Closing in on the Higgs Boson at CDF

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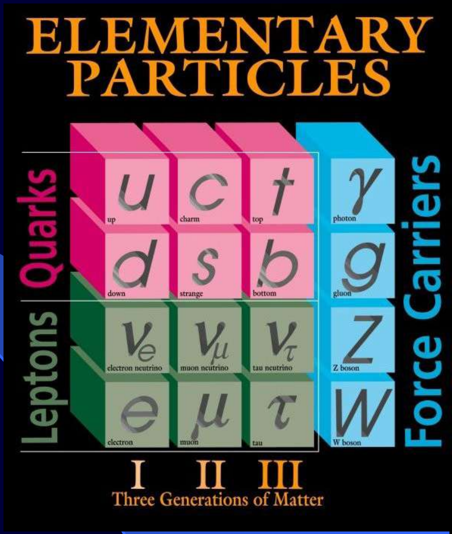
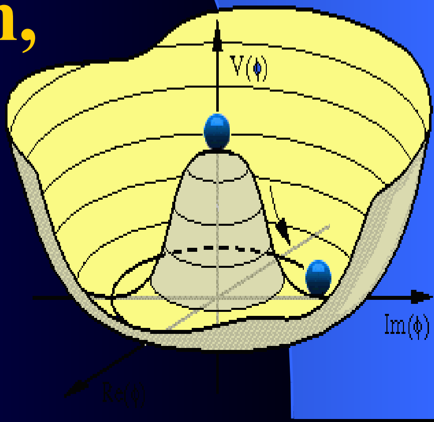
OutLine

- Introduction
- SM Higgs Search Strategies and Challenges
- SM Results with up to $1.9fb^{-1}$
- Combinations
- Future Prospects
- MSSM Higgs Search at CDF
- Conclusion

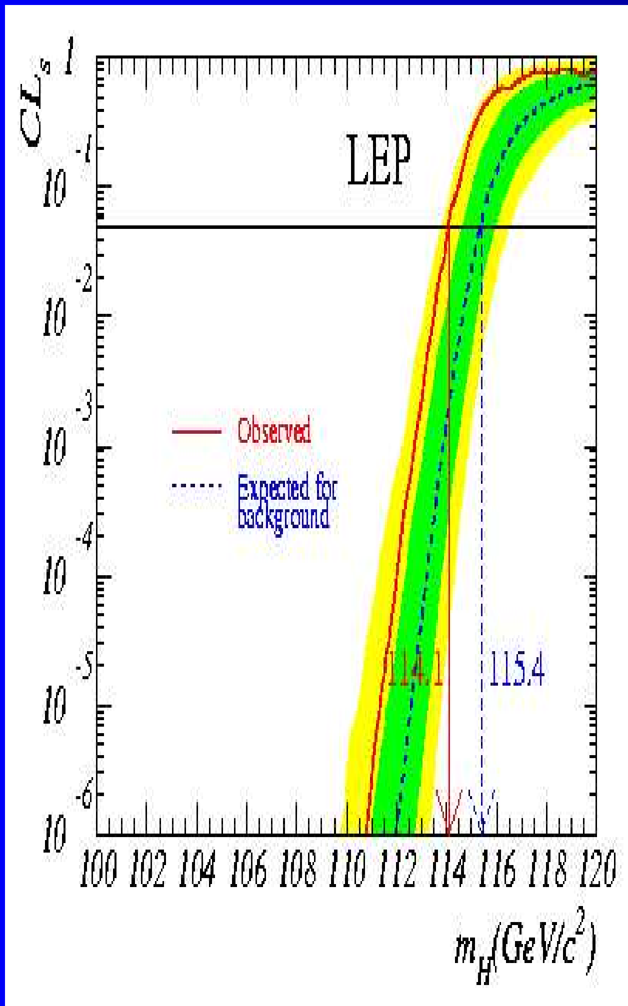
Introduction

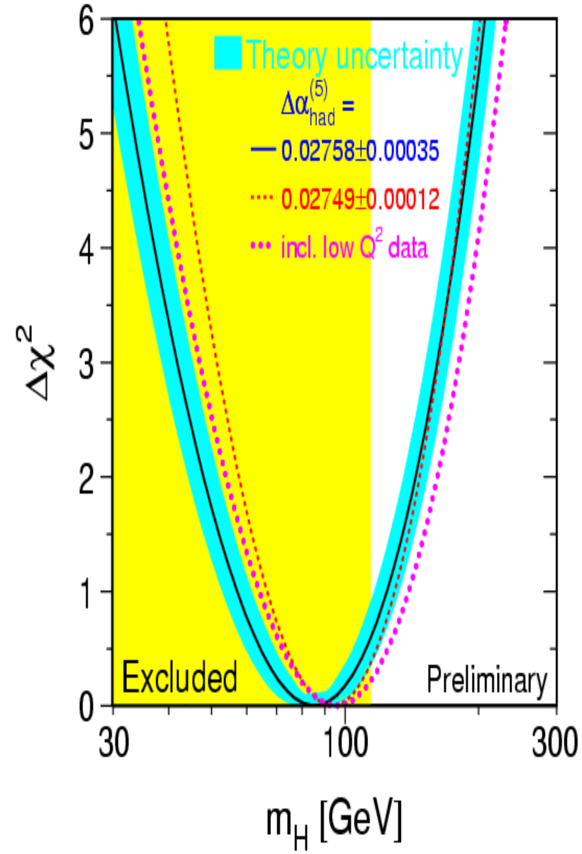
- **The Standard Model describes nature well in terms of fundamental particles, but provides no explanation about the origin of masses.**
- **All tests so far show no sign of deviation**
- **The Higgs mechanism provides for EWSB and predicts the existence of Higgs boson, that has yet observed experimentally.**
- **The SM is an effective theory at EW scale and there must be new physics to stabilize the Higgs mass, such as SUSY, extra-dimension, Little higgs and Higgsless...**

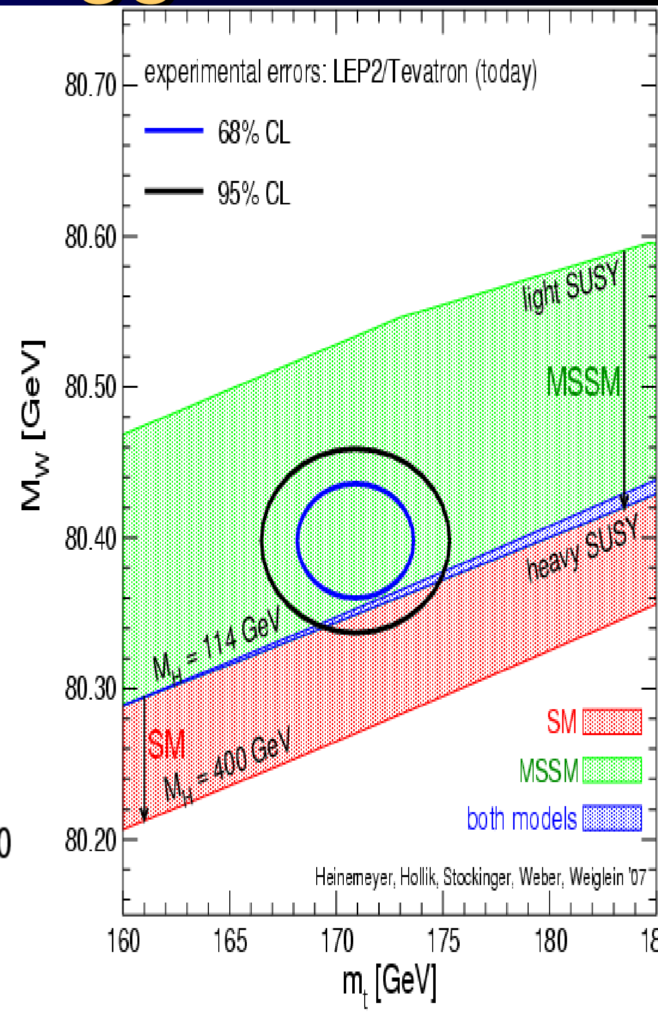




What we know about the Higgs Boson

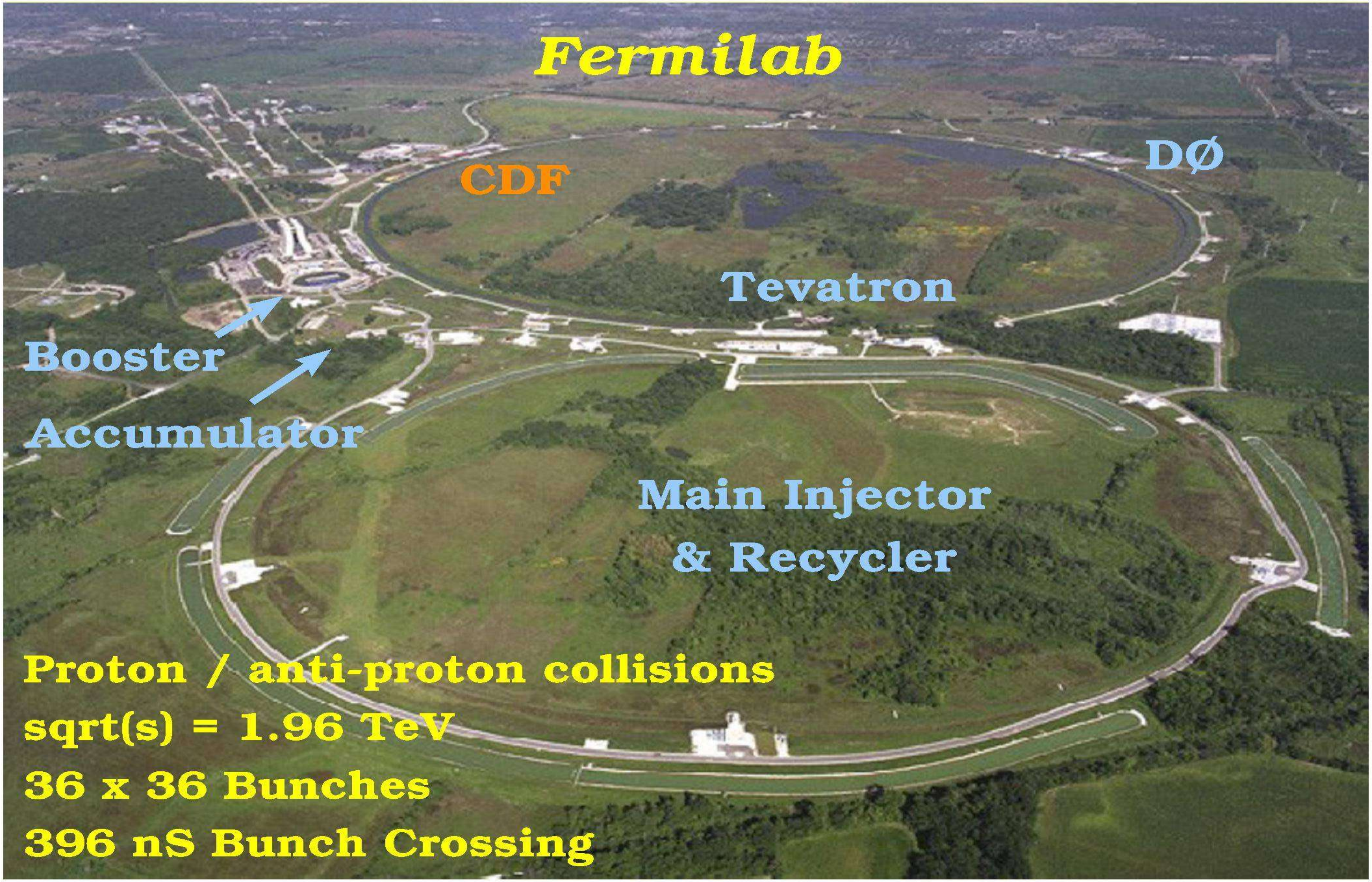




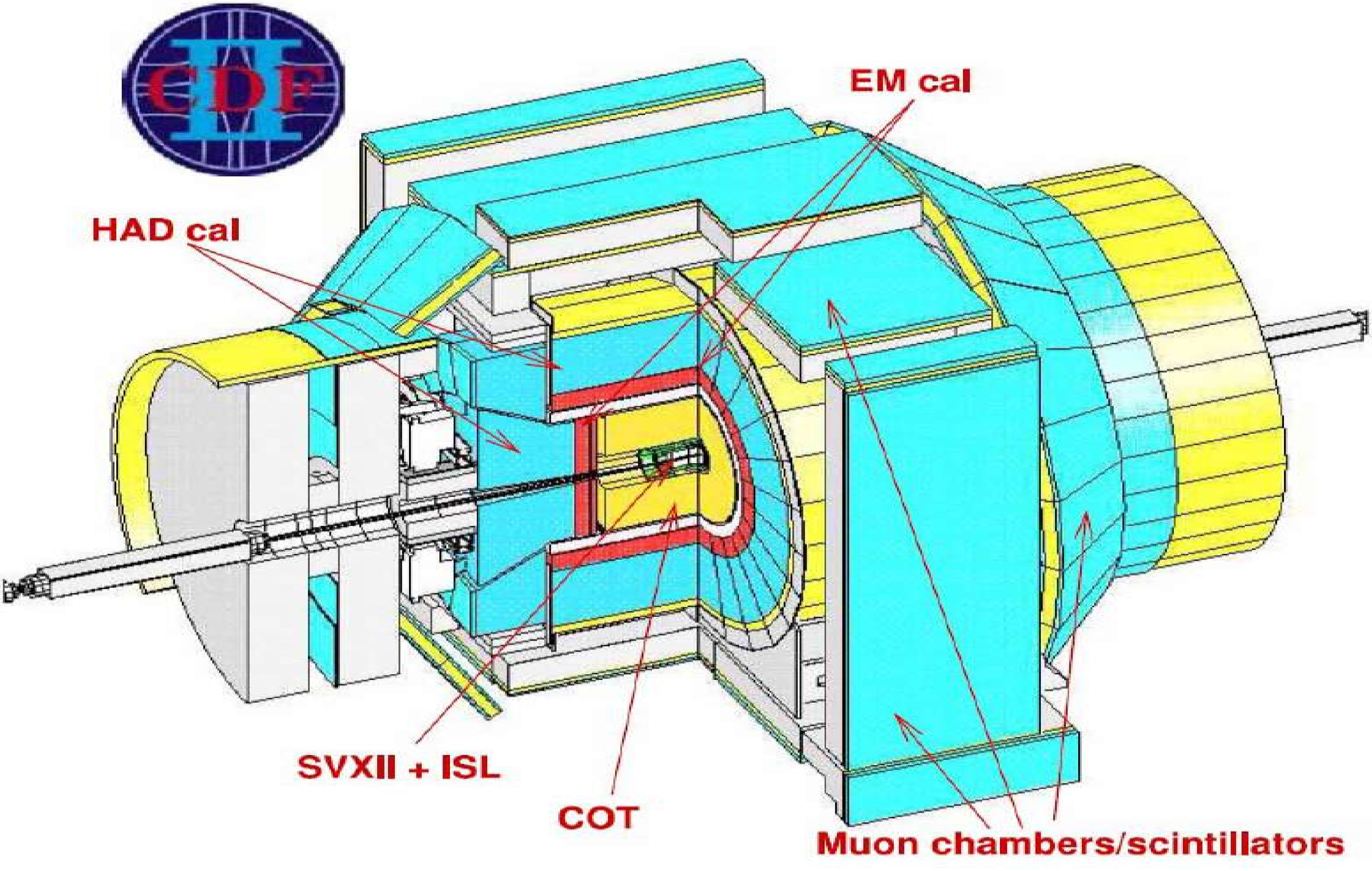


- **Direct Searches at LEP: excludes M_H<114.4 GeV at 95% C.L.**
- **Global fit give best fit of M_H= 76^{+33}_{-24} or <144 GeV at 95% C.L.**
- **The low-mass Higgs will be hard to reach with early LHC data.**

