Associated Production for the Standard Model Higgs at CDF

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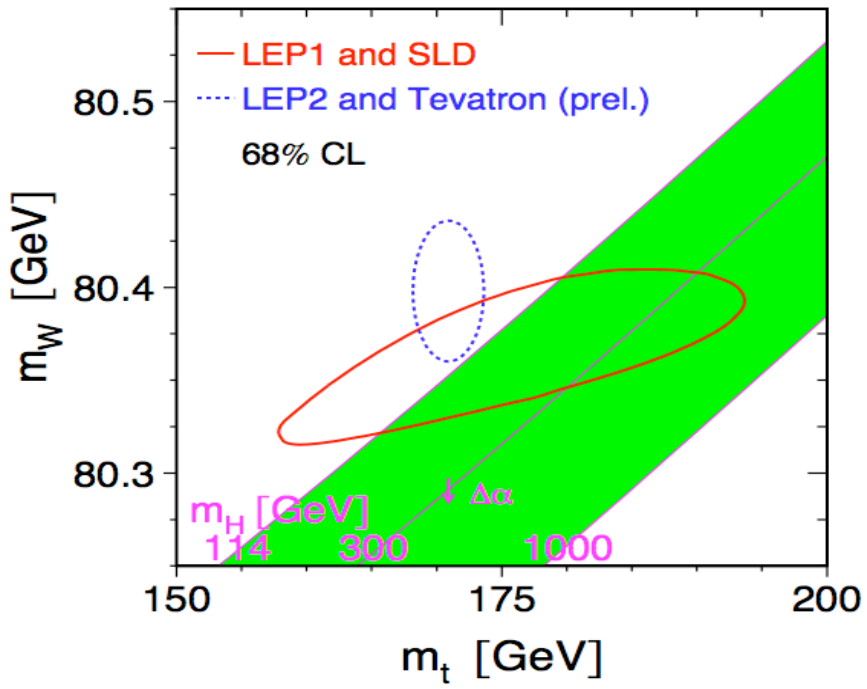
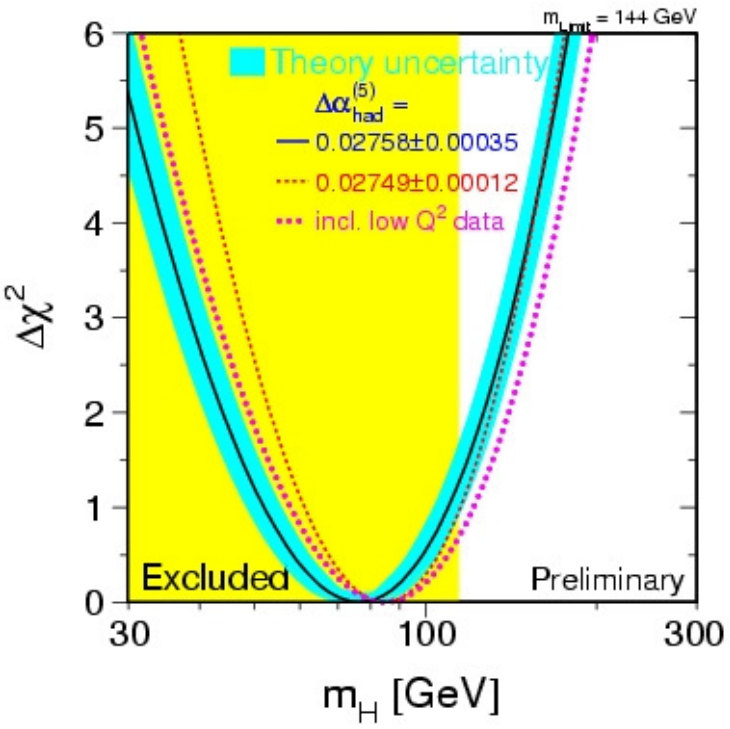
- **Outline:**
  - **Higgs at the Tevatron**
    - **WH$\rightarrow \ell\nu$ bb**
    - **ZH $\rightarrow \ell\ell$ bb**
    - **WH and ZH $\rightarrow$ met bb**
  - **Outlook**

SM Higgs

- **The Higgs remains the Holy Grail of Particle Physics**
  - **Direct LEP searches: M_H>114 GeV at 95 %CL**
  - **Indirect searches improving. Smaller error on top and W mass: M_{top}=170.9 ±1.8 GeV and M_W=80.398 ±0.25 GeV**



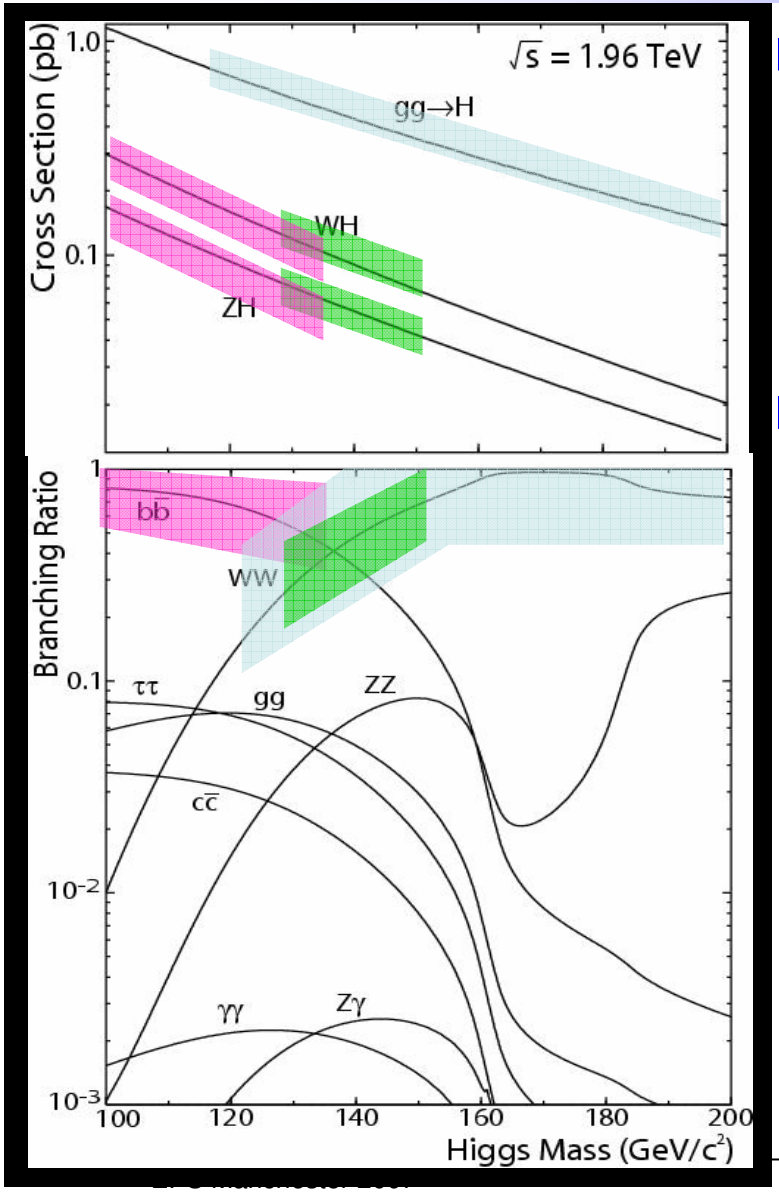


$$M_H = 76^{+33}_{-24}\ GeV$$

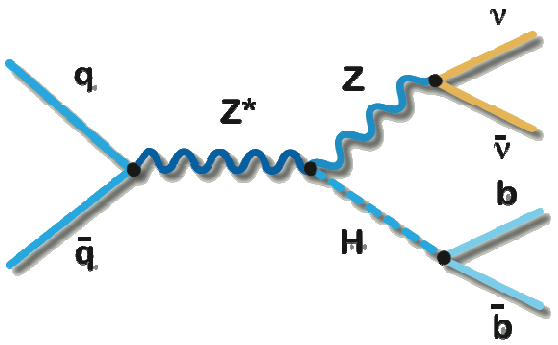
M_H<144 GeV (ignoring direct limit)

M_H<182 GeV (including 114 GeV limit)

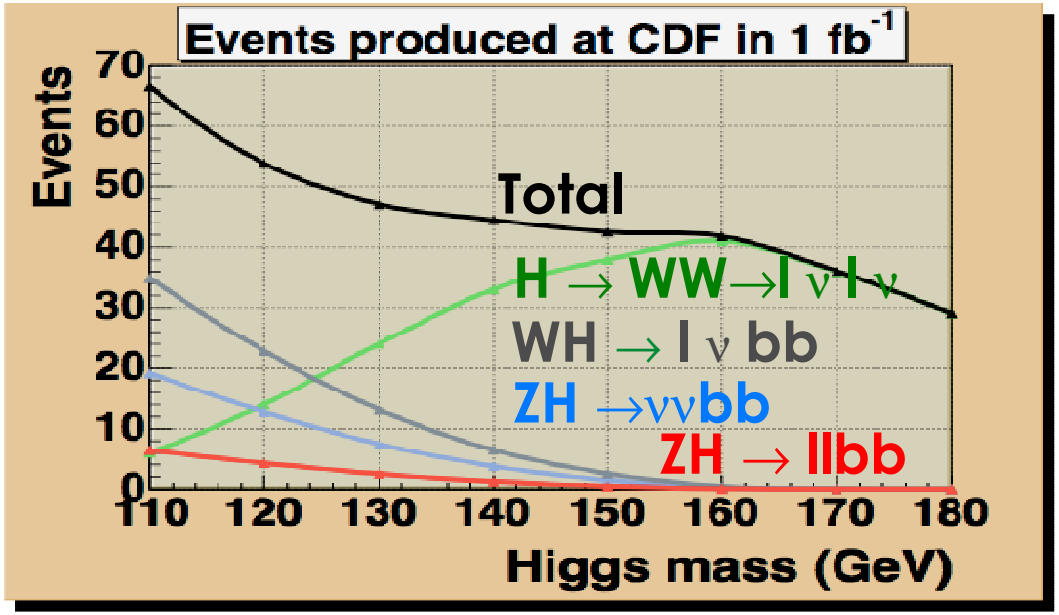
Higgs at the Tevatron



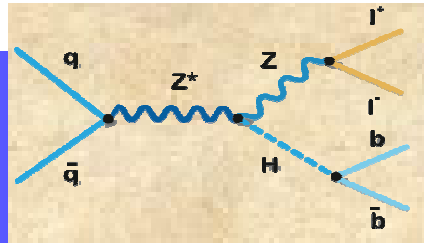
- m_H<135 GeV use W/Z H and H→bb
  - Trigger on leptons or met



