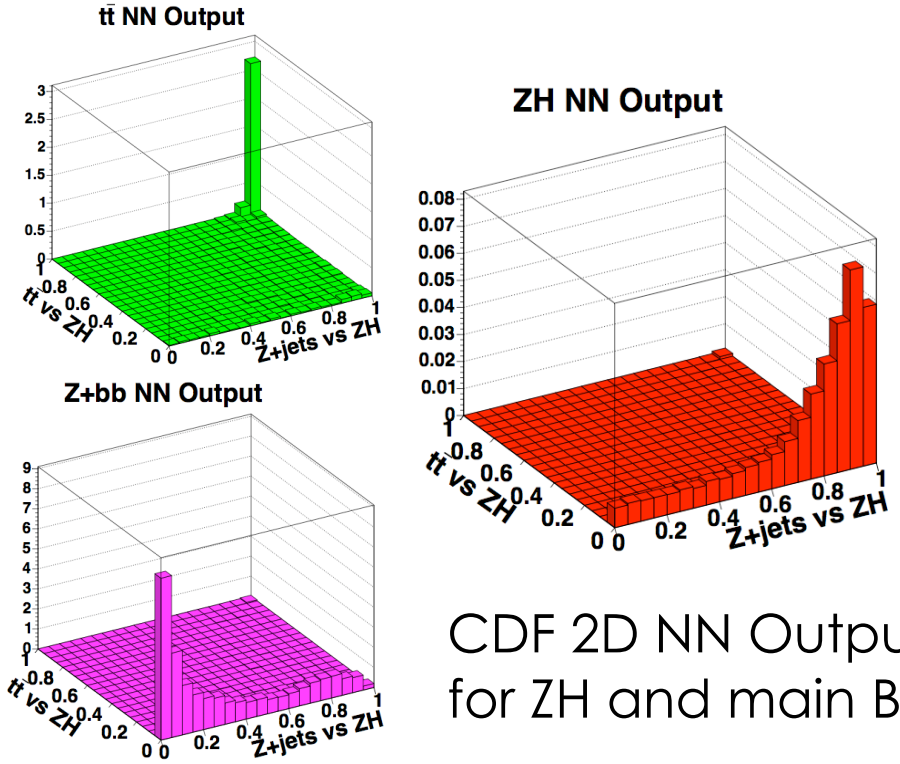
- uses 2-D Neural Network discriminant
- for m_H = 115 GeV,
- Observed limit < 2.2 pb

< 27 times SM (23 expected)

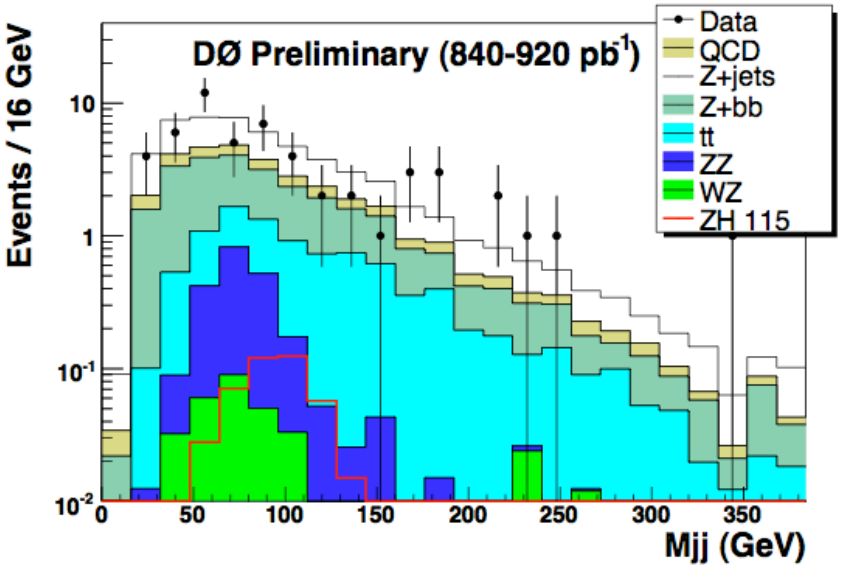
D0 November 2006 analysis

- fits dijet mass
- 1-tag & 2-tag samples
- Observed limit < 2.7 pb

< 33 times SM (34 expected)