The Tevatron Complex



The CDF II Detector

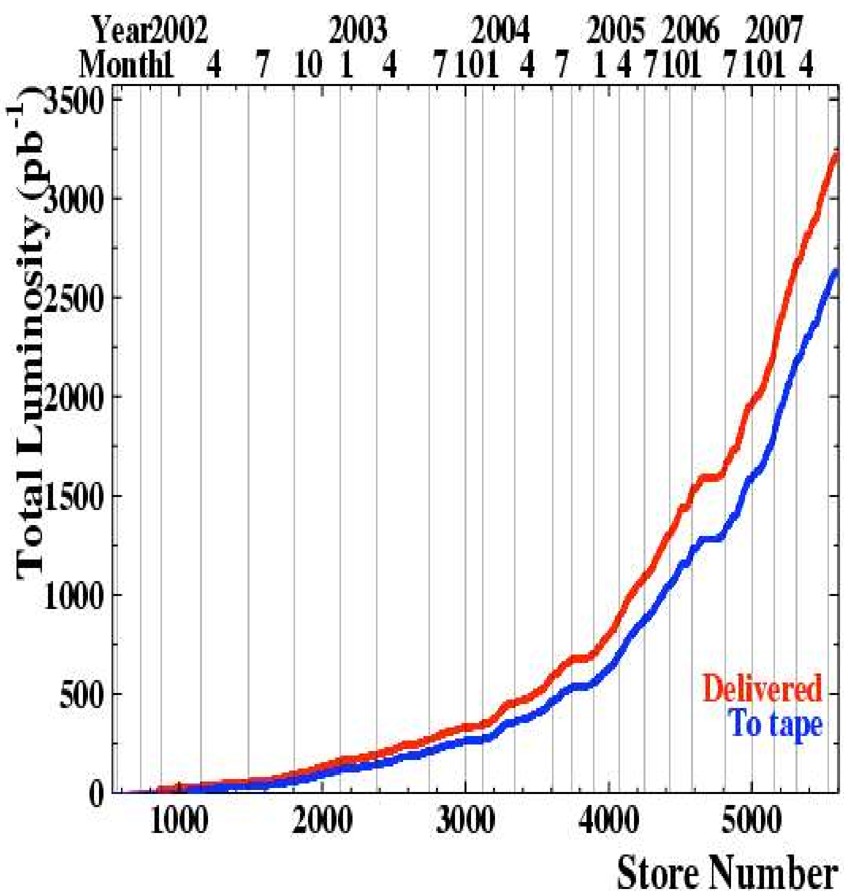


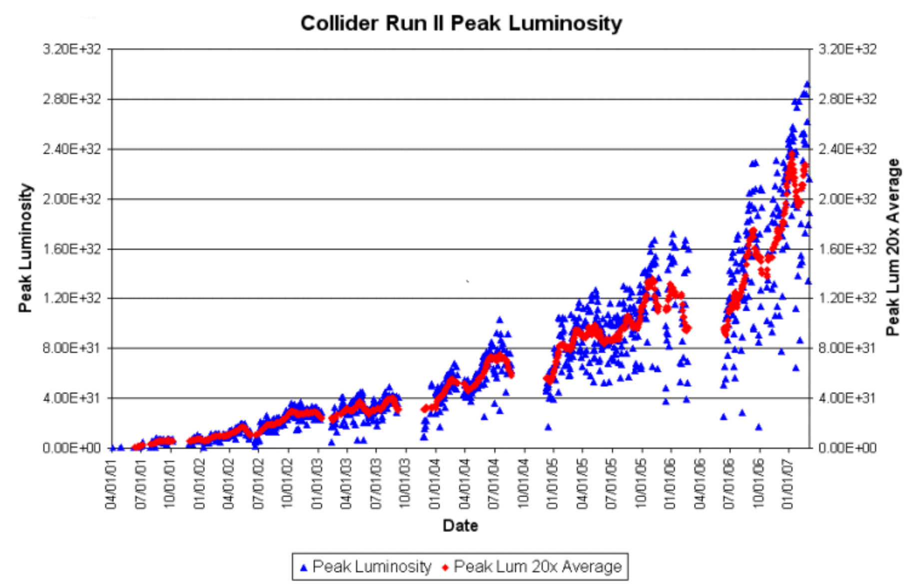
Tevatron Status and Plans

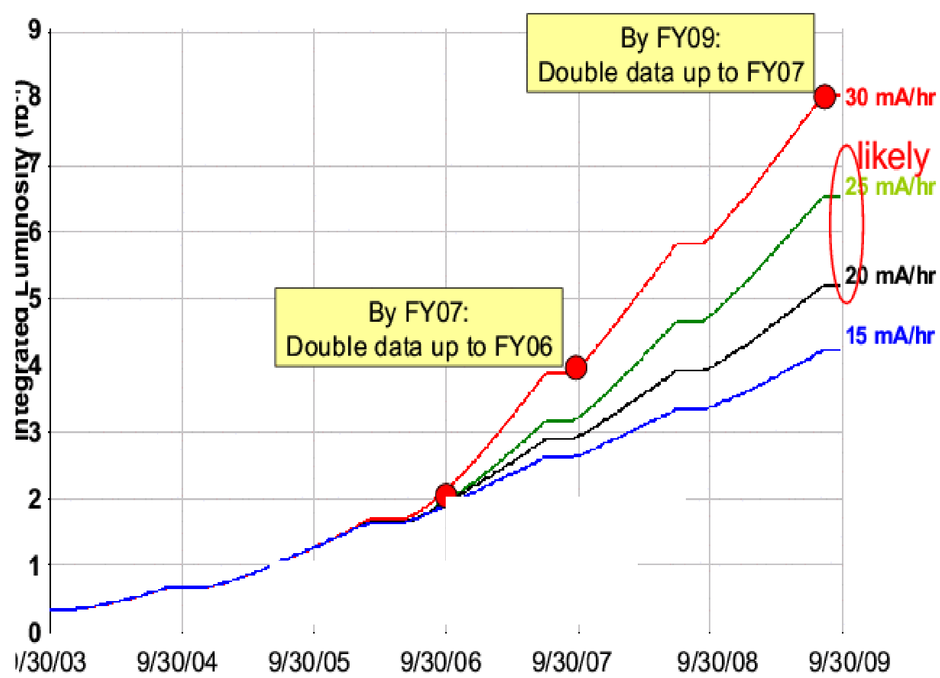
Tevatron has been doing great !

Record luminosity: *2.90x10³²*

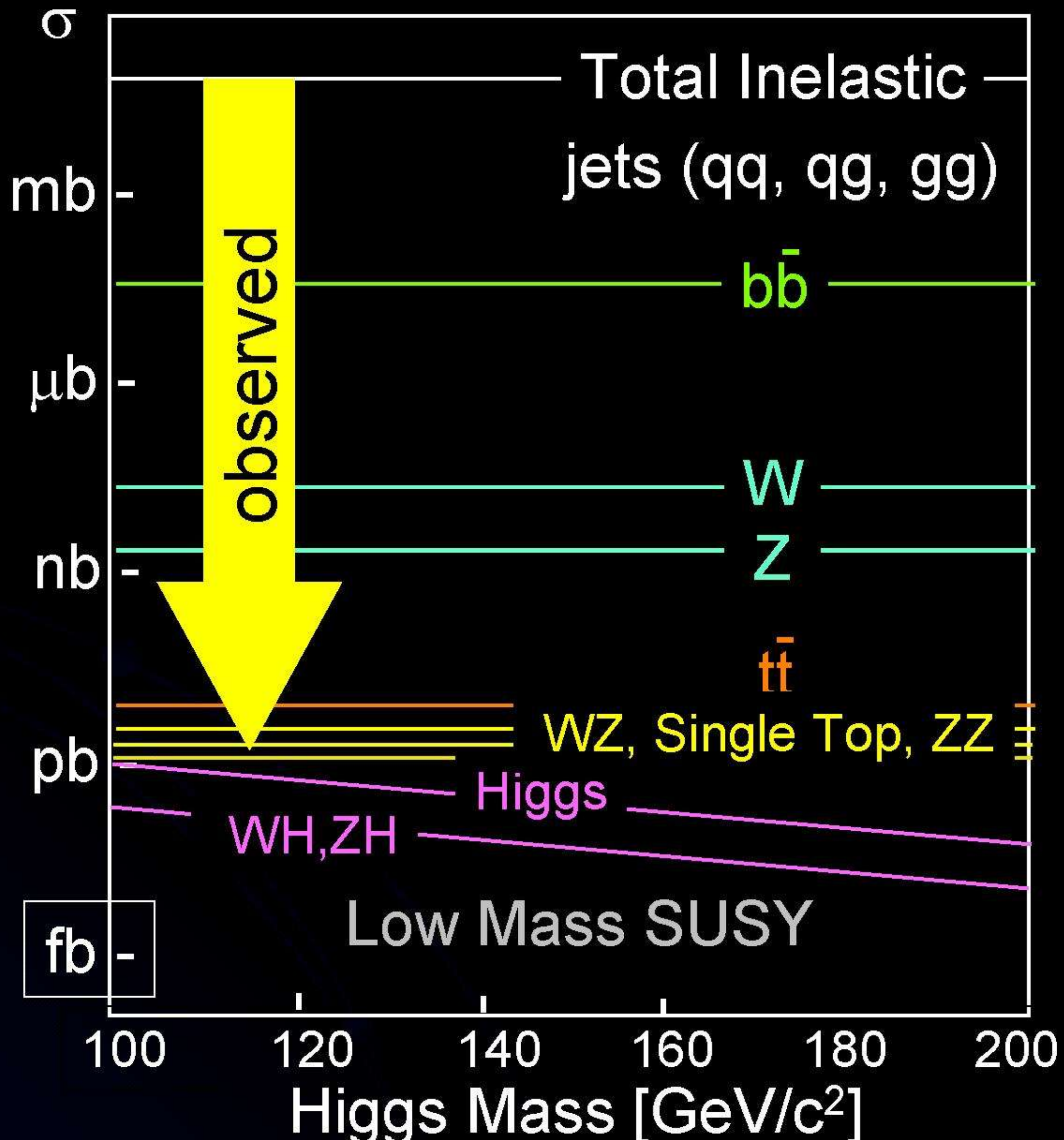
Delivered 3.2 fb⁻¹ and 5-8 fb⁻¹ by FY09, and more if running 2010







Road to Higgs and Beyond



B_s–B_s Oscillation, Ξ_b Discovery + Precision Meas.

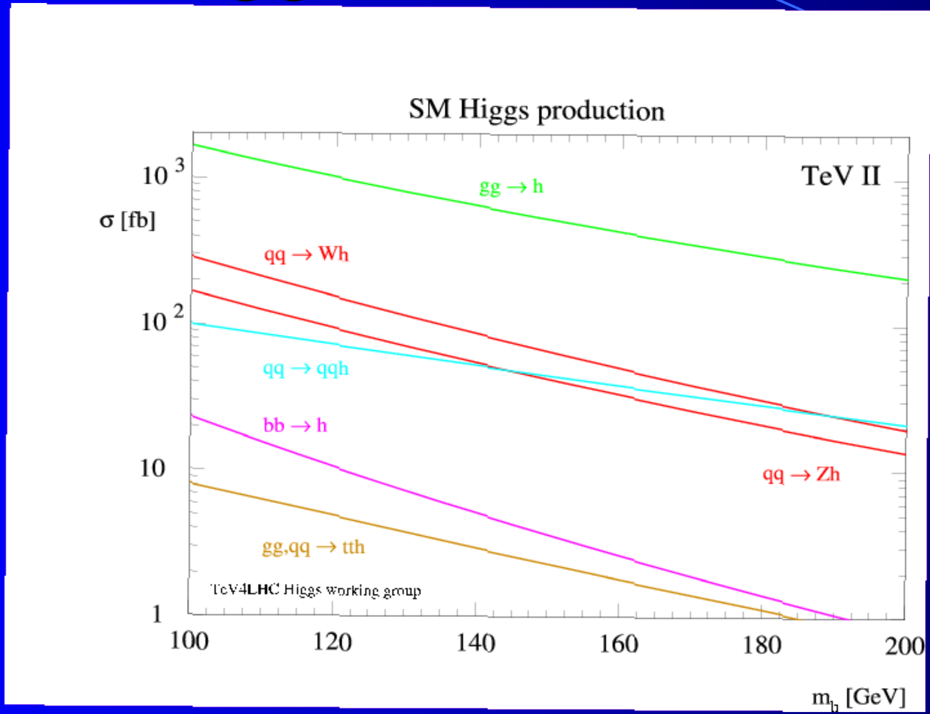
M_W ~0.05%

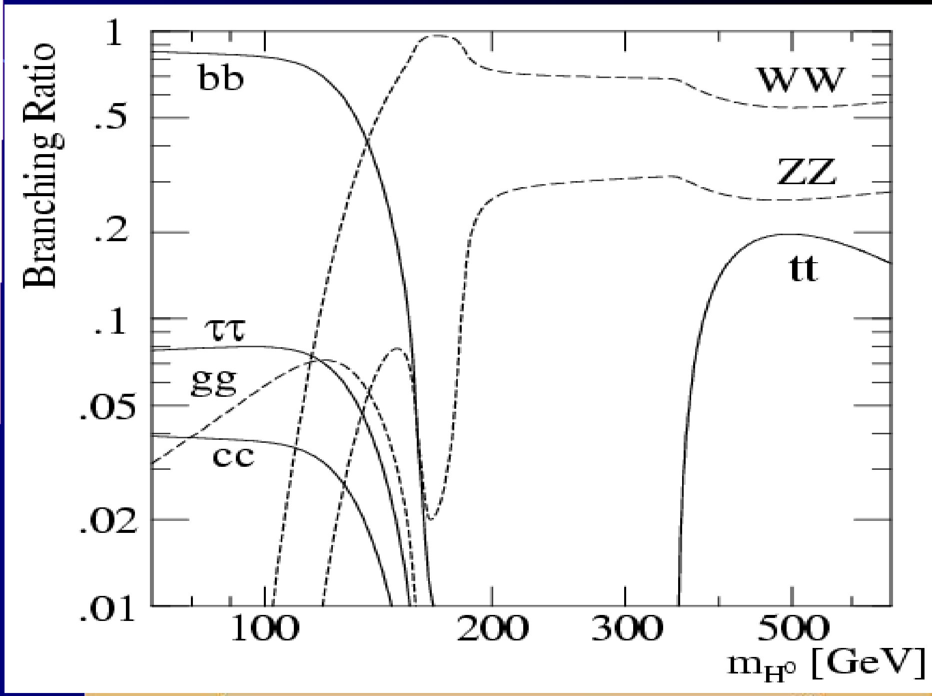
M_{top} ~1.2%

Observed WZ, Evidence for ZZ and Single Top

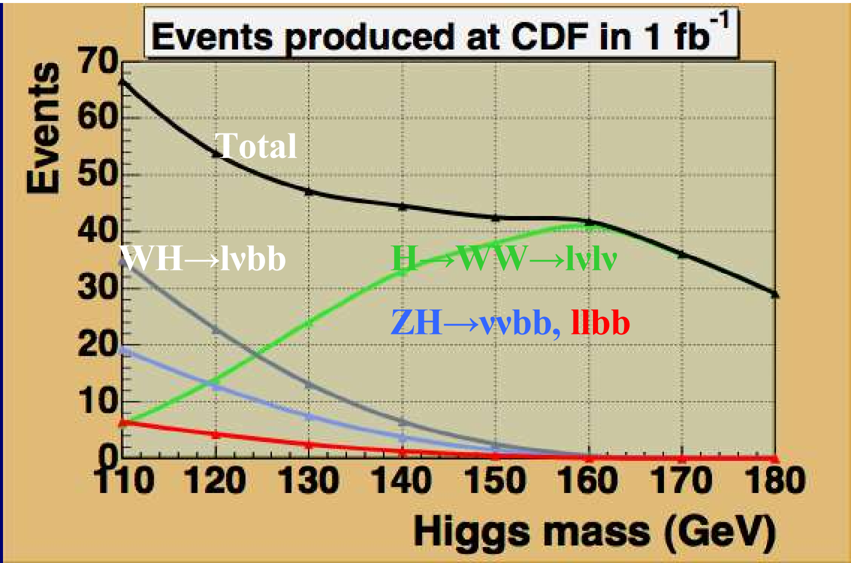
M_{Higgs} < ? GeV at 95% CL

Higgs Production and Search Strategies

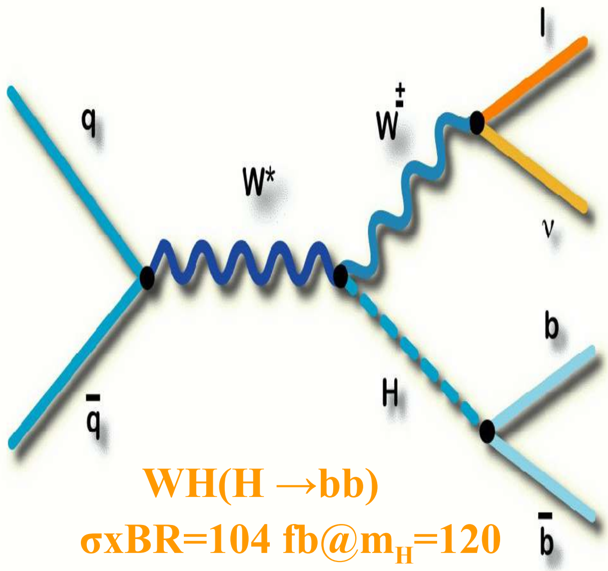




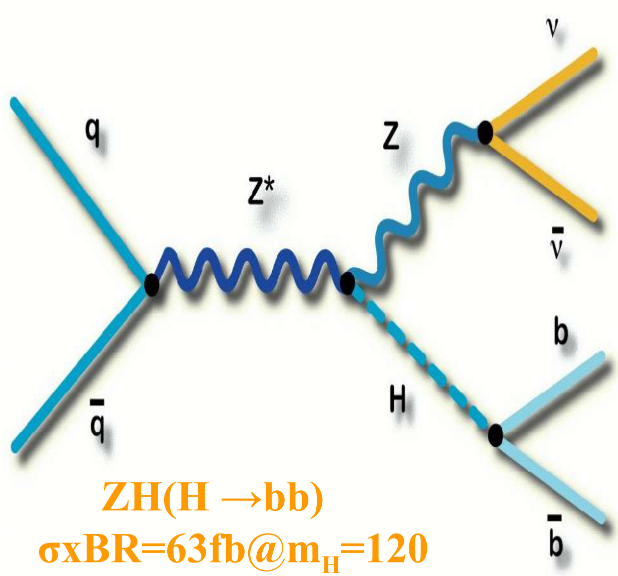
- M_H<130 GeV: H→bb
  - WH, ZH most accessible
  - Excellent b-tag and dijet mass
- M_H>140 GeV: H→WW*
  - Exploit the large σ(gg→H)
  - Identify clean final states with leptons