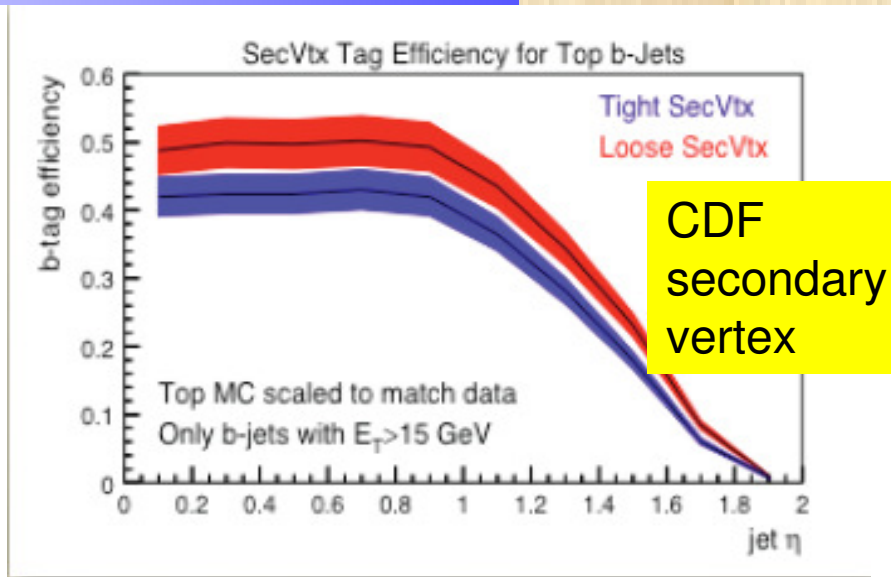
- m_H>135 GeV direct production and H→WW



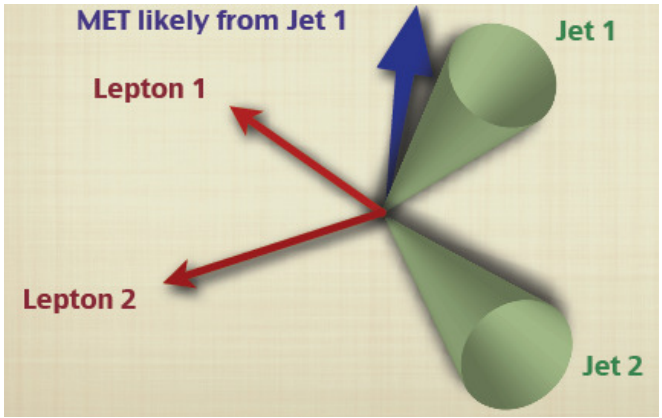
$ZH \rightarrow \ell\ell b\bar{b}$

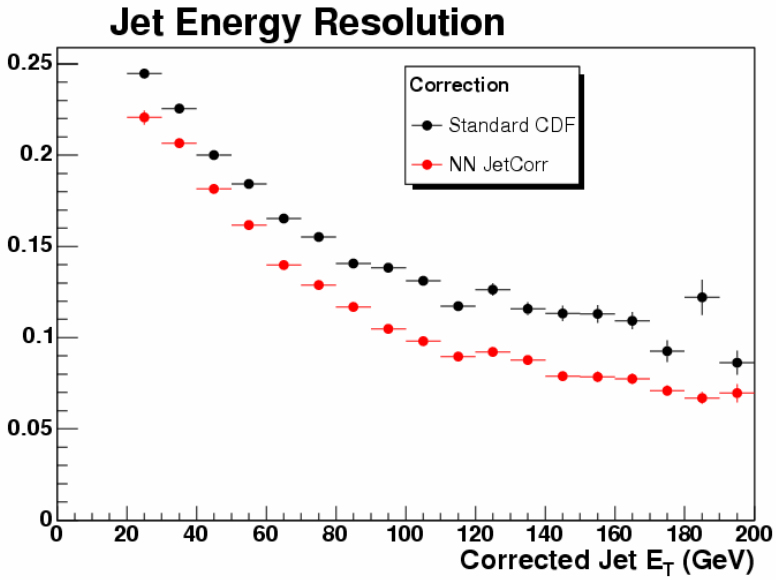


- Strategy:
  - Optimize lepton selection to improve $Z \rightarrow \ell\ell$ acceptance by 70%
  - Improve S/B :
    - Two loose b-tag: 50% efficient, 1.5% fake rate
    - One tight b-tag: 40% efficient, 0.5% fake rate
  - Improve mass resolution
    - Use MET to improve mass resolution using NN since no real MET expected



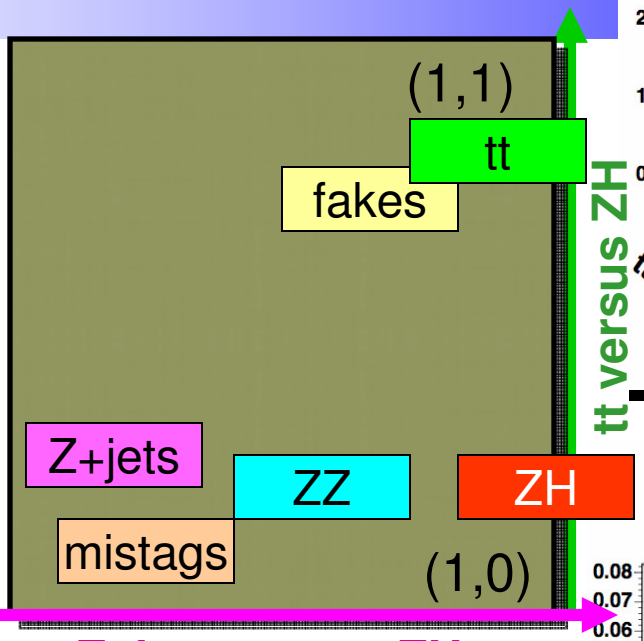
CDF secondary vertex

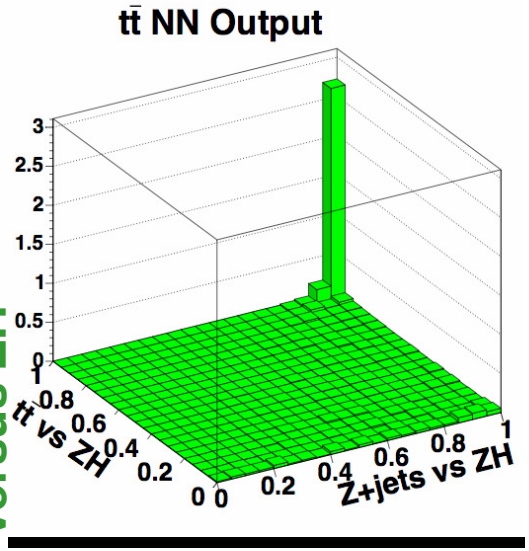


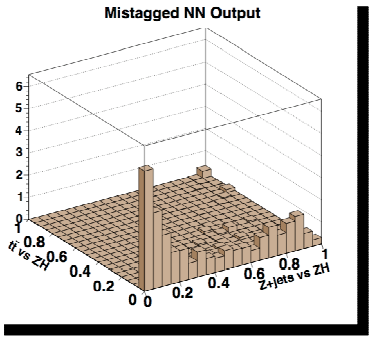


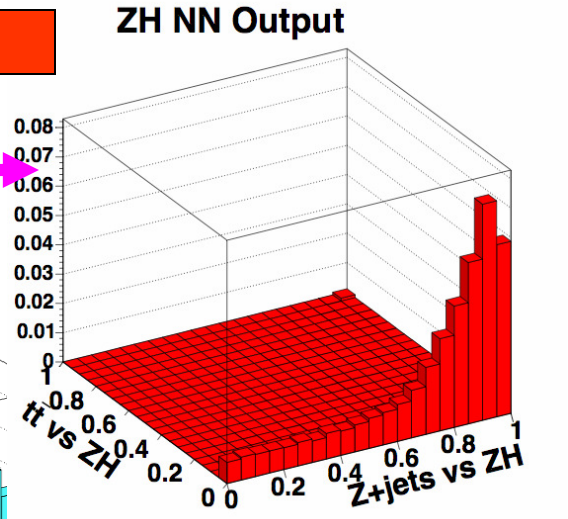
$ZH \rightarrow \ell\ell b\bar{b}$

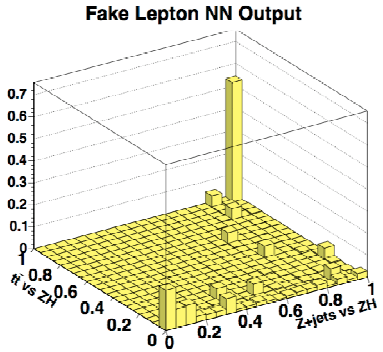
- Reduce the background with 2D NN:
  - –Training on ZZ, Z+bb, tt and ZH MC
  - –Fakes and mistags from data