CDF 2D NN Outputs
for ZH and main BKGs

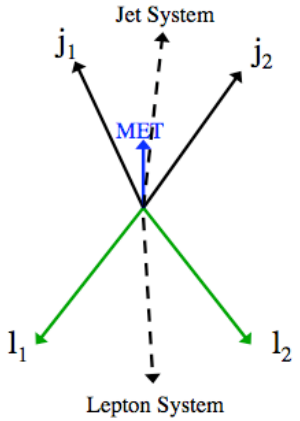


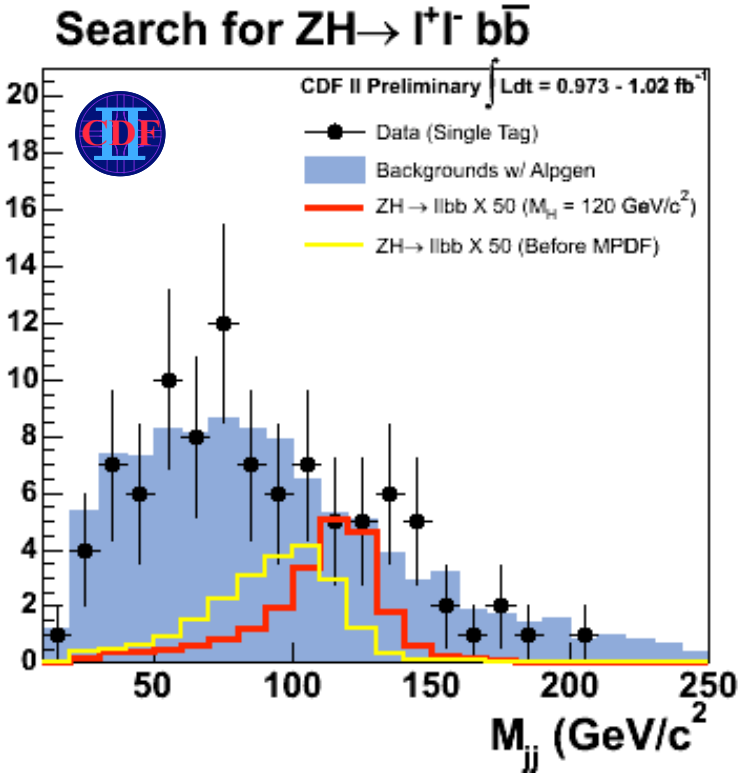
D0 Dijet mass

ZH → llbb

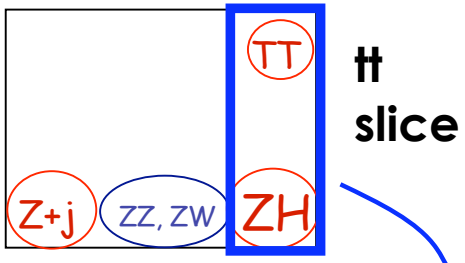
- **New CDF result for Moriond QCD 2007** using the same dataset

- **Reduce backgrounds**
  - **split data** into 2 loose b-tags and 1 tight single b-tag
- **improve dijet mass resolution**
  - **Corrects jets** based on their MET projection
    - no real MET in Z+jets
  - Improves dijet mass resolution
    - from 17% to 10%
  - **Results in 30% effective luminosity increase**