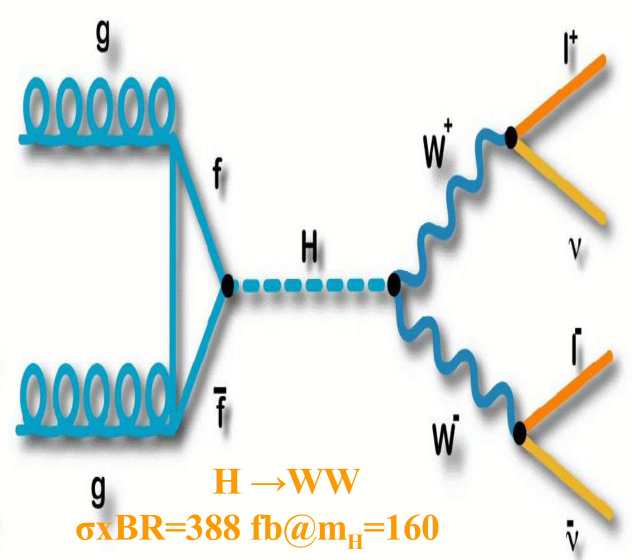
Signal and Background Rates



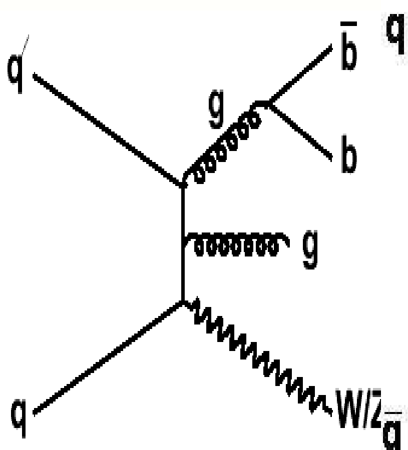
WH(H →bb)
σxBR=104 fb@m_H=120

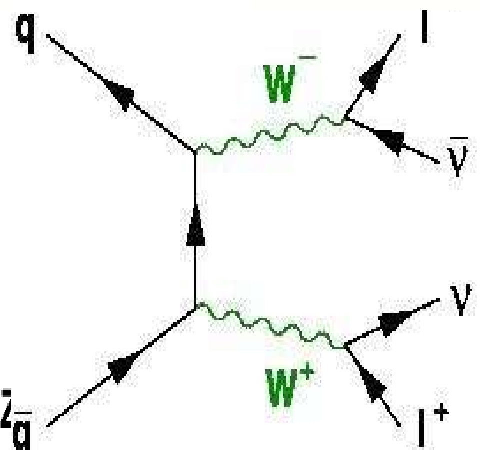


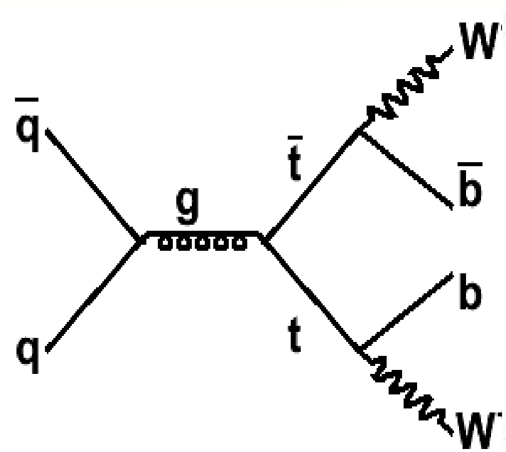
ZH(H →bb)
σxBR=63fb@m_H=120

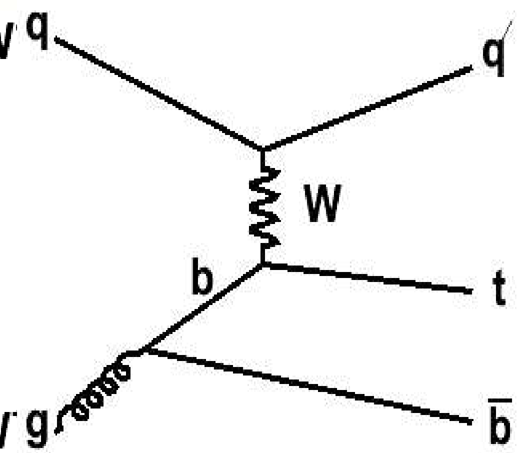


H →WW
σxBR=388 fb@m_H=160









W+qq=2nb
W+bb=40 pb

WW=13 pb
WZ=4 pb
ZZ=1.5 pb

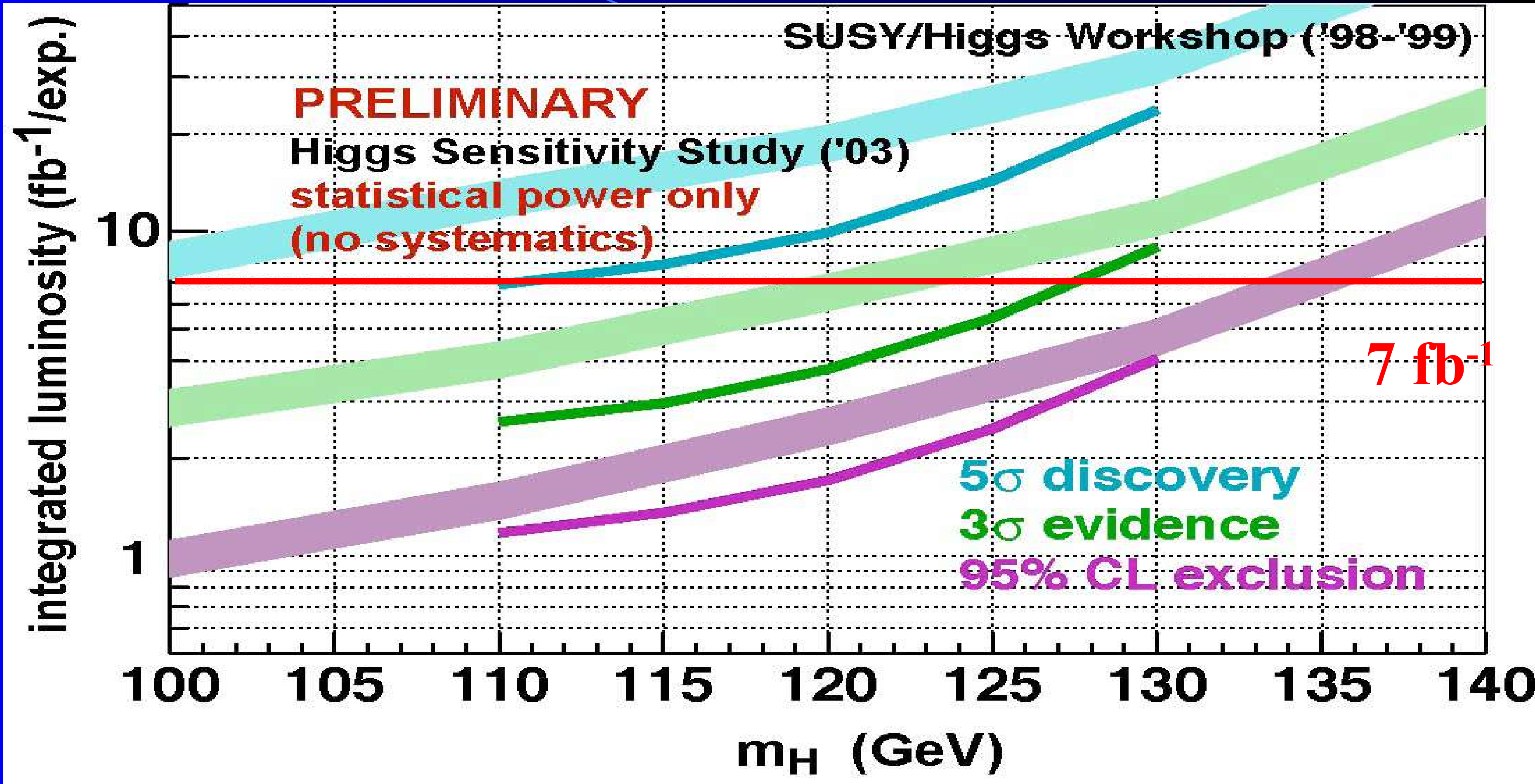
ttbar =6.8 pb

Single t=3 pb

Analysis RoadMap

- **Search for events consistent with:**
  - $WH\rightarrow l\nu bb$, $ZH\rightarrow llbb$ (Lepton +Jets)
  - $WH\rightarrow \not{l}\nu bb$, $ZH\rightarrow \nu\nu bb$ (Missing Et +Jets)
  - $H\rightarrow WW^{*}\rightarrow l\nu l\nu$ (Dilepton)
- **Perform careful estimation of backgrounds:**
  - W+jets, W+bbbar, W+ccbar, and Wc
  - Top production (single +pair)
  - Diboson WW, WZ and ZZ
  - QCD multijet events
- **Devise a discriminating variable to increase separation between signal and background (NN, ME, DT) than m_{jj} or $\Delta\varphi_{ll}$ only.**
- **Perform a likelihood fit to search for signal**
- **In absence of signal, set 95% limit on $\sigma\times BR$ vs m_H**

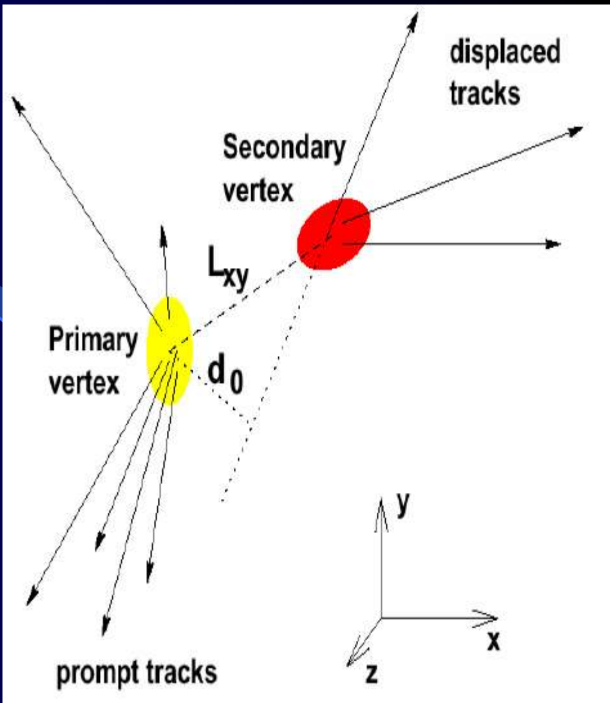
Higgs Sensitivity at Tevatron

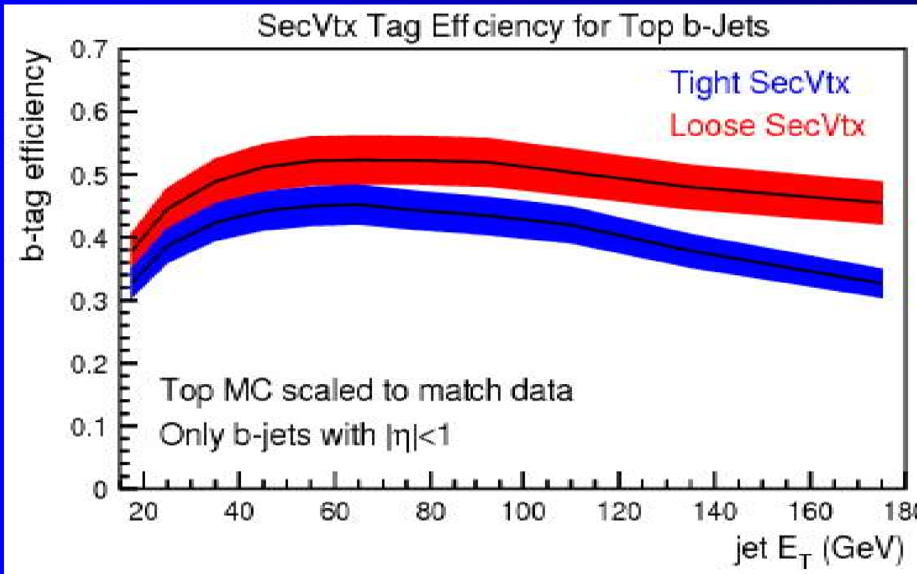


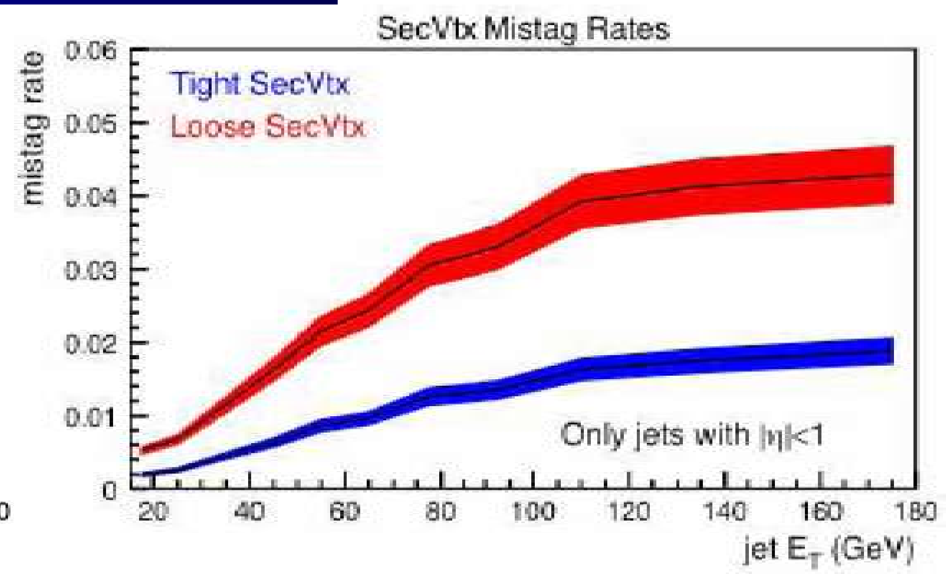
- Tevatron SM Higgs is extremely difficult
- Low-mass Higgs requires great b tagging, dijet mass resolution , and control of backgrounds

B-jet Identificaton (B-tagging)

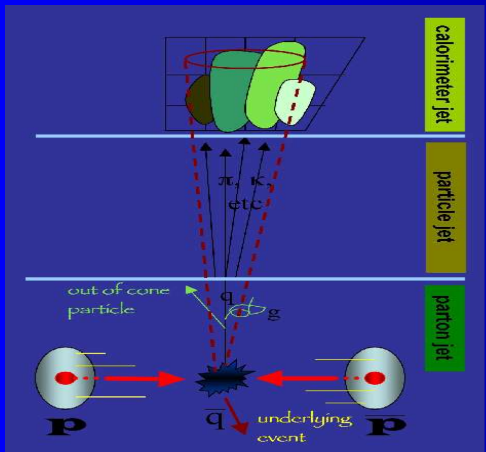
- **B-hadron are long-lived – search for displaced tracks/vertex inside the jet**
  - **SECVTX: select good displaced tracks and fit a displaced vertex with Lxy/σ>7**
  - **JetPrb: combine the track probability that originated from event vertex**
  - **More advanced NN btag would help further...**
- **Require to calibrate the tagging efficiency and mistag rate from data**