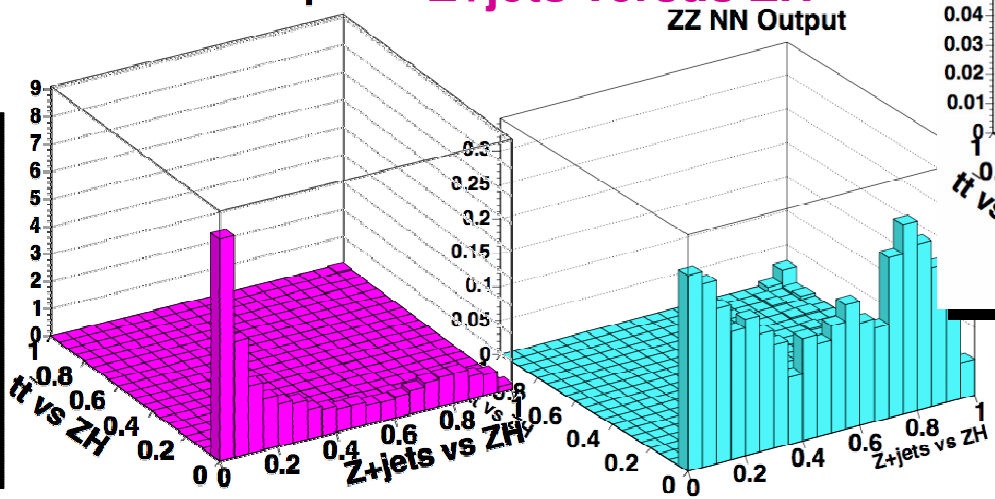




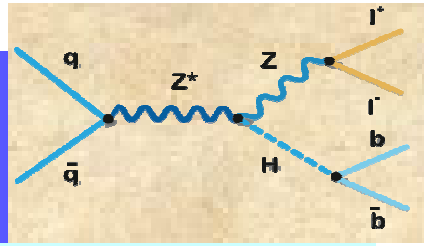




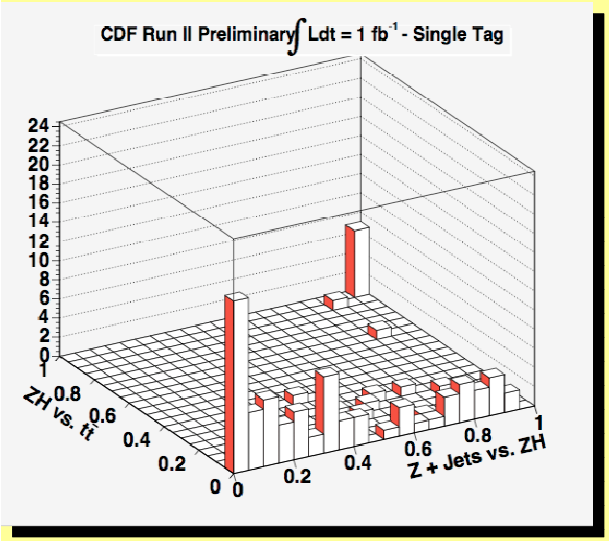




Signal region



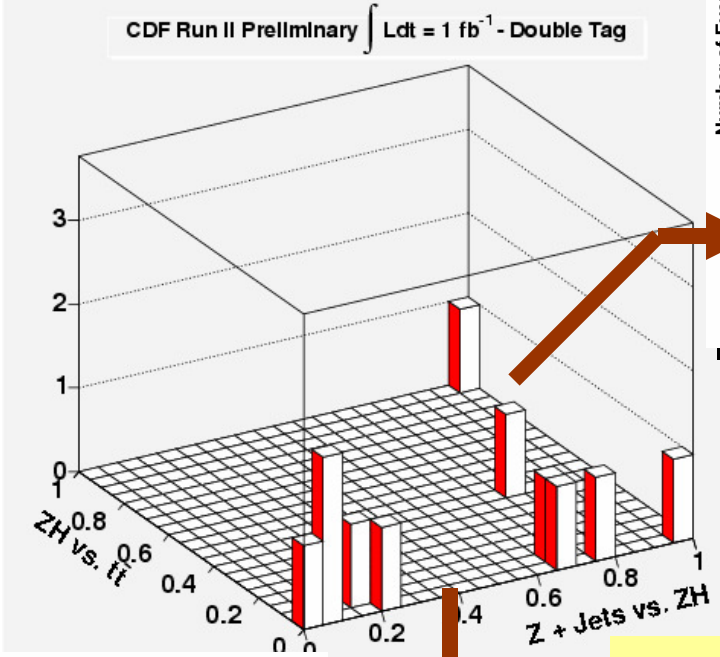
Single tag

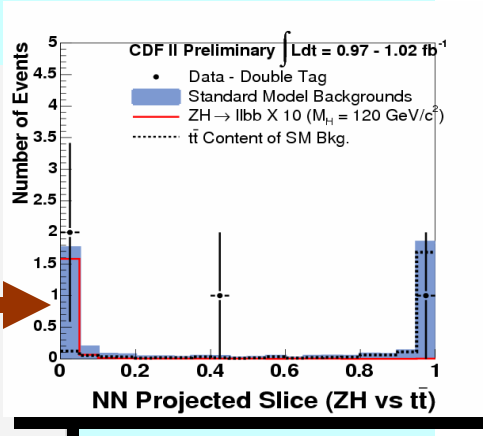


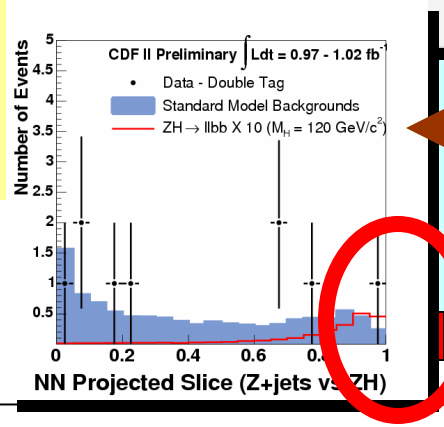
Expected: 101.6 ±17.8

Data: 100 events

Double tag





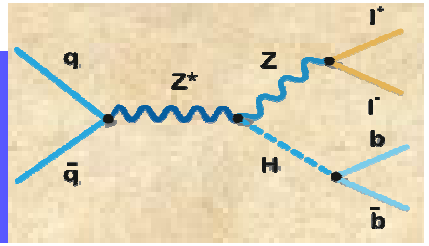


Expected: 12.8 ±3.5

Data: 11 events

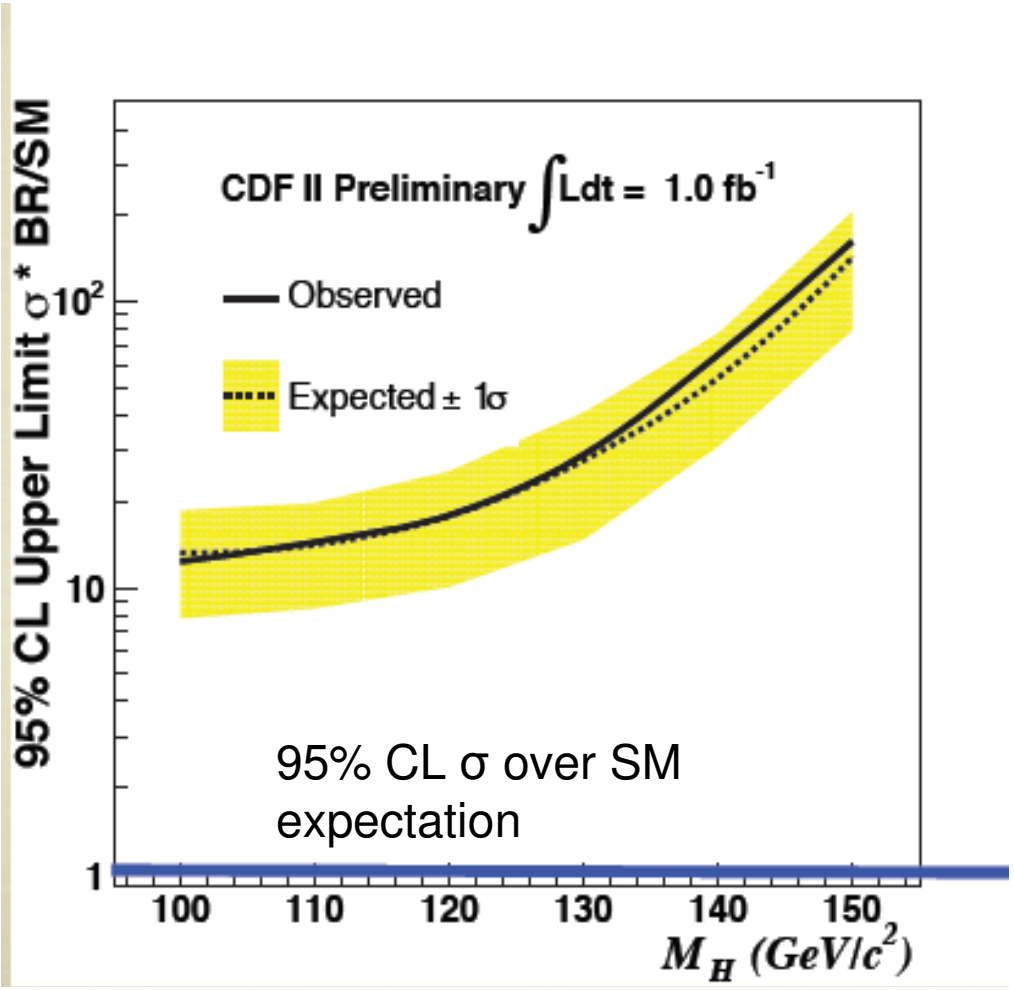
S/B =1/4 (before selections 5/10^{15})

Limits



m_H=115 GeV

1fb^{-1}	1 tag	2 tag	Comb.
σ×BR (pb) Observed (expected)	2.3 (2.2)	1.9 (1.8)	1.2 (1.3)
Limit/SM Observed Expected	28 (27)	23 (22)	16 (16)



Major systematic uncertainties:

Z+ jet Background shape

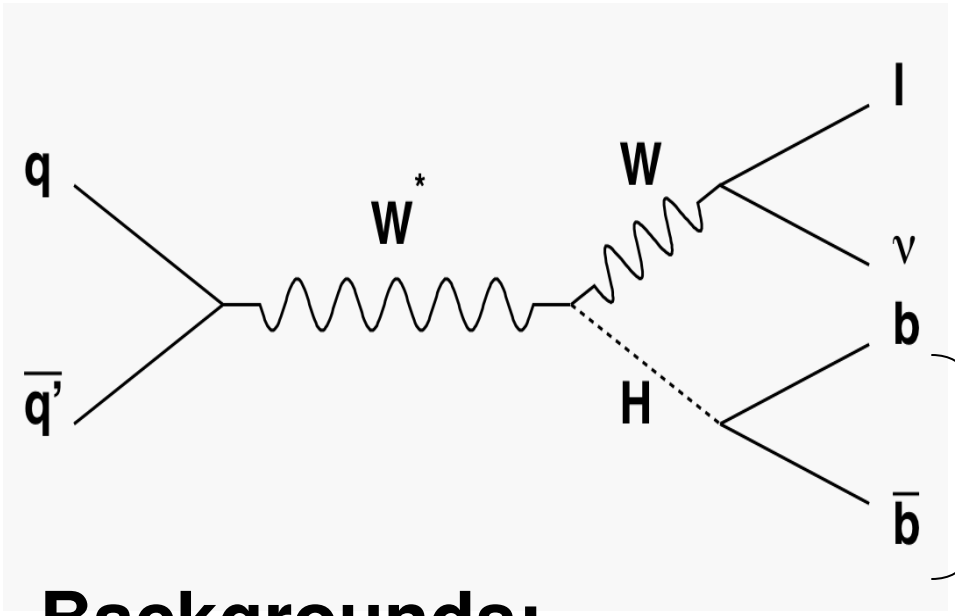
Z+ heavy flavor

Jet Energy scale

Total systematic shift in σ~ 0.19 pb

WH→ℓνbb

Parton Process



Observable

Lepton(e/μ): P_T>20 GeV, $|\eta|$<1

Missing E_T>20 GeV

2 jets >15 GeV (and b-tagging)

Backgrounds:

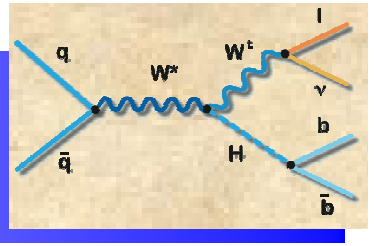
Non-*W* QCD (lepton fakes): Data based estimation

Mistag : Data based estimation

***W*+Heavy Flavor (Wbb, Wcc, Wc): Data and MC based estimation**

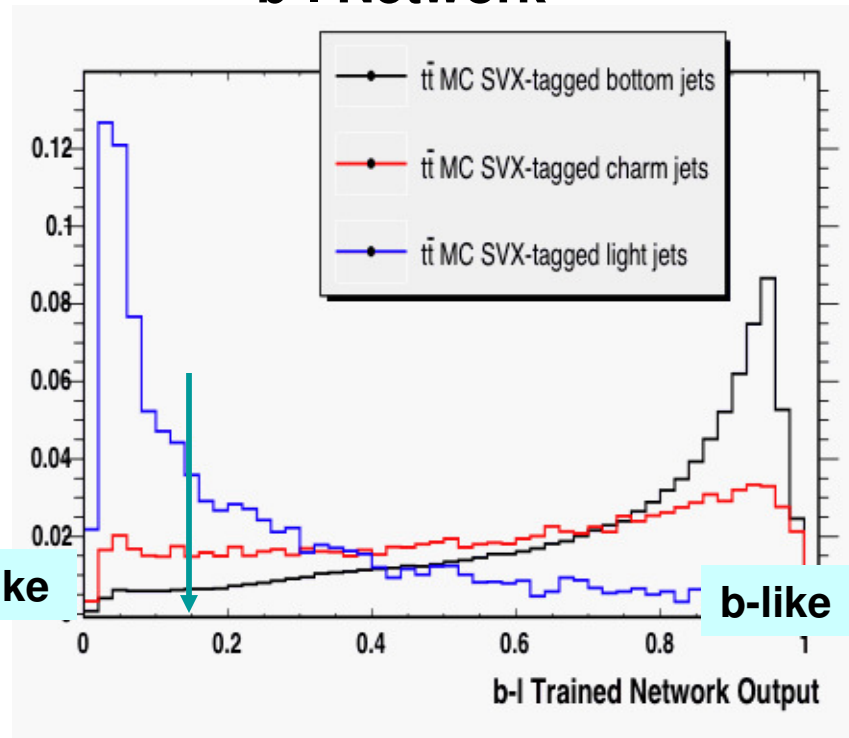
Other standard model background (tt, single top, di-boson, Z→tau tau): MC based estimation