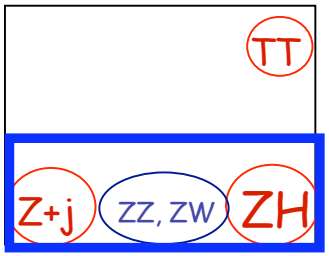


ZH → l l bb

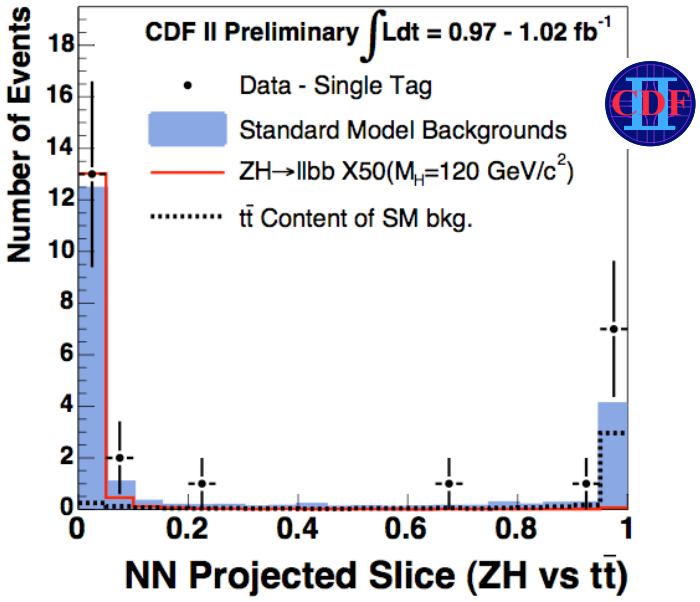


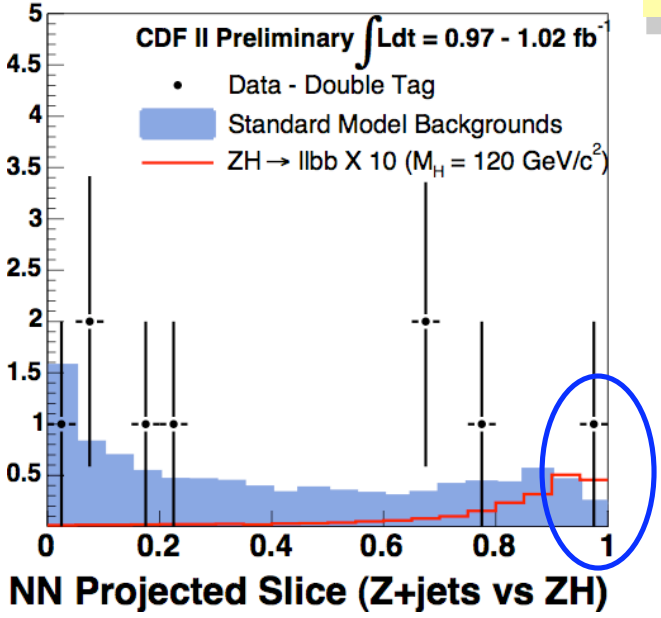
tt slice

Z+jets slice



CDF new result
Expect. 95% CL limit (m_H=115 GeV)
< 1.3 pb
< 16 times SM
Observed limit
< 1.7 pb
< 16 times SM

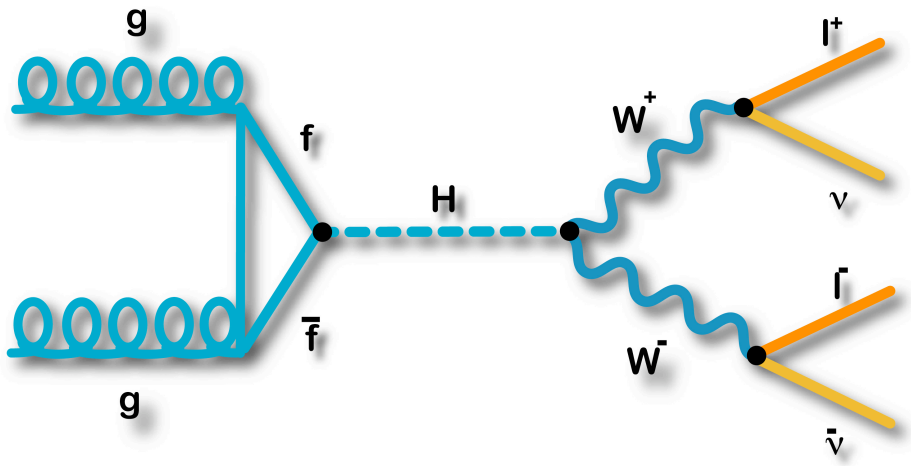




S/B = 1 / 4

New limit equivalent to previous analysis with twice as much data !

