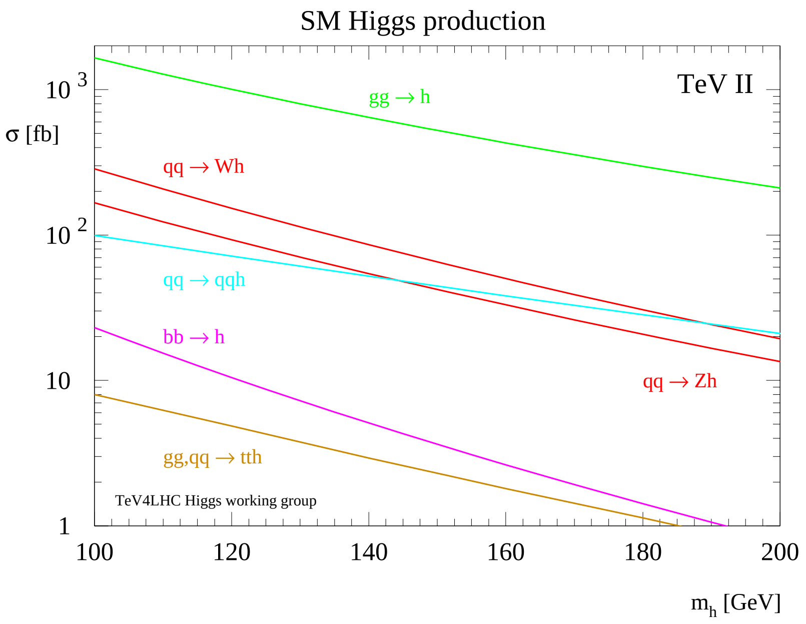
Search for the SM Higgs Boson in the Missing E_T + b-jets Final State at CDF

V. Veszpremi (Purdue University)

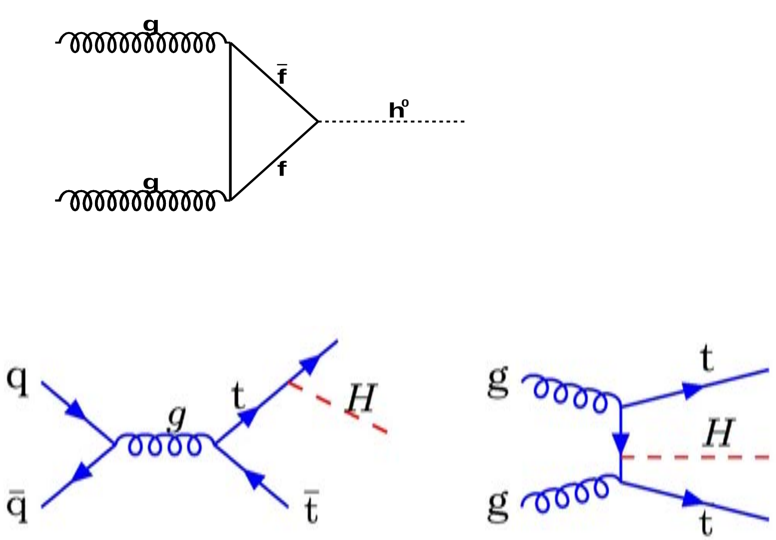
CDF Collaboration

SM Higgs production at Tevatron

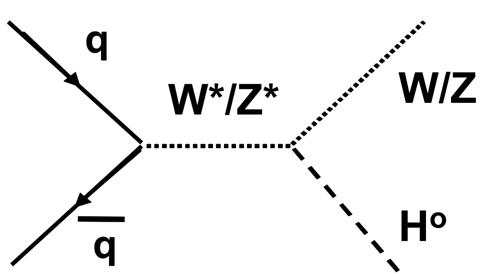


Gluon Fusion

ttH



Higgsstrahlung



- Cross-section is an order of magnitude below the gluon fusion
- Decay products of Z/W provide a handle to separate signal from h.f. dijet events
- At Tevatron, the ZH/WH production cross-section is more significant (w.r.t gluon fusion) than at LHC

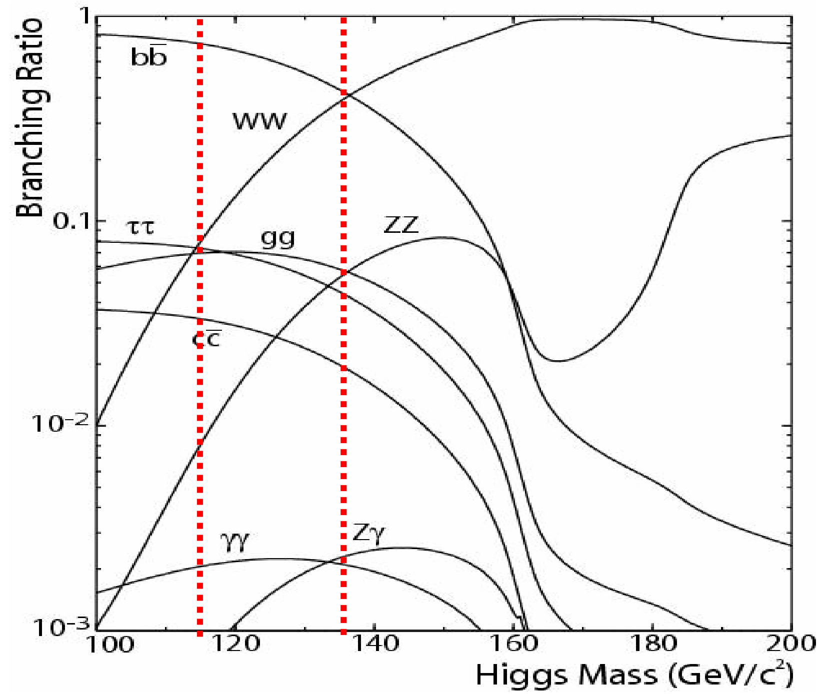
Preferred search channels in CDF

- Low mass SM Higgs (<135 GeV)
  - Decays to b-quarks
  - ZH/WH searches are favored
  - Photon branching ratio is lower by a factor of ~400

- High mass SM Higgs (>135 GeV)
  - Decays to W/Z-bosons
  - WW/ZZ searches are favored with leptons in the final states

- With the luminosity achievable at the Tevatron, no searches in single production channels are sensitive to the light Higgs