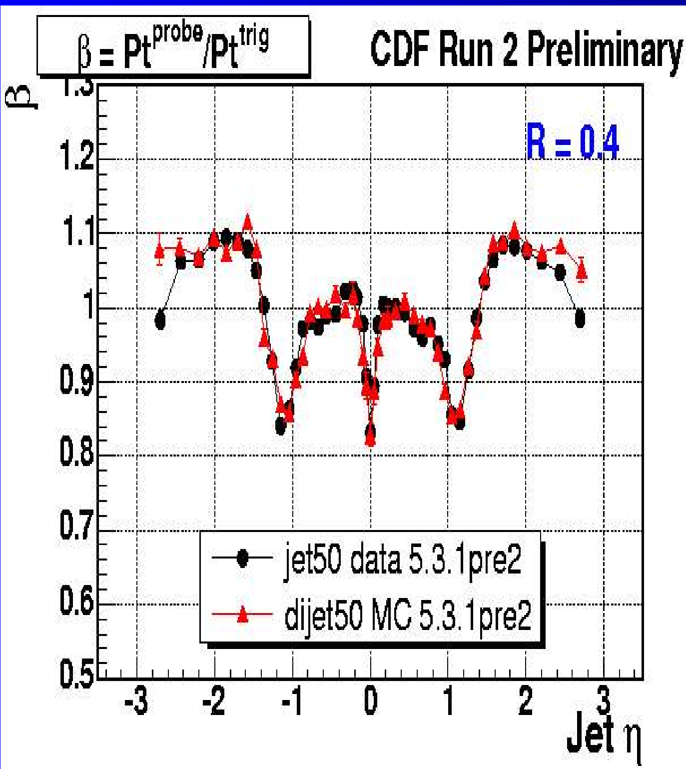


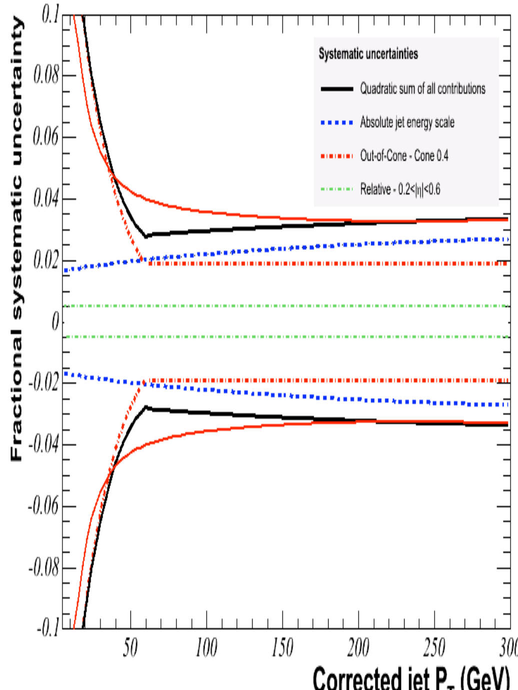


Jet Energy Correction

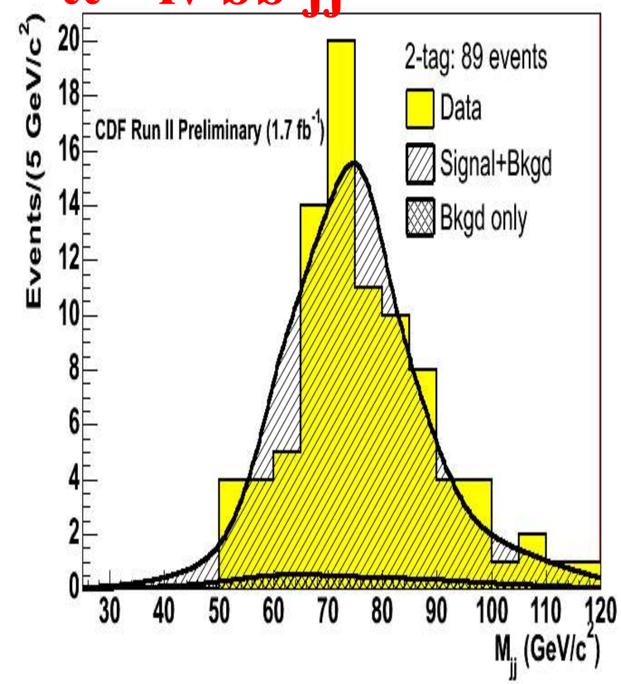


- Measured jet Et depends on the cal. response to hadrons: energy scale, non-linearity, out-cone, underlying activities.
- Need to calibrate each pieces with data and Monte Carlo modeling
- Particle flow, more advanced corrections would help…



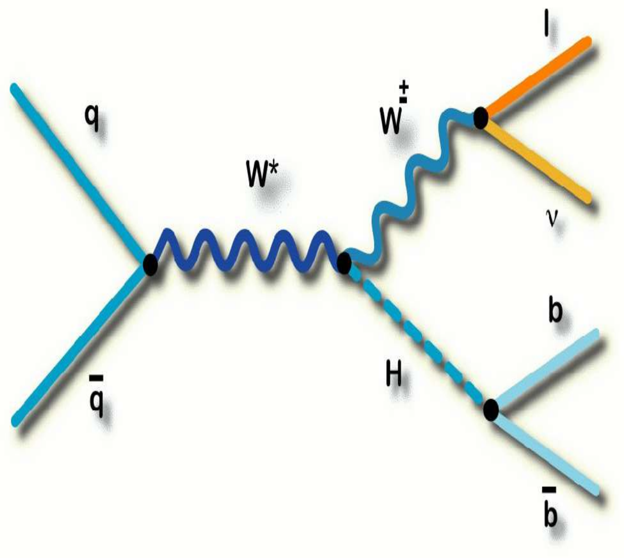


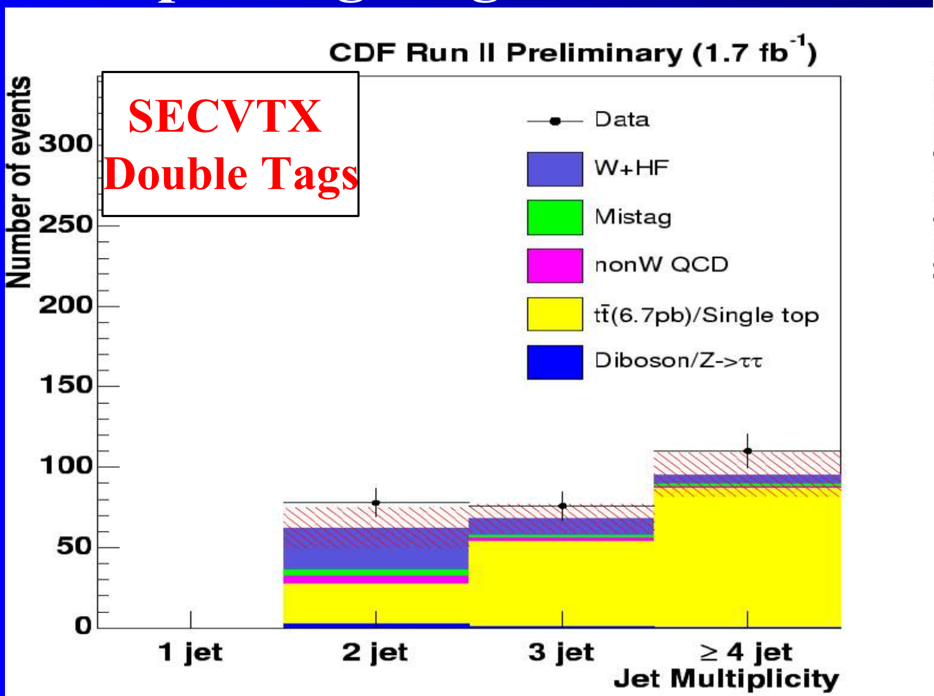
tt->lν bb jj

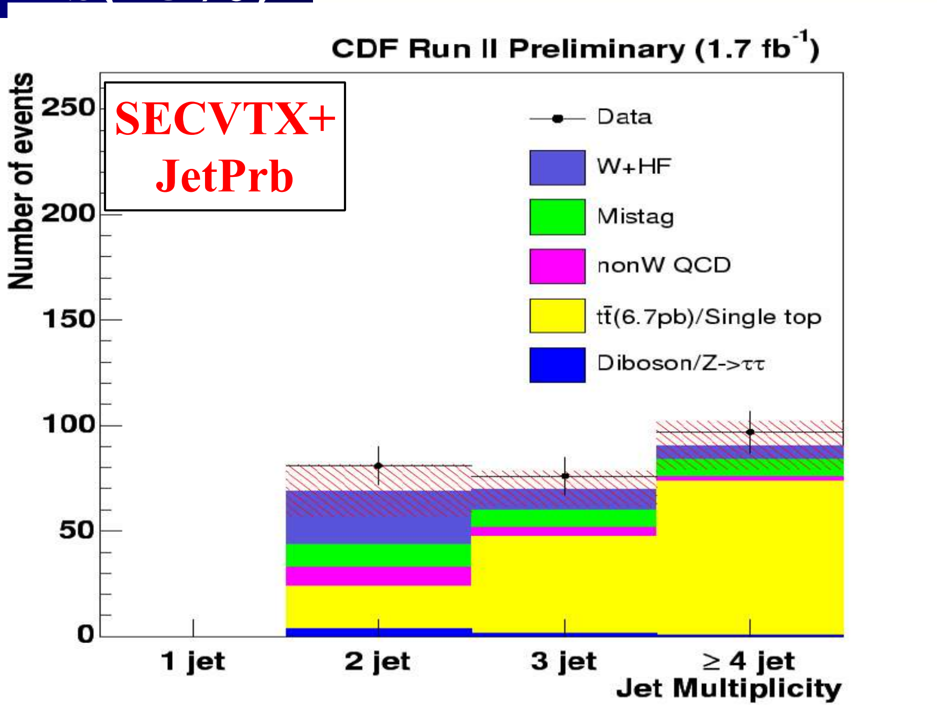


Search for WH→lvbb

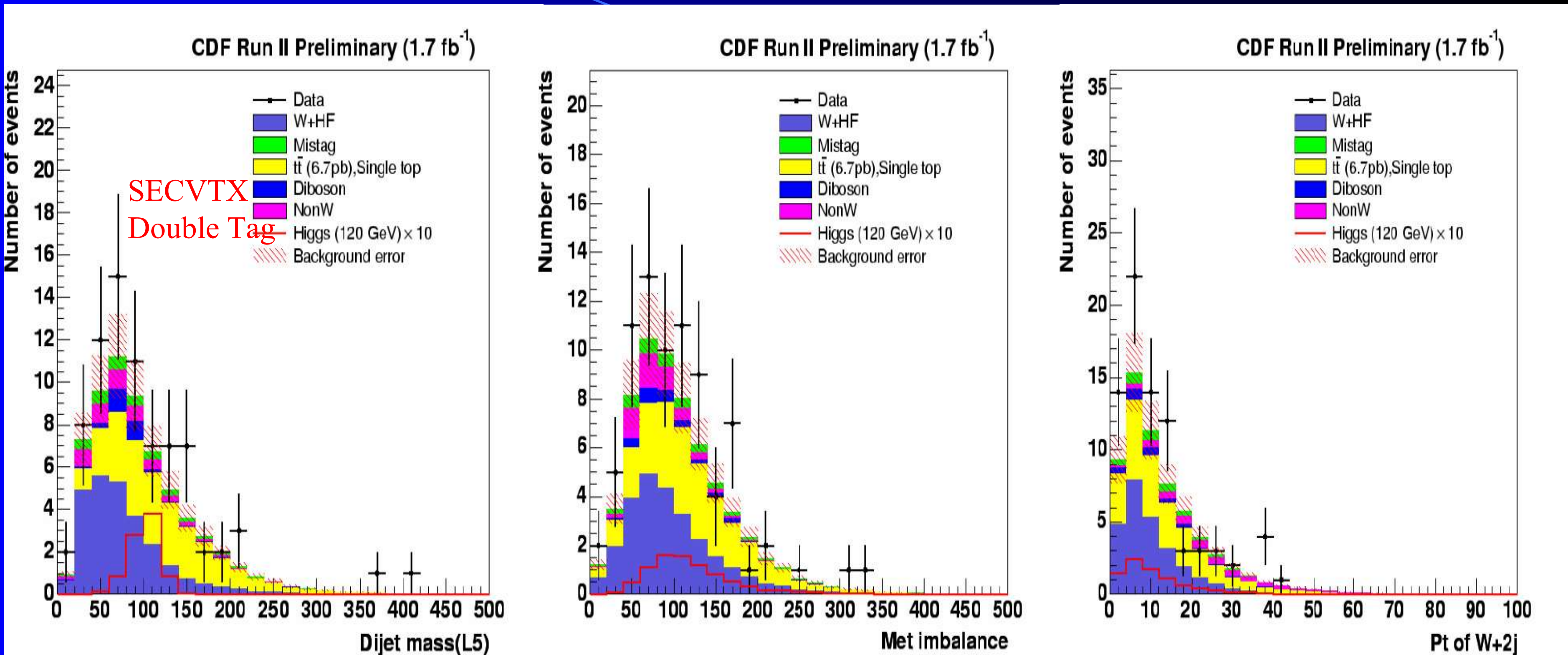
- **Basic Event Selections:**
  - **High Pt lepton: P_T>20 GeV**
  - **Neutrino as missing E_T>20 GeV**
  - **Two Jets: E_T>20 GeV & |η|<2**
  - **Double b-tags**
- **Improving btag: SECVTX +JetPrb(<5%)**







Advanced Analysis Technique

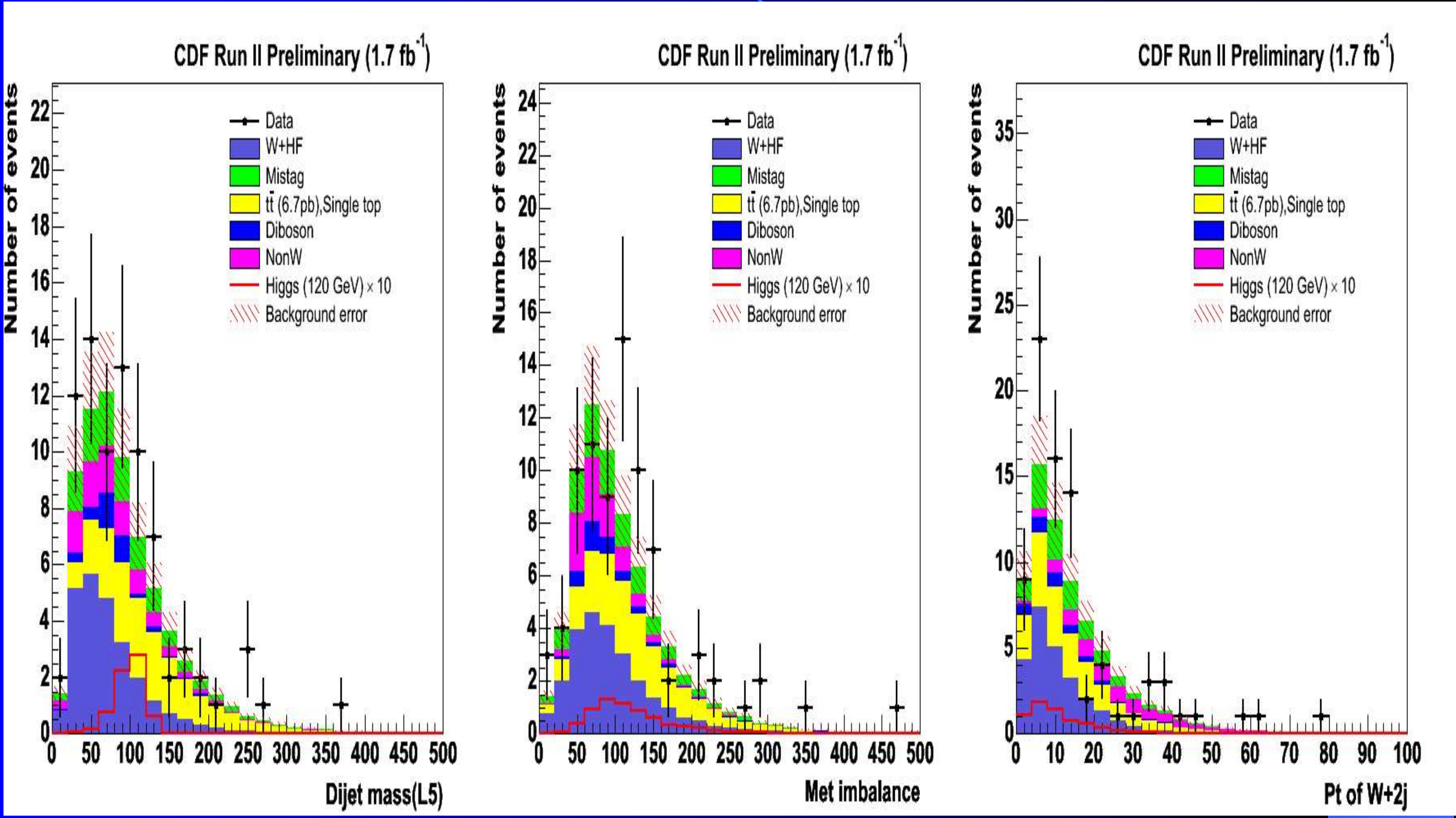


Dijet Invariant Mass **ΣE_T(l, jets)-MET** **P_T of W+2jet**

- In the past, we fit dijet mass to improve search sensitivity
- Several multivariate approaches emerged as more data
- Used optimization procedure to combine 3 most sensitive variables using Neural Network (NN)

