Searching for the Standard Model Higgs Boson in the Missing E_T and b-jets Signature

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The Standard Model Higgs Boson

- Unification of the electromagnetic and weak interactions based on $SU(2)_L \otimes U(1)_Y$ gauge symmetry

- W/Z vector bosons, generators of the gauge transformations, remain massless

- Solution provided by the Higgs mechanism
  - Introduces a complex scalar doublet that represents a self-interacting scalar field
  - Due to a spontaneous symmetry breaking in the ground state, three of the four real fields have no mass
  - Fixing the gauges of the three EW vector bosons with the three massless components of the Higgs field, the gauge bosons become massive
  - The remaining massive, forth component of the complex doublet is called the Higgs boson

Predictions from the Higgs Mechanism

- Important properties:
  - The mass of the Higgs boson:

$$m_H = v\sqrt{2\lambda}$$

  - Mass of the gauge bosons:

$$m_W = \frac{1}{2}vg, \qquad m_Z = \frac{m_W}{\cos\theta_W}$$

  - where "v" is the vacuum expectation value of the Higgs field

$$v^2 \equiv \frac{-\mu^2}{\lambda} = \frac{\sqrt{2}}{2G_F} = 246 \quad GeV$$

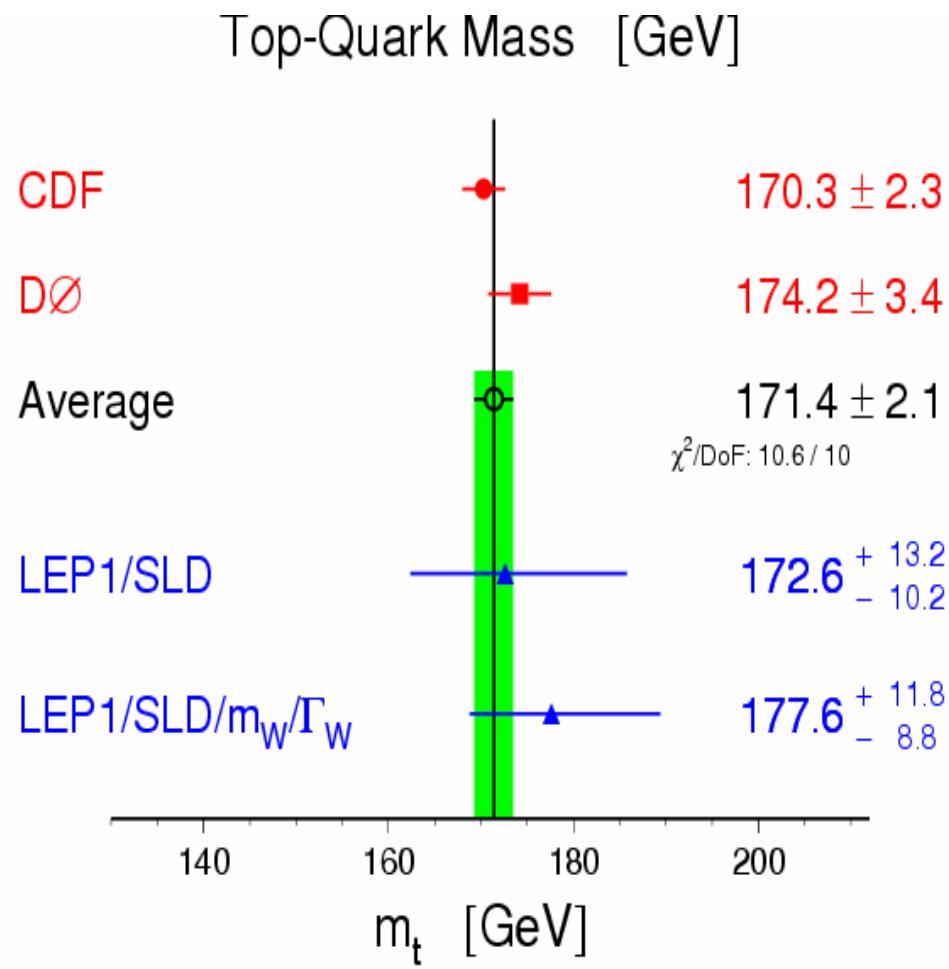
- By measuring the Fermi G_F constant, the Weinberg angle θ_W , and the fine structure constant, the masses of the gauge bosons can be determined

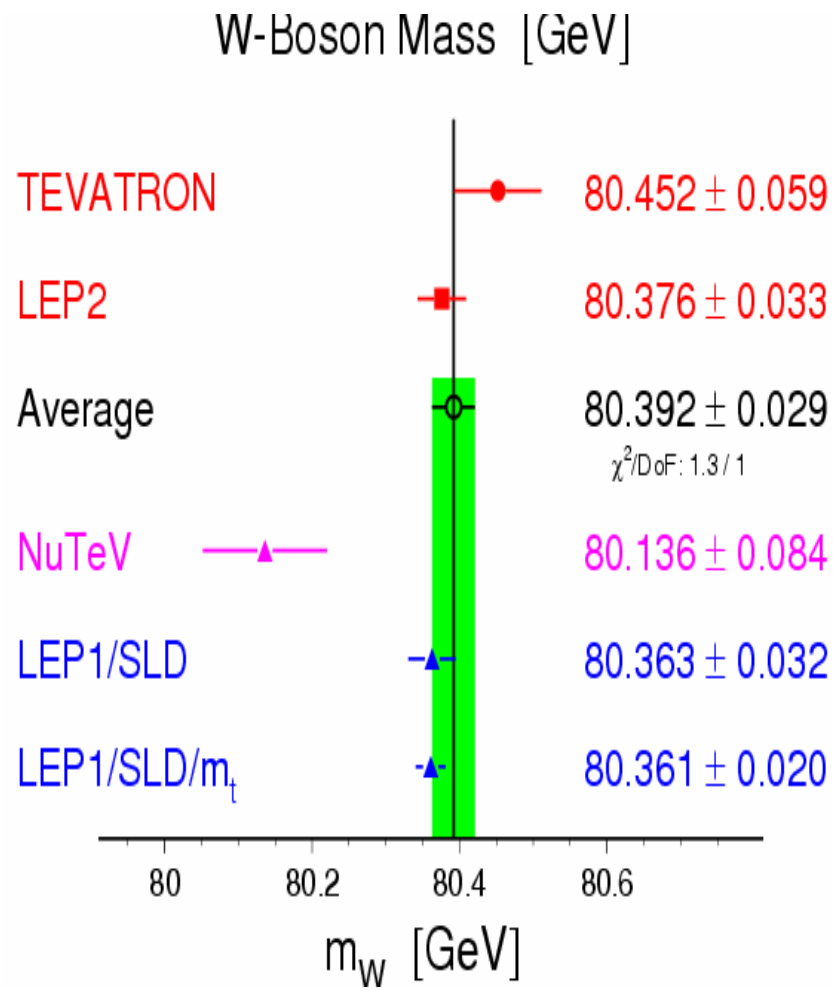
- No information on Higgs mass - λ is still a free parameter

- The fermion-Higgs interaction term:

$$L_{FH} = -\frac{1}{v} m_f \overline{\psi}_f \psi_f H$$

Indirect Higgs Searches



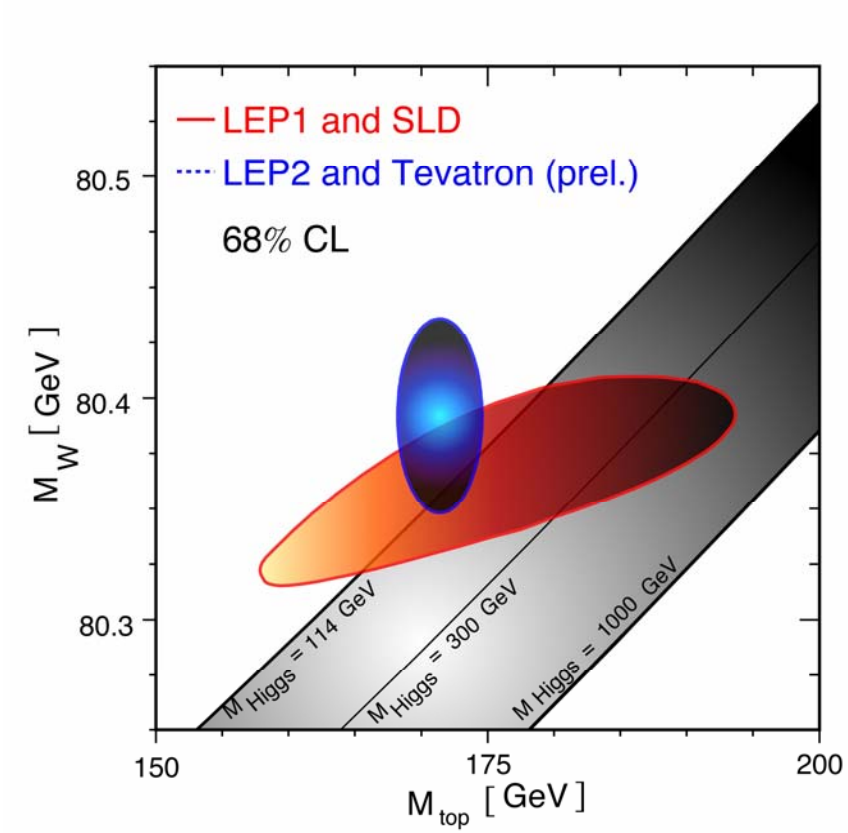


Indirect Higgs Searches

• With precise measurements of the parameters $\sin\theta_W$, m_t, α_s, m_W, α, the SM Higgs mass can be estimated

$$m_w = 80.392 \pm 0.029 GeV$$
$$(LEP / Tevatron\, average)$$

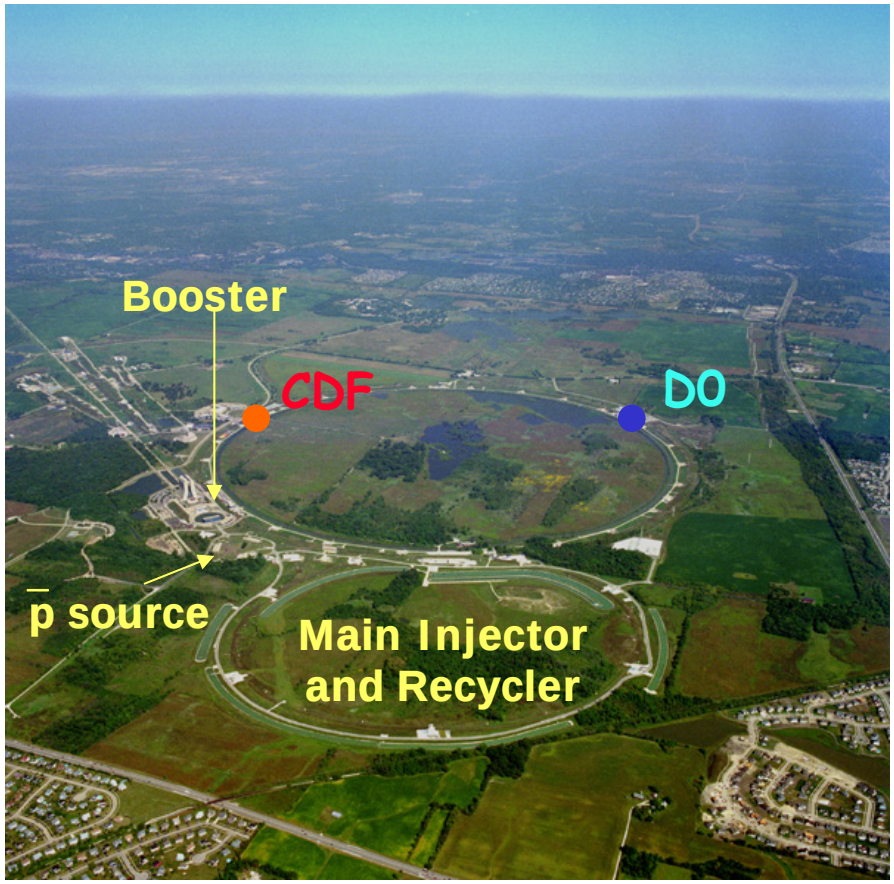
$$m_{top} = 171.4 \pm 2.1 GeV$$
$$(CDF / D0\, average)$$



• Last LEP result was mH>114.4 GeV with 95 % C.L.

• Direct searches are currently performed at Tevatron

Higgs Searches at the Tevatron



- Tevatron: currently only place for direct Higgs searches

- Proton-antiproton collider
  - higher occupancy in the events
  - larger background

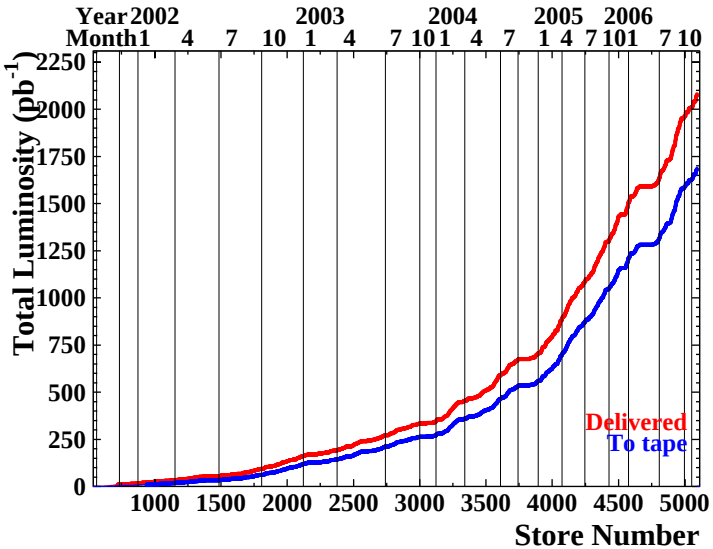
- Run I (1992-1996) with $\sqrt{s}$ = 1.8 TeV
  Integrated luminosity 120 pb^{-1}

- Run II (2001-present) with $\sqrt{s}$ = 1.96 TeV
Integrated luminosity by November '06:
  - Delivered > 2 fb^{-1} / Recorded > 1.6 fb^{-1}
  - **Higgs analyses use up to 1 fb^{-1}**
  - Design goal of 8 fb^{-1} by 2008

- How long can we run? How much time we have until LHC starts?