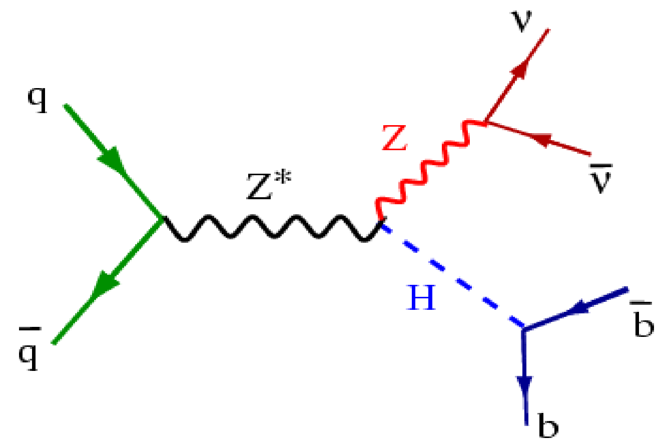
- Channels must be combined



Low **High mass**

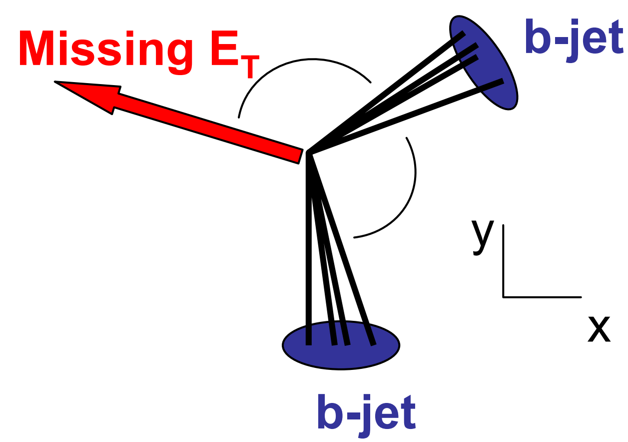
Higgs in the $\not{E}_T$+b-jets final state

- Higgs processes leading to missing E_T and b-jets:
  - ZH → νν bb
  - WH → lν bb (where l is not identified)
  - gg → H → bb – missing E_T too low, analysis is not feasible



- Events with isolated tracks or electrons are discarded to avoid overlap with the dedicated WH search

- **Basic Selection cuts:**
  - At least one central jet
  - 1^{st} Jet E_T > 35 GeV
  - 2^{nd} Jet E_T > 20 GeV
  - No other jets with E_T> 20 GeV
  - Missing E_T (MET) > 55 GeV
  - No leptons
  - 1 or 2 tight b-tag(s)

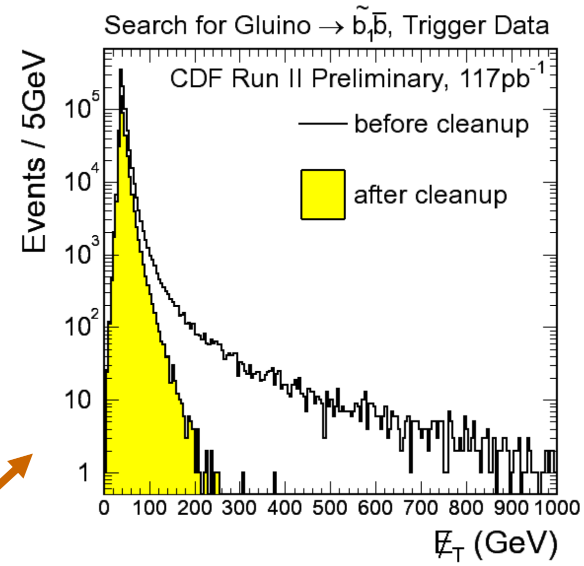


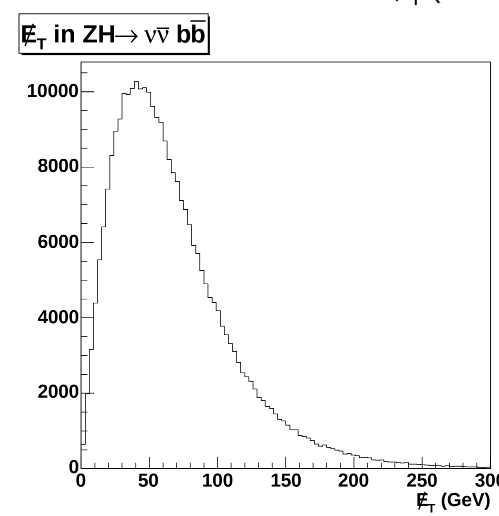
Distinctive event topology

Origin of missing E_T

- Called missing E_T rather than p_T: calculated from the calorimeter tower energies (vector-sum)

- Origin of Missing E_T in an event
  - "Real"; a weakly interacting particle, such as a neutrino, escapes detection
  - "Instrumental"; the transverse momentum of an object is mismeasured
    - muon
    - jets – esp. in QCD background
  - Beam effects – eliminated by quality cuts



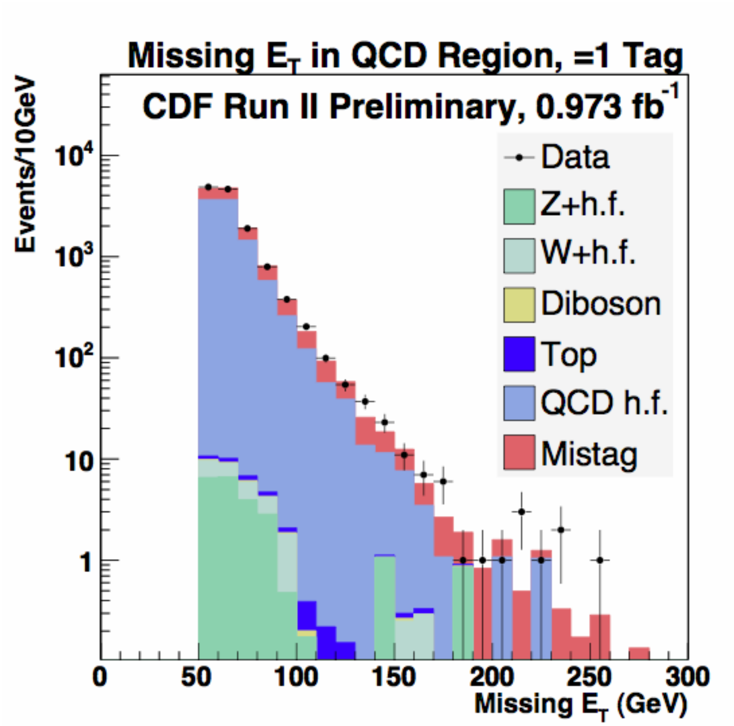


MET in ZH → νvbb events

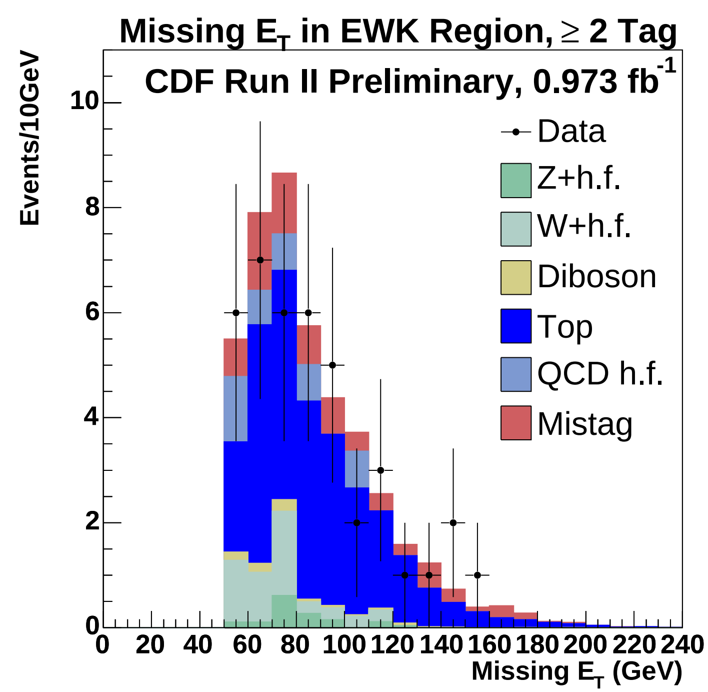
- These effects increase or decrease the missing E_T depending on the kinematics
  - e.g. MET in W → ev bb is higher than in W → μv bb
  - MET in the signal is lower than expected