NN Tagging

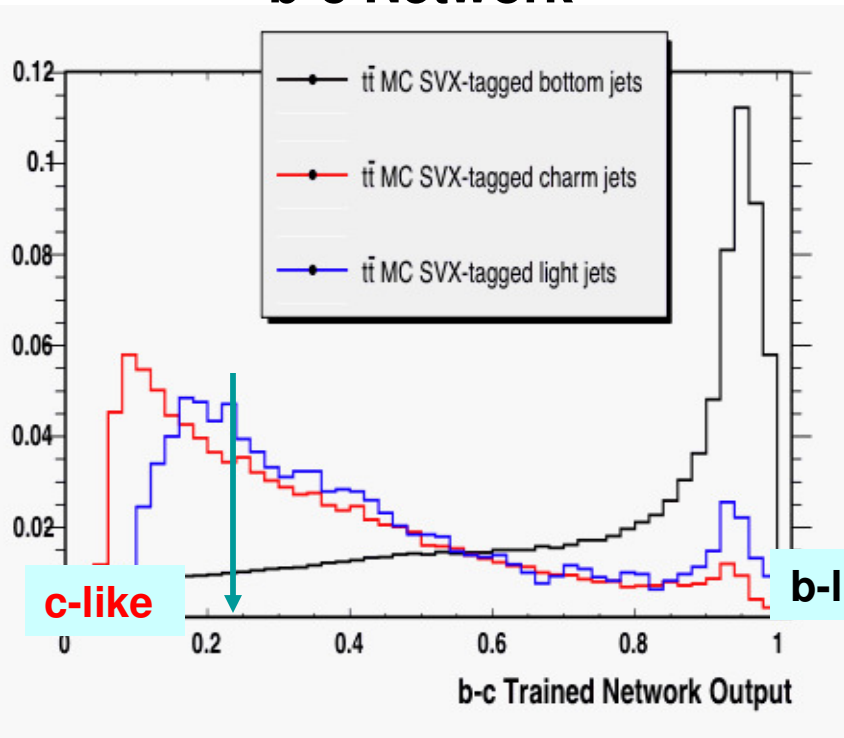


- Apply neural net b-tagger on the information of SECVTX to improve the separation between b-jets and c-jets or light-jets
- NN input: Lxy significance, vertex mass, pseudo-ct…

b-l Network

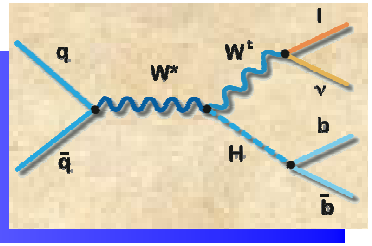


b-c Network



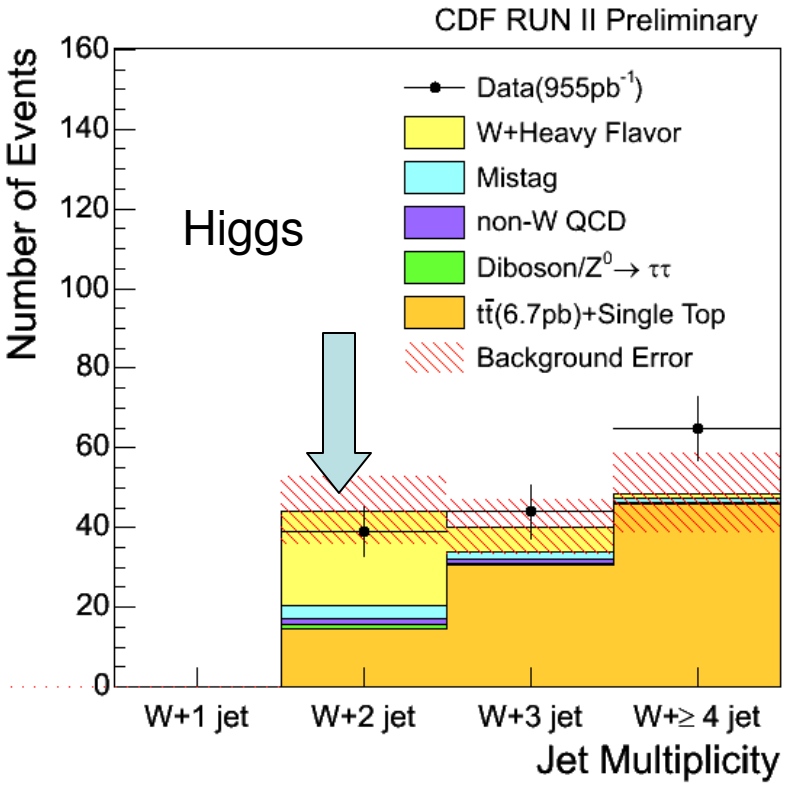
Keeping 90% of true b-jets, 65% of l-jets and 50% of c-jets are removed!

Results WH→ℓνbb

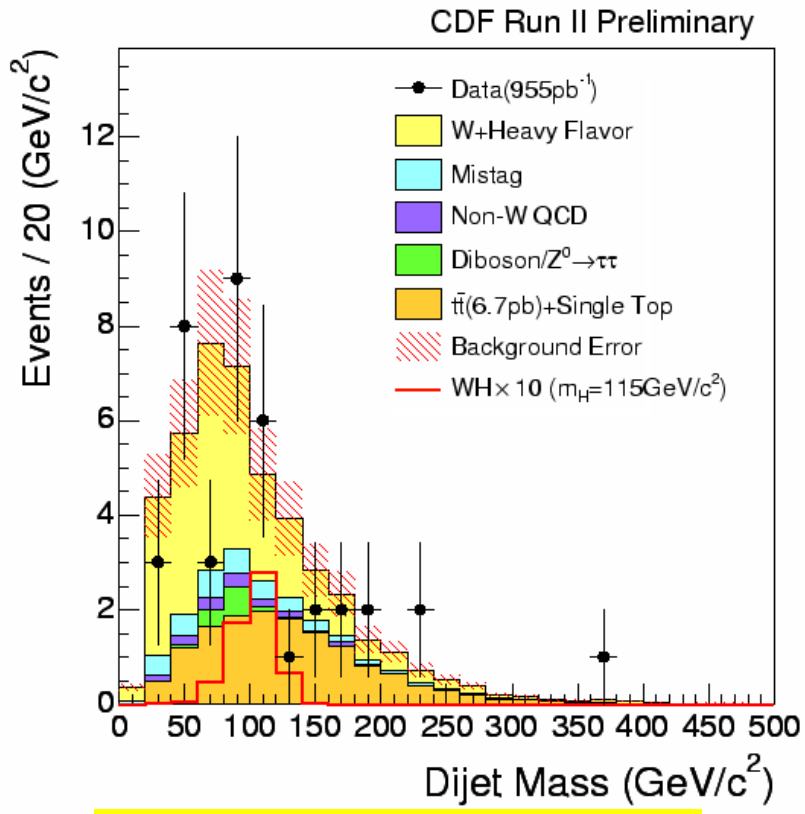


At least 2 b-tagging (double tag)

NN b-tagging is NOT applied

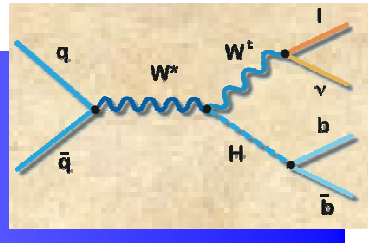


≥2 SECVTX without NN



Expected 44.2 ± 8.5
Observed 39

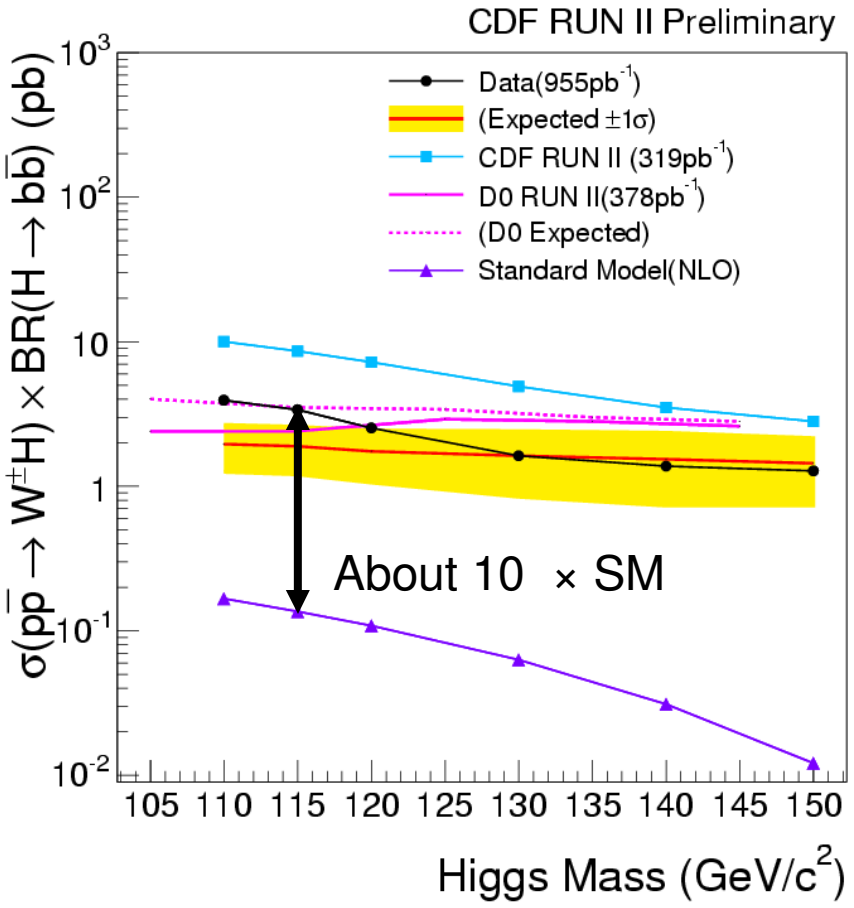
Limits



Systematic Uncertainty

Source	Uncertainty (%)	
	= 1tag w/ NNtag	≥ 2tag
Lepton ID	~2%	
Trigger	< 1%	
ISR	1.8%	4.3%
FSR	3.2%	8.6%
PDF	1.7%	2.0%
JES	2.3%	3.0%
b-tagging	5.3%	16%
Total	7.2%	19.1%