- How much data can we collect ? – Tevatron and detector performance

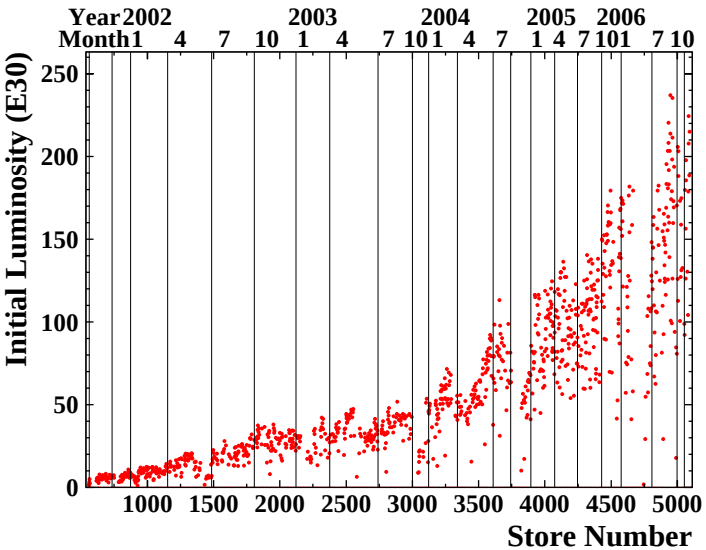
Performance of the Tevatron



- Tevatron performance is improving
- CDF data taking efficiency is ~ 85 % - 90 %
- Due to the increased initial instantaneous luminosity, we experienced higher dead-times

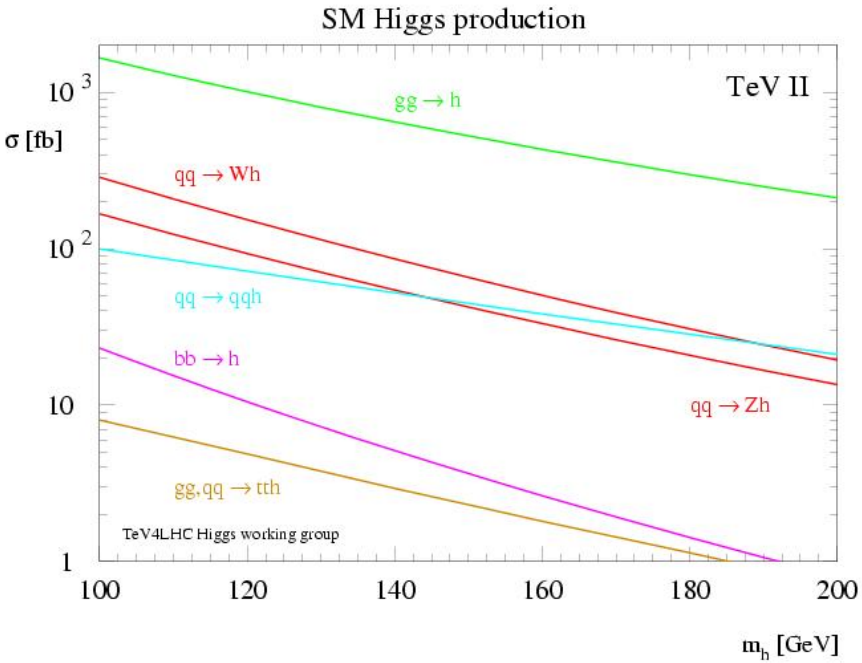
- High instantaneous luminosity:
  - event occupancy is higher
  - increased number of multiple interactions (multiple vertices)
  - trigger level reconstruction is deteriorated

- Need to upgrade triggers and redesign online selection

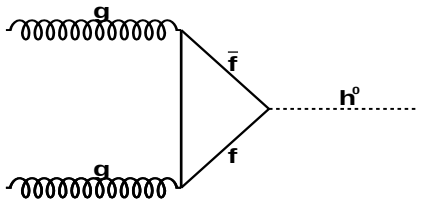


SM Higgs Production at Tevatron

Tevatron:

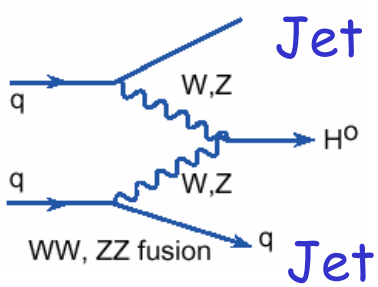


Gluon fusion



- Highest cross-section at all Higgs masses
- Dominated by top-loop due to large top mass
- Cross-section sensitive to new heavy particles

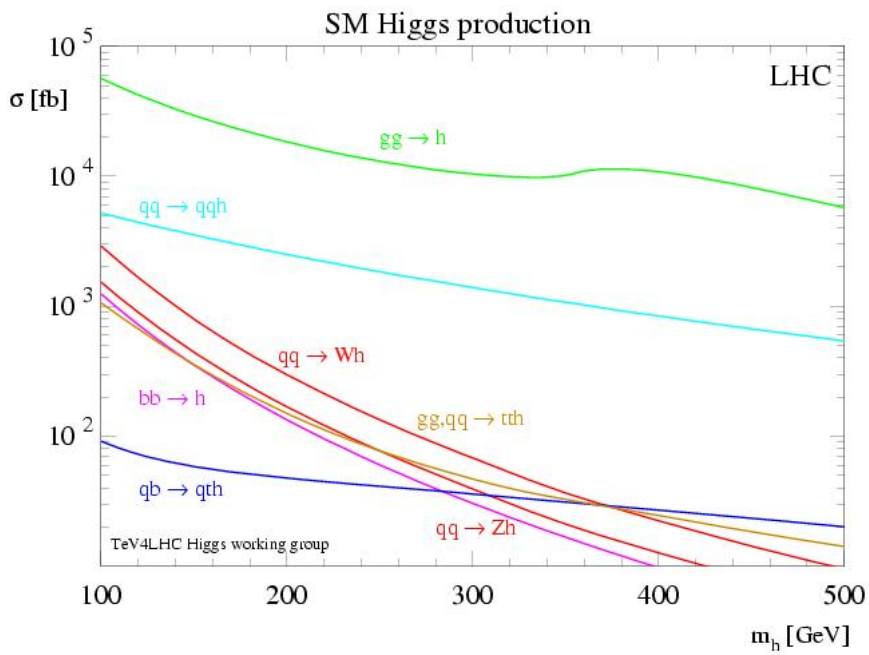
Vector boson fusion



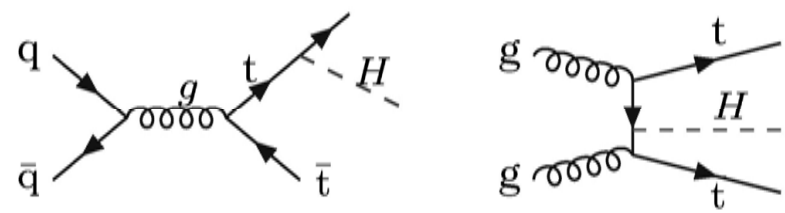
- Relevant at high Higgs masses
- Not relevant at the Tevatron, but important at the LHC
- Forward jets provide unique signature

SM Higgs Production at Tevatron

LHC:

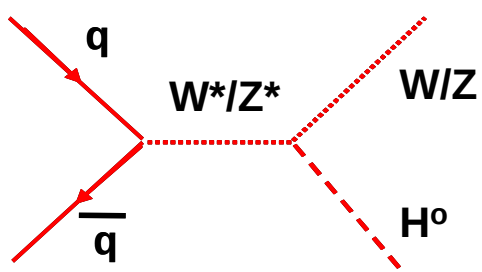


ttH



- Very small cross-section at Tevatron, but promising channel at LHC
- Provides additional sensitivity to other searches at the low mass region in CDF

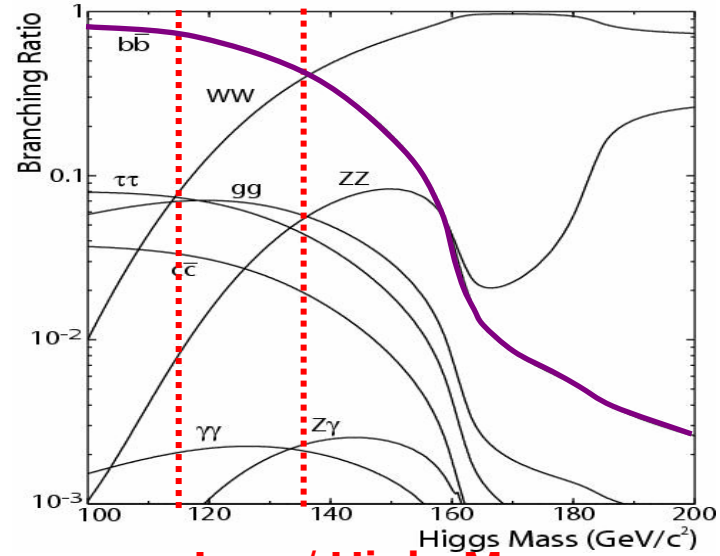
Associate production



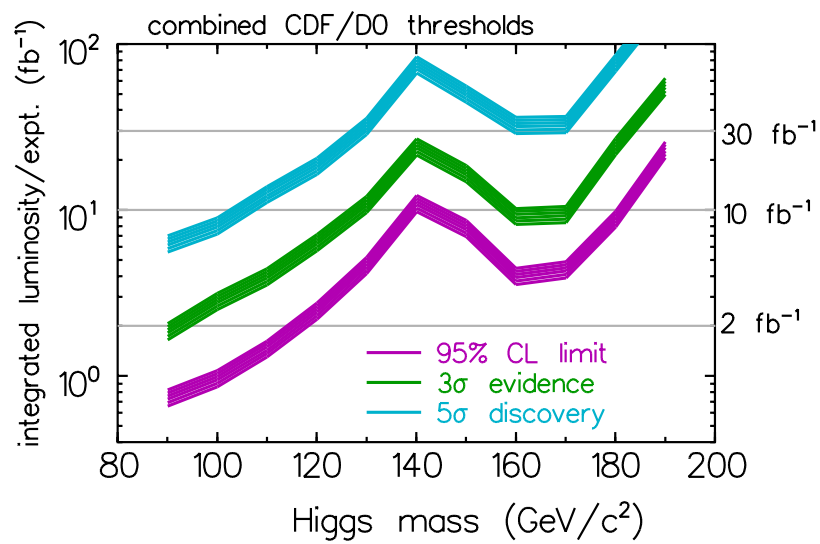
- Cross-section is only an order of magnitude below the gluon fusion at Tevatron
- Decay products of Z/W provide a handle to separate signal from h.f. dijet events
- Somewhat unique to the Tevatron – advantage at low Higgs masses

Decay Channels of the Higgs Boson

- 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 → limited sensitivity in the H→γγ search
- 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 single search is sensitive to the light Higgs
- Channels must be combined



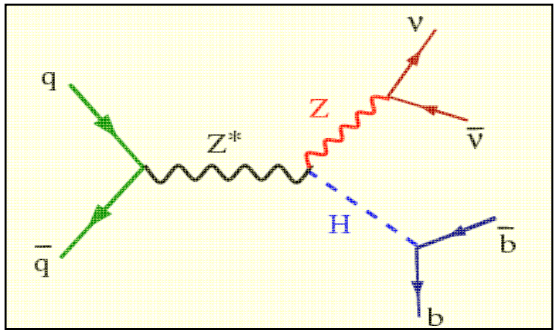
Low / High Mass



Direct SM Higgs Searches in CDF

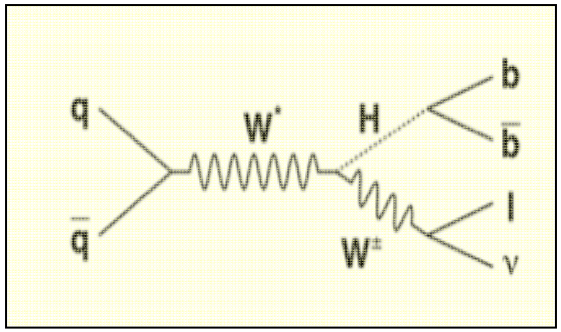
Higgs Mass < 135 GeV

$ZH \rightarrow \nu\nu\ bb$



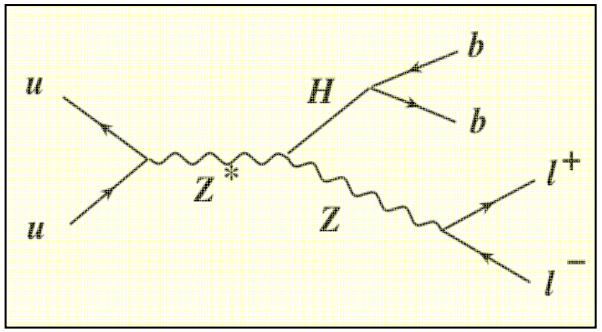
2 b jets + Missing ET
0 leptons
Highest sensitivity

$WH \rightarrow l\nu\ bb$



2 b jets + 1 lepton
Highest production cross-section

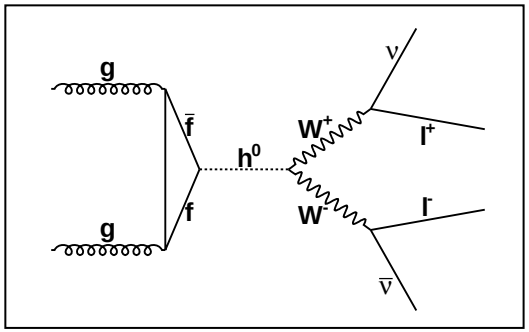
$ZH \rightarrow l^+l^-\ bb$



2 b jets + 2 leptons
Z mass constraint
Cleanest signal

Higgs Mass > 135 GeV

$gg \rightarrow H \rightarrow W^+W^- \rightarrow \nu\nu\ l^+l^-$

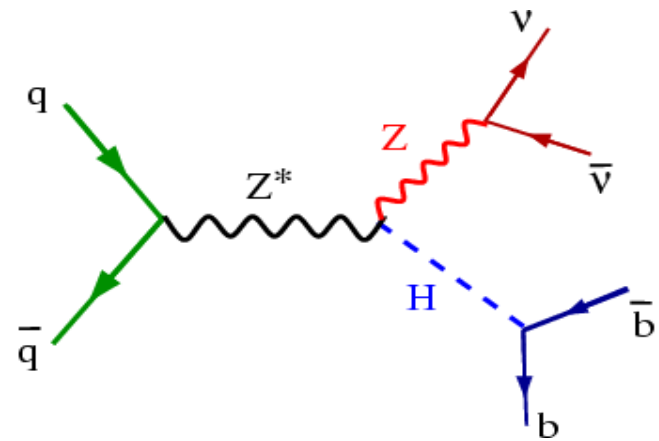


2 leptons + Missing E_T
2 leptons are parallel
Very clean signal, large cross-section

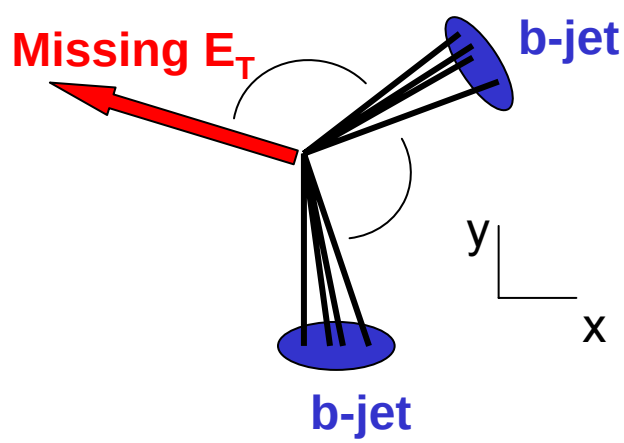
- Highest sensitivity for Higgs beyond 130 GeV
- Currently the closest to be able to exclude the Higgs boson

Higgs in the $\not{E}_T$+b-jets Final State

- Higgs processes leading to missing E_T and b-jets:
  - $ZH \rightarrow \nu\nu\, bb$
  - $WH \rightarrow l\nu\, bb$ (where l is not identified)
  - $gg \rightarrow H \rightarrow bb$ – 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

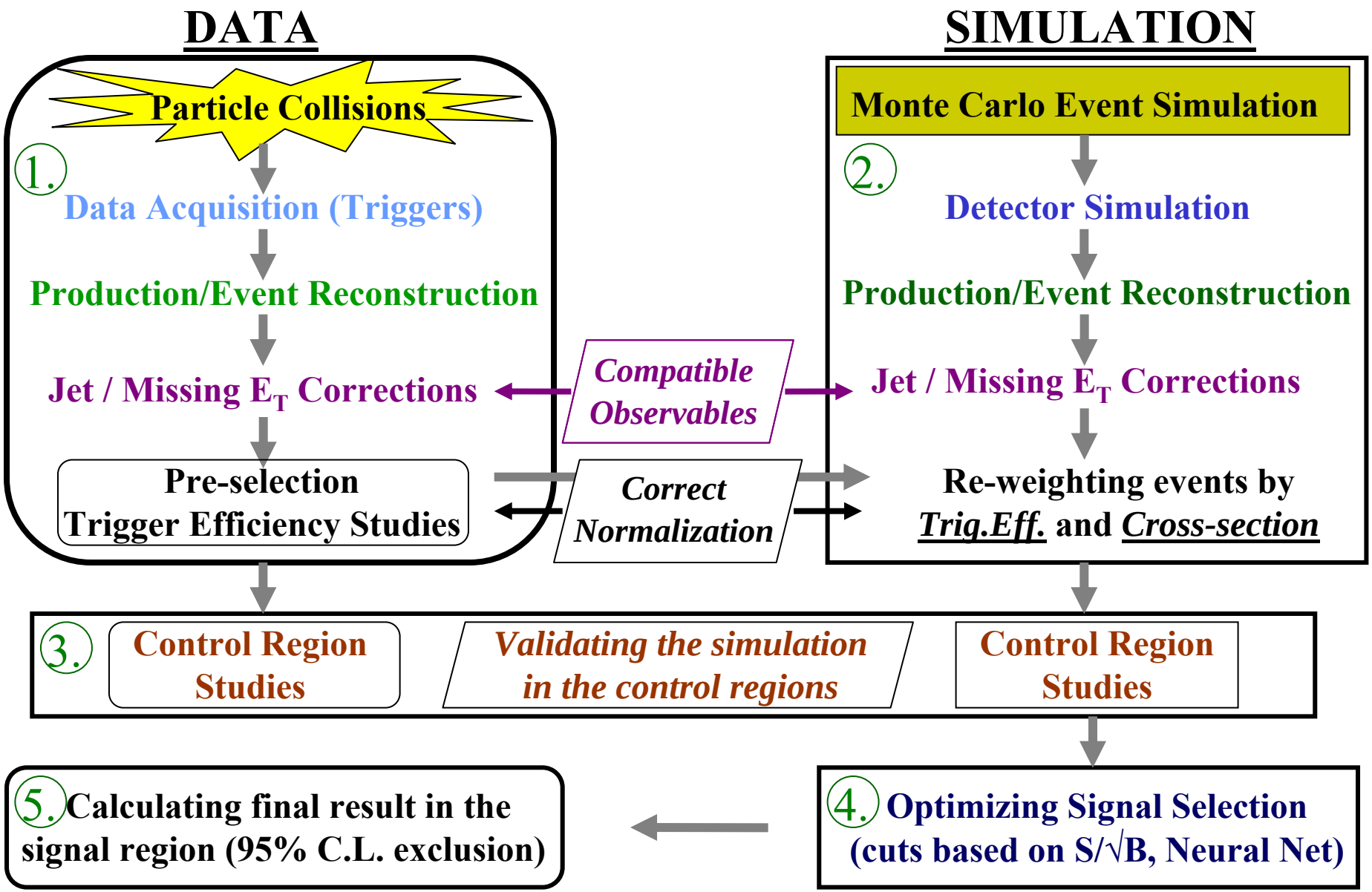


- **Basic Selection cuts:**
  - 1st Jet $E_T > 35$ GeV
  - 2nd Jet $E_T > 20$ GeV
  - No other jets with $E_T > 20$ GeV
  - At least one jet is central
  - Missing E_T (MET) > 55 GeV
  - No leptons (electron or isolated track)
  - 1 or 2 tight b-tag(s)