$\not{E}_T$ simulation

- All background processes are simulated
  - better understanding of correlation between MET and event kinematics
  - allowing for better signal selection (using ANN in progress)
- The detector simulation reproduces well the “fake” missing E_T



“fake” MET in QCD events

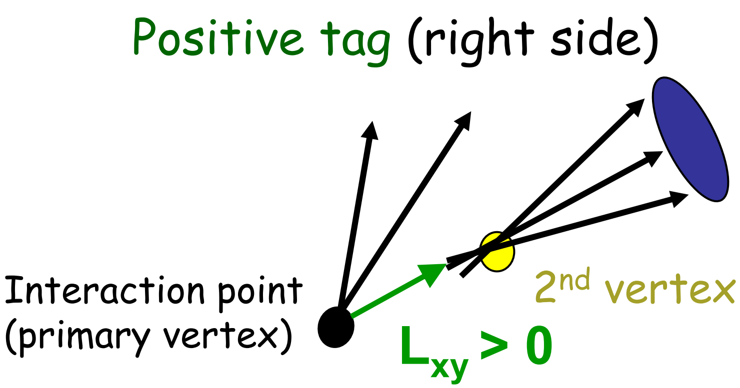


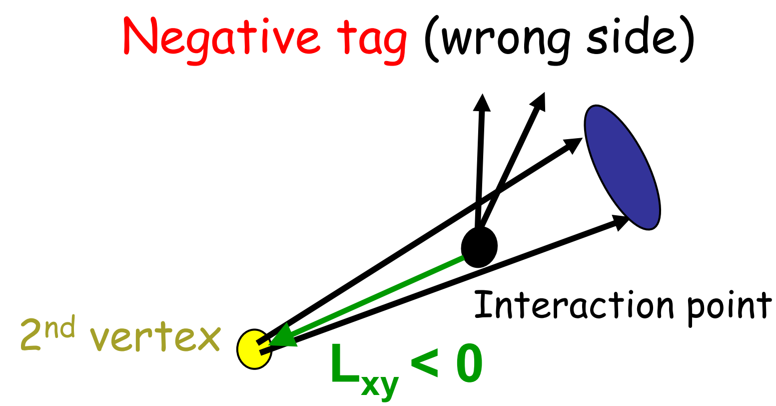
MET in top events

High P_T b-tagging at CDF

- SecVtx tagging algorithm takes advantage of the long b lifetime
- Heavy flavor measured by counting the positive tags

- Negative tags are caused by the limited resolution in the tracking
- Mistag events estimated from the data



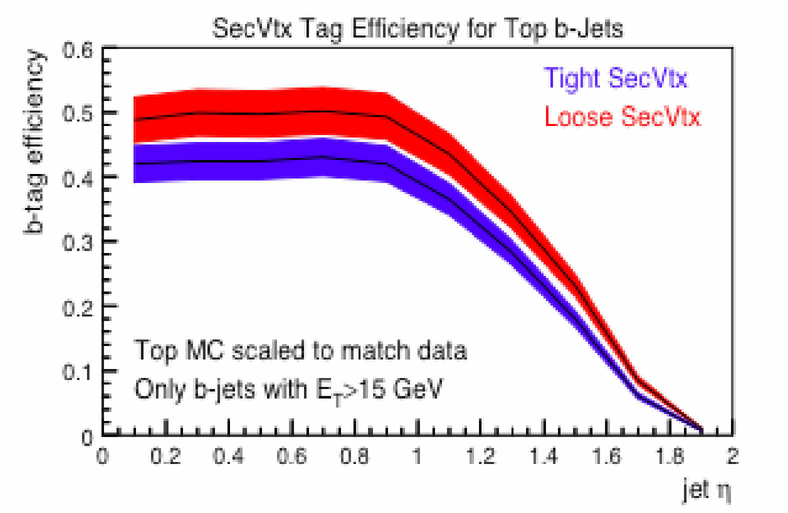


- b, c, and light quark jet content depends on the cut on $\mathbf{L_{XY}} / \sigma_{XY}$
- Signal events have two b-jets
- Events are classified by having one (exclusive single) or two (double) tags
  - Single tag: contains more mistag and charm jets
  - Double tag: purer in b, but lacks in statistics, has lower signal acceptance

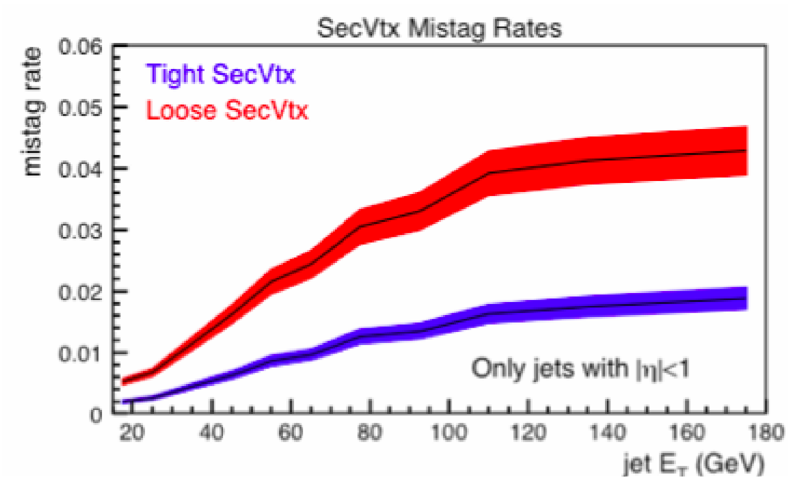
B-tagging at CDF

• Currently two operation points were considered: tight and loose tag selection

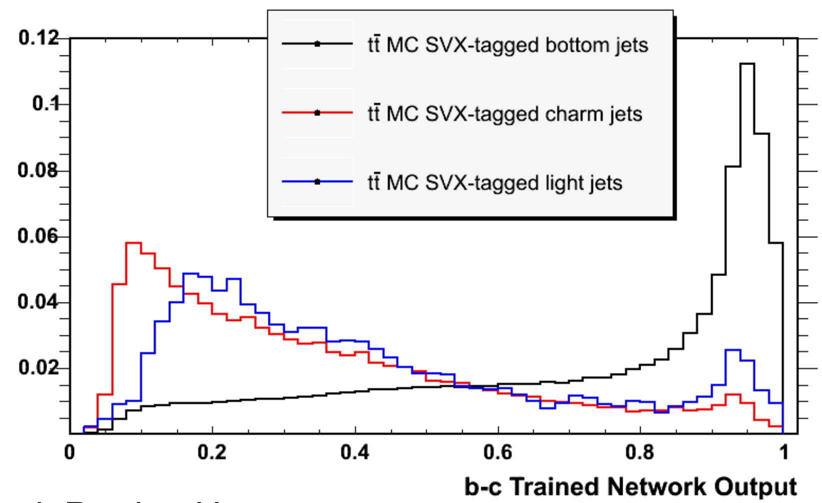
B-Tag Efficiency (Positive Tag)