Higgs Mass	Upper Limit (pb)	
(GeV/c^2)	Observed	Expected
110	3.9	2.2
115	3.4	2.2
120	2.5	2.0
130	1.6	1.8
140	1.4	1.7
150	1.3	1.5

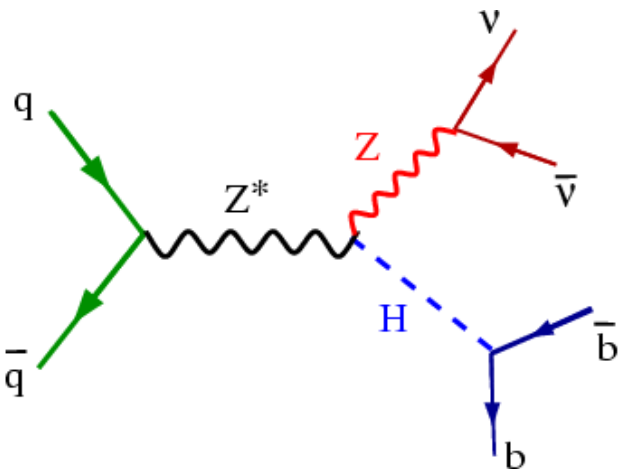


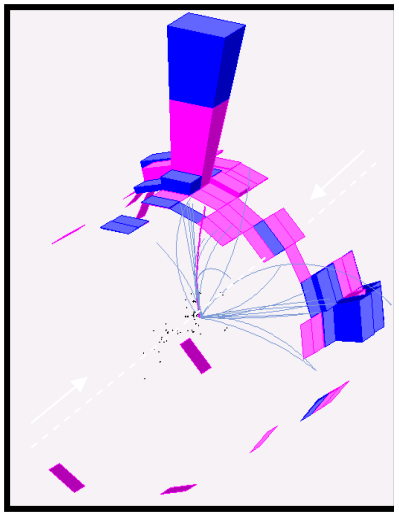
W/Z→MET and H→$\bar{b}b$

- **This final state can be used to search for:**

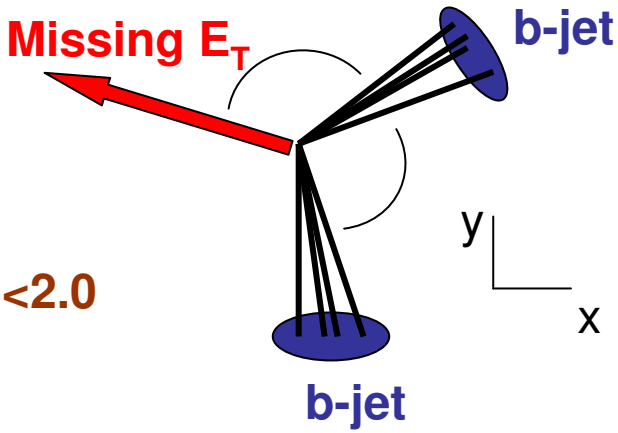
$$ZH \rightarrow \nu\bar{\nu}b\bar{b}$$

$$WH \rightarrow \ell\bar{\nu}b\bar{b}$$



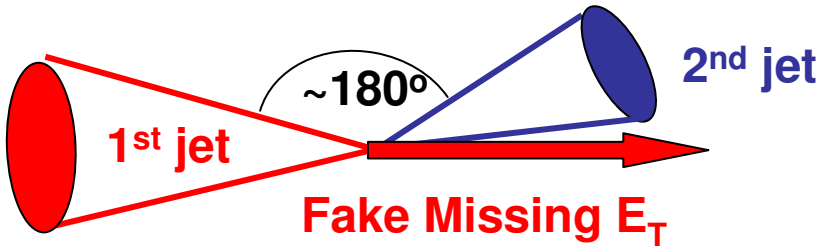


- **Signal has a distinctive topology**
  - **Two jets**
    - **|η|<2.0 and one |η|<0.9**
    - **ET,jet1 > 35 GeV**
    - **ET,jet2 > 25 GeV**
    - **ΔR(j1,j2)>1.0**
    - **No other jets with ET> 20 GeV, |η|<2.0**
  - **Large MET (>50 GeV)**
  - **b-jets (use b-tagging)**



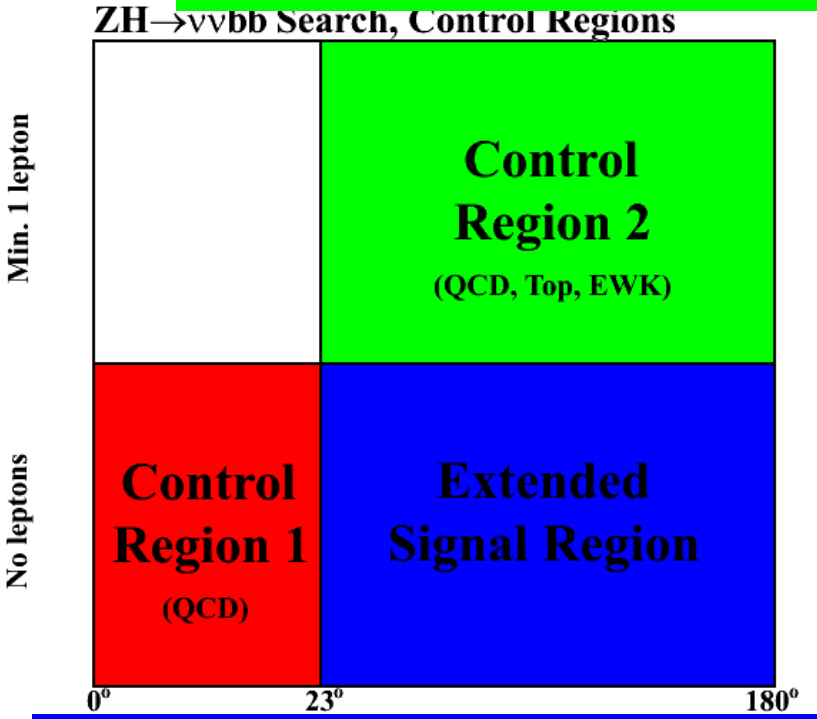
Z/W→MeT and H→$b\bar{b}$

- Unbiased analysis



Control Region 1 – QCD
- Veto events with identified leptons
- ΔΦ(j2, MET)<0.4

Control Region 2 – EWK
- 1 identified lepton
- ΔΦ(j2, MET)>0.4



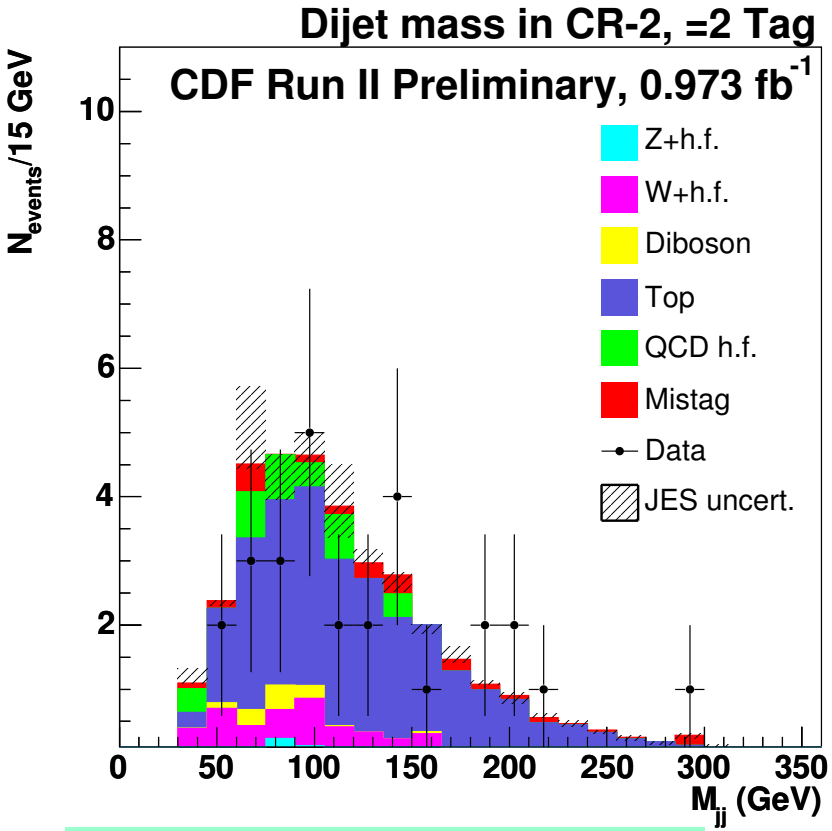
Extended Signal Region
- Veto events with leptons
- ΔΦ(j2, MET)>0.4

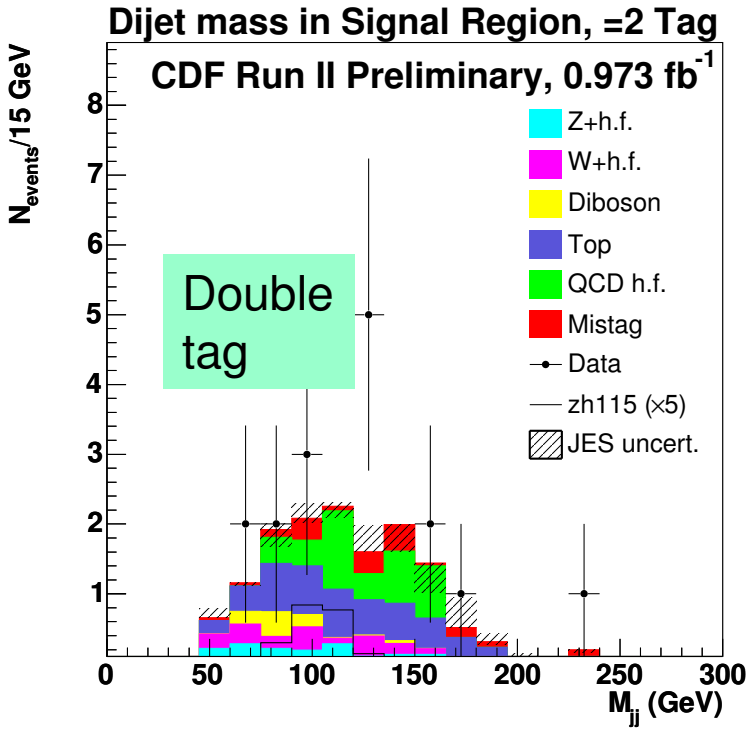
Results

Tight SECVTX applied to this analysis both for single and double tagging

Sensitivity Optimization performed in extended signal region:

- $E_{T,1}$ > 60 GeV and $\phi(E_{T,1}, MET)$ > 0.8
- MET > 70 GeV
- H_T =scalar sum of the jet Et-s
- Missing H_T (vectorial sum of jet Et-s)
- Missing H_T / H_T > 0.45