Distinctive event topology

Schematic Diagram of the (Blind) Analysis



1. Definition of the Missing E_T

• The Missing E_T is the total missing transverse momentum from the Electromagnetic and Hadronic calorimeters.

$$\not{E}_x = -\sum_{(i,j)\ towers} (E_{HAD}^{i,j} + E_{EM}^{i,j}) \cdot \sin\varphi_{i,j}$$

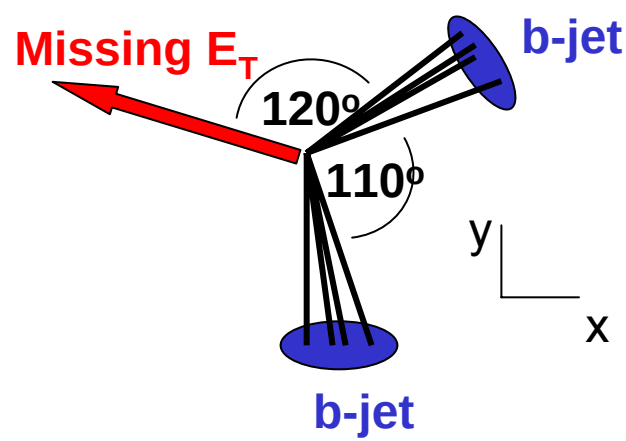
$$\not{E}_y = -\sum_{(i,j)\ towers} (E_{HAD}^{i,j} + E_{EM}^{i,j}) \cdot \cos\varphi_{i,j}$$

• After offline jet-corrections, the clustered part of the Missing E_T (represented by the jets) is also corrected:

$$\not{E}_{x,y}^{Corr} = \not{E}_{x,y}^{Raw} - \sum_{jet\ \ i} \left(E_{x,y}^{Corr,i} - E_{x,y}^{Raw,i} \right)$$

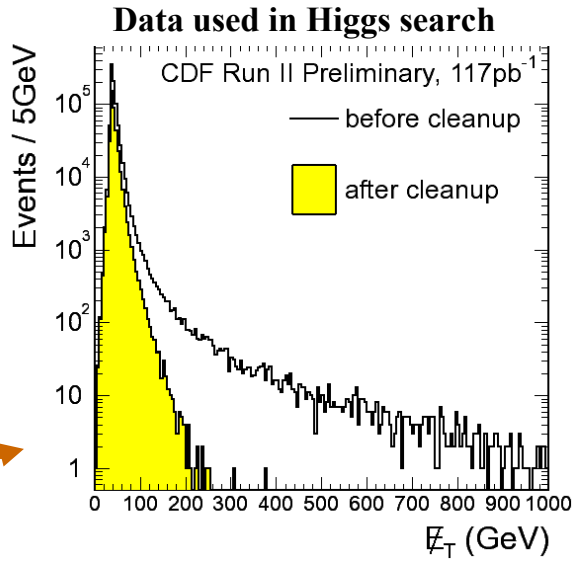
where E_x and E_y are the x and y projections of the jet energies

• The magnitude and direction of the Missing E_T provide the most significant difference between the signal and other heavy-flavor Standard Model backgrounds

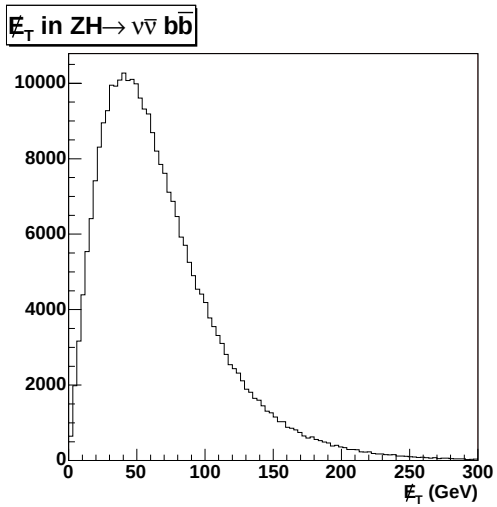


1. Origin of the Missing E_T

- 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



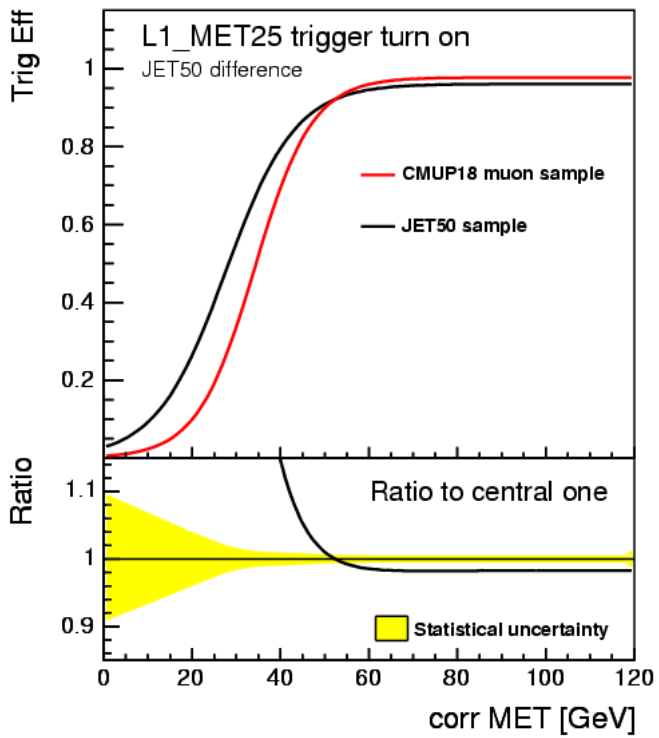
- These effects increase or decrease the missing E_T depending on the kinematics
  - e.g. MET in $W \rightarrow e\nu$ bb is higher than in $W \rightarrow \mu\nu$ bb !!!
  - MET in the signal is much lower than the Z mass



MET in ZH → vvbb events

1. Triggering on Missing E_T

- CDF has a 3-level online data selection system
  - Each level performs a slower but more accurate event reconstruction
  - At the current instantaneous luminosity, the Level 2 output rate is too high
- Using the MET35_TWO_JET10 trigger:
  - Level 1: L1_MET > 25 GeV
  - Level 2: 2 clusters with E_T>10 GeV
  - Level 3: L3_MET > 35 GeV
- Large systematic uncertainty from the Level 1 Missing E_T
- Missing E_T is not reconstructed at Level 2



"Turn on" is different for real and for instrumental missing E_T

1. Efficiency of the MET35 trigger

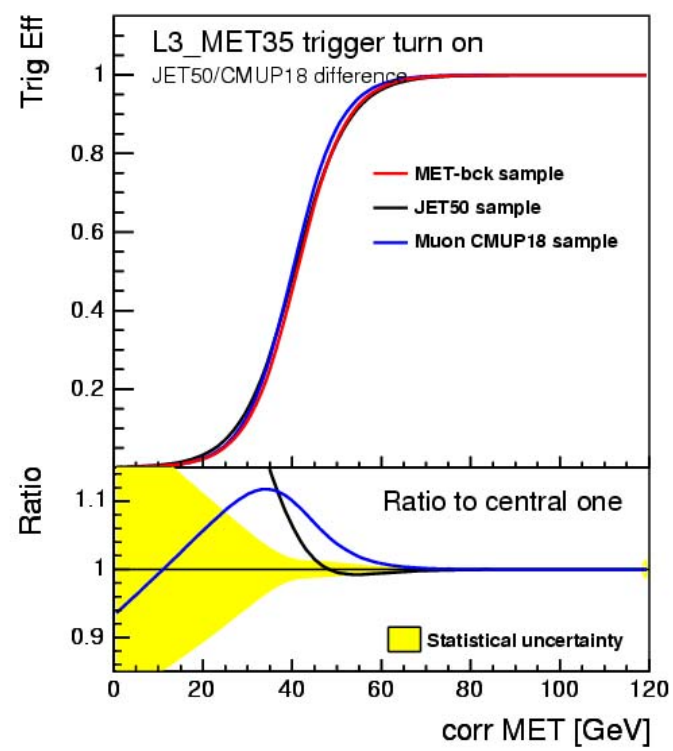
- Efficiency is a function of the two-jet and the MET requirements: $\varepsilon(\text{jet 1, jet 2}, \not{E}_T)$

- Assume: two-jet requirement is not correlated with MET: $\varepsilon(\text{jet 1, jet 2}, \not{E}_T) = \varepsilon(\text{jet1, jet2}) \cdot \varepsilon(\not{E}_T)$

- Trigger efficiency is expressed as a function of Missing E_T after requiring offline:
  - 1st Jet $E_T > 35$ GeV
  - 2nd Jet $E_T > 20$ GeV
  - One jet is central
  - Consider the two-jet requirement fully efficient $\varepsilon(\text{jet1, jet2}) = 1.0$

- Small systematic uncertainty from the L3 MET

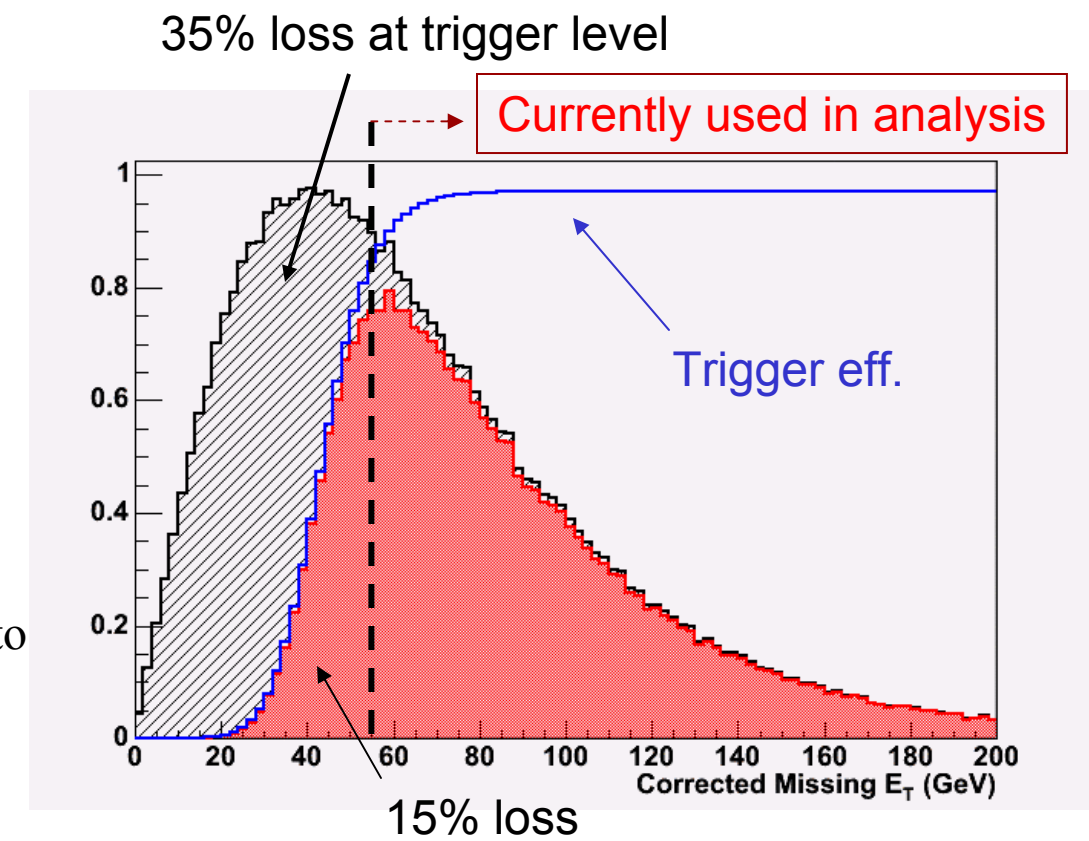
- The final Missing E_T selection (after optimization) is $\not{E}_T > 75$ GeV, where the efficiency is 0.97 ± 0.03



"Turn on" is independent of the origin of the Missing E_T

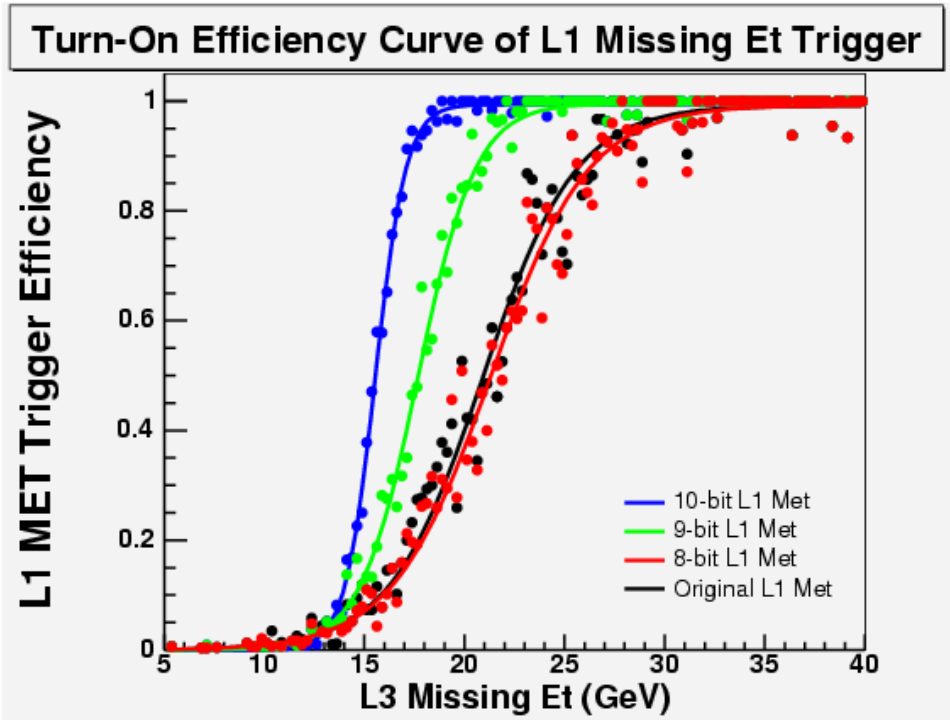
1. Re-weighting with the Trigger Efficiency