Light quark mistag rate (Negative Tag)



• New taggers have been developed using Neural Network trained to discriminate b-, c- and light quark jets (presented in WH search)



B-tag simulation

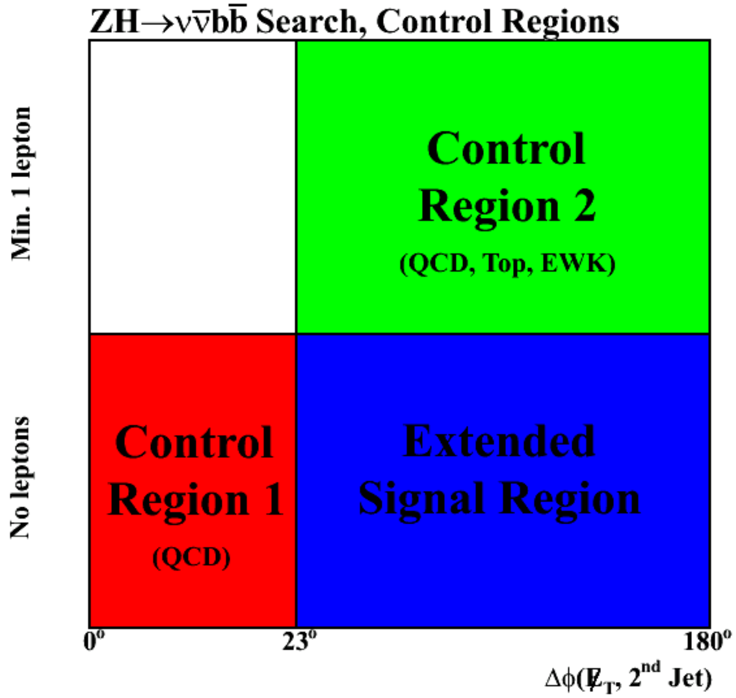
- Simulation is a technical challenge due to the large cross-section of SM background

- Simulating Tags
  - Only events with taggable objects (b, c, or tau) are simulated, a b/c filter is applied at generator level
  - Positive tag assumes a b- or c-quark in the 0.4 radian cone of the tagged jet to avoid double counting
  - Do not have a pre-tag sample

- The mistags are calculated from the data
  - estimating the rate of the negative tags
  - scaling it up by an asymmetry factor
    (Ratio between the positive and negative tag-rates for light flavor jets; needed to account for the decays of the long lived hadrons)

Analysis regions

For h.f. events passing basic selection:



Control Region 2 – EWK

- Require 1 identified lepton (electron or isolated track
- Missing E_T and 2nd leading jets are not parallel

Extended Signal Region

- Veto events with leptons
- Missing E_T and 2nd leading jet are not parallel
- Cut optimization is performed in this region based on Monte Carlo simulation before looking at the real data

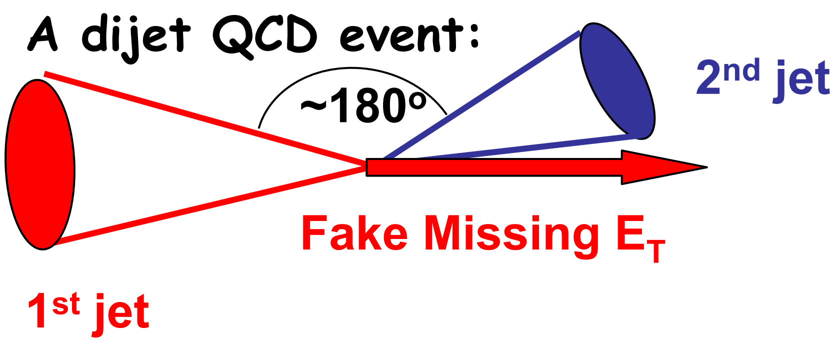
Control Region 1 – QCD

- Veto events with identified leptons
- Require MET and 2nd leading jet to be parallel

QCD Control Region

QCD event topology:

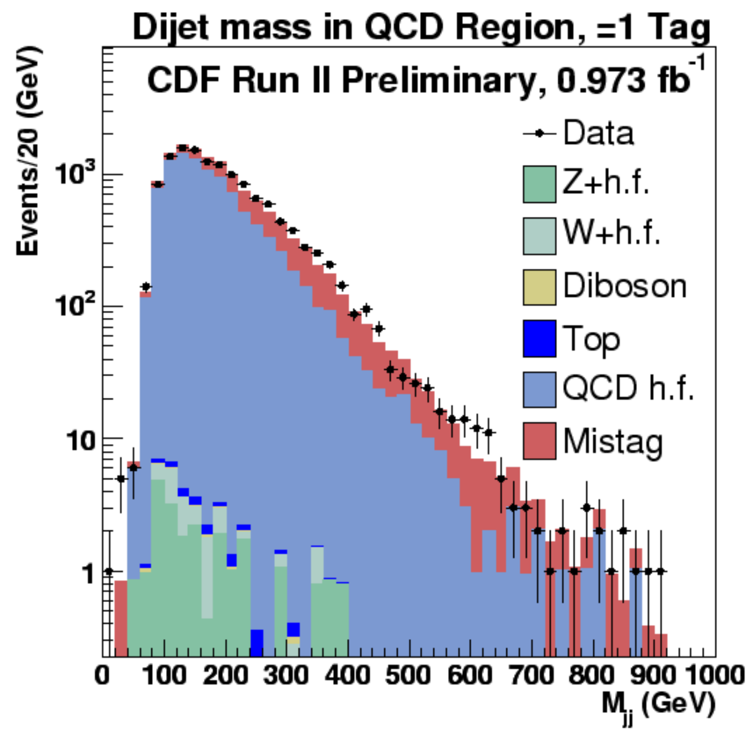
- **Jets are back-to-back**
- **"Missing E_T" points along the 2nd jet**



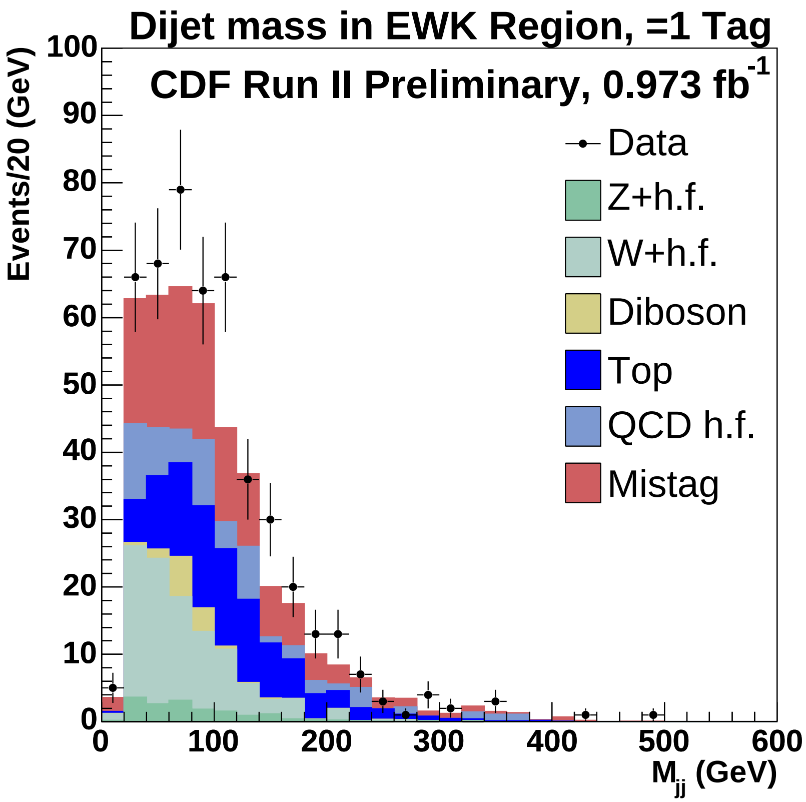
Control Region 1:

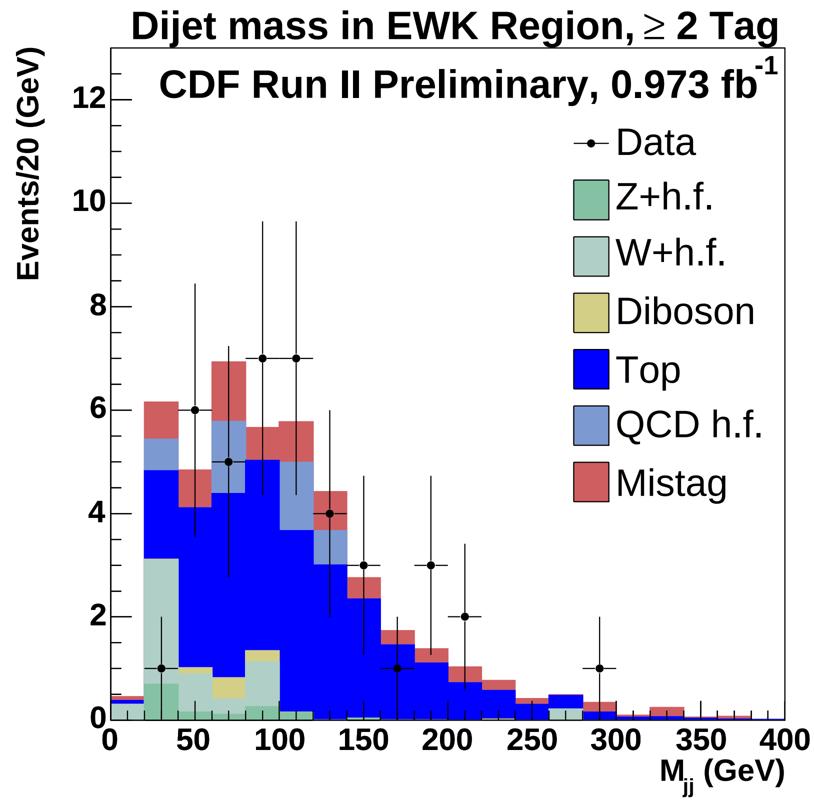
- QCD multi-jet is the dominant
- MET is due to the mismeasurement of the jets

- b-production cross-section not well predicted
- QCD events are normalized to data after basic selection: **normalization is confirmed**



EWK Control Region





Single tag: sensitive to all backgrounds with leptons

Double tag: dominated by top

Predicted and observed events in the control regions

	QCD Control Region (CR 1)		EWK Control Region (CR 2)	
	Exclusive 1 Tag	2 Tags	Exclusive 1 Tag	2 Tags
QCD h.f.	9833 ± 99 ± 1087	688 ± 21 ± 64	58 ± 8 ± 30	2.7 ± 1.3 ± 1.4
Mistag	3081 ± 10 ± 524	257 ± 2 ± 44	135 ± 1.6 ± 23	7.0 ± 0.3 ± 1.2
Top	3.8 ± 0.2 ± 0.5	0.7 ± 0.07 ± 0.13	100.2 ± 0.9 ± 14.2	25.6 ± 0.3 ± 5.2
W + h.f.	10.7 ± 2.0 ± 1.4	0.8 ± 0.6 ± 0.2	93 ± 7 ± 19	6.8 ± 1.7 ± 1.6
Z + h.f.	22.9 ± 3.9 ± 3.7	5.3 ± 2 ± 1.2	16.8 ± 1.3 ± 3.2	1.5 ± 0.4 ± 0.3
Diboson	0.9 ± 0.1 ± 0.1	0.03 ± 0.02 ± 0.006	12.6 ± 0.5 ± 1.9	0.86 ± 0.08 ± 0.18
Total Predicted	**12953 ± 99 ± 1208**	**952 ± 22 ± 78**	**416 ± 11 ± 51**	**44.5 ± 2.3 ± 6.9**
Observed	**13020**	**974**	**482**	**40**

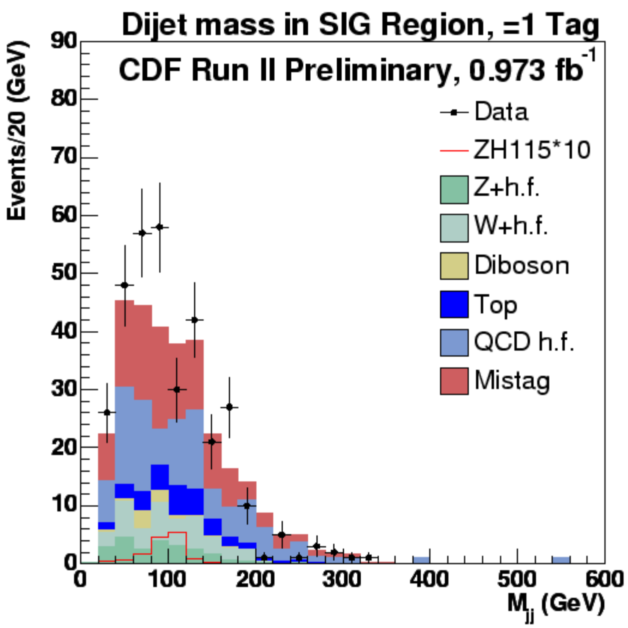
- First error is systematic, second is statistical