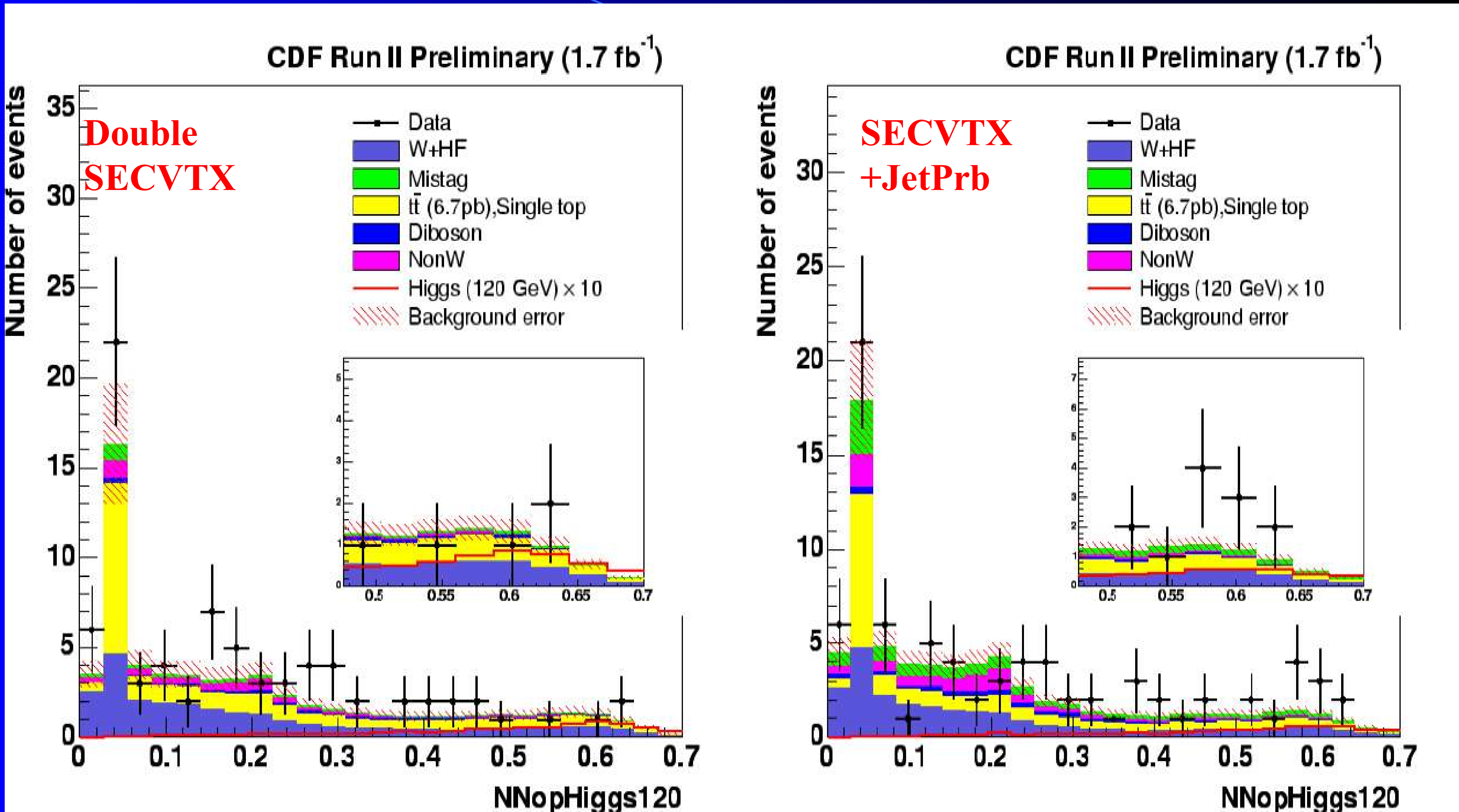
Advanced Analysis Technique

- **Double tags with SECVTX + JetPrb**



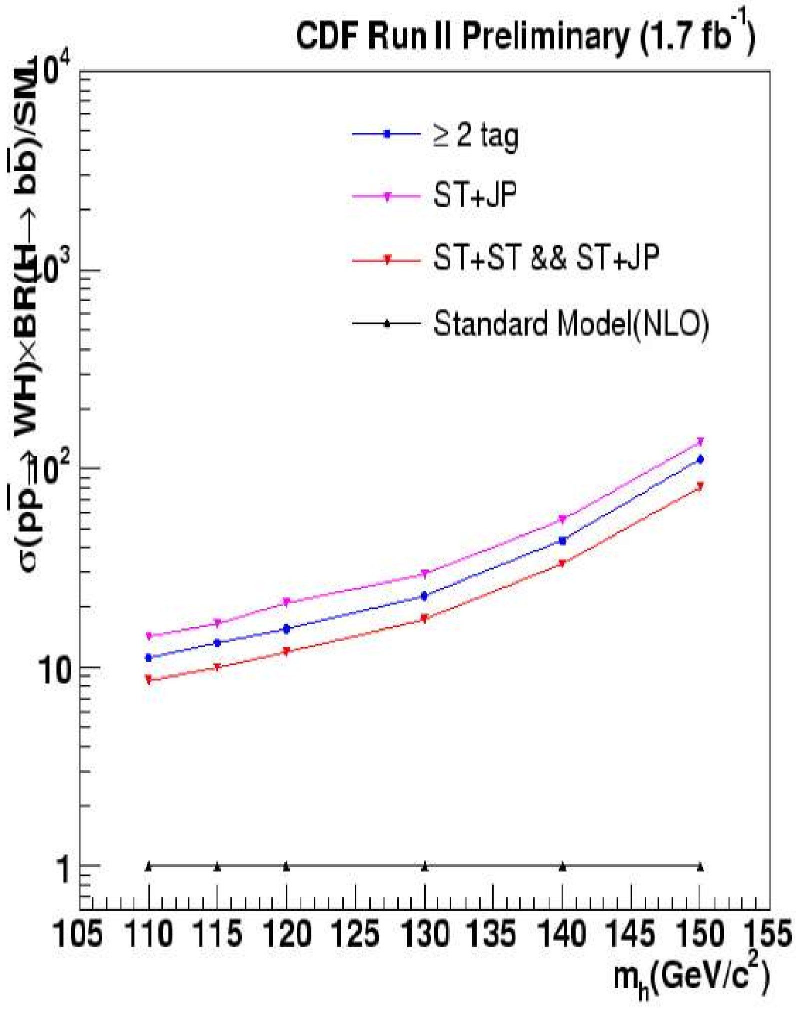
Dijet Invariant Mass **ΣET(l, jets)-MET** **PT of W+2jet**

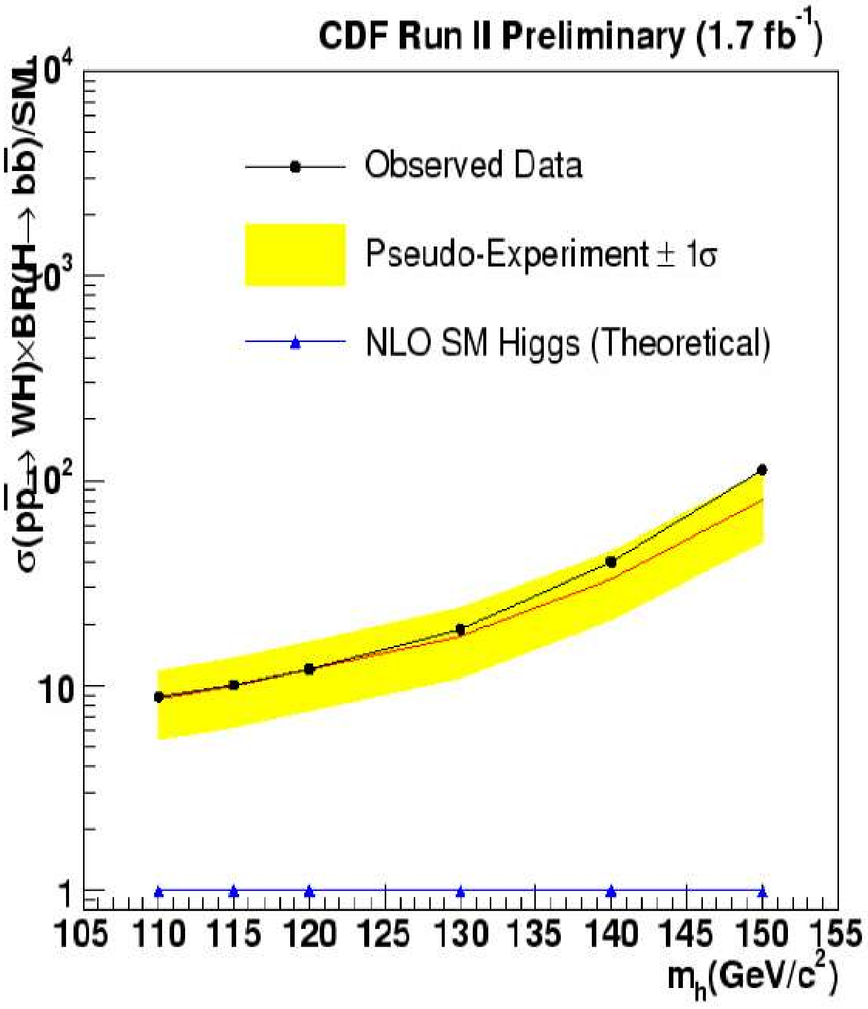
Neural Network Output



- Improves sensitivity by 10% over dijet mass alone
- Analysis refinement and optimization still ongoing

Expected and Observed Limits





- **Expected and observed limit agree well over m_H range**
- **Observed limit is 10.1 times SM at m_H=115 GeV**

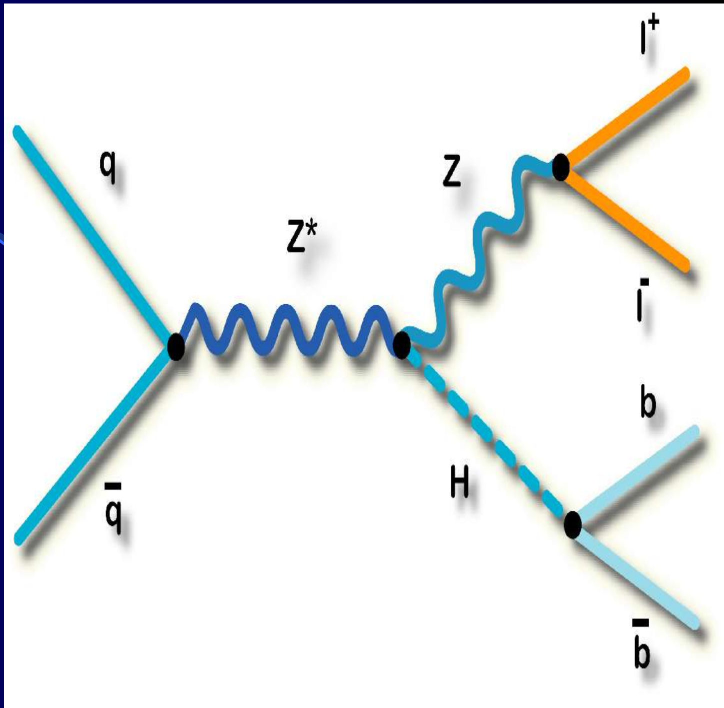
Comparison to Previous Result

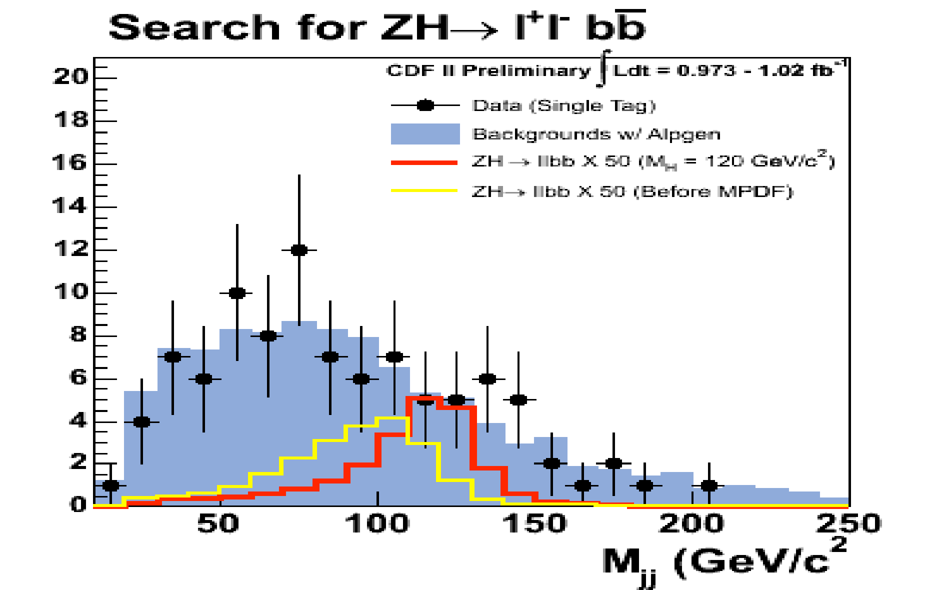
mH=115 GeV	Summer06	Summer07	Improvement
Luminosity	955 pb^{-1}	1.7 fb^{-1}	1.8
Expected Limit/SM	16.8	10.0	1.7
Observed Limit/SM	25.9	10.1	2.6

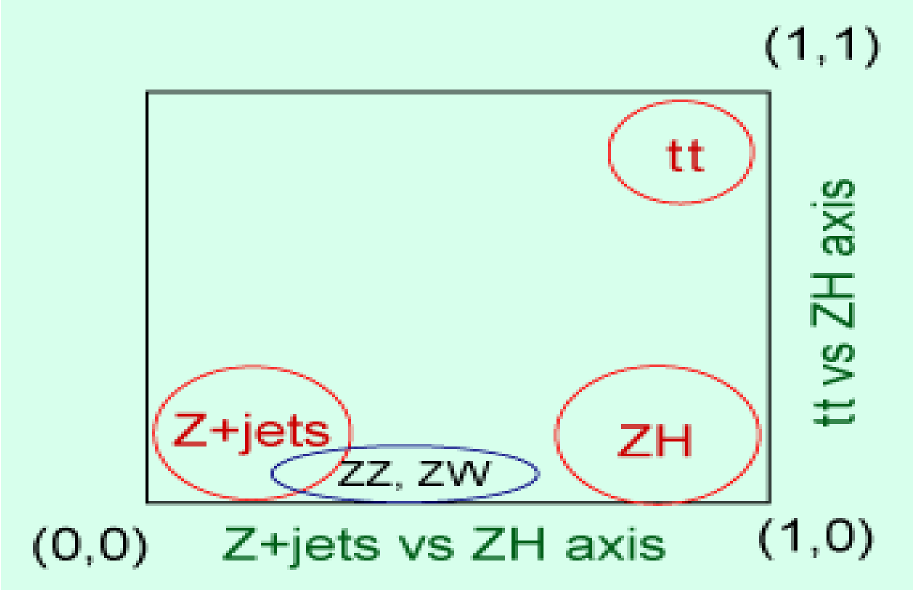
- Improvement from just luminosity: sqrt(1.8)=1.34
- Additional 25% improvement from analysis technique
  - Include loose double tag (SECVTX+JetJpb)
  - Use NN output instead of dijet mass
- Previous observed limit fluctuated high
  - Multivariate technique less susceptible to fluctuation

Search for ZH→llbb

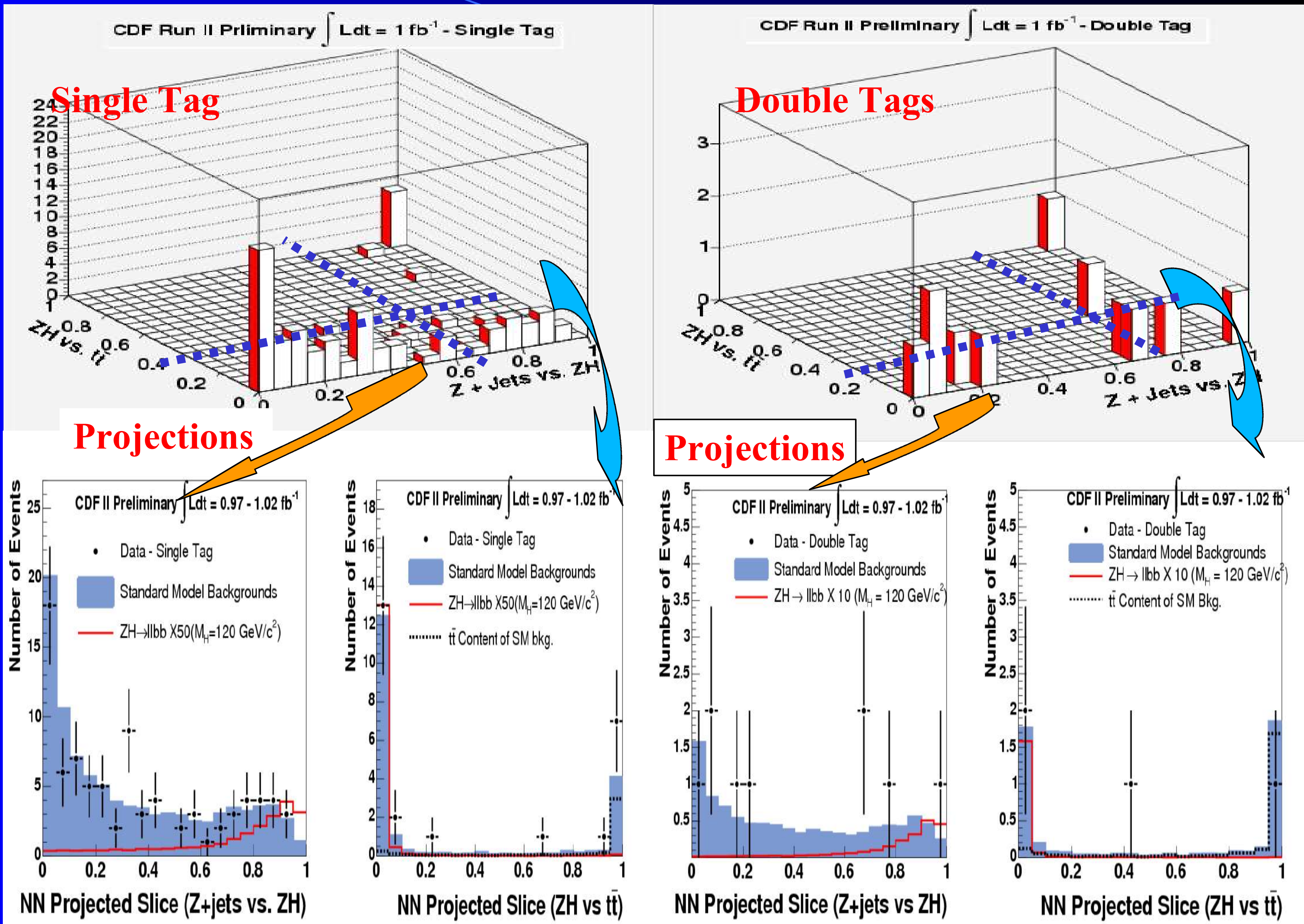
- Low rate but clean signature
- Select two high Pt leptons from Z
- Two jets with 1 or 2 b-tags
- Improve dijet mass resolution using measured missing Et
- 2D Neural Network trained to separate ZH from Z+jets and ttbar