$gg \rightarrow H \rightarrow WW$



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

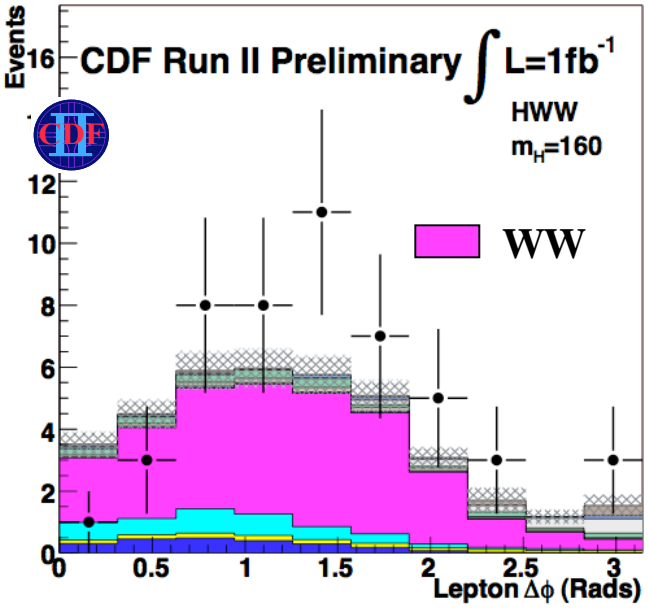
gg → H → WW

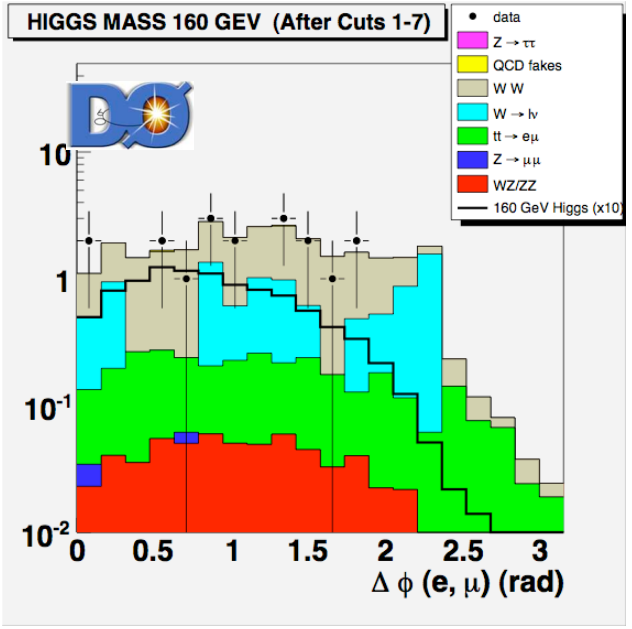
- WW vs. H → WW
  - spin-0 higgs results in different angular correlations of leptons
  - $\Delta\Phi$(lepton,lepton) good discriminant
- Both CDF and D0 have results with fit of $\Delta\Phi$(lepton,lepton)

Expect. 95% CL limit (m_H=160 GeV)

CDF Aspen 2007:
< 9 times SM
< 6 (expected)

D0 ICHEP 2006:
< 4 times SM
< 5 (expected)



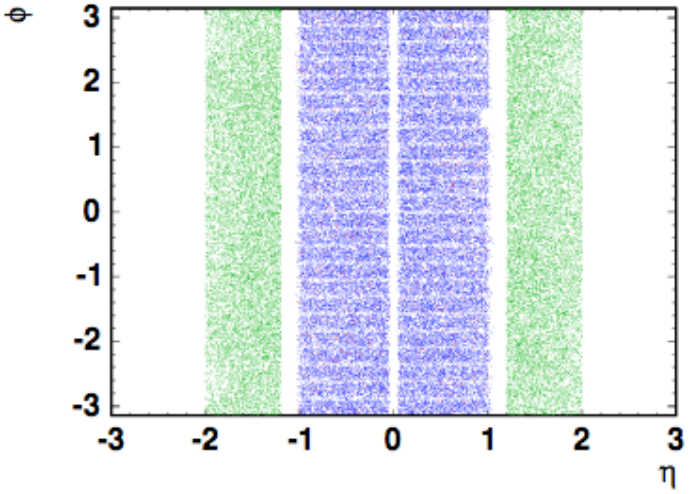


- Now, CDF has **new analysis results for Moriond QCD 2007**
  - Improved lepton acceptance
  - Matrix Element approach

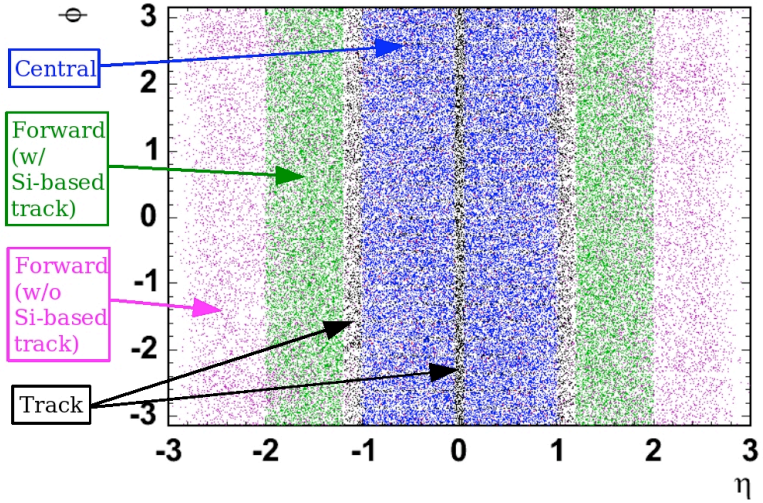
gg → H → WW: lepton acceptance

- New lepton categories developed for the WZ → lνll analysis
  - WZ **signal doubled - proportional background increase**
  - led from evidence to **5.9 sigma discovery of WZ**
    - see Frank Wuerthwein's talk yesterday