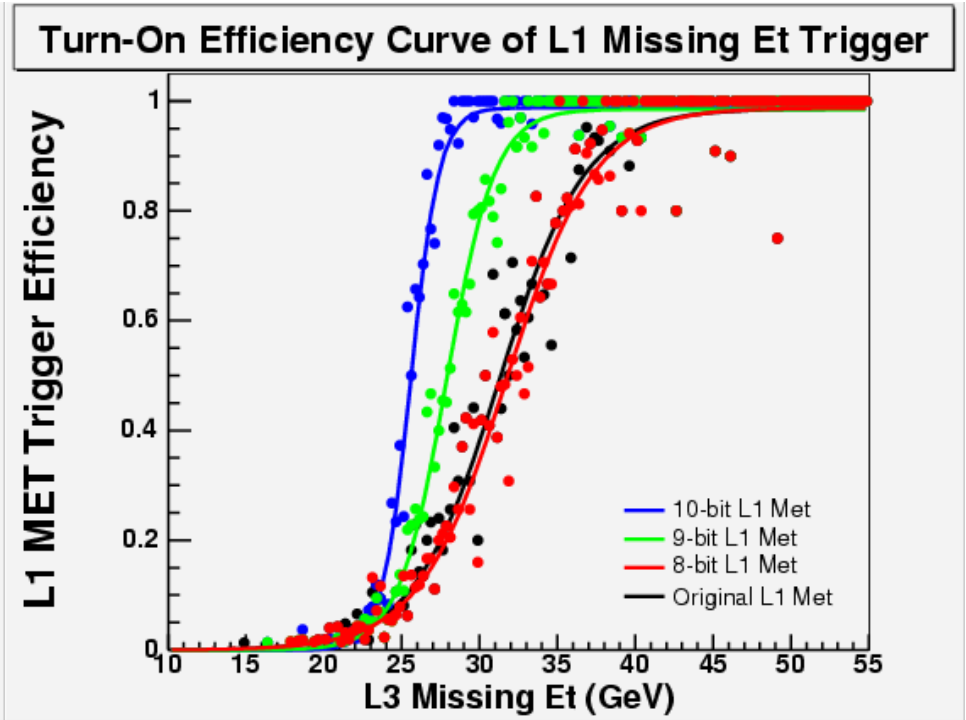
- Trig.Eff. for QCD dijet h.f. is determined from a Jet-data sample (MET is instrumental)
- Trig.Eff. for the signal is calculated using a High P_T muon sample (MET is physical)
- Red full histogram shows the signal after applying the trigger efficiency
- Trigger is very inefficient
  - Loss in acceptance is ~15 % due to avoiding large systematic uncertainties in the trigger turn-on
  - ~35% of signal loss is due to the online data selection
  - **Total 50% trigger related loss in signal yield**



Corrected Missing E_T of the SM Higgs
$ZH \rightarrow \nu\nu bb$, M_H=120 GeV
(arbitrary normalization)

1. Improving the Trigger Level Missing E_T





Efficiency of a Met > 15 GeV cut calculated with different granularities

Efficiency of a Met > 25 GeV cut

- With a modification at L1 a sharper turn-on is feasible
- With the L2 upgrade, the full calorimeter information is available for clustering and Met calculation (blue curve) → accuracy nearly equivalent to L3

2. Standard Model Background

- **QCD dijet:** 2 h.f. jets + missing energy
  - Missing E_T is instrumental (due to jet energy mismeasurement)
  - Cross-section 10^9 times larger than ZH production
  - Missing E_T is generally smaller than in the signal events (instrumental)

- **"Electroweak":** unidentified leptons + h.f. jets + missing energy
  - Missing E_T from missing lepton and/or mismeasured jets
  - W + 1/2 h.f. jet(s) – 500 times the signal
    - W(-> e/μ, ν) + cq/bb/cc
  - Z + 2 h.f. jets – 50 times the signal
    - Z(-> $l^+ l^-$) + bb/cc (l: tau/muon)
    - Z(-> ν ν) + bb/cc – irreducible background, similar to the signal
    - Z-> τ τ
  - Z-> bb – similar to QCD background

2. Standard Model Background

- **Top/Single Top:** 2 b-jets + missing energy
  - Missing E_T is from decay products of W from the top decay
  - ~10 times the signal
  - Higher jet multiplicity
  - Jets are more energetic

- **Diboson** : unidentified lepton + 2 taggable jets + missing energy
  - WW, WZ, ZZ
  - One boson decays leptonically, the other hadronically
  - ~ 5 times the signal before lepton veto
  - $ZZ \rightarrow \nu\nu$ bb is irreducible

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

2. Monte Carlo Samples (1 fb^{-1} run range)

Pythia	Luminosity being generated (fb^{-1})	Luminosity in blessed results (fb^{-1})
QCD h.f.	**~ 5**	**~ 1**
$t\bar{t}$	**~ 200**	**~ 233**
$W \to e\nu$	**12.2**	**~ 2**
$W \to \mu\nu$	**22.3**	**~ 1**
$W \to \tau\nu$	**12.2**	**~ 3**
$Z \to e\bar{e}$	**22.8**	**~ 6**
$Z \to \mu\bar{\mu}$	**22.8**	**~ 6**
$Z \to \tau\bar{\tau}$	**11.5**	**~ 18**
$Z \to \nu\bar{\nu}$	**44.5**	**~ 9**
$Z \to b\bar{b}$	**Not simulated**	**~ 1**
WW	**41.6**	**~ 30**
WZ	**136**	**~ 105**
ZZ	**380**	**~ 276**

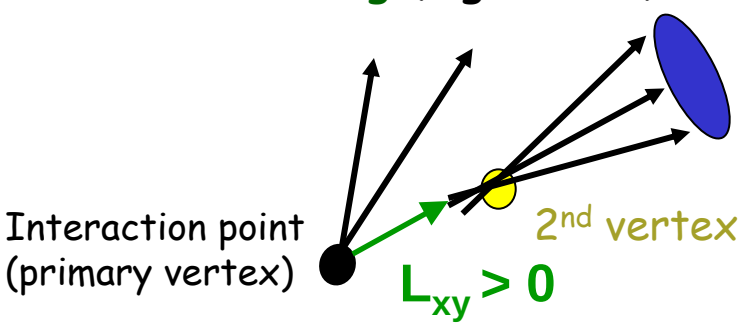
- MC events are normalized to luminosity
- LO (Pythia) cross-sections are corrected by a k-factor
- Number of QCD h.f. events (passing basic selection) are normalized to data
- Due to large cross-section, only heavy flavor QCD events are simulated
  - MC simulation and data can be compared ONLY in h.f. events → requires b-tagging

2. High P_T b-tagging at CDF

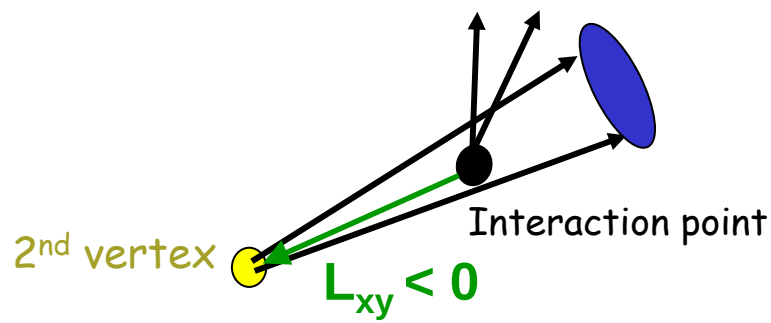
- SecVtx tagging algorithm takes advantage of the long b lifetime
- Heavy flavor measured by counting the positive tags

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

Positive tag (right side)



Negative tag (wrong side)

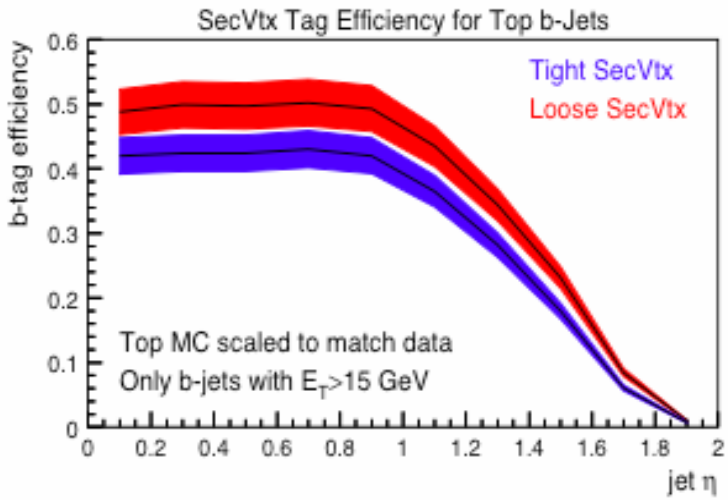


- b, c, and light quark jet content depends on the cut on $\mathbf{L_{XY}} / \sigma_{XY}$
- Signal events have two b-jets
- Events are classified by having one (exclusive single) or two (double) tags
  - Single tag: contains more mistag and charm jets
  - Double tag: purer in b, but lacks in statistics,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

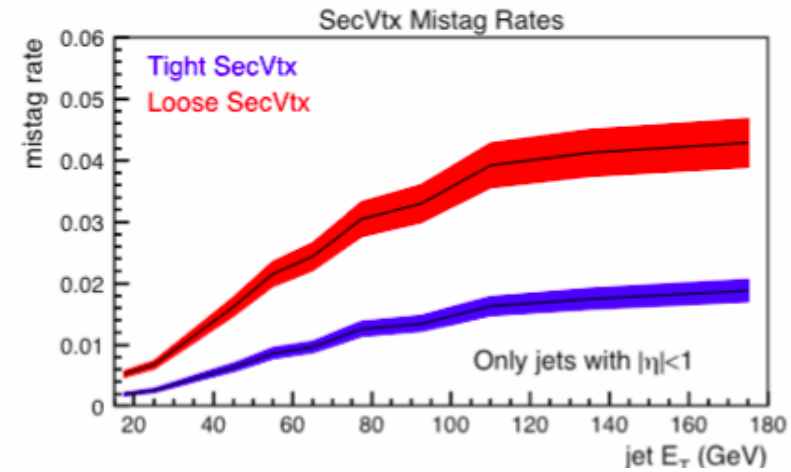
2. b-tagging at CDF

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

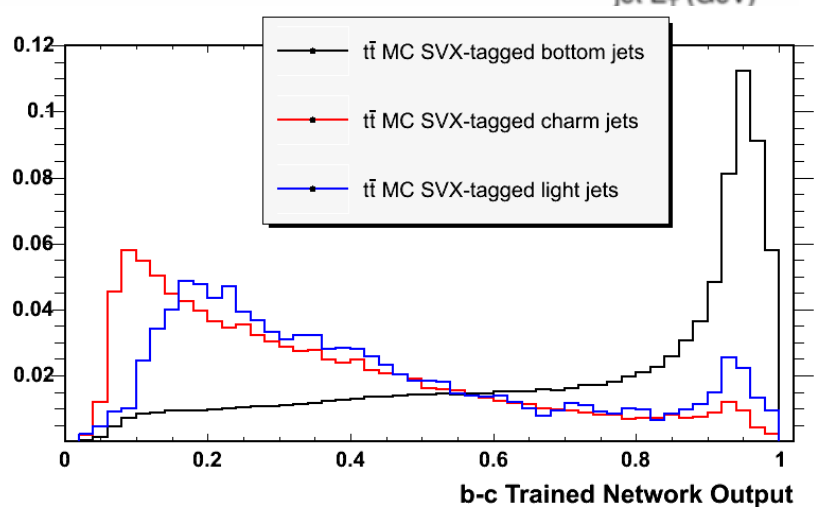
B-Tag Efficiency (Positive Tag)



Light quark mistag rate (Negative Tag)



- New taggers being developed using Neural Network trained to discriminate b-, c- and light quark jets



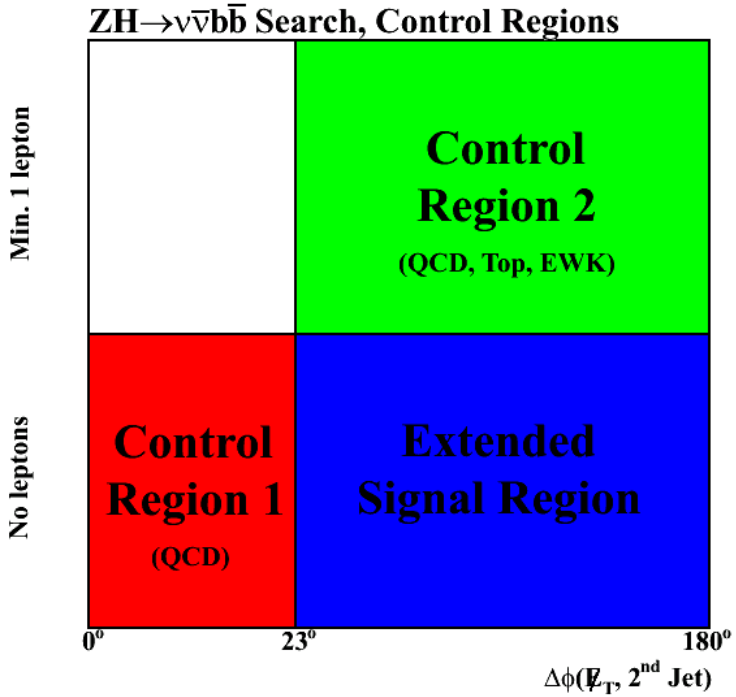
2. Heavy Flavor Background Simulation and Mistag Estimation

- Simulating Tags
  - Only events with taggable objects (b, c, or tau) are simulated
  - Positive tag assumes a b- or c-quark in the 0.4 radian cone of the tagged jet (avoid double counting)
  - Uncertainties in tagging efficiency scale factor 8% or 16% for single and double tagged events

- Mistags estimated from the data
  - Calculating the rate of the negative tags
  - Scaling it 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)
  - Uncertainties from Mistag matrix (statistical 1%-5% and systematic ~17%)

3. 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

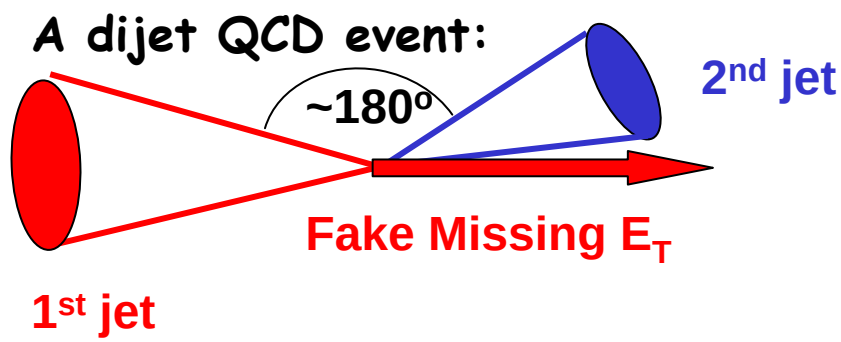
- Veto events with leptons
- Missing E_T and 2nd leading jet are not parallel
- Cut optimization is performed in this region based on Monte Carlo simulation before looking at the real data

Control Region 1 – QCD

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

3. Control Region 1

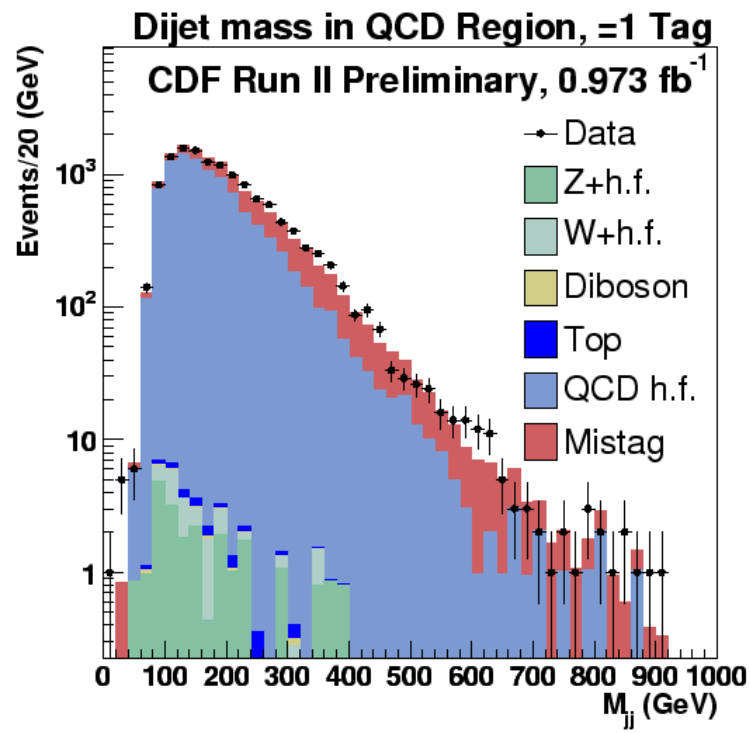
QCD event topology:
- **Jets are back-to-back**
- **"Missing E_T" points along the 2nd jet**



Control Region 1:

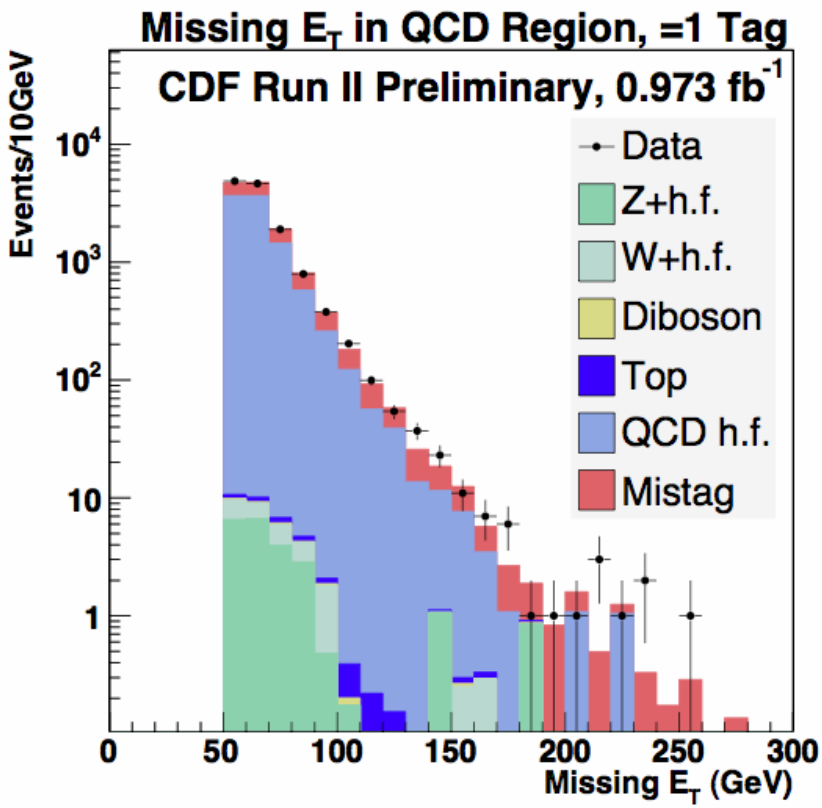
- QCD multi-jet is the dominant process
- MET is due to the mismeasurement of the jets

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



3. Control Region 1 : $\not{E}_T$ simulation

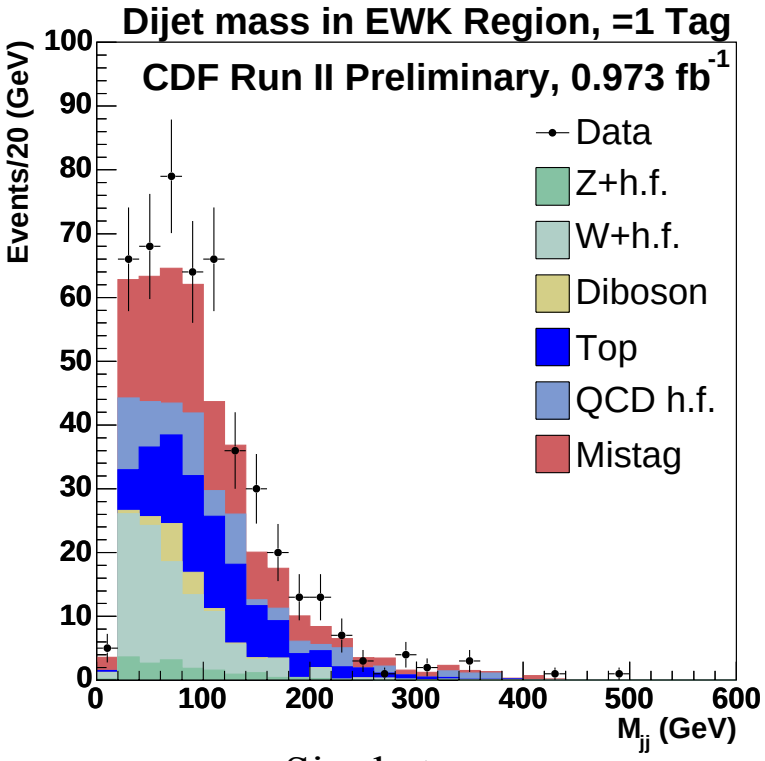
- All background processes are simulated
  - better understanding of correlation between MET and event kinematics
  - allowing for better signal selection (using ANN in progress)
- The detector simulation reproduces well the "fake" missing E_T



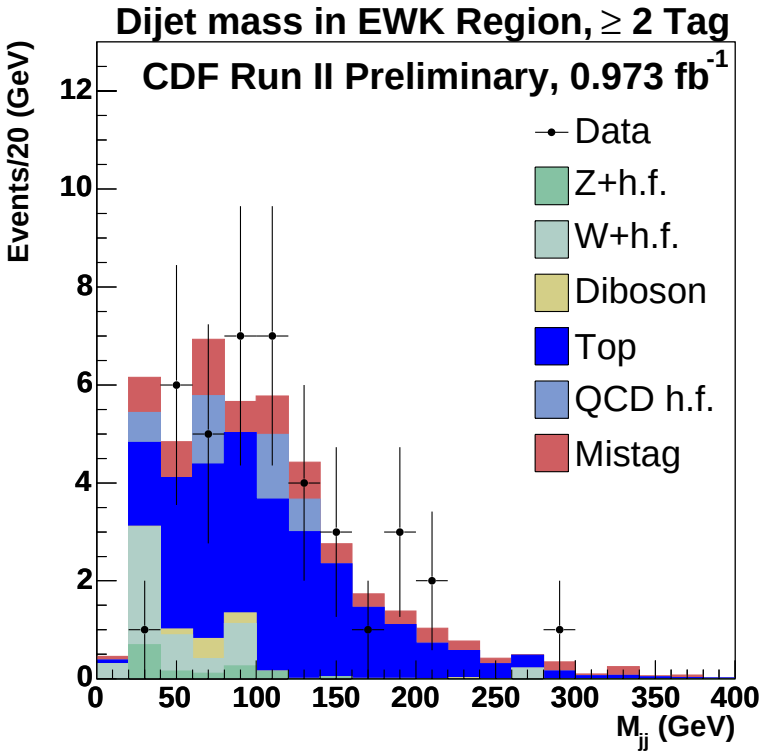
"fake" MET in QCD events

3. Control Region 2

- Single tag: all background processes are tested
- Double tag: dominated by top
- Overall normalization is confirmed



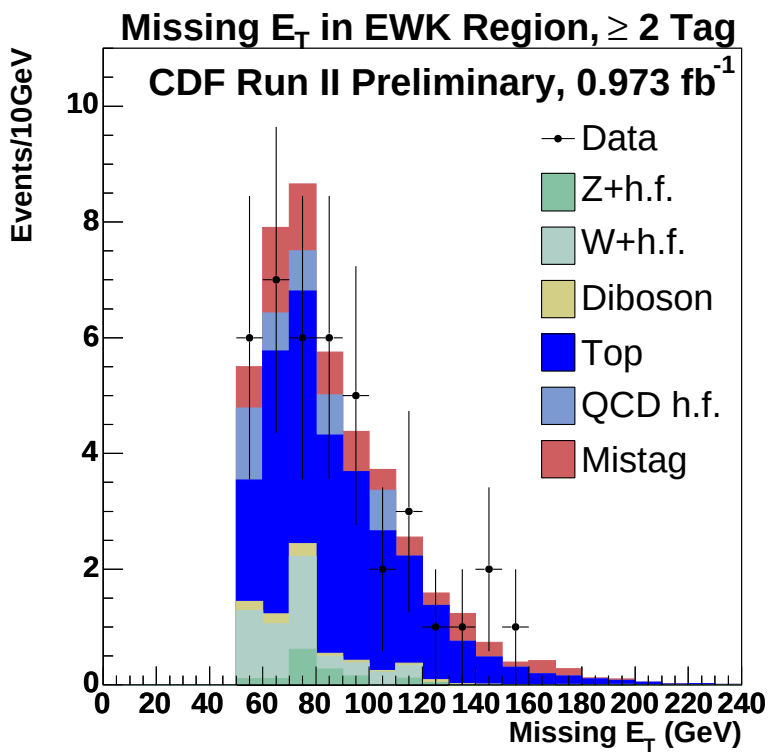
Single tag



Double tag

3. Control Region 2 : $\not{E}_T$ simulation

- Missing E_T is due to mismeasured/undetected leptons and jets
- The detector simulation reproduces well the missing E_T



Double tag sample in CR2: 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

4. Signal Selection

- Good agreement between Data and Monte Carlo simulation in the control regions
- Perform selection cut optimization in the Signal Region using the simulation
- Current selection
  - Simple orthogonal cuts
  - Only appropriate because of poor statistics in the Monte Carlo
- New selection being developed
  - Using Artificial Neural Net
  - Possible with improved Monte Carlo statistics produced this year
  - Developing an advanced selection technique based on Neural Networks

4. Higgs Invariant Mass

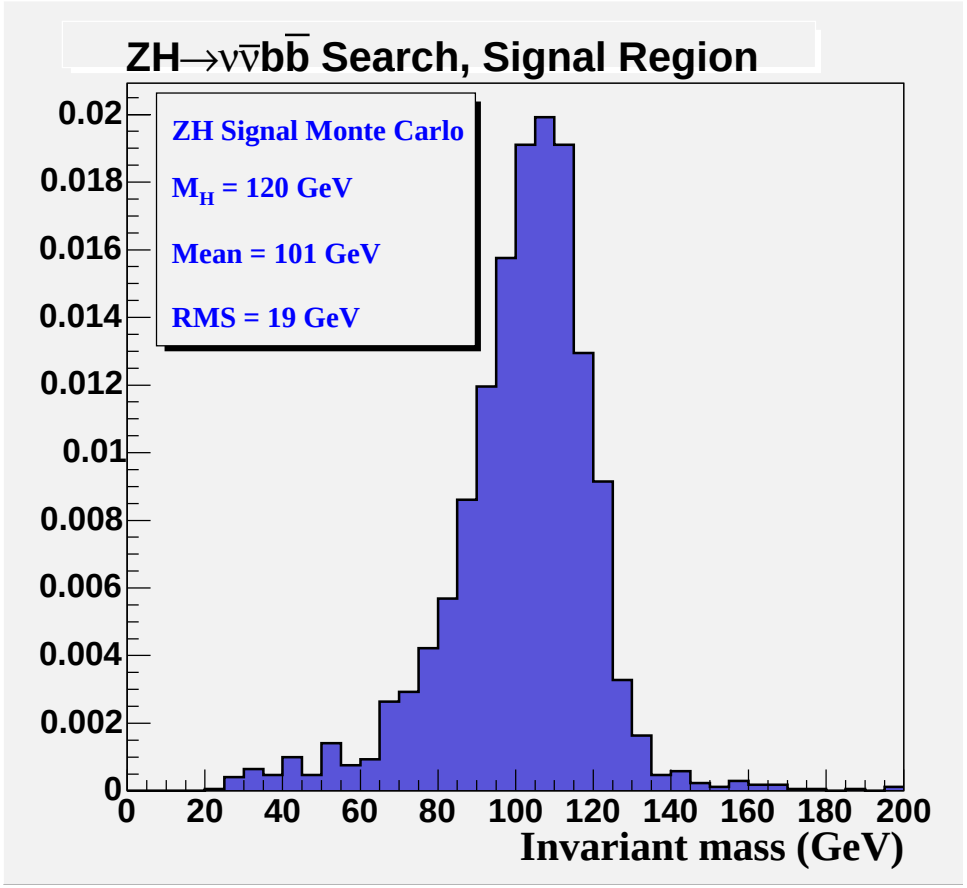
- Dijet mass is used to extract the limit

- Average mass is lower than generated Higgs mass
  m_H=120 GeV → 101 GeV ± 19 GeV

- Dijet mass resolution is ~19 %

- Actual dijet mass resolution can be tested in Z → bb decays

- Improving dijet mass reconstruction is one of the major efforts at CDF



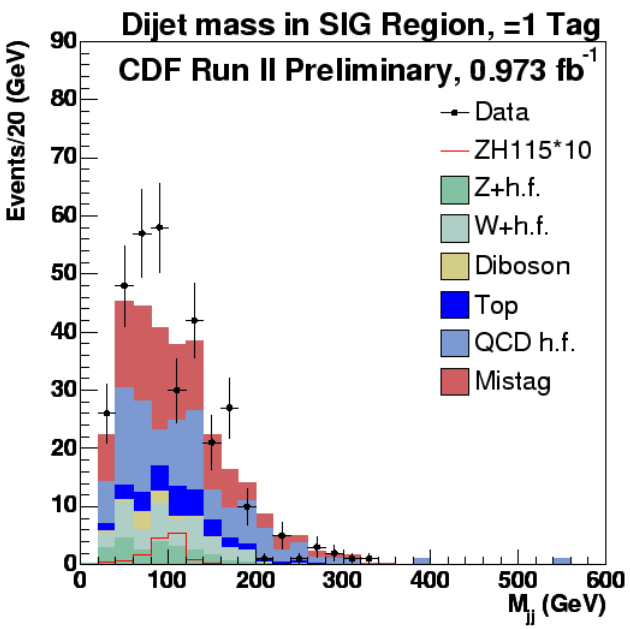
Dijet invariant mass in Higgs signal simulation

5. Signal Region

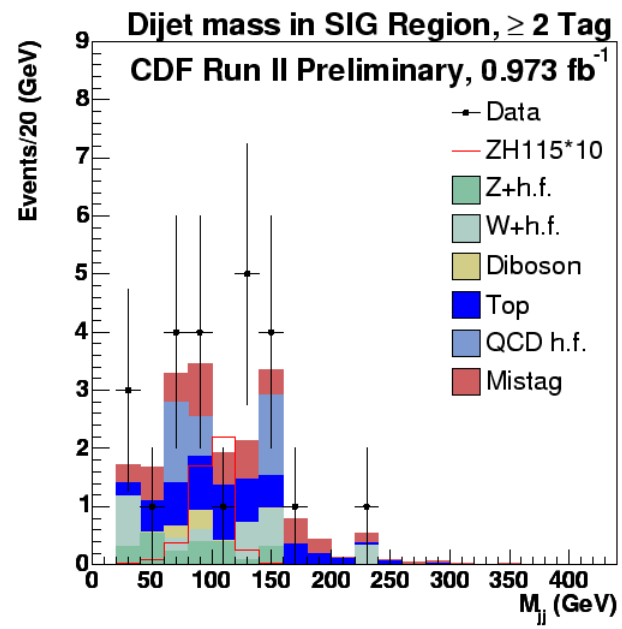
Events are classified in two sets with one or two identified heavy flavor jets after passing the optimized cuts:

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

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



Single Tag



Double Tag

Signal acceptance

5. Results

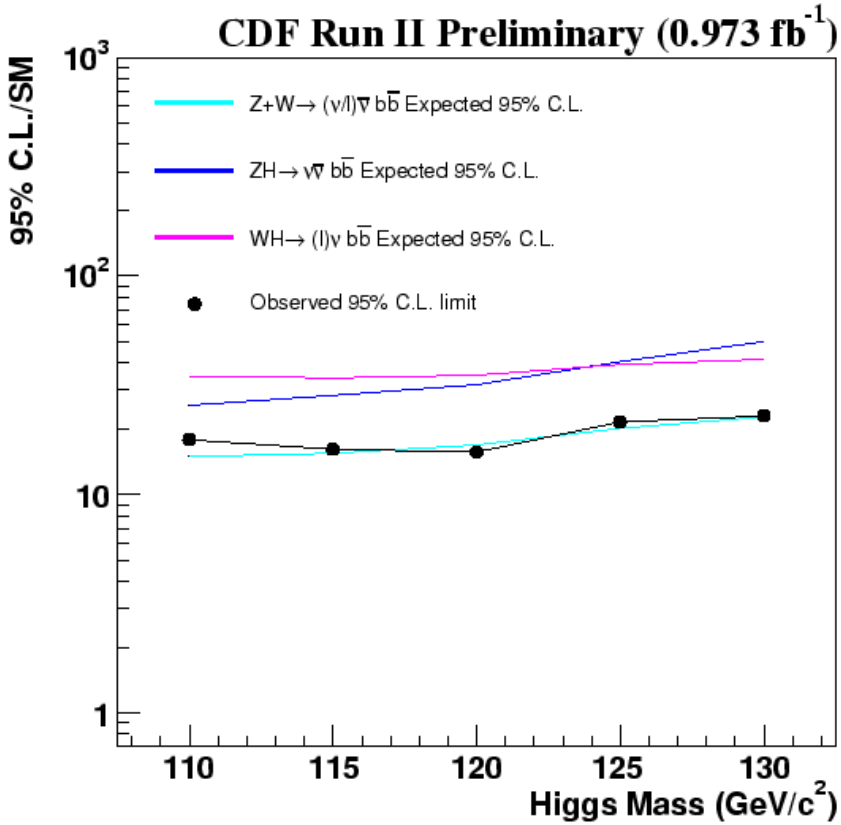
95% C.L. limit/SM cross-section set in the ZH and WH samples separately at each Higgs mass, and combined:

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 ($L \sim 300\ pb^{-1}$)
  - Improved lepton veto
  - Separate single and double b-tags
  - Include WH as signal
  - Use fit to dijet mass spectrum

- Using Neural Net selection is the last improvement planned for the 1 fb^{-1} publication

5. The 95% C.L. limits

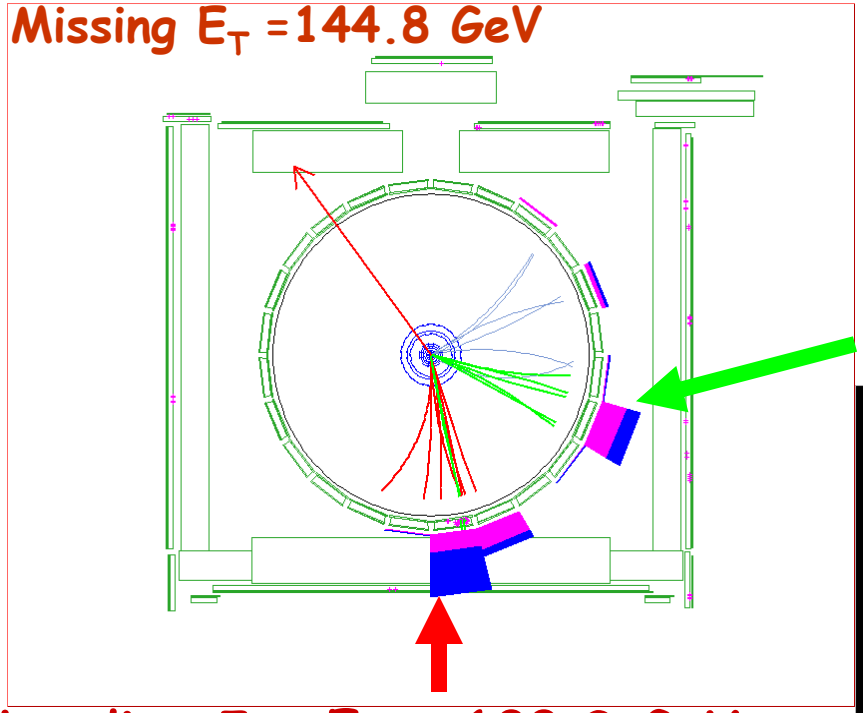


- Observed and expected limits are consistent
- Largest systematic uncertainties
  - Correlated:
    - Jet energy scale 3%-20%
    - Luminosity 6%
    - Trigger efficiency 3%
    - b-tag efficiency 8% or 16%
  - Uncorrelated:
    - Cross-sections 12%
    - Lepton identification 2%
    - Mistag asymmetry 17%
    - MC statistics 3%-44%

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

Candidate Event

Missing E_T =144.8 GeV



Leading Jet E_T = 100.3 GeV

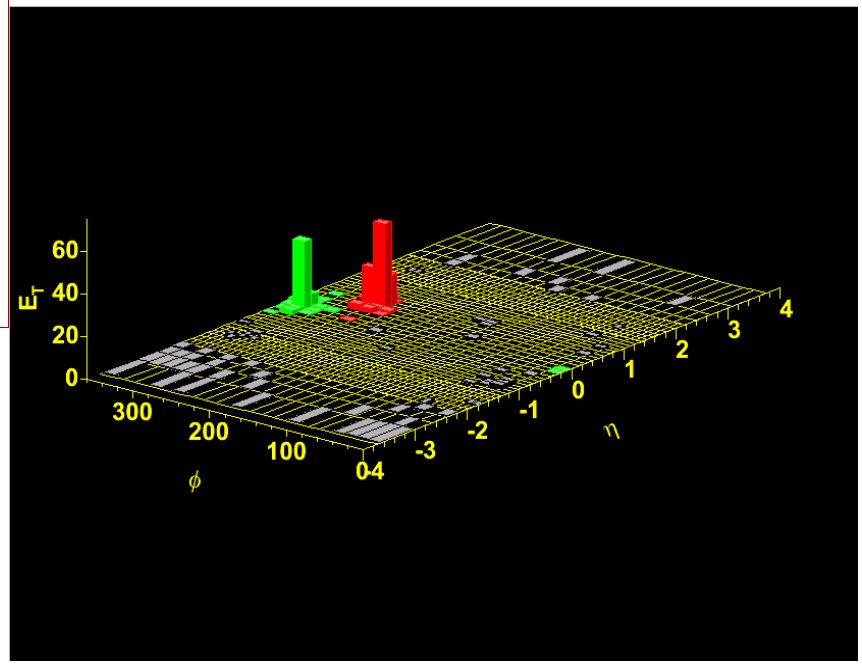
Di-jet invariant mass = 82 GeV

Data event from Signal Region

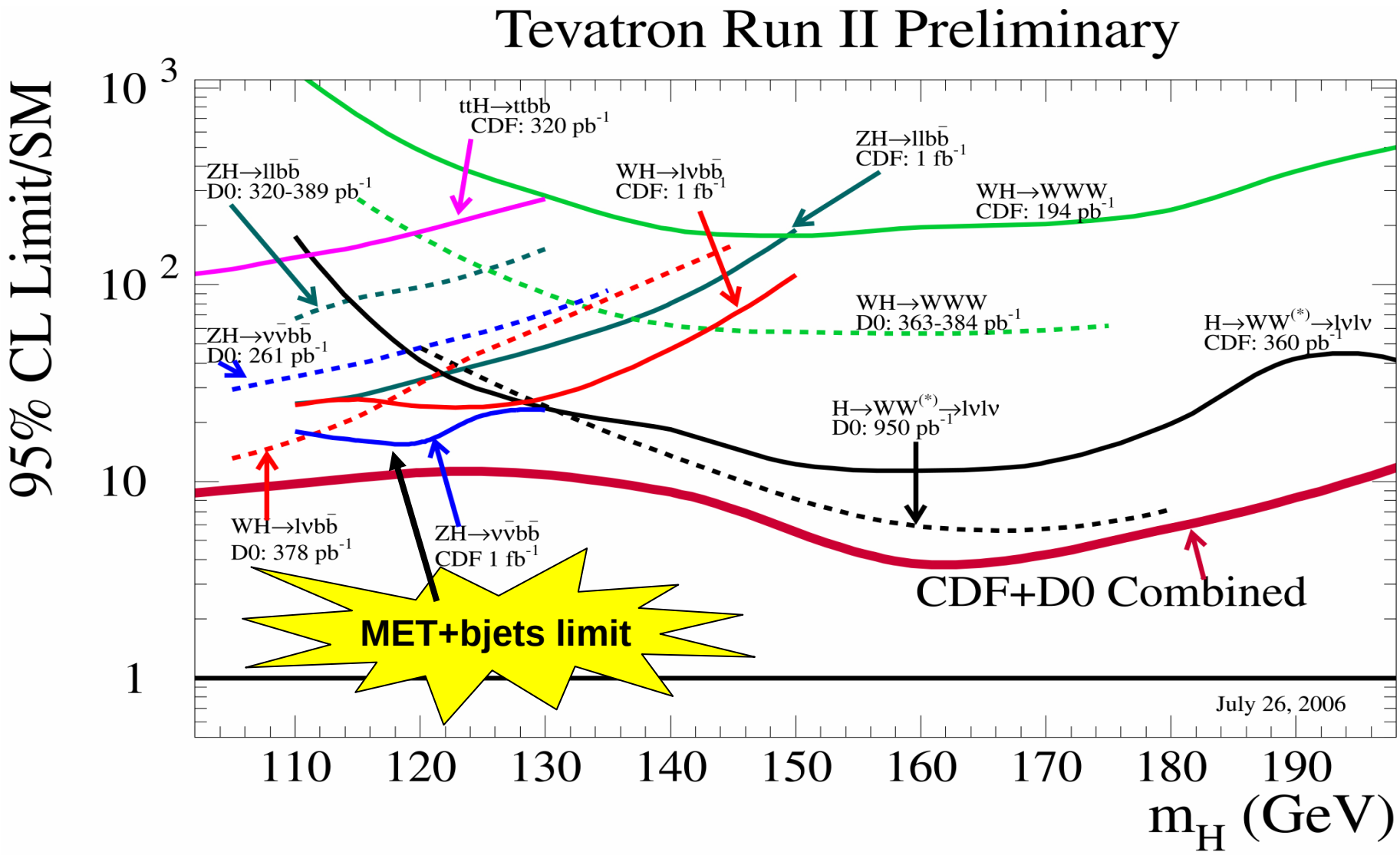
- Passed all selection cuts
- Candidate in the 80-120 GeV mass window

Double-tagged event

Second Jet E_T = 54.7 GeV



Combined Tevatron Limits



Summary of Observed Limits at the Tevatron

Analysis	CDF limit @ M_H = 115 GeV (factor above SM)	D0 limit (factor above SM)
ZH -> ννbb	Includes WH (miss lep) (14)	3.4 pb (41)
WH -> lνbb	3.4 pb (23)	2.4 pb (16)
ZH -> llbb	2.2 pb (27)	6.1 pb (75)

95% C.L. exclusion limits in the low mass searches at the Tevatron

Summary

- Performed analysis on 0.97 fb^{-1} data in 2006
- MET + b-jet search is the most sensitive in the low Higgs mass region; techniques/tools are still improving
- 95% C.L. cross-section limit is ~16 times over the Standard Model expectation
- Inspired a new search using MET + Isolated track + b-jet final states
- Motivates Level 2 trigger upgrade for more efficient data taking
- CDF+D0 combined limit is now only ~10 times the SM Higgs cross-section in the low mass region

Backup Slides

Higgs Sensitivity Projections

- Limit
  - ~10 times larger than SM prediction at 115 GeV/c2
  - ~3 times larger than SM prediction at 160 GeV/c2

- Will gain in a long term
  - 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 √(L/1 fb-1) with increasing Luminosity

- Still need analysis improvements (see table)

- 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

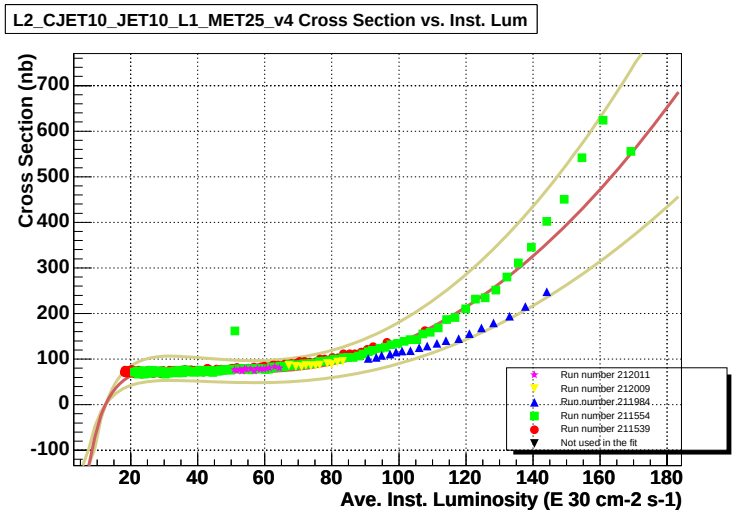
L2/L3 output rate of the MET35 + 2 Jets trigger

- First, we need to make these triggers ***survive at high luminosities*** without losing sensitivity in the physics searches

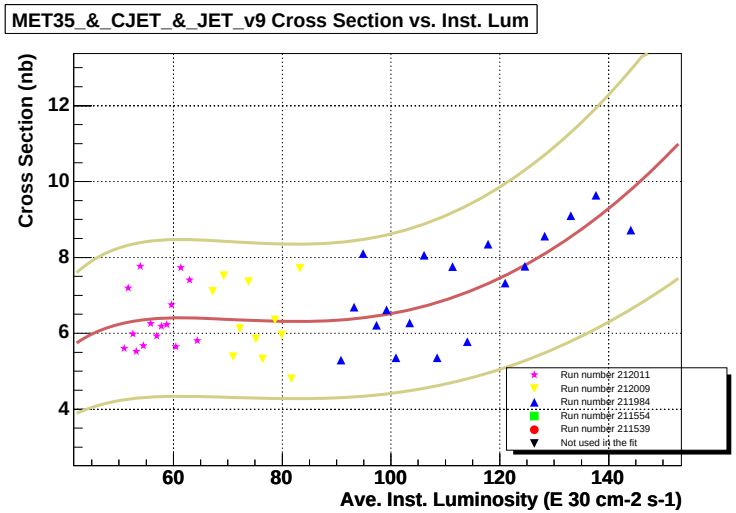
- With the L2 upgrade, it would be possible to recalculate Missing E_T with a precision similar to that at L3 (see rate reduction in plots, below)

  - Solves the rate problem without tightening the requirements

  - Improves L2 triggering on jets



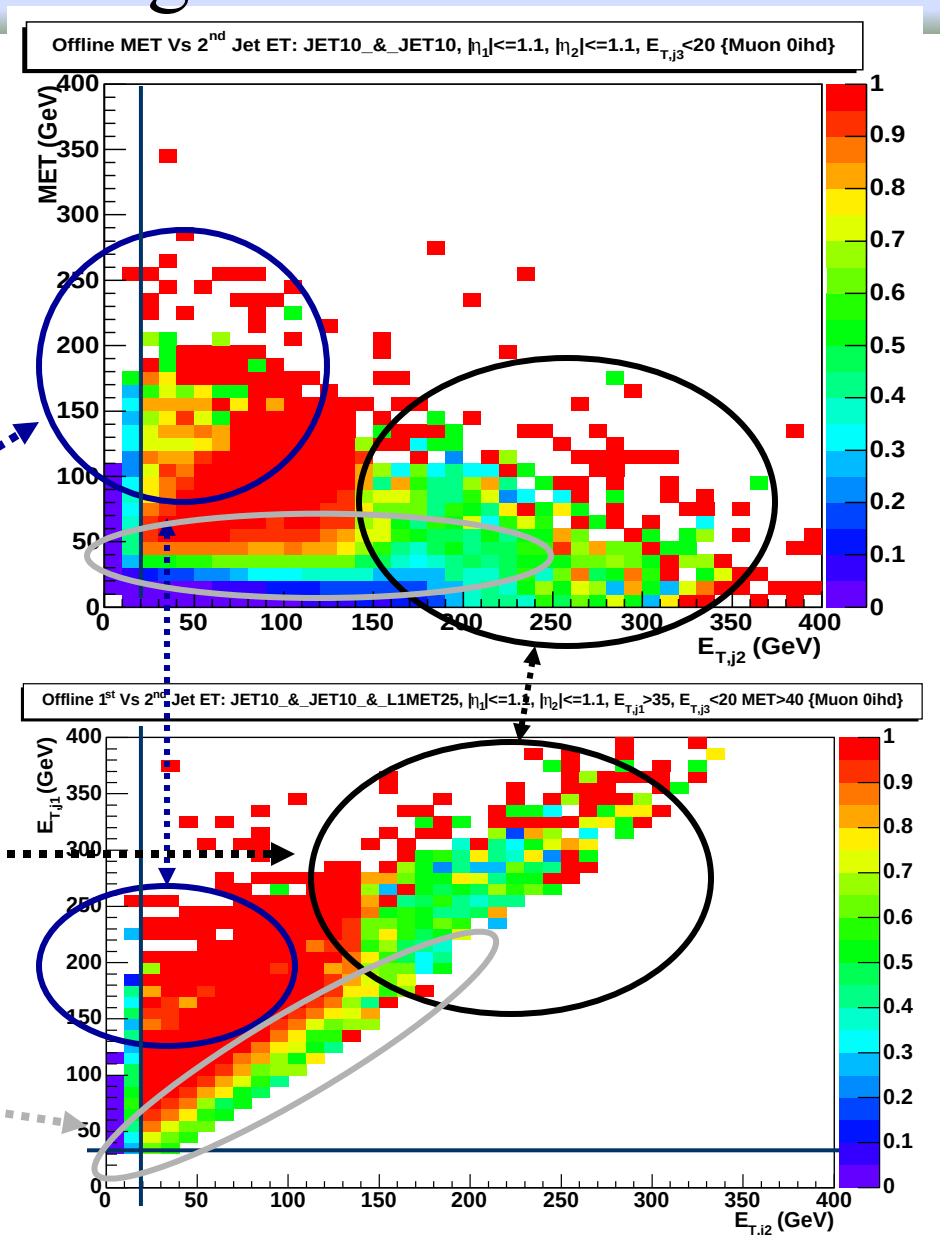
L2 output rate of MET35 + 2jets, L1 Met > 25 GeV