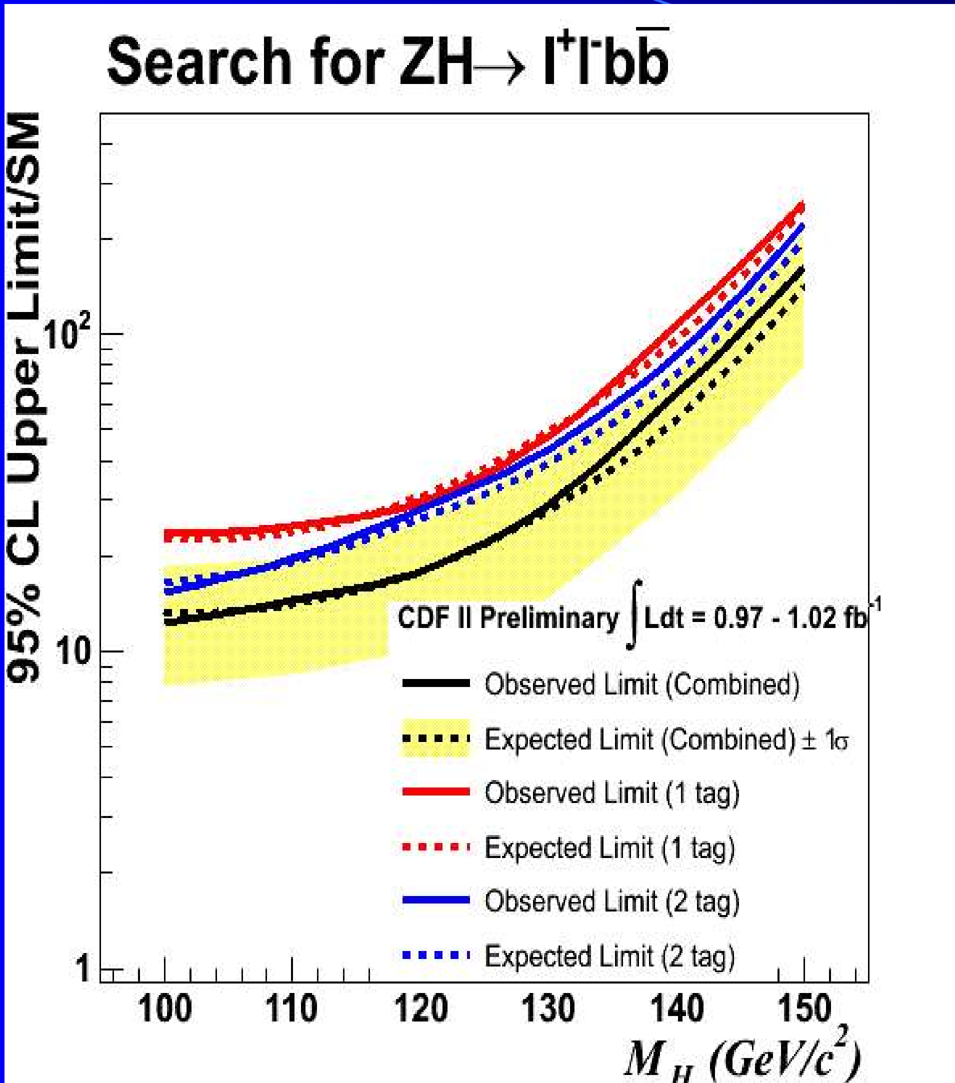


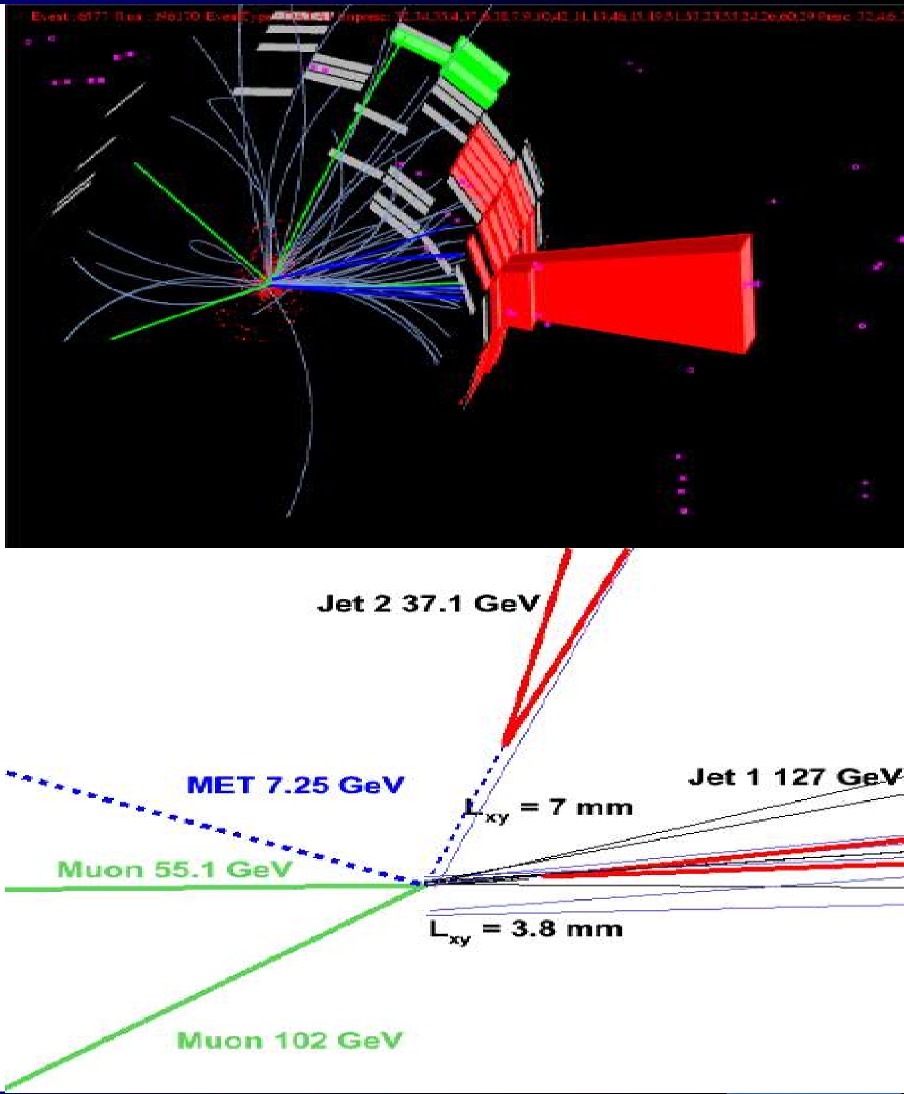


Search for ZH→llbb



Search for ZH→llbb

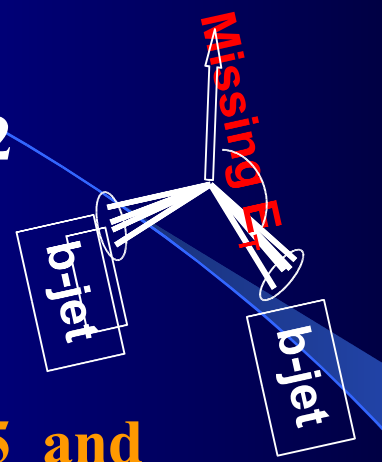


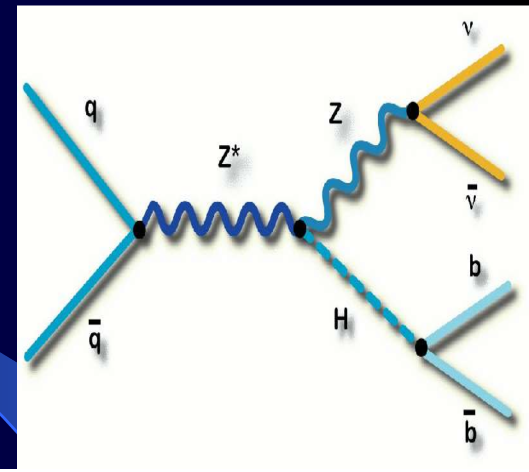


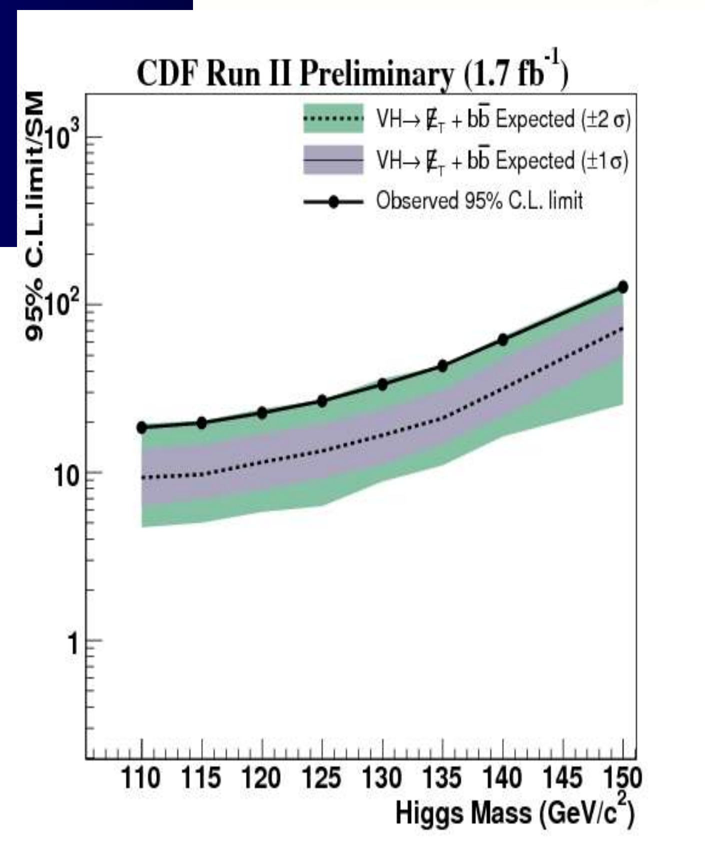
- **Observed limit is 16 x SM @ m_H =115 GeV**
- **Double tagged event: NN(0.958, 0.009), m_{bb}=120 GeV**

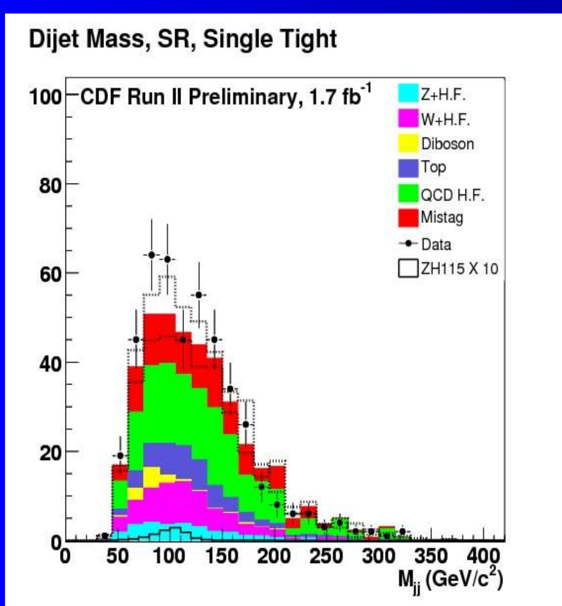
Search for WH→~~l~~vbb and ZH→vvbb

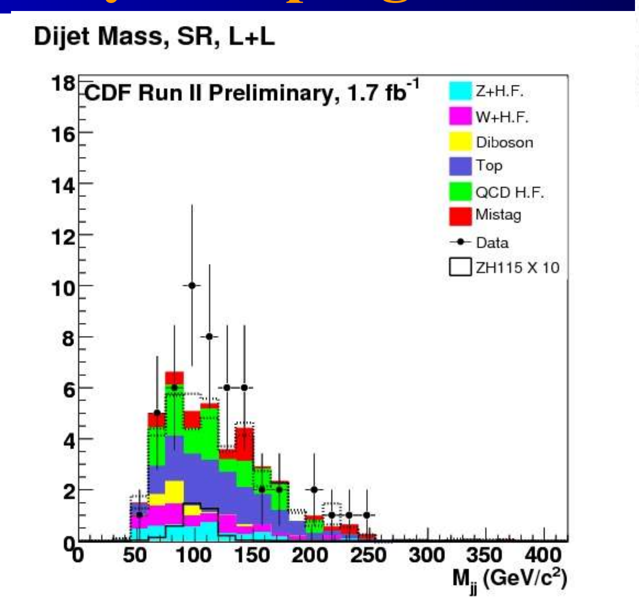
- **Rely on large Met>70 GeV**
- **Two jets:$E_{T1,2}$>60,25 GeV & |η|<2**
- **dφ(Et1, MET)>0.8**
- **Requiring 1 or 2 b-tags**
- **Obsved limit is 22xSM @m_H=115 and 2σ higher than expected**
- **More advanced analysis in progress**





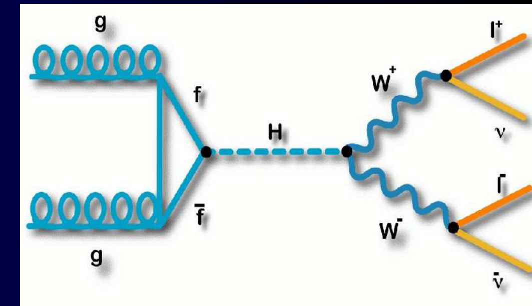


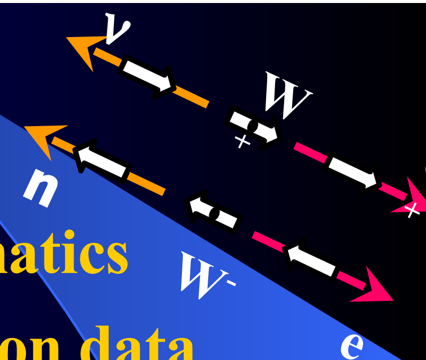


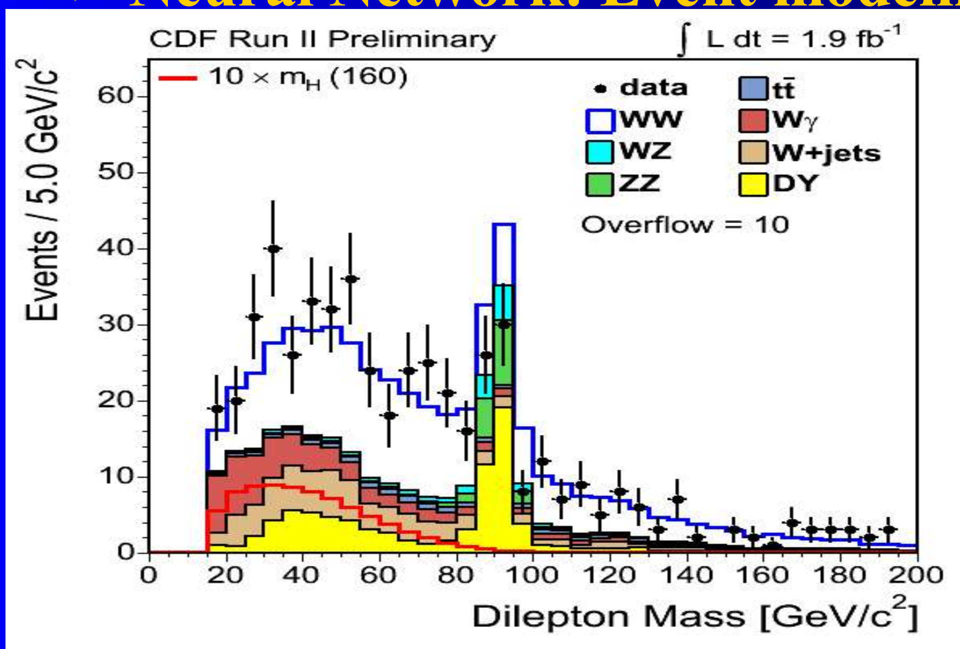


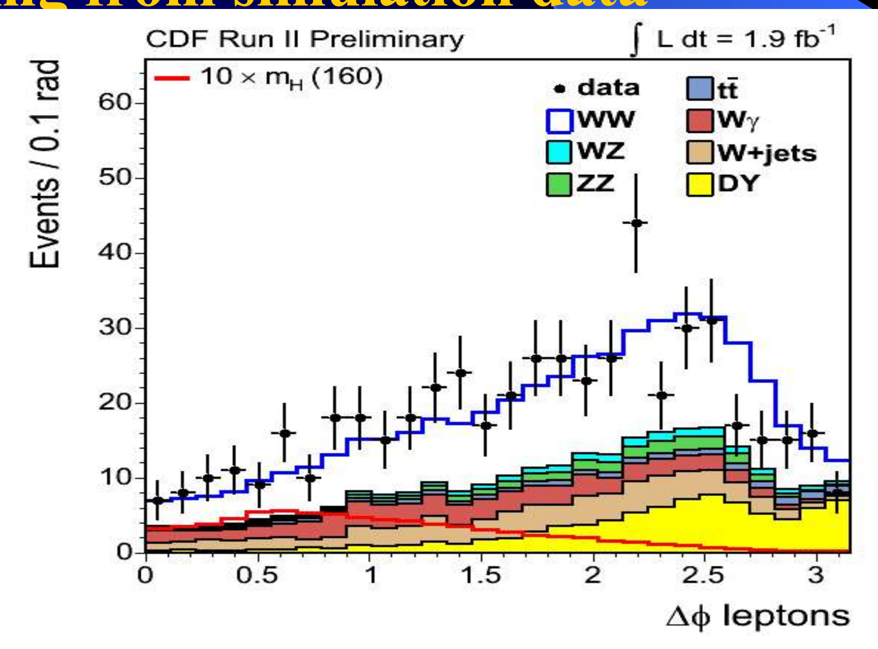
Search for H→WW→lνlν

- Two opp-sign high Pt leptons $P_{T1,2}$>20,10 GeV
- Large Met>25 and Met/sqrt(ΣE_T)>2.5
- Bckgrnds: WW*,DY,W+jets, ttbar,WZ/ZZ
- Scalar higgs provides handle to reduce WW
- Divide two regions: high and low S/B:
  - Matrix Element: Probability of full event kinematics
  - Neural Network: Event modeling from simulation data