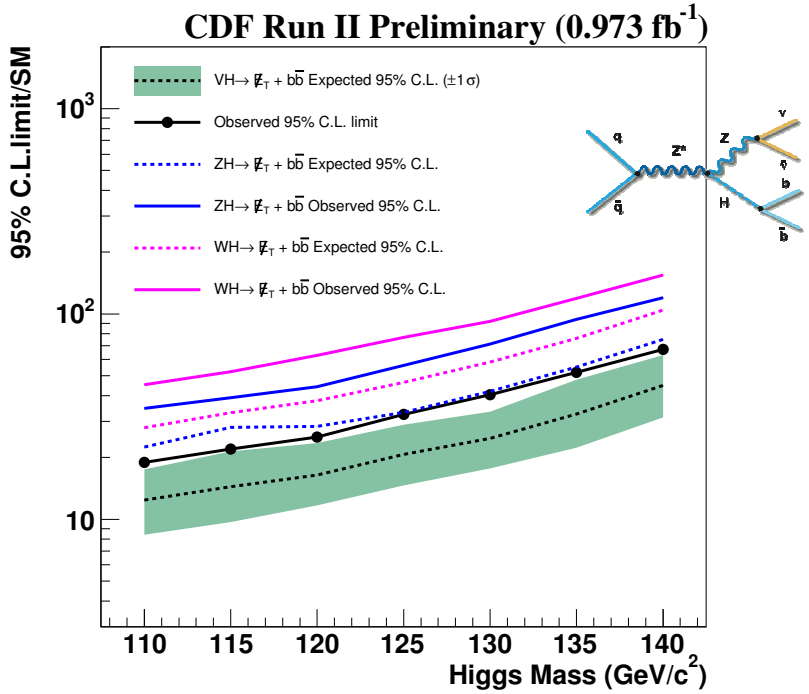




Double b- tag CR2 : Dominated by top

Expect 14.8 ± 2.65
Observe 16

Exclusion limits

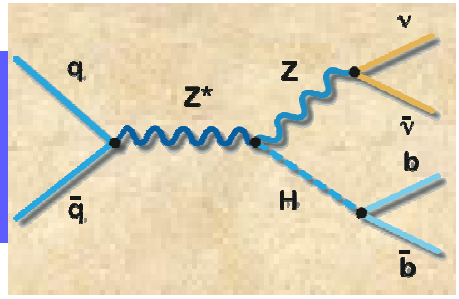


Systematic uncertainties:

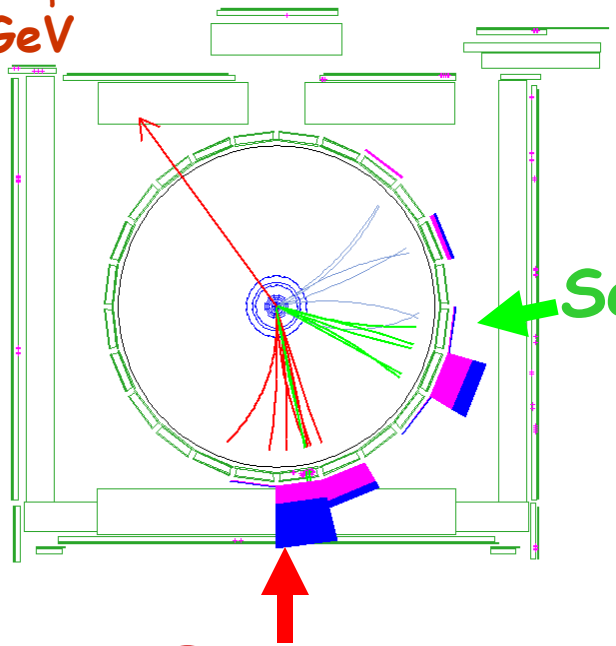
- B-tagging: 8.6 % for double tags
- Jet energy scale: 7%-26%
- Luminosity: 6%
- Z/W + heavy flavor normalization: 40%

Mass (GeV)	$R_{expected}/\sigma\times BR$ ZH	$R_{expected}/\sigma\times BR$ WH	$R_{expected}/\sigma\times BR$ VH	$R_{observed}/\sigma\times BR$ VH
110	**22.5** / 2.2 pb	**27.9** / 4.6 pb	**12.4** (+5.1 / –4.0) / 3.3 pb	**18.9** / 5.0 pb
115	**28.0** / 2.2 pb	**33.0** / 4.5 pb	**14.4** (+7.0 / –4.7) / 3.1 pb	**22.0** / 4.7 pb
120	**28.3** / 1.8 pb	**37.8** / 4.1 pb	**16.4** (+7.1 / -4.7) / 2.8 pb	**25.1** / 4.3 pb
125	**33.1** / 1.6 pb	**46.5** / 3.9 pb	**20.7** (+8.2 / -6.1) / 2.8 pb	**32.4** / 4.3 pb
130	**42.0** / 1.6 pb	**58.3** / 3.7 pb	**24.8** (+8.6 / -7.1) / 2.5 pb	**40.4** / 4.1 pb
135	**55.1** / 1.5 pb	**76** / 3.4 pb	**32.6** (+15.2 / -10.3) / 2.4 pb	**51.9** / 3.8 pb
140	**75.3** / 1.4 pb	**104.7** / 3.2 pb	**44.9** (+18.2 / -13.5) / 2.2 pb	**67.3** / 3.4 pb