Electrons before



Electrons after



- **CDF H → WW** analysis uses many of these lepton categories
  - Signal yield increases from **2.5 to 4** expected events

gg → H → WW: matrix element

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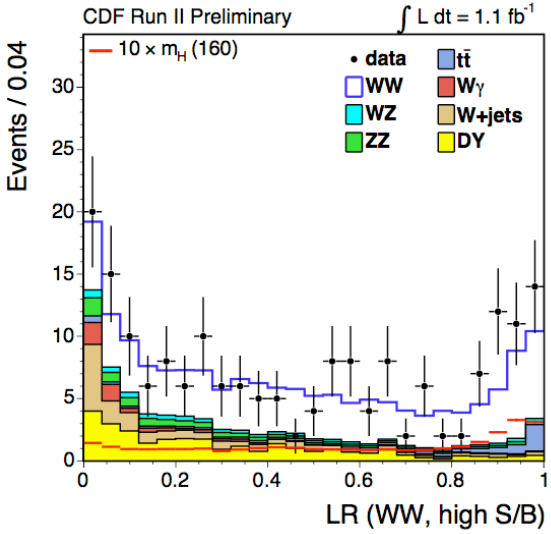
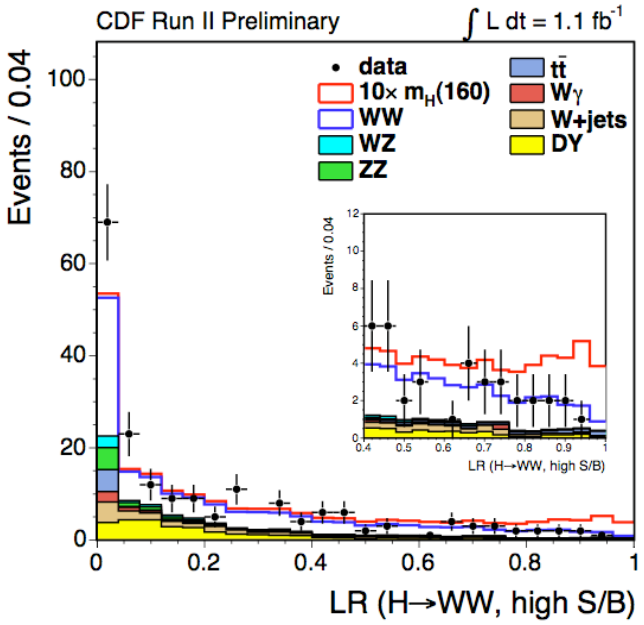
- Likelihood Ratio from Matrix Element probabilities of H → WW, WW, ZZ, W+fakes & conversions

$$LR = \frac{P_{Higgs}(M_H)}{P_{Higgs}(M_H) + \sum_i f_{bkg,i} P_{bkg,i}}$$



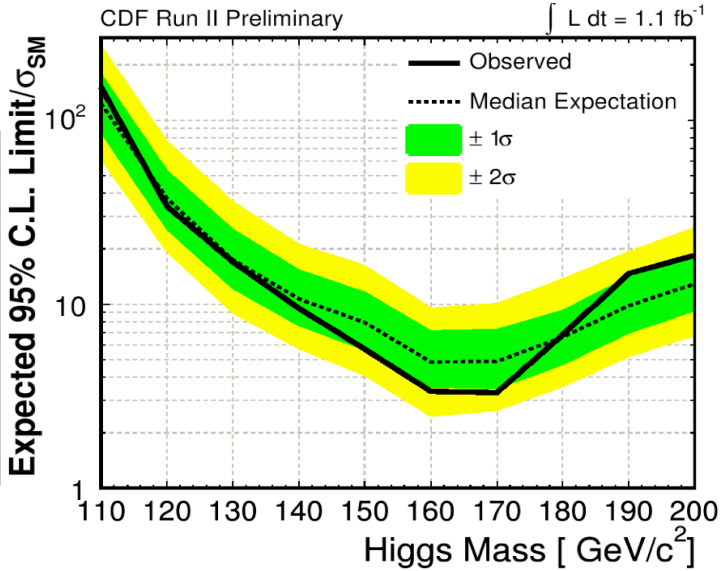
Validation of LR for leading WW background