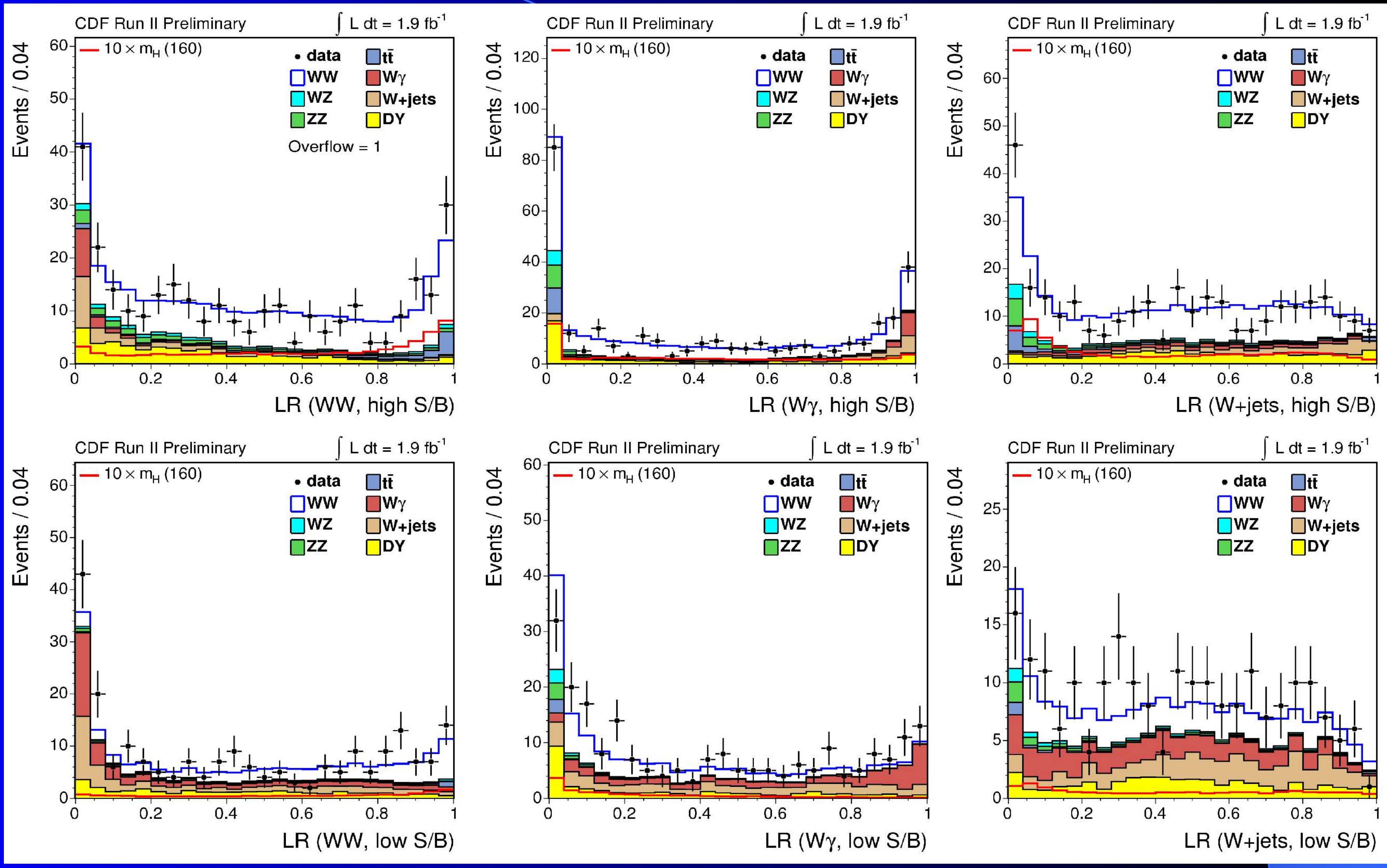




Checks on Background Modeling

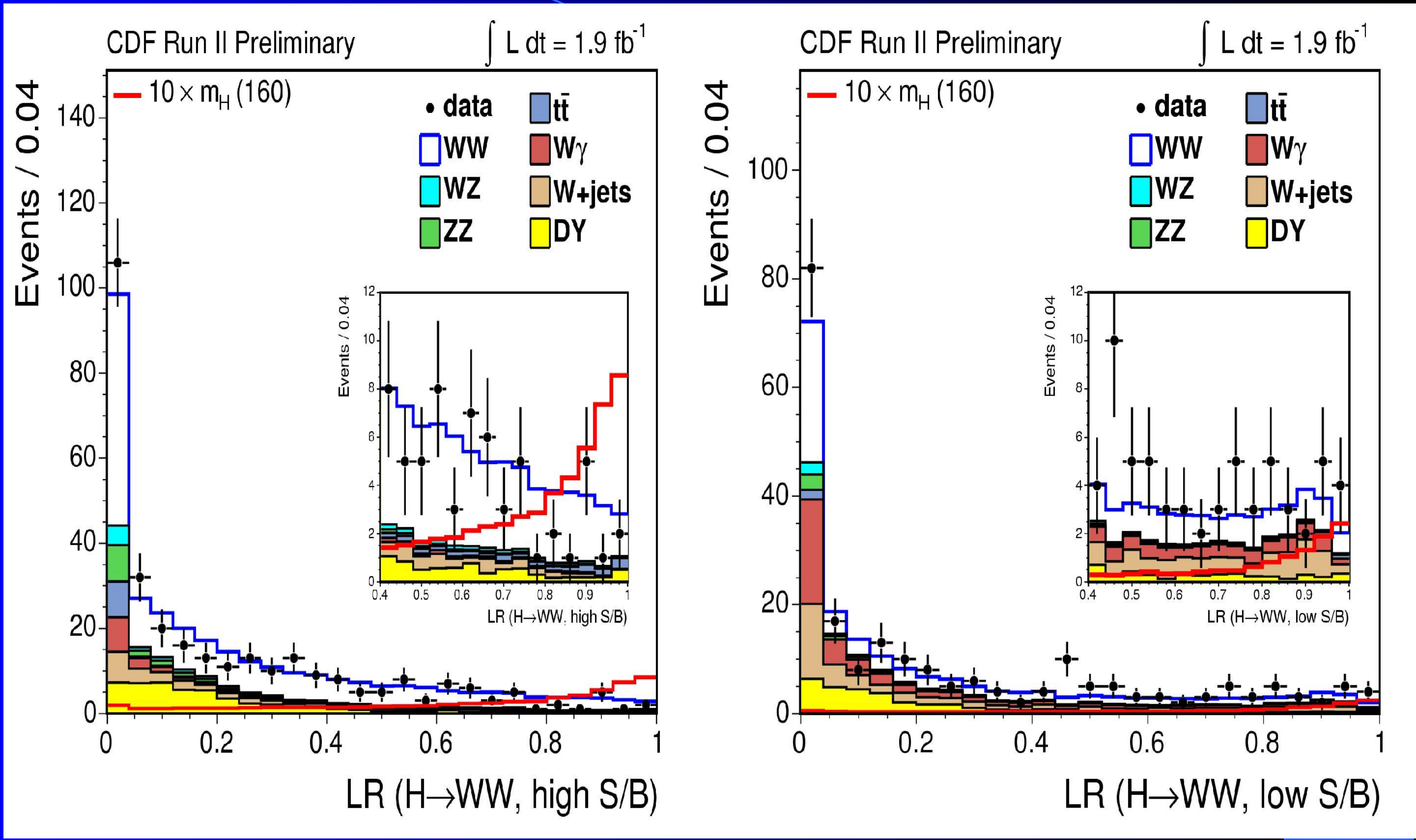
High Signal/Background

Low Signal/Background



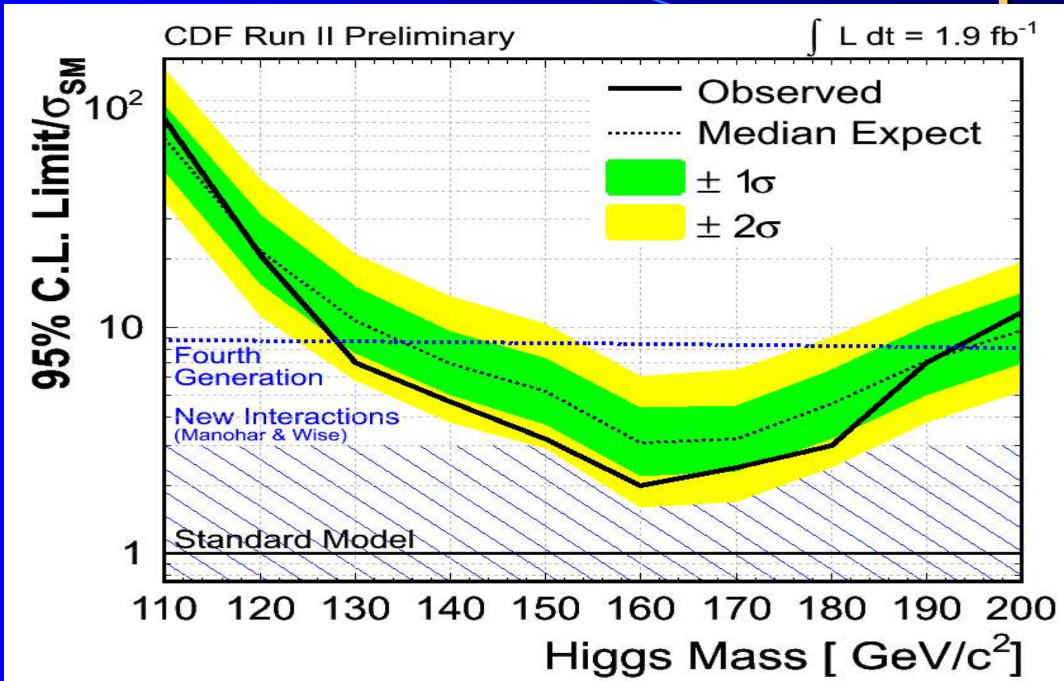
$$\frac{P_{ww}}{P_{ww}+\Sigma_i f_{bkgi} P_{bkgi}} \qquad \frac{P_{wg}}{P_{wg}+\Sigma_i f_{bkgi} P_{bkgi}} \qquad \frac{P_{wjet}}{P_{wjet}+\Sigma_i f_{bkgi} P_{bkgi}}$$

Higgs Likelihood Ratio Discriminant



$$\mathrm{LR} = \frac{P_{higgs}(M_H)}{P_{higgs}(M_H) + \Sigma_i f_{\mathbf{bkgi}} P_{\mathbf{bkgi}}}$$

Observed and Expected Limit



- **The analysis of NN is in progress**
- **Expect to gain 30% by combination of two**
- **Sensitive to New Physics**

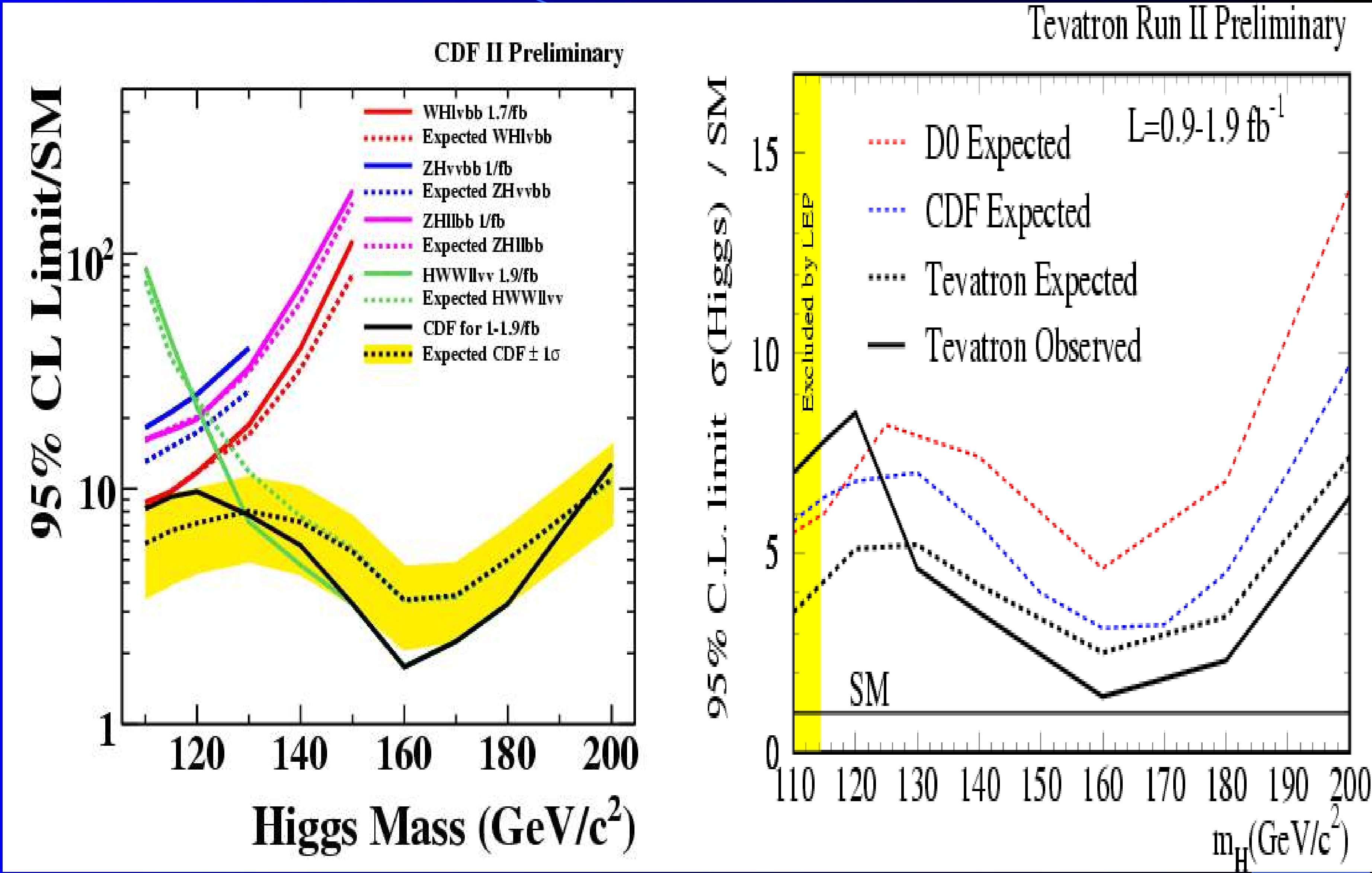
$M\_H(GeV/c^2)$	110	120	130	140	150	160	170	180	190	200
$\sigma_{SM}(HWW)(pb)$	0.057	0.134	0.230	0.312	0.358	0.388	0.344	0.278	0.194	0.155
$median(pb)$	3.9	2.9	2.4	2.2	1.8	1.2	1.1	1.3	1.4	1.5
$Observed(pb)$	4.8	2.8	1.6	1.5	1.1	0.8	0.8	0.8	1.4	1.9
$+2\sigma/\sigma_{SM}$	139.4	45.1	21.0	13.7	10.4	6.1	6.5	9.1	13.7	19.5
$+1\sigma/\sigma_{SM}$	96.4	31.7	15.2	9.6	7.3	4.4	4.5	6.5	10.2	14.1
$median/\sigma_{SM}$	69.0	21.7	10.7	6.9	5.2	3.1	3.2	4.6	7.1	9.7
$-1\sigma/sigma_{SM}$	48.9	15.4	7.7	5.0	3.7	2.2	2.3	3.2	5.0	6.9
$-2\sigma/\sigma_{SM}$	35.9	11.2	5.8	3.8	2.9	1.6	1.7	2.4	3.8	5.2
$Observed/\sigma_{SM}$	83.0	20.9	7.0	4.7	3.2	2.0	2.4	3.0	7.0	11.6

Table 1: Expected and Observed Limit for Higgs at 1.9 fb^{-1} with Systematics (the ratios include the uncertainty on σ_{SM}).