Signal Region

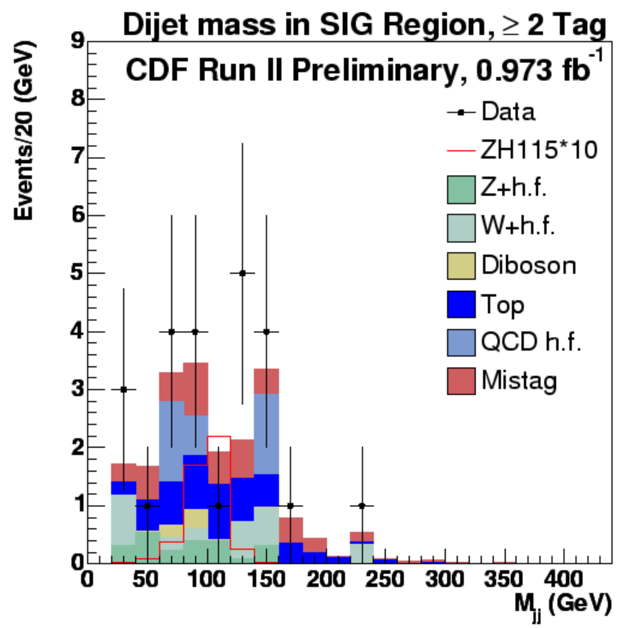
Events are classified in two sets with one or two identified heavy flavor jets after passing the optimized cuts:

$$\Delta\varphi\left(1^{st}\ Jet, \not{E}_T\right) > 0.8\ , \qquad 1^{st}\ JetE_T > 60GeV\ ,$$

$$\not{H}_T / H_T > 0.45\ , \qquad \not{E}_T > 75GeV$$



Dijet invariant mass in the single tag region



Dijet invariant mass in the double tag region

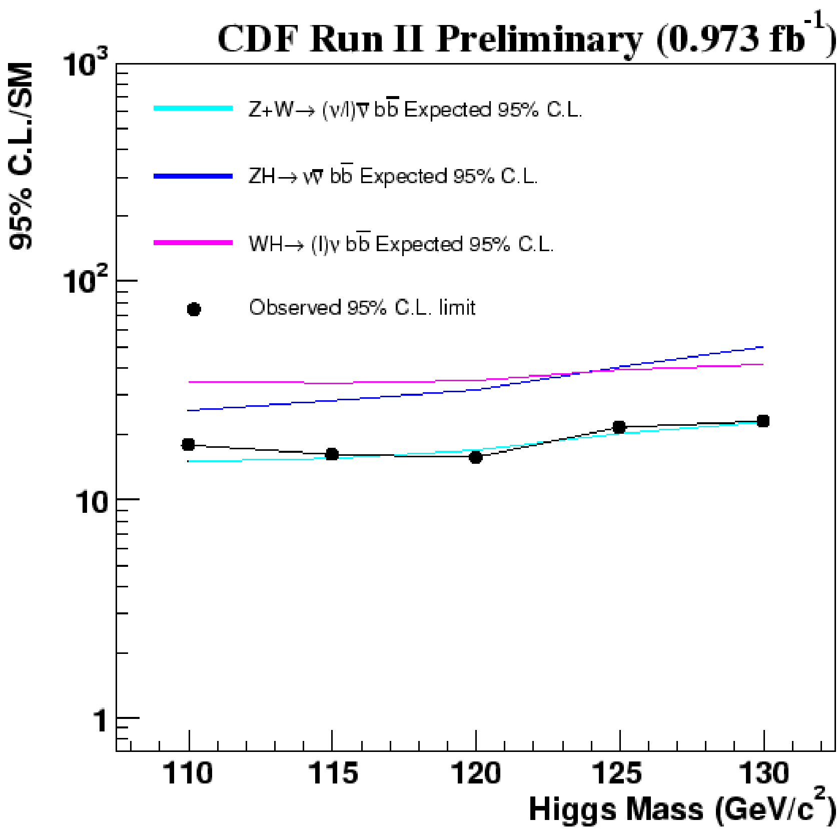
Results

95% C.L. limit/SM cross-section set in the single and double tag, ZH and WH samples separately at each Higgs mass, then combined:

Higgs mass (GeV)	ZH Exp.	WH Exp.	Combined Exp.	Combined Obs.
110	25.5	34.8	14.9	17.8
115	28.4	34.0	15.4	16.0
120	31.7	35.1	16.8	15.6
125	40.5	39.2	20.0	21.4
130	50.0	41.5	22.6	22.8

- Improvements lead to effective luminosity gain of $(S/\sqrt{B})^2$=6.3 with respect to last year analysis (L ~ 300 pb^{-1})
  - Improved lepton veto
  - Separate single and double b-tags
  - Include WH as signal
  - Use fit to dijet mass spectrum

95% CL limits

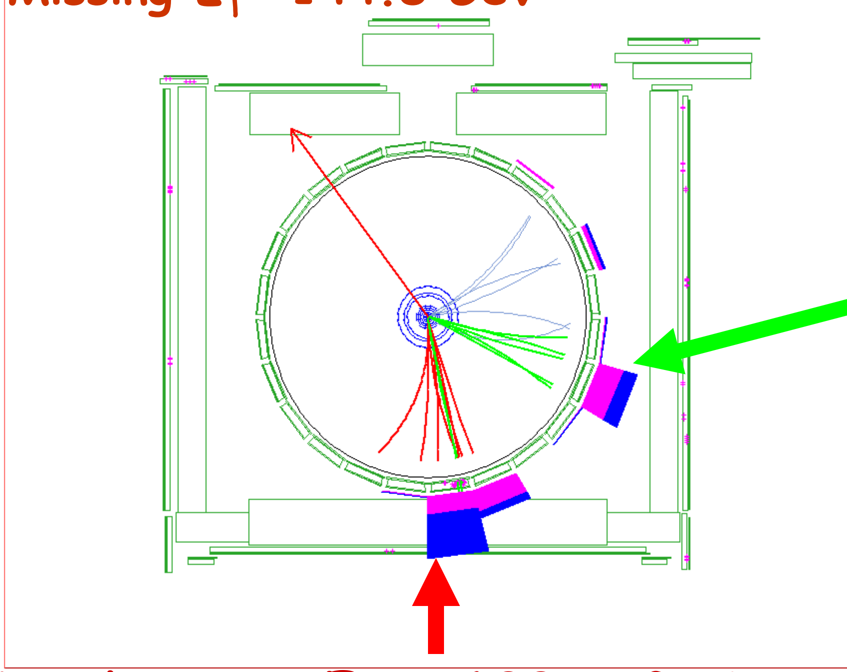


- Largest systematic uncertainties
  - Correlated:
    - Jet energy scale 3%-20%
    - Luminosity 6%
    - Trigger efficiency 3%
    - b-tag efficiency 8% or 16%
  - Uncorrelated:
    - (N)NLO correction 12%
    - Lepton identification 2%
    - Mistag asymmetry 17%
    - MC statistics 3%-44%