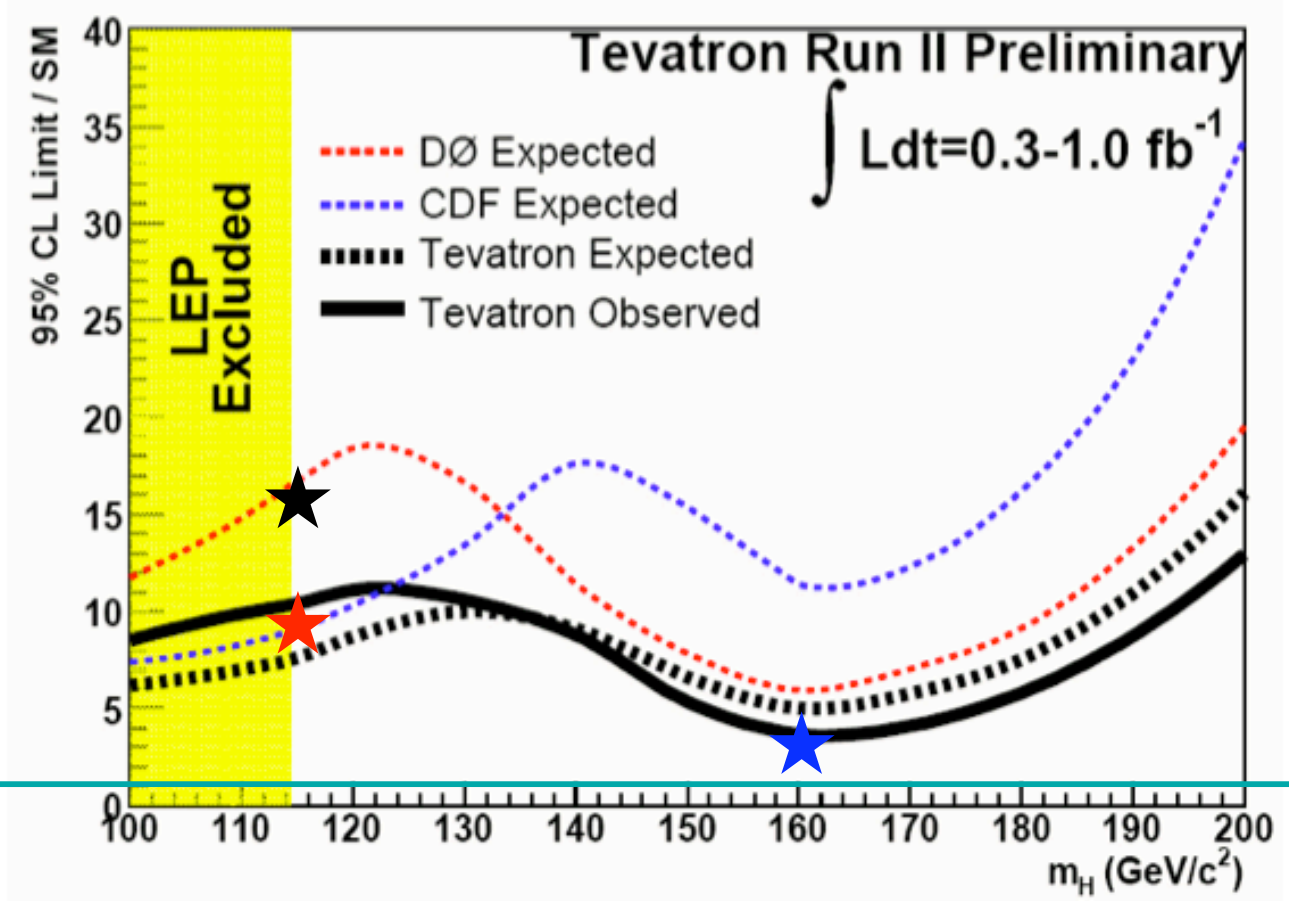
Result of signal LR

CDF new result

- **Expected limit**
  < 5 times SM
- **Observed limit**
  < 3.5 times SM



Combinations



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

H → WW contributes more at 135 as WH

Summary of Tevatron Results

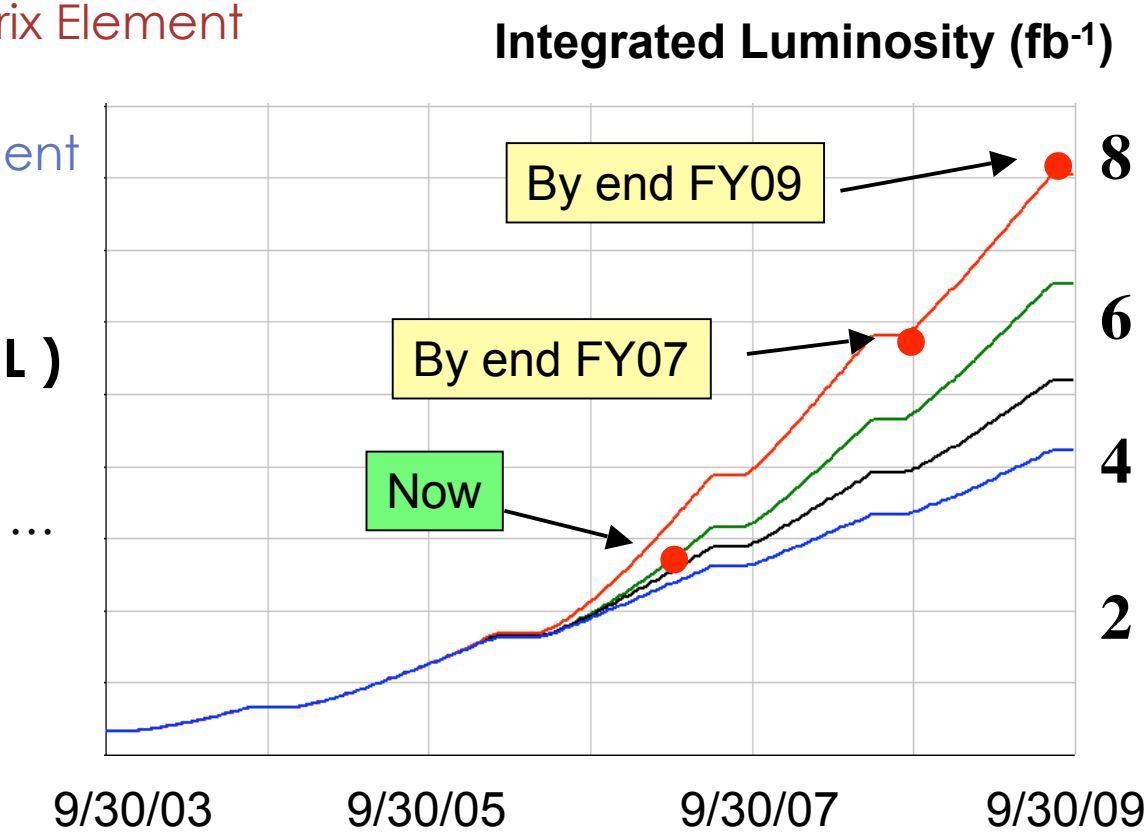
Ben Kilminster, OSU
Moriond QCD '07
p. 25

Analysis	CDF limit ($1fb^{-1}$) factor above SM observed (expected)	D0 limit ($1fb^{-1}$) factor above SM observed (expected)
$ZH \to \nu\nu\, b\bar{b}$ @ 115 Technique: M_{jj}	16 (15)	40 (34)*
$WH \to l\nu\, b\bar{b}$ @ 115 Technique: M_{jj} Technique: ME	26 (17)	★ 10 (9) ★ 13 (10)
$ZH \to ll\, b\bar{b}$ @ 115 Technique: NN2D	★ 16 (16)	33 (34)
$H \to WW \to l\nu l\nu$ @ 160 Technique: $\Delta\Phi$ (l,l) Technique: ME	9 (6) ★ 3.5 (5)	4 (5)

*0.25 pb^{-1}, WH fit separately

Conclusions

- First time Higgs searches shown
  - CDF ZH → llbb improved 1 fb^{-1} Neural Net
  - CDF H → WW 1 fb^{-1} Matrix Element
- New from last week
  - D0 WH 1 fb^{-1} Matrix Element
  - D0 WH 1 fb^{-1} Dijet mass
- New results are scaling much **better than 1/ sqrt(L)**