Combination Procedures

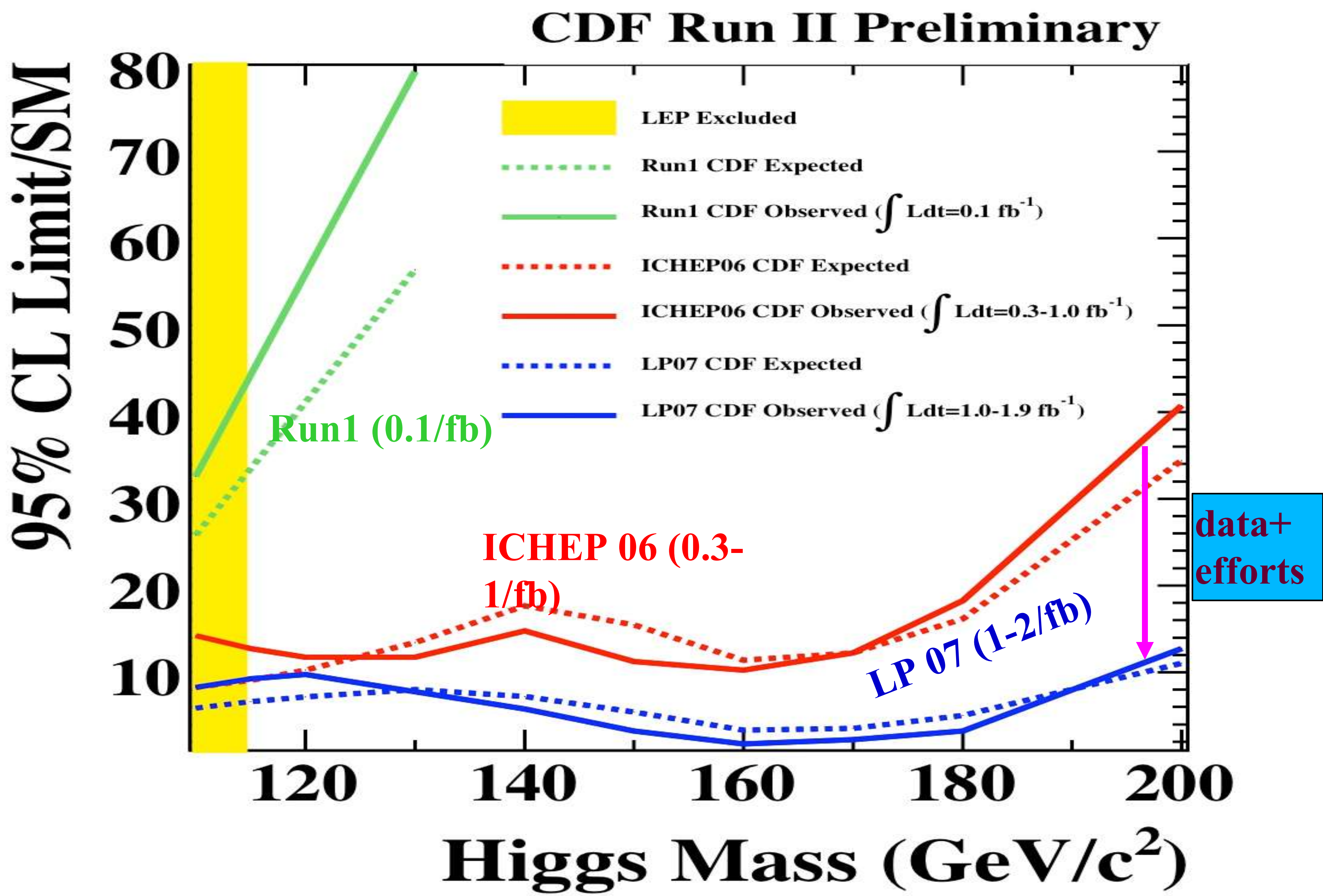
- **Normalized to SM rate, we can combine σ×Br/SM statistically to improve the final result.**
- **Use Bayesian and Frequentist approaches:**
  - **Bayesian:** $$L(R,\vec{s},\vec{b}|\vec{n},\vec{\theta})=\prod_{i=1}^{Nc}\prod_{j=1}^{Nbins}\mu_{ij}^{nij}e^{-\mu_{ij}}/n_{ij}!\times\prod_{k=1}^{n}e^{-\theta_k^2/2}$$
  - **Frequentist (CLs):** $$LLR_n=2\sum_{i=1}^{N}(s_i-n_i Log(1+\frac{s_i}{b_i}))$$
  - **All systematics treated as nuisance parameters with truncated Gaussian constrain**
- **If the excess is significant after combination, do more checks to make sure not statistic fluctuation.**
- **If no excess, set 95% CL upper limit vs m_H**

Combination of CDF and Tevatron Limits



Results shown at LP07 and will update soon with more data

CDF's Progress in Perspective…



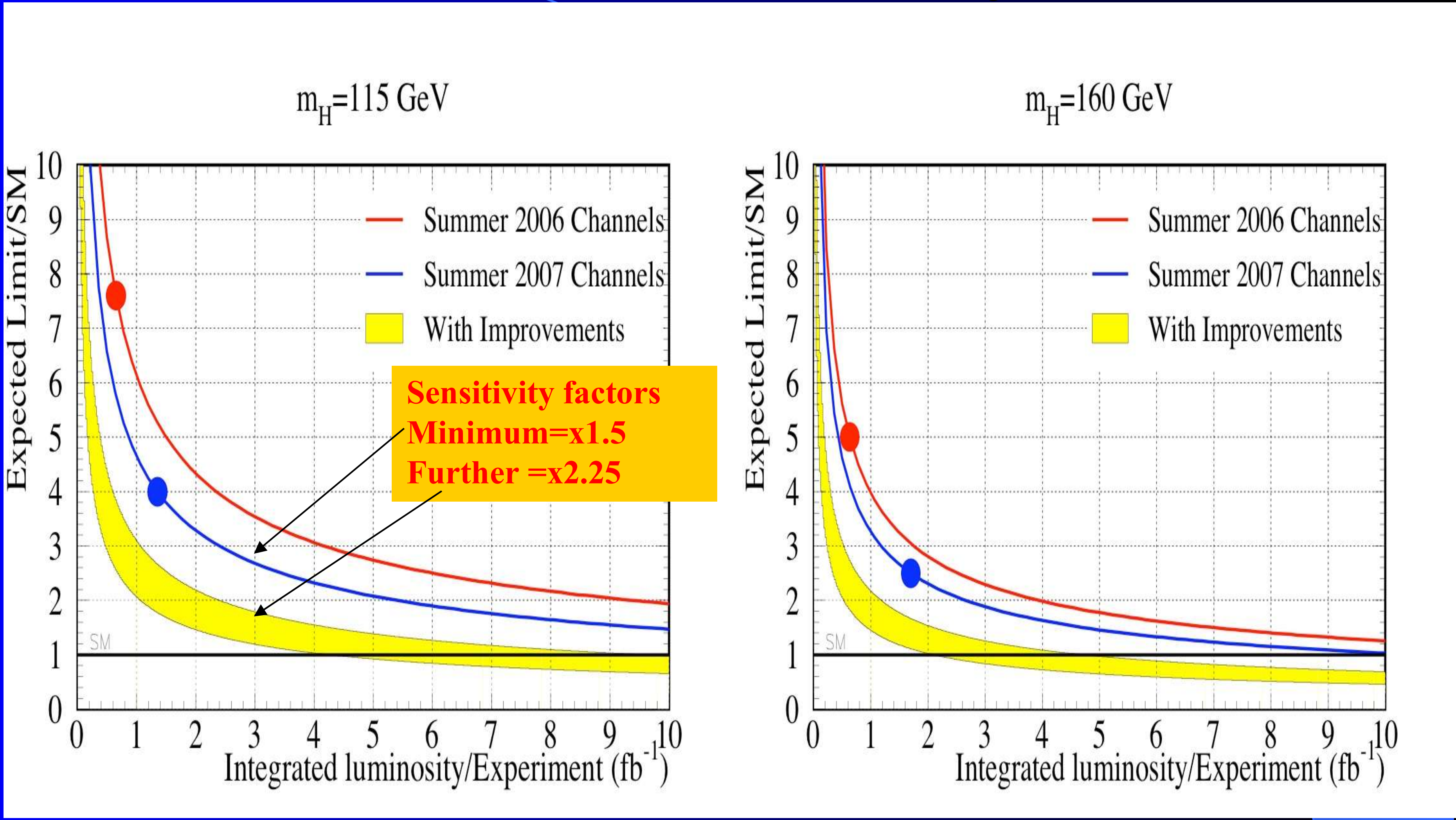
Future Prospects

- Not far from the expectation of Higgs sensitivity studies
- Proven ideas need to implement cross different channels
- More powerful techniques become feasible in growing dataset

	Triggers	Lepton ID	Btag	Advanced techniques	Dijet Mass
WH→lvbb	1.25	1.25	1.25	1.2 ?	1.2 ?
ZH → llbb	1.25	1.25	1.5	1.0	1.0
VH → vvbb	1.25		1.5	1.2 ?	1.2 ?
H → WW* → lvlv	1.5	1.2		1.2	

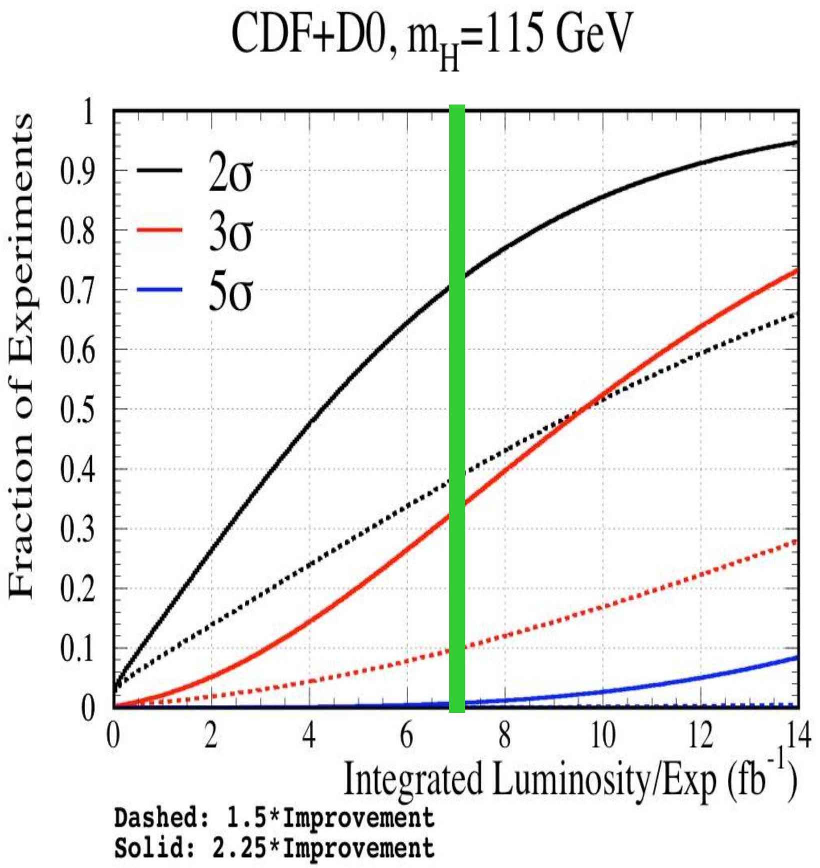
- All improvements validated with analysis in real data
- Improvement range from 1.7 – 2.2 in sensitivity

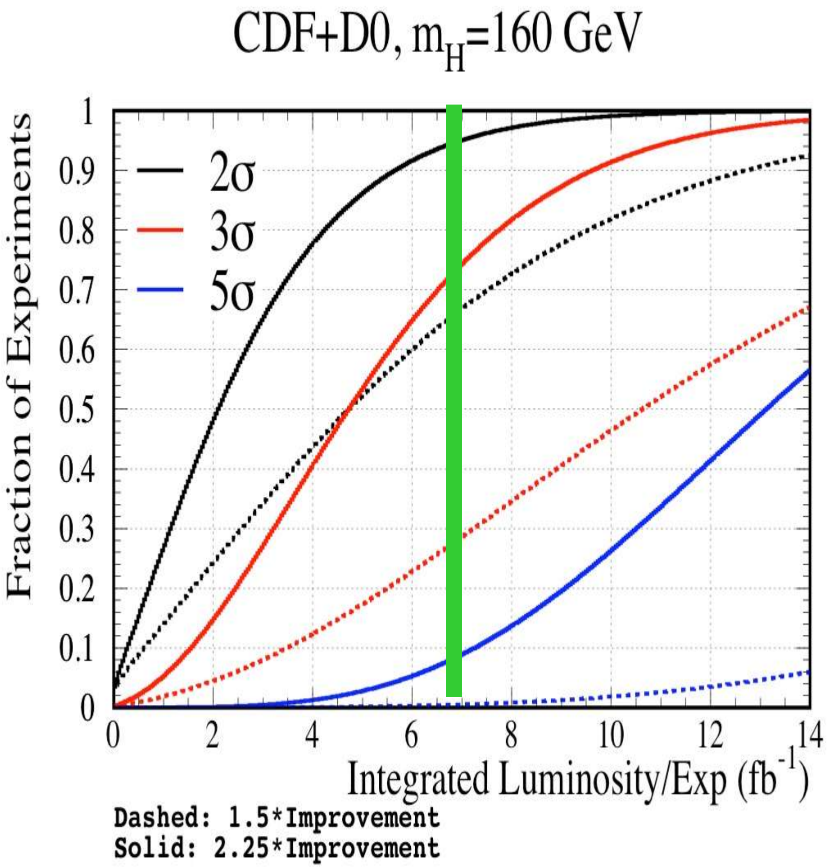
Achievable Sensitivity



- **CDF+D0 combined and same improvement assumed**
- **Curves scaled by 1/sqrt(L) with analysable luminosity**

Probability of Success

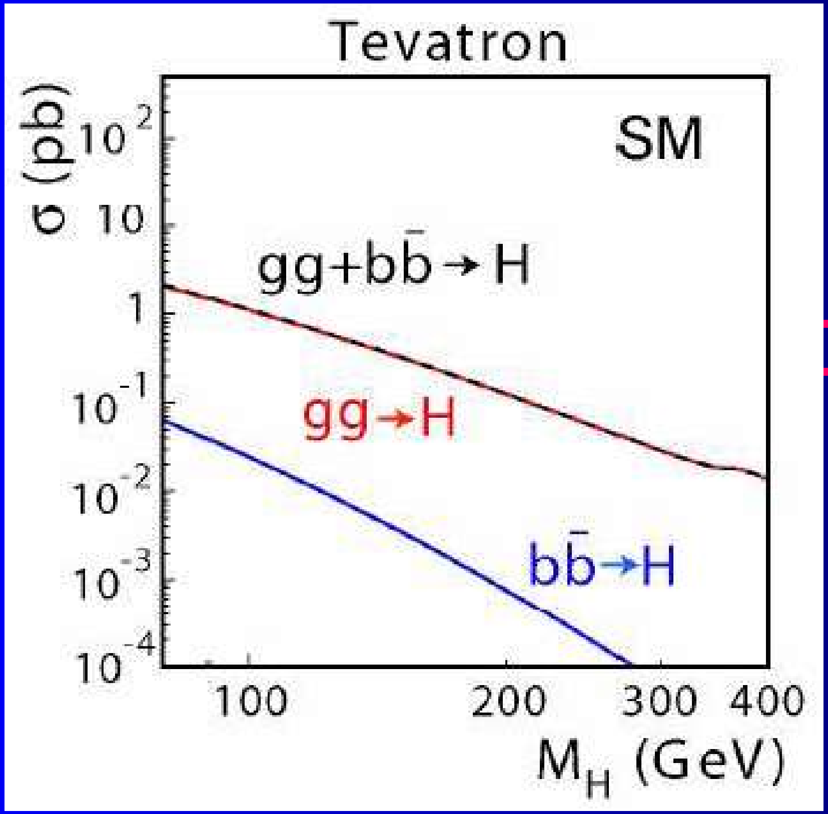