Candidate event

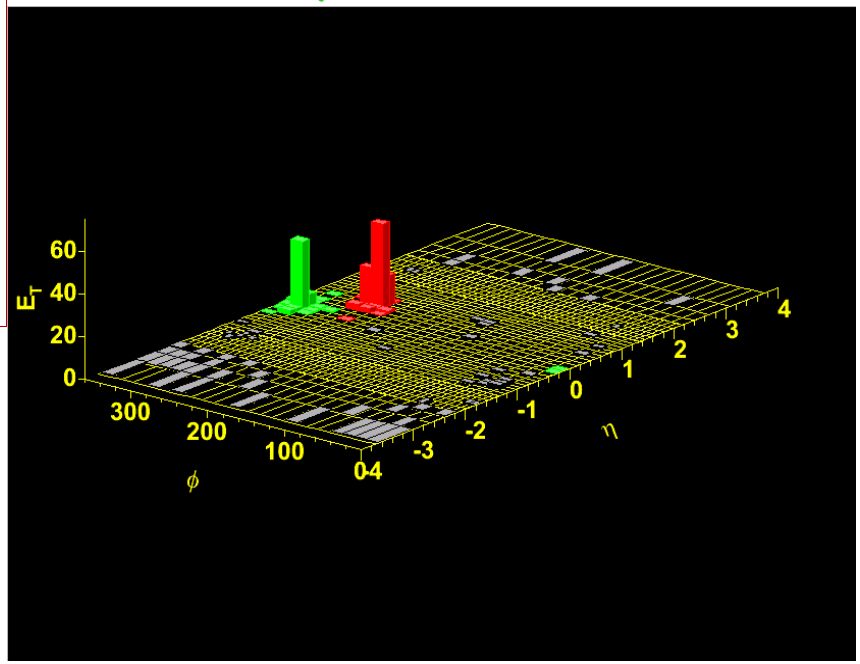


Missing E_T
144.8 GeV



Double-tagged event

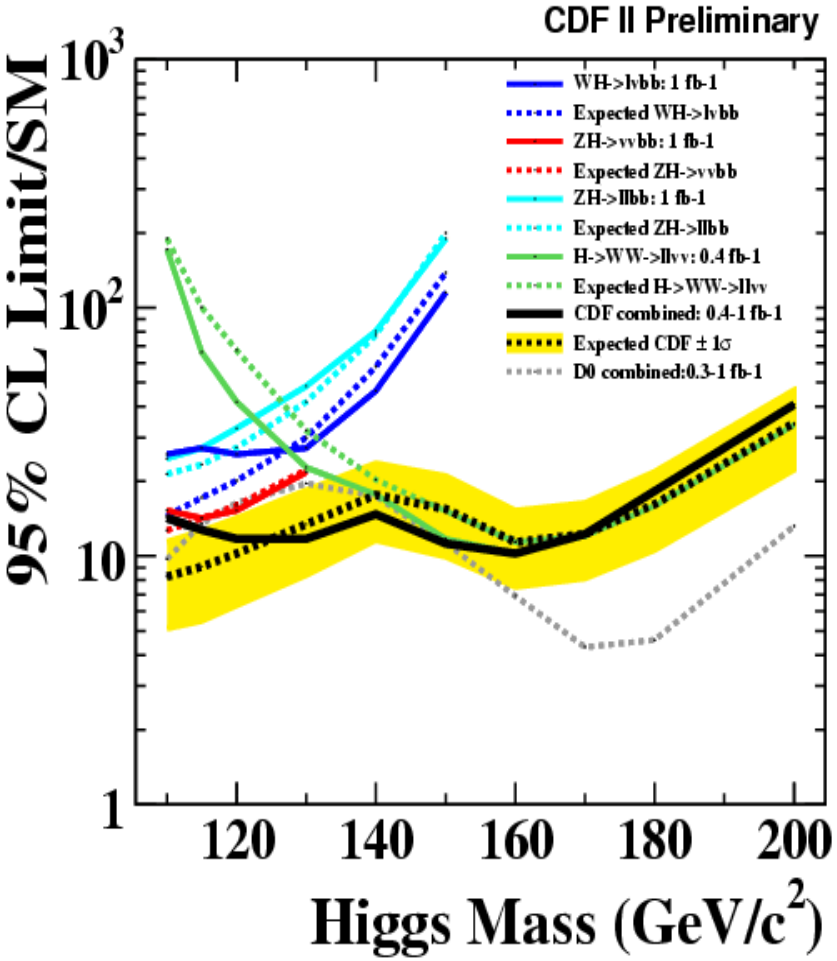
Second Jet E_T = 54.7 GeV



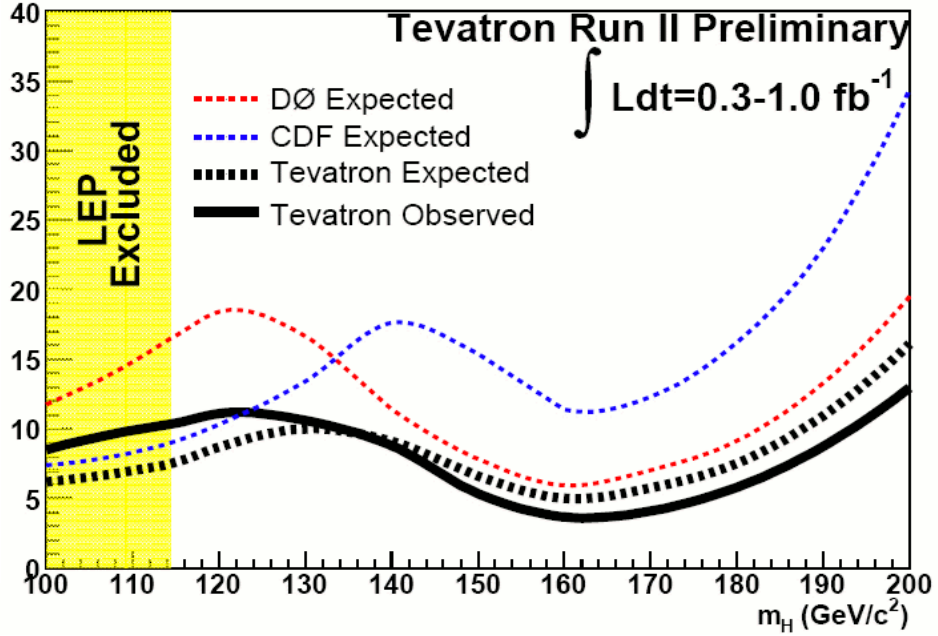
Leading Jet E_T = 100.3 GeV

Di-jet invariant mass = 82 GeV

Combination



- Combination of all CDF channels and with D0 in ongoing



CDF Combination does not include the improved llbb analysis

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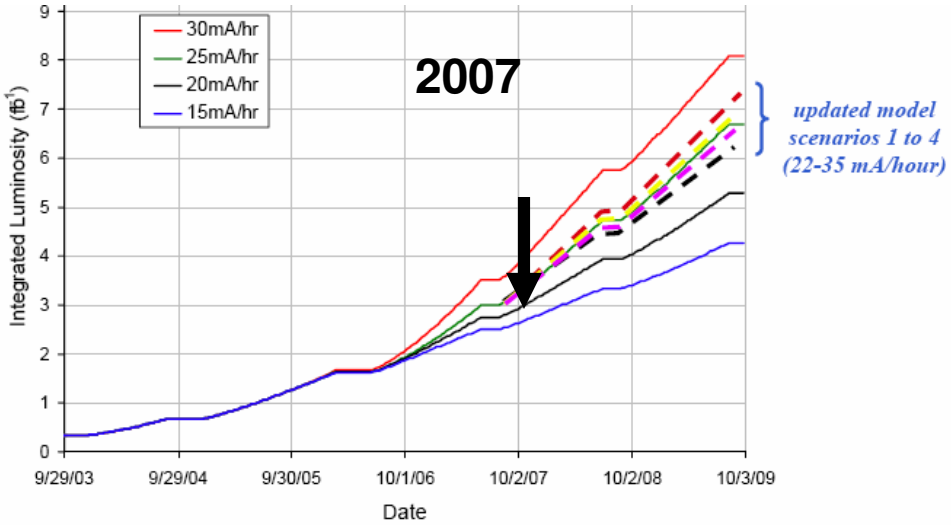
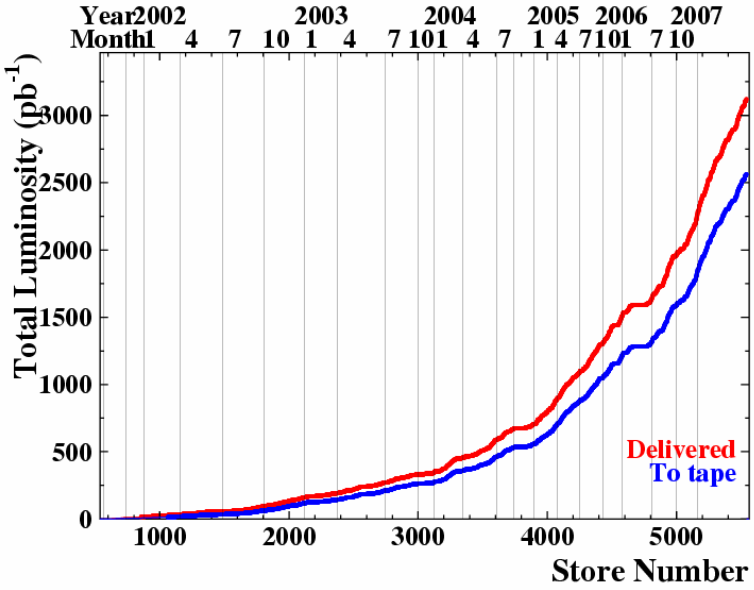
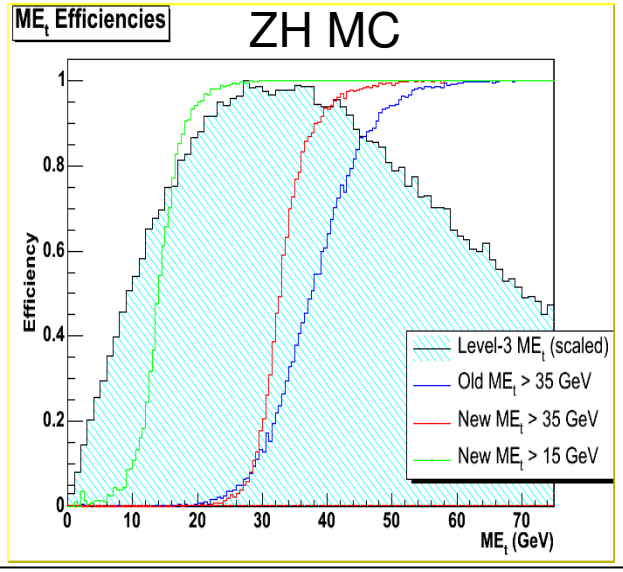
Outlook

- Current limits with 1 fb^{-1}
- 2.5 fb^{-1} have been collected
- Tevatron operating well ≈ 6 fb^{-1} by 09





- Improved analysis methods
- Improved triggers implemented
  - Ex. New Calorimeter trigger
- We keep working and searching

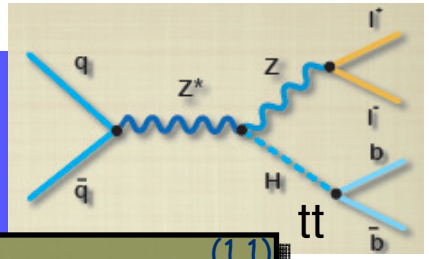


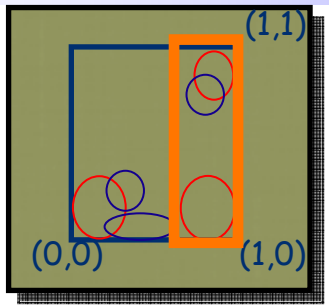
PURDUE
UNIVERSITY

Backup slides

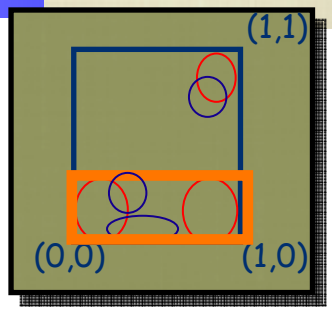
Validation

Pre-tagged sample

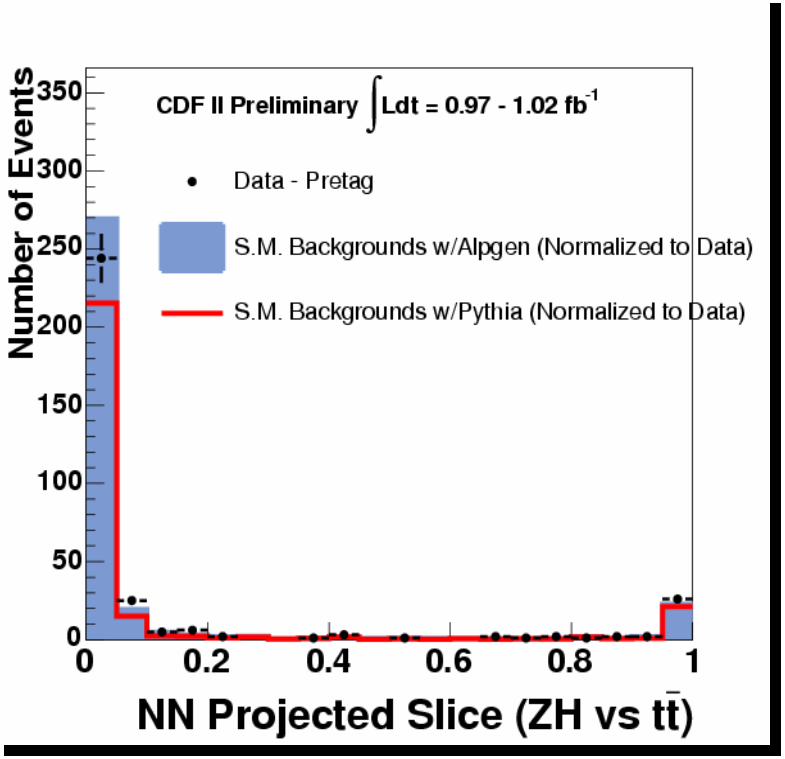


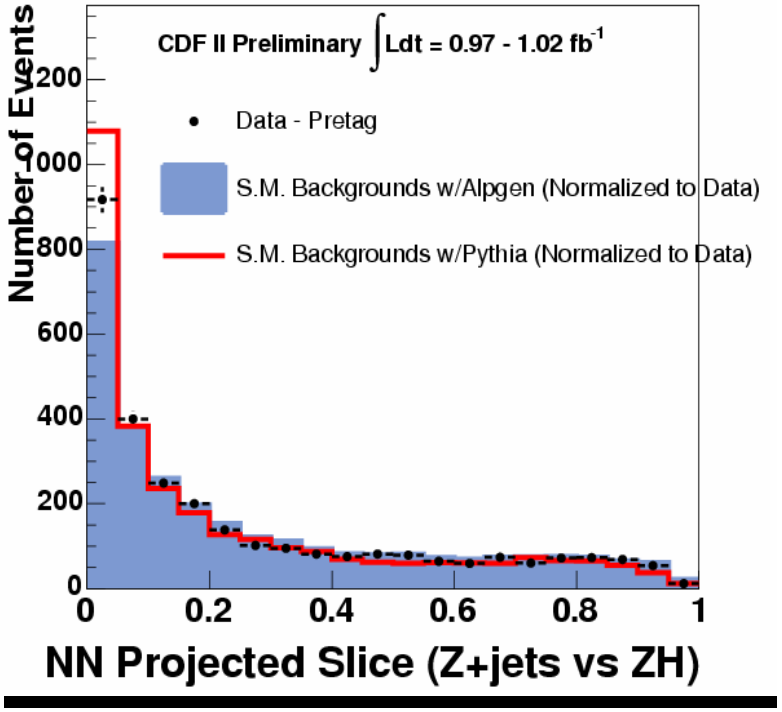


Z+jets ZH



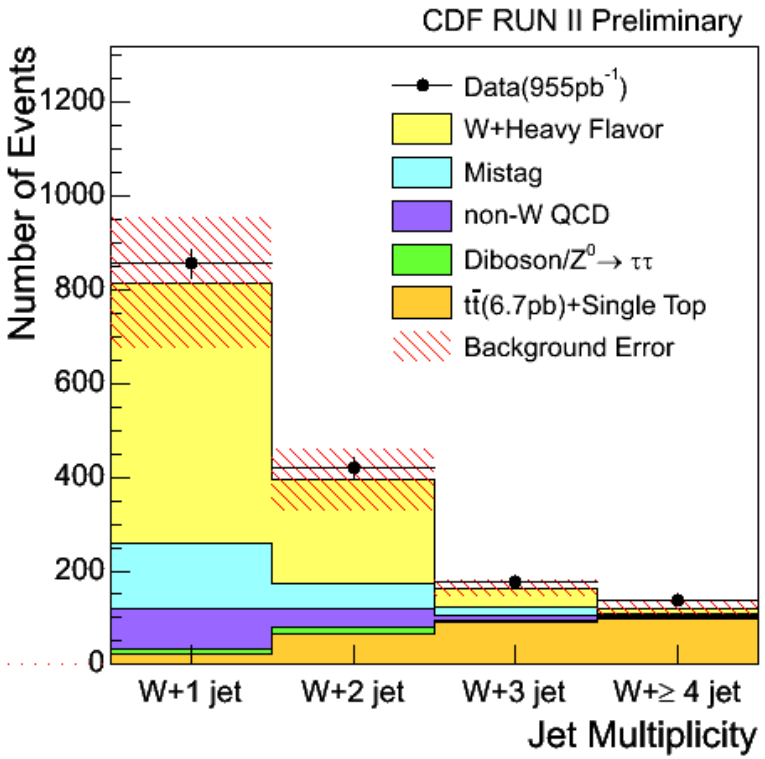
Z+jets ZH

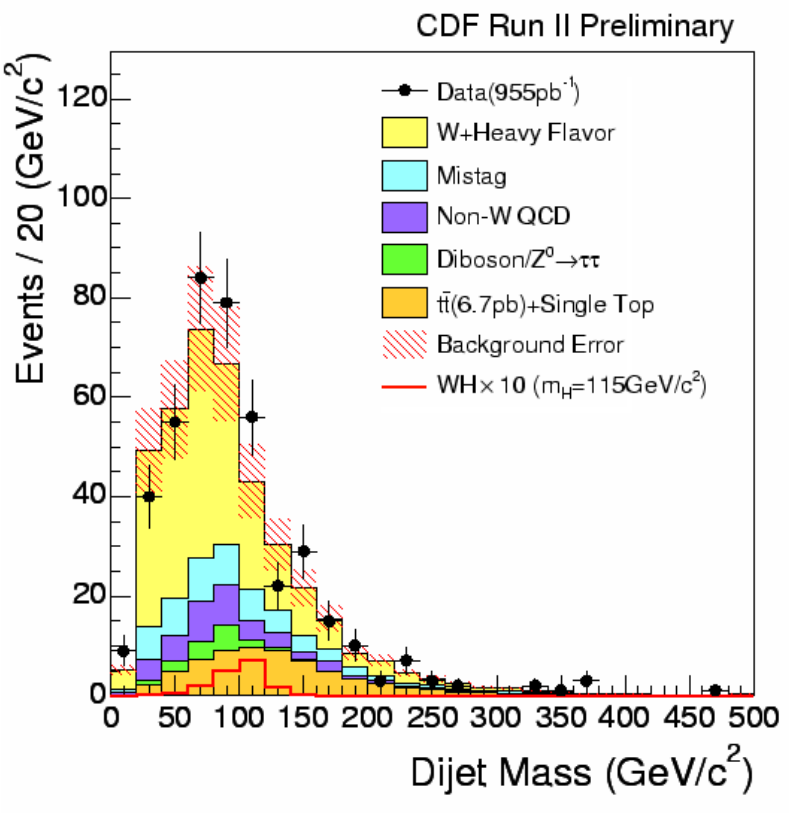




Results $WH \rightarrow \ell\nu bb$

=1 SECVTX with NN tagging

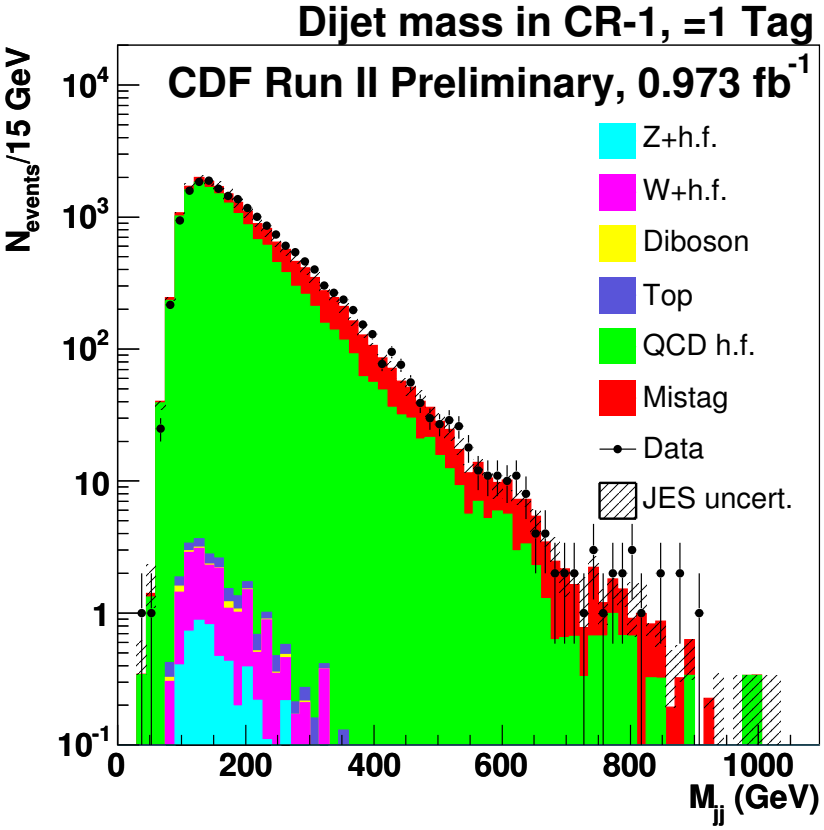




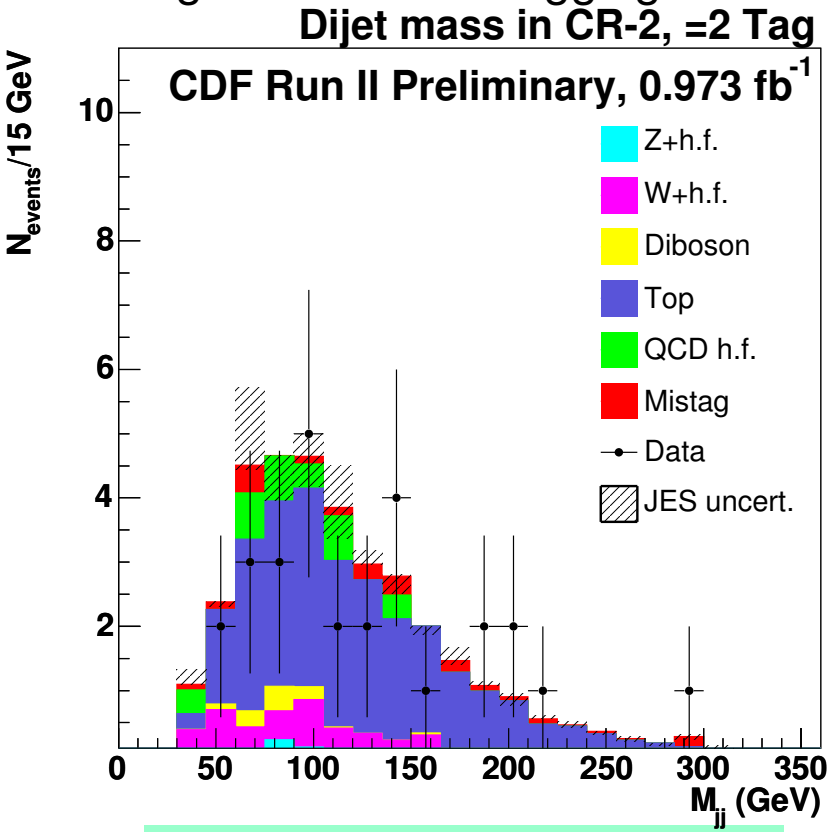
Expected 394.4 ± 66.6
Observed 421

Backgrounds

A few examples!



Tight SECVTX applied to this analysis both for single and double tagging



Single tag CR1: Dominated by QCD and mistags

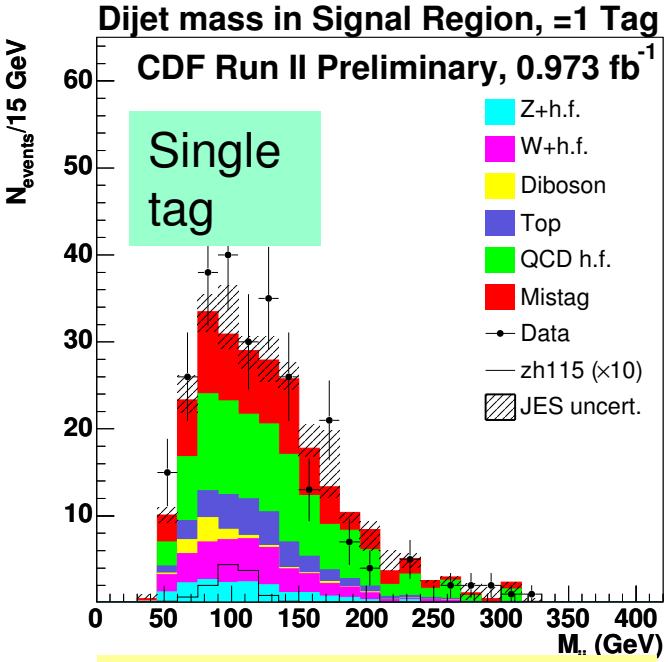
Double b- tag CR2 : Dominated by top

Signal Region

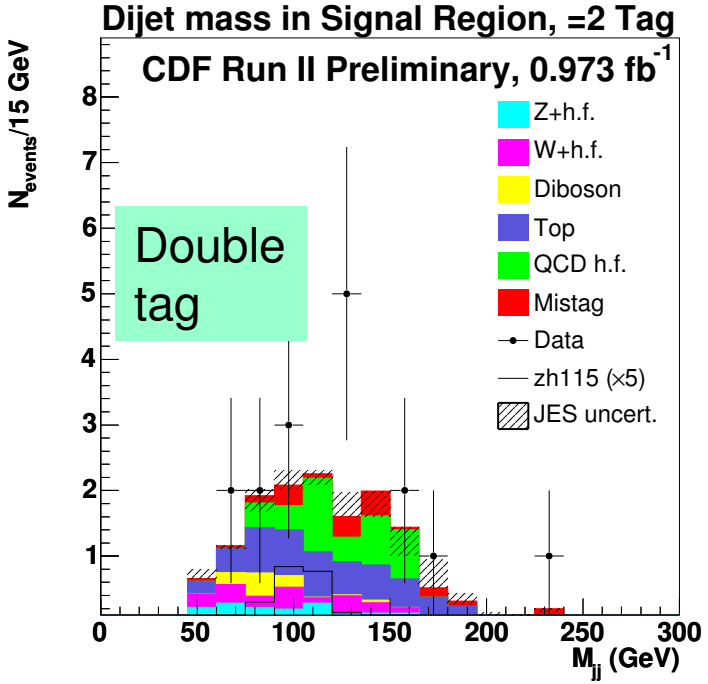
S/B Optimization is performed in extended signal region

- **Jet energy**
- **Missing ET**
- **HT =scalar sum of the jet Et-s**
- **Missing HT (vectorial sum of jet Et-s)**

- **ϕ(1st Jet, Missing E_T) > 0.8**
- **Missing E_T > 70 GeV**
- **Missing H_T / H_T > 0.45**
- **1st Jet E_T > 60 GeV**



Expect 251.0 ± 43.2
Observe 268



Expect 14.8 ± 2.65
Observe 16