L3 output rate – much lower, after applying a L3 Met > 35 GeV

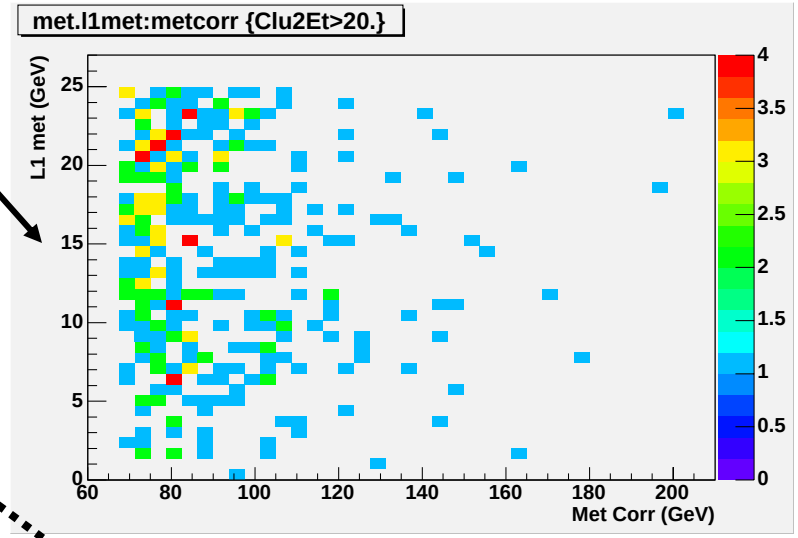
Inefficient regions

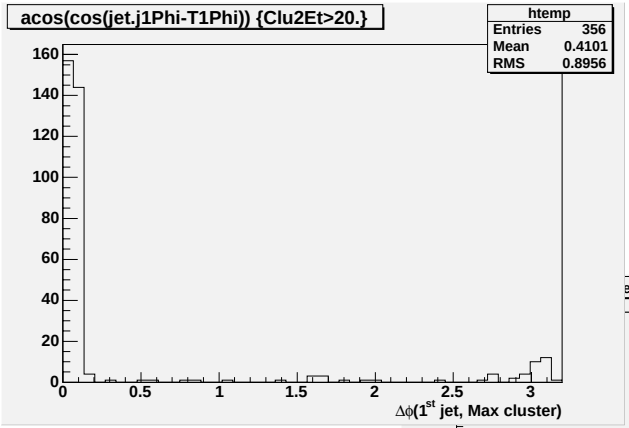
- Require offline selections to satisfy two-cluster cut (lower plot)
  - 1st E_T > 35 GeV
  - 2nd E_T > 20 GeV
  - MET > 40 GeV
- Plot efficiency vs MET and 2nd jet E_T
  - use it to correct Monte Carlo
- 1. High missing E_T region:
  - low efficiency because of incorrect L1 met calculation
- 2. Low missing E_T region, large 2nd E_T
  - efficiency loss due to L2 cluster merging
- 3. L1 missing E_T cut (resolution)
  - attempt to correct it (Artur's talk)



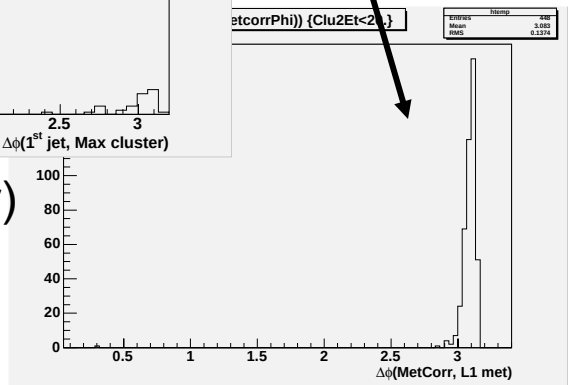
1. Incorrect L1 met calculation

- Where trigger should be 100%, MET fails
  - Select large MET>70 GeV
  - 2nd cluster > 20 GeV
  - Plot events not passing trigger
- Efficiency loss due to very small L1 met
  - Leading jet has a tower >> 127 GeV
  - tower E_T truncated at 127 GeV
  - L1 met changes direction

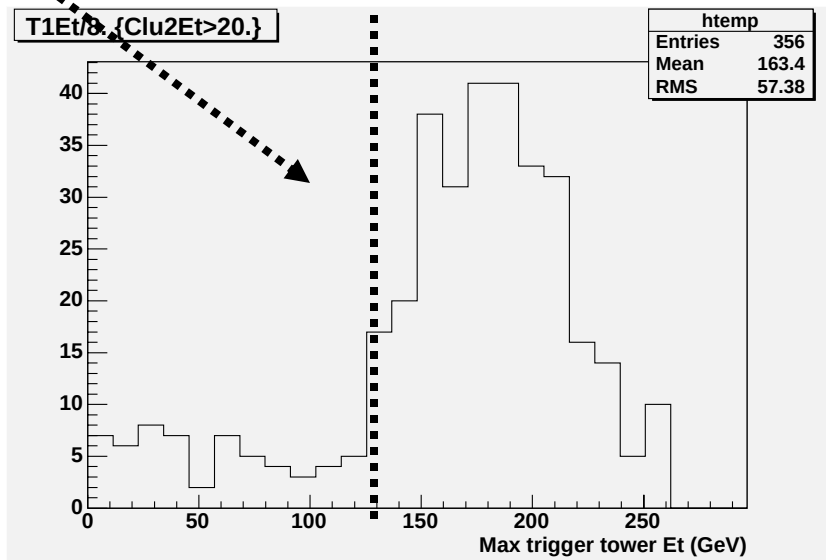




Phi(1st jet, Tower)



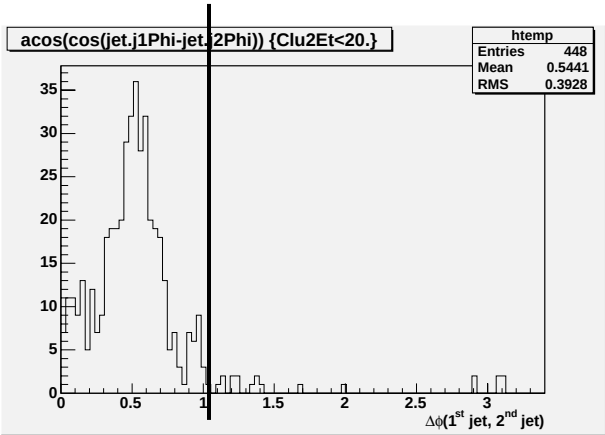
Phi(Offline MET, L1 met)



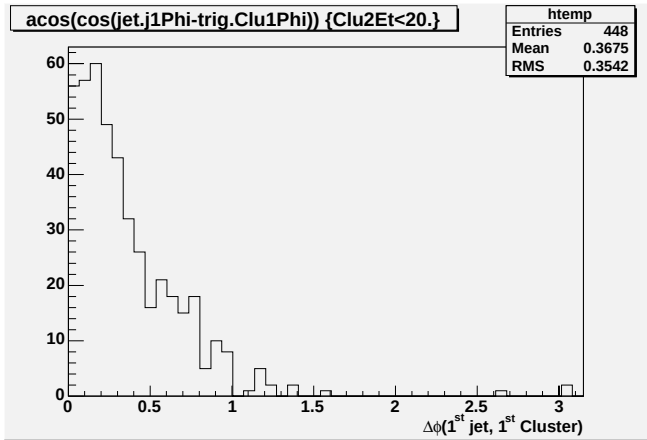
Leading trigger tower

2. Jet merging

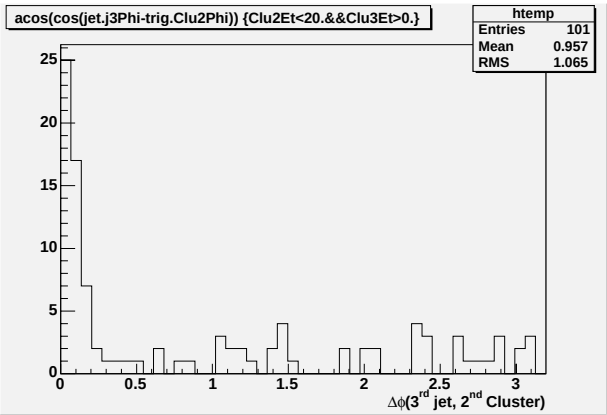
- When the L2 second cluster fails, the leading jets are almost parallel

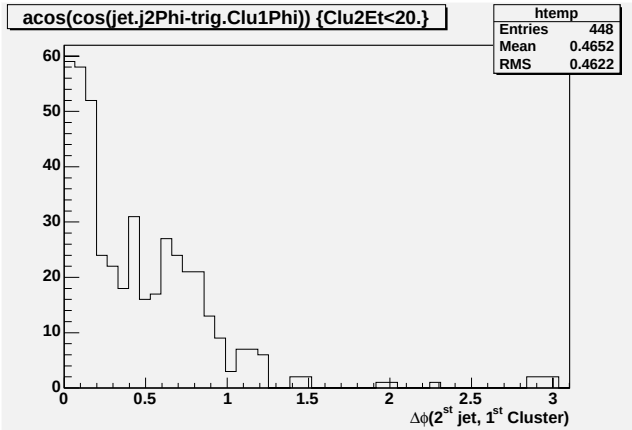


- Both leading jets are parallel with the leading cluster



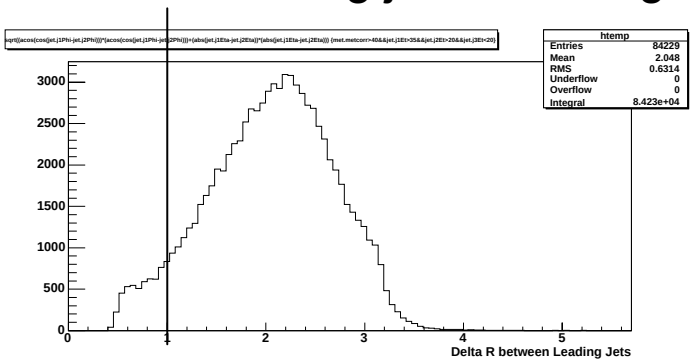
- So the leading jets merge. The third jet (if exists) becomes the second cluster

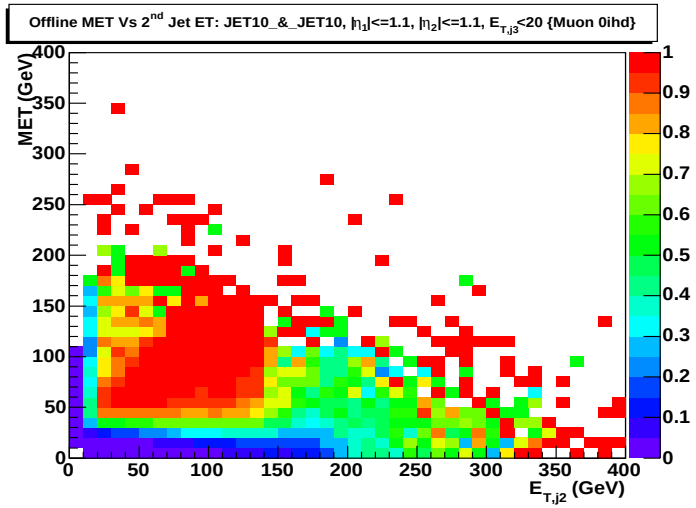


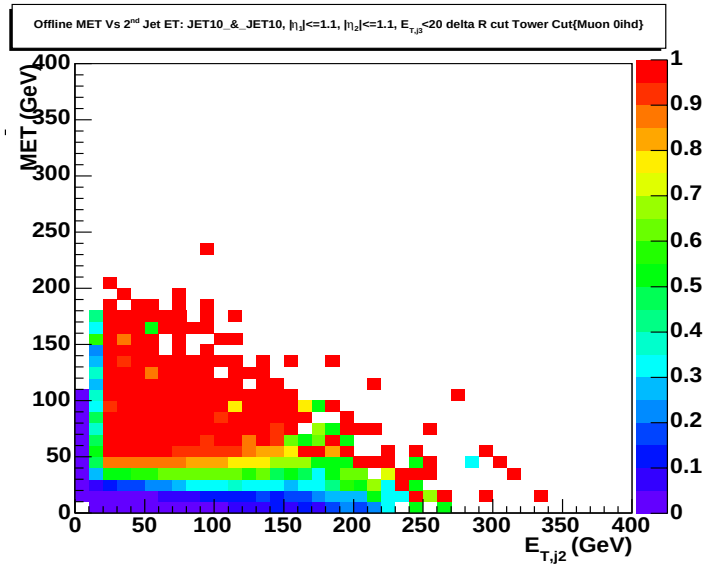


Solution

- Avoid merging, require separation between jets > 1.0
  - 6.4% signal loss before, < 2% after dijet mass cut (between 75 and 115 GeV)
- Tower saturation does not have simple solution
  - simulated L1 tower information should not be used (cannot discard events)
  - present also in MET45 trigger, JET100 could be an alternative trigger path
  - try to estimate systematic uncertainty
- Separation of leading jets in the signal:





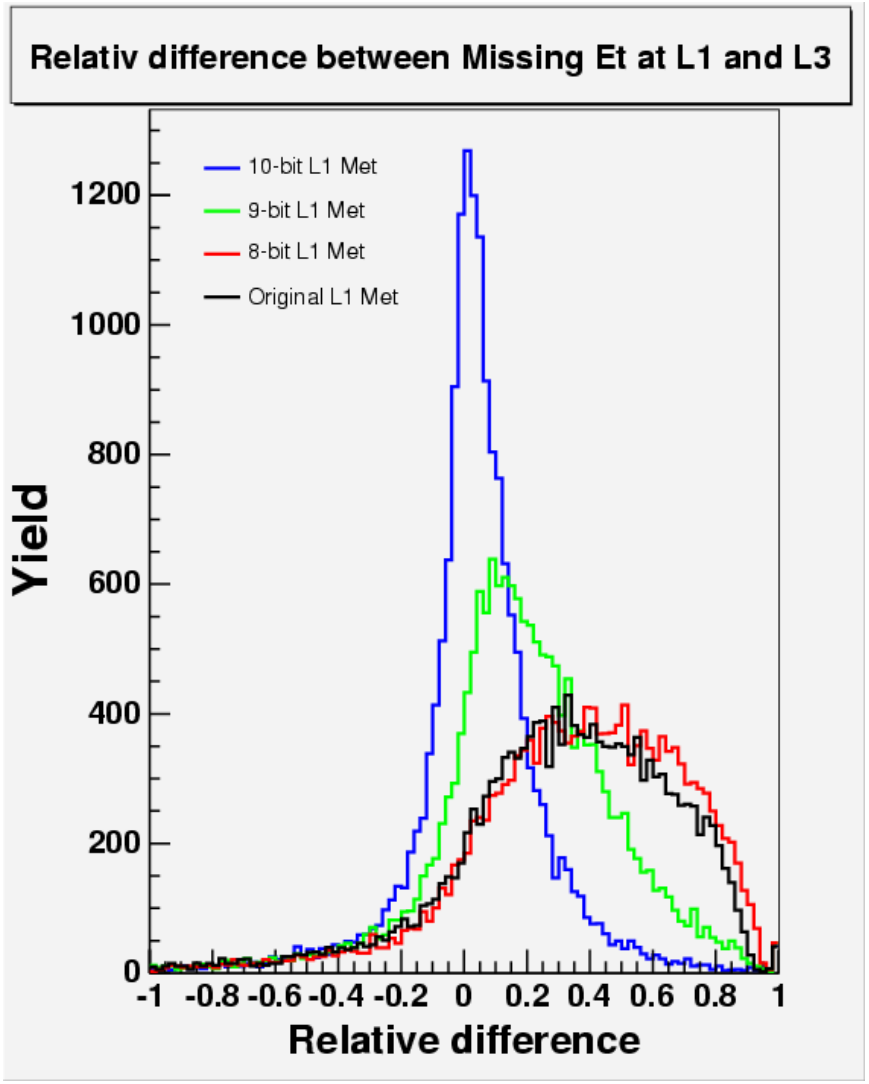


Top: before, bottom: after jet separation, and Max Tower < 127 GeV

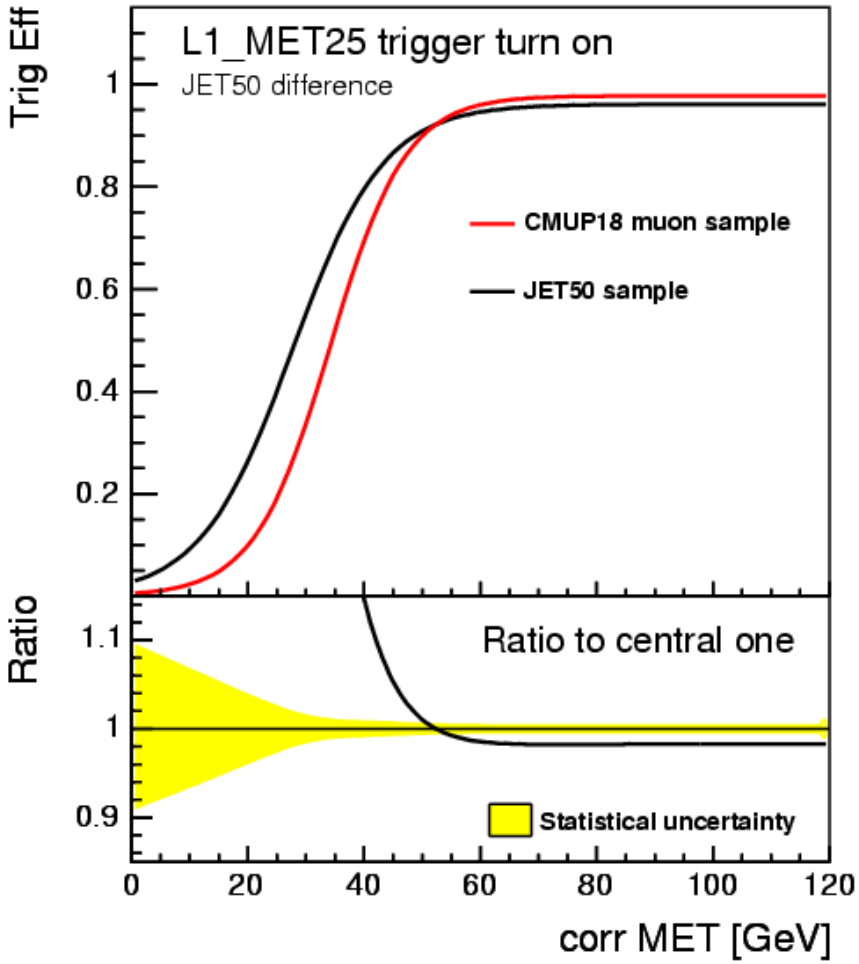
Proposed L1/L2 Missing E_T

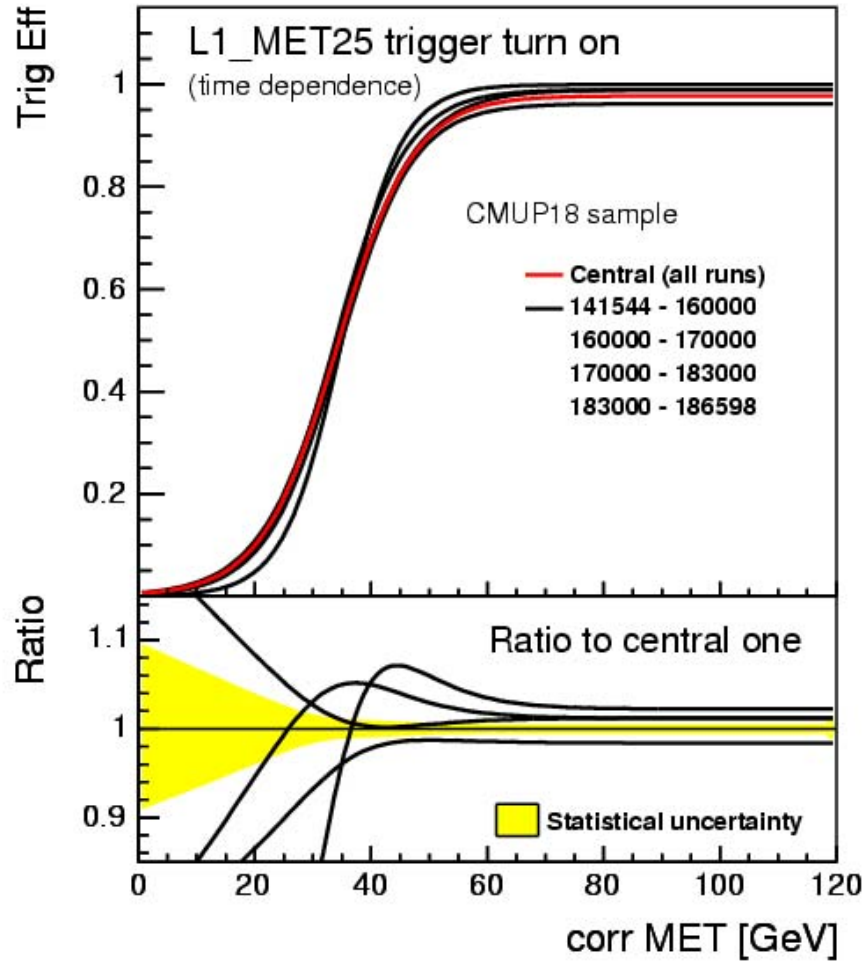
- A High-pt muon sample was used to study the efficiency of the L1 Met cut
- Met was calculated using
  - 125 MeV (blue),
  - 250 MeV (green),
  - 500 MeV (red)

  granularities.
- Black graph, the actual L1 Met, agrees with the red one which was reconstructed with the same precision
  - Main differences are in the projection along x and y (the real L1 Met uses a look-up table), and I also ignored possible overflows

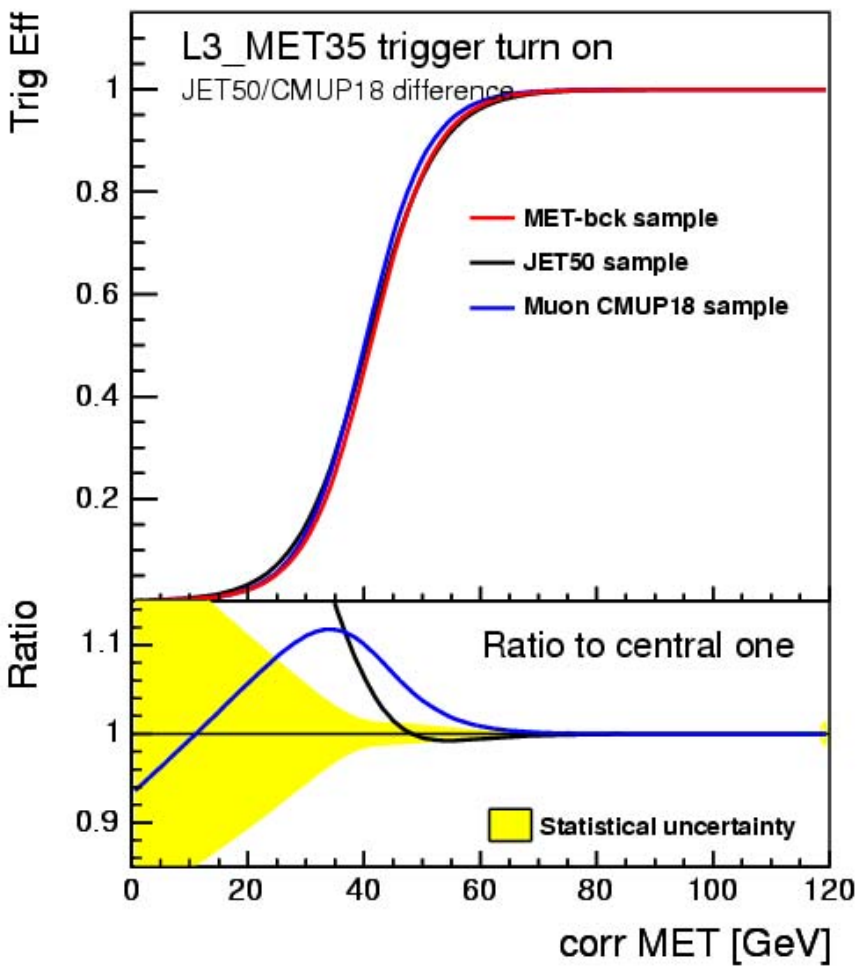


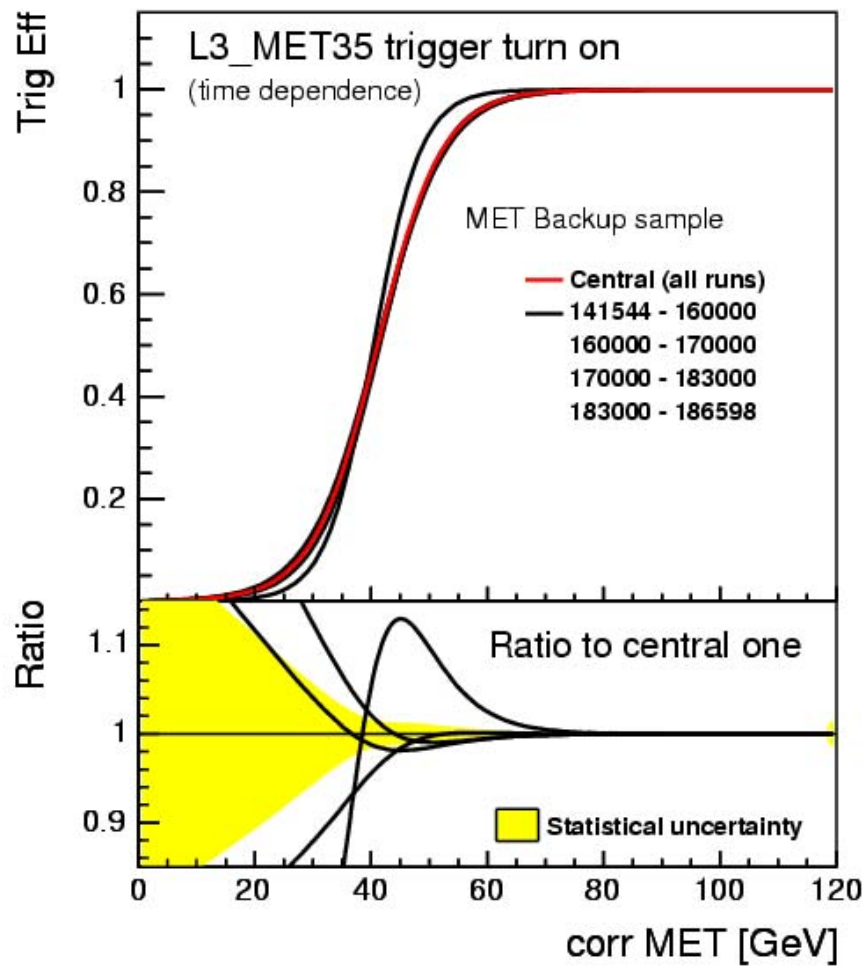
Trigger Efficiency – Level 1





Trigger Efficiency – Level 3



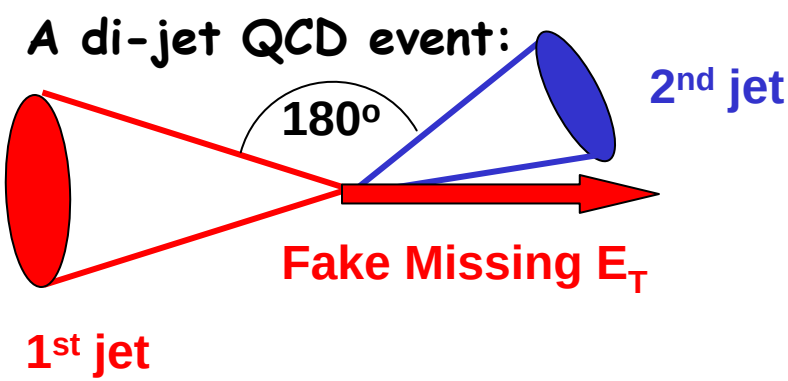


2. QCD Heavy Flavor Simulation

- Most of the triggered events are dijet events with fake Missing E_T
- After b-tagging, heavy flavor component is dominant
- Use Pythia to simulate it:
  - ~ 500 M events represent 1 fb^{-1} data
  - events are b-filtered (6%),
  - only events with Missing E_T >15 GeV are kept (32%)
  - few fb^{-1} data represents a great computational challenge
- Mistagged light flavor QCD is estimated from the data
- The simulation is normalized so that the sum of that and the estimated mistag is equal to the data in Control Region 1 with a 50 GeV MET threshold

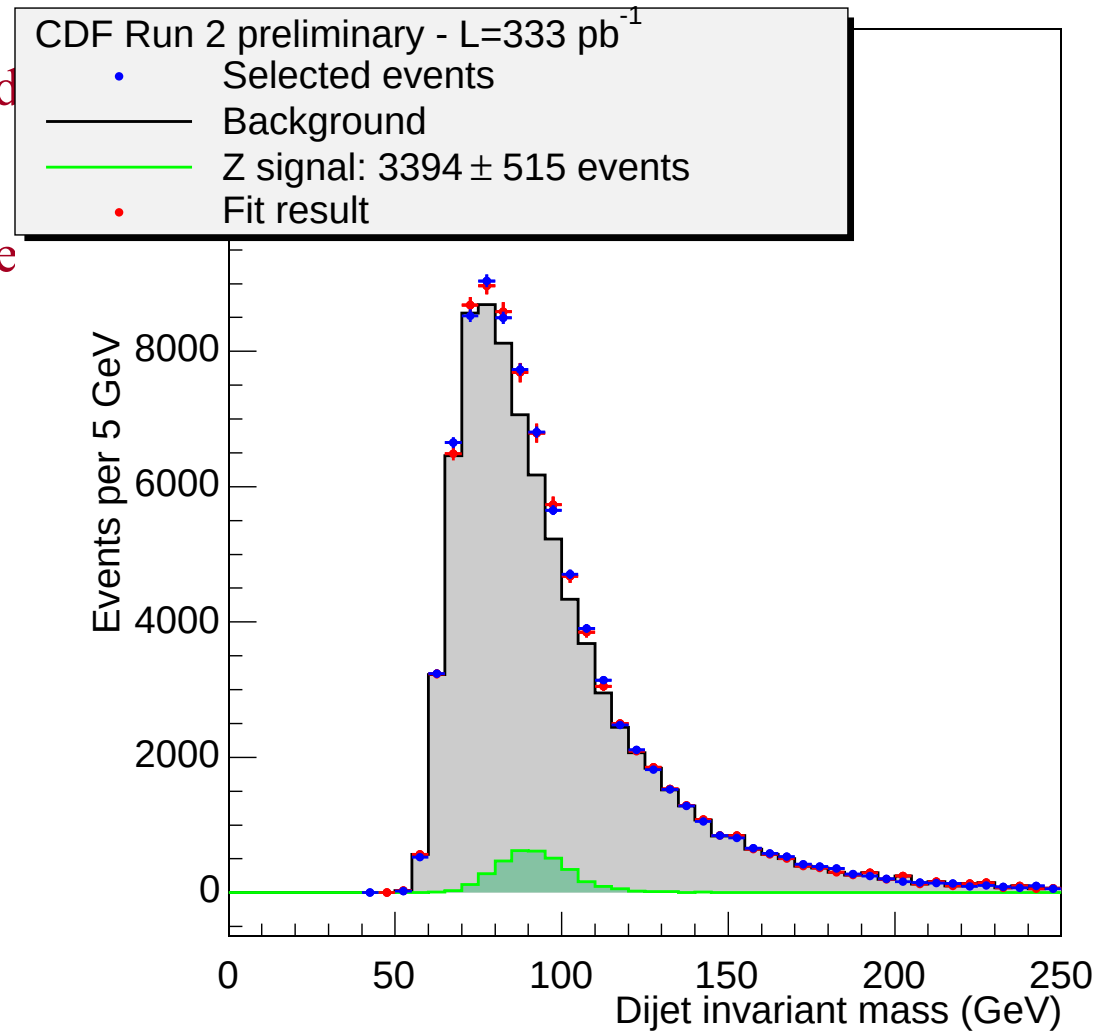
QCD events also have a particular topology:

- **jets are back-to-back**
- **Fake missing E_T points along the leading jet**



4. 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 je 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})



5. 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

5. 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

- Largest uncertainty from limited Monte Carlo statistics