The expected and observed limit in the Missing E_T + b-jet analysis

Candidate event

Missing E_T =144.8 GeV



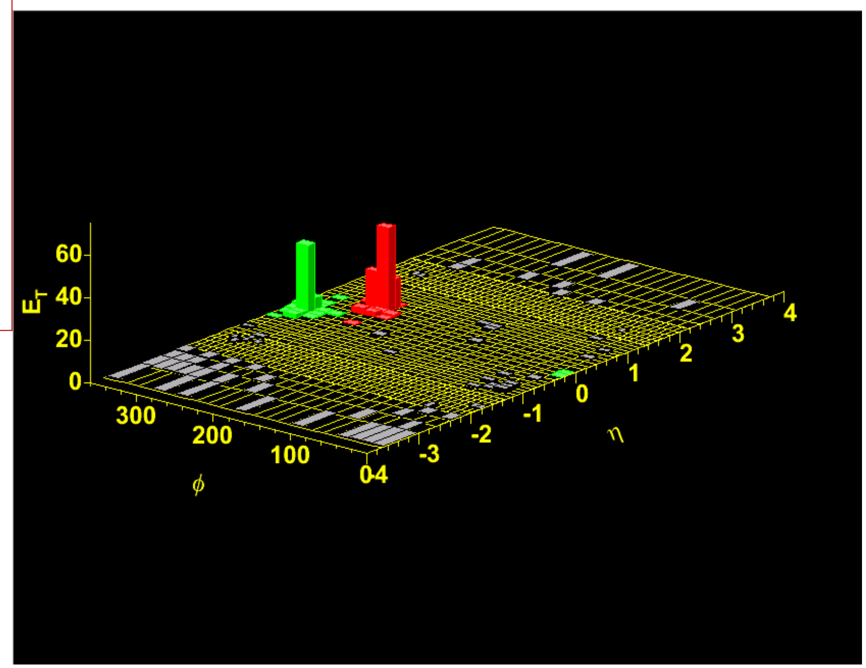
Leading Jet E_T = 100.3 GeV

Di-jet invariant mass = 82 GeV

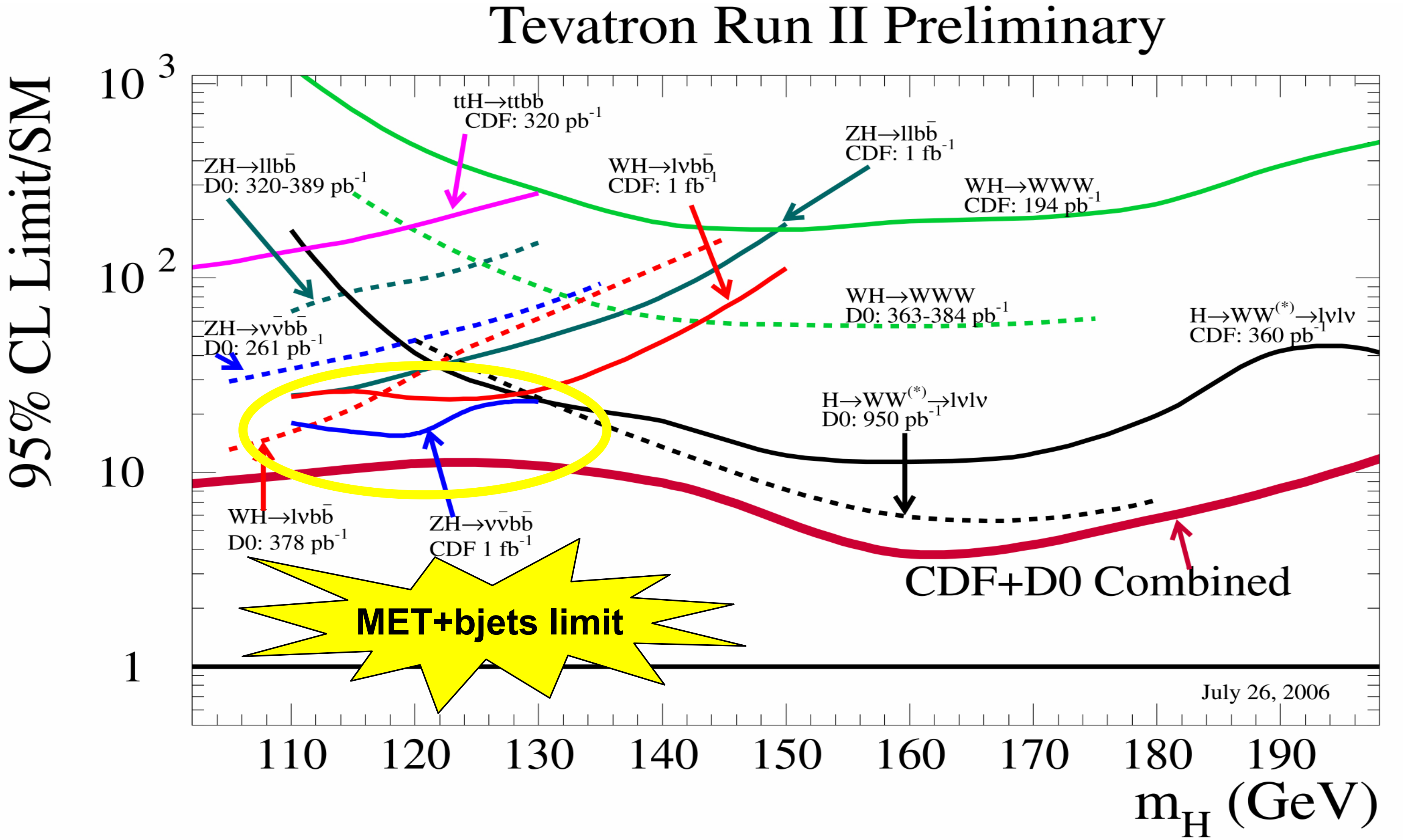
Data event from Signal Region
- Passed all selection cuts
- Candidate in the 80-120 GeV mass window

Double-tagged event

Second Jet E_T = 54.7 GeV



Combined Tevatron limits



Conclusions

- Performed analysis on 0.97 fb^{-1} data
- Improvements w.r.t last year results
  - Improved lepton veto
  - Split single and double tag events
  - Included WH signal where lepton is not identified
  - Used dijet shape to constrain the background in limit calculation
  - Encouraging overall improvement equivalent to a factor of 6.3 luminosity increase
- Combined 95% C.L. cross-section limit is ~16 times over the Standard Model expectation
- CDF+D0 combined limit is now only ~10 times the SM Higgs cross-section in the low mass region

Backup Slides

Systematic errors in the Signal Region, =1 Tags

	Correlated				Uncorrelated							
	JES	**Lumi**	**Trigger Eff**	**B-Tag**	**Statistical**	**Cross-sec**	**Lepton ID**	**QCD Norm**	**Mistag Asymm**	**PDF**	**ISR**	**FSR**
Mistag					0.014		0.02		0.17			
QCD	0.21				0.10		0.02	0.02				
TOP	0.004	0.058	0.03	0.08	0.017	0.12	0.02			0.02		
W + h.f.	0.154	0.058	0.03	0.08	0.1	0.12	0.02			0.02		
Z + h.f.	0.156	0.058	0.03	0.08	0.06	0.12	0.02			0.02		
Diboson	0.081	0.058	0.03	0.08	0.049	0.12	0.02			0.02		
ZH 115	0.0586	0.058	0.03	0.08	0.006		0.02			0.02	0.01	0.03
WH 115	0.0647	0.058	0.03	0.08	0.011		0.02			0.02	0.01	0.03