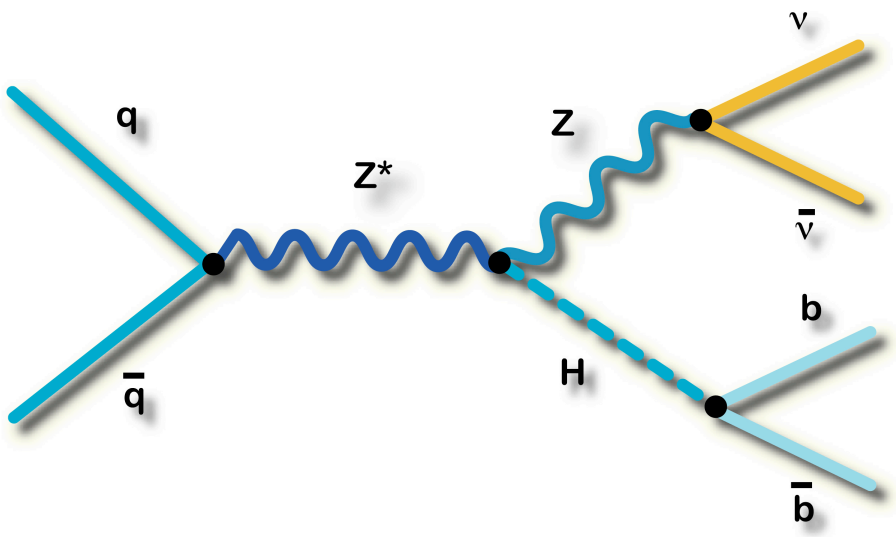


- CDF and D0 not just talking …
- working hard to improve
  - b-tagging
  - lepton acceptance
  - jet resolution
  - analyses techniques
- Expect more : groups are growing

This one's going to be close !

BACKUPS

ZH → ν ν bb

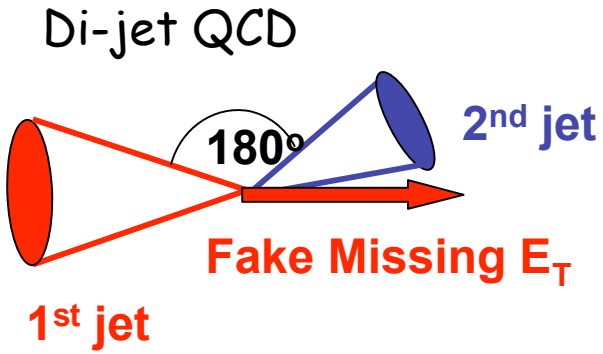


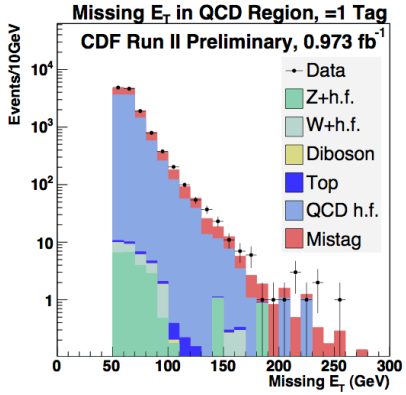
- **Signature**
  - two high transverse energy jets
  - one or two b-tags
  - recoil against large missing transverse energy
  - no leptons or isolated tracks
- **Main backgrounds**
  - 50% W/Z + jets
  - 1 tag
    - 10% ttbar, 30% QCD
  - 2 tags
    - 30% ttbar, 20% QCD
- **Bonus:** event selection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

ZH → ν ν bb

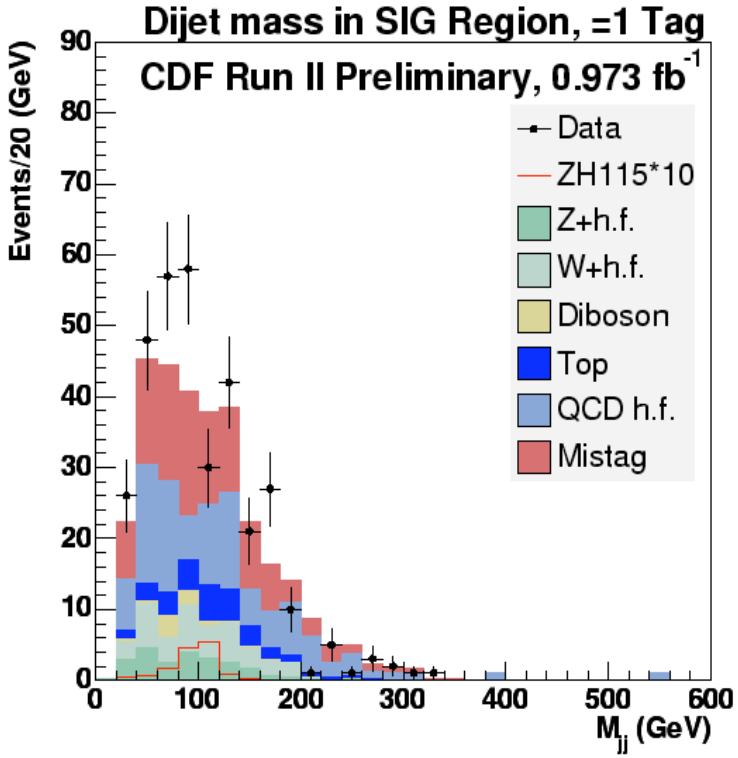
- CDF results presented at ICHEP 2006
- Fit done of dijet mass
- 1 b-tag and 2 b-tags separated

- 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