Systematic errors in the single-tag events after applying optimized selections

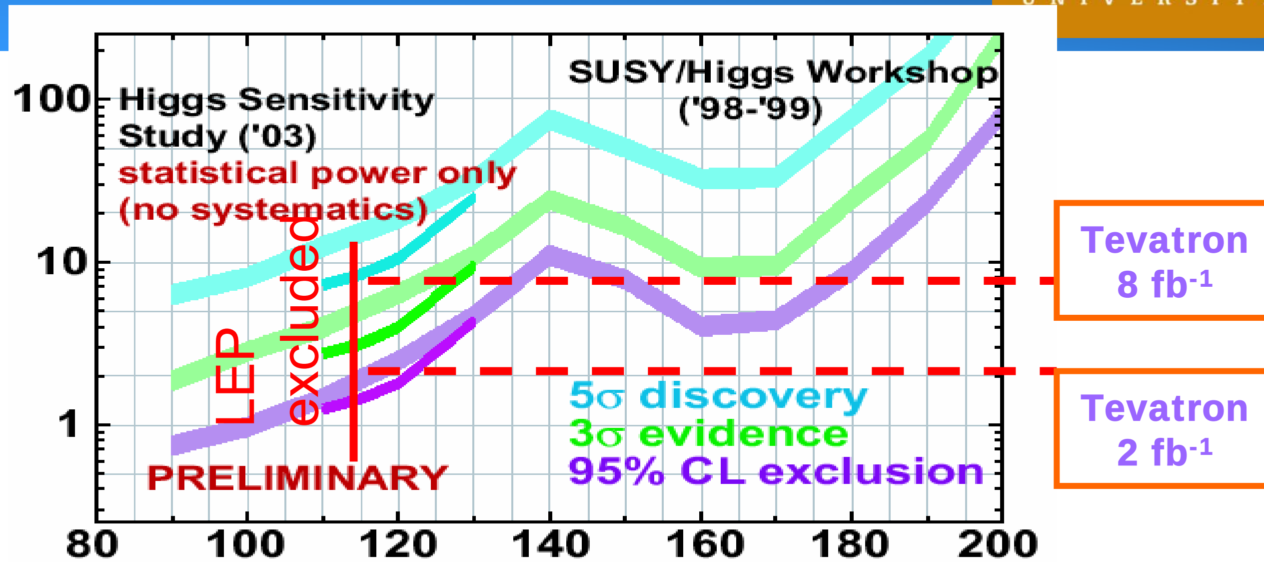
Systematic errors in the Signal Region, =2 Tags

	Correlated				Uncorrelated							
	JES	Lumi	Trigger Eff	B-Tag	Statistical	Cross-sec	Lepton ID	QCD Norm	Mistag Asymm	PDF	ISR	FSR
Mistag					0.05		0.02		0.17			
QCD	0.20				0.44		0.02	0.02				
TOP	0.016	0.058	0.03	0.16	0.03	0.12	0.02			0.02		
W + h.f.	0.07	0.058	0.03	0.16	0.42	0.12	0.02			0.02		
Z + h.f.	0.06	0.058	0.03	0.16	0.19	0.12	0.02			0.02		
Diboson	0.034	0.058	0.03	0.16	0.10	0.12	0.02			0.02		
ZH 115	0.037	0.058	0.03	0.16	0.006		0.02			0.02	0.02 (+0.003 -0.032)	0.04 (+0.02 -0.06)
WH 115	0.052	0.058	0.03	0.16	0.03		0.02			0.02	0.02 (+0.003 -0.032	0.04 (+0.02 -0.06)

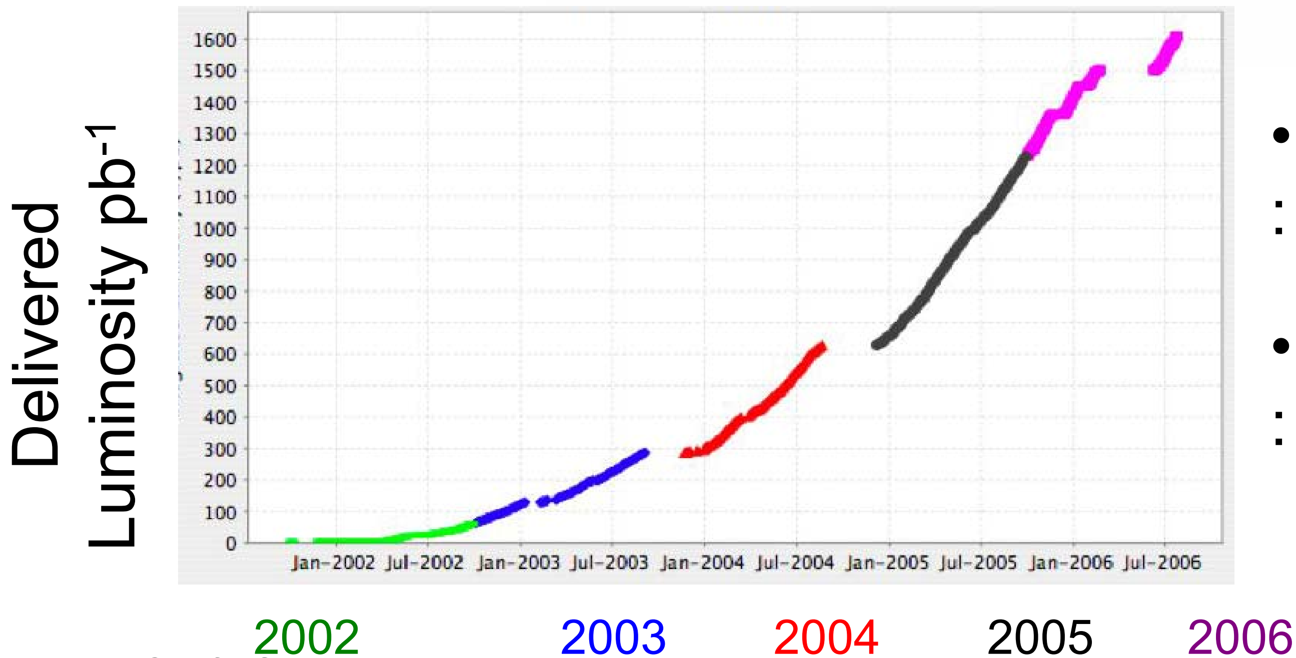
Systematic errors in the double-tag events after applying optimized selections

Performance of the Tevatron

- Future expectations based on the Higgs sensitivity study in 2003.



- Below is the instantaneous and integrated luminosities recorded at CDF so far



- ICHEP-04 Results : 200 pb^{-1}

- ICHEP-06 Results : 1000 pb^{-1}

(per experiment)

Higgs sensitivity projections

- Limit
  - ~10 times larger than SM prediction at 115 GeV/c^2
  - ~3 times larger than SM prediction at 160 GeV/c^2
- Will gain
  - Factor ~ √2 from combination of CDF and D0 (note that D0 did no update low mass analysis, and CDF did not update high mass analysis
  - factor $\sqrt{(L/1\ fb^{-1})}$ with increasing luminosity
  - Still need analysis improvements
  - Trigger improvements are critical for the Tevatron

	Luminosity equivalent=$(S/\sqrt{B})^2$
Improvement	**ZH->vvbb**
mass resolution	**1.7**
Continuous b-tag (NN)	**1.5**
Forward b-tag	**1.1**
Forward leptons	**1.0**
Track-only leptons	**1.0**
NN selection	**1.7**
WH signal in ZH	**1.0**
Product of above	**4.7**
CDF+DØ combination	**2.0**
All combined improvement	**9.5**

Similar improvements expected in the other analyses

Z invariant mass reconstruction in b-decays

- Reconstuction of Z decaying to b-jets
  - Measure jet energy scale and resolution
  - Provides a tool for investigating b-jet specific jet energy corrections
- Looking for Z in double tagged events with
  - no additional jets above 10 GeV
  - Jets are back-to-back topology
- 3394±515 Z→bb events were found in a sample of 85,784 double-tagged events. ($333pb^{-1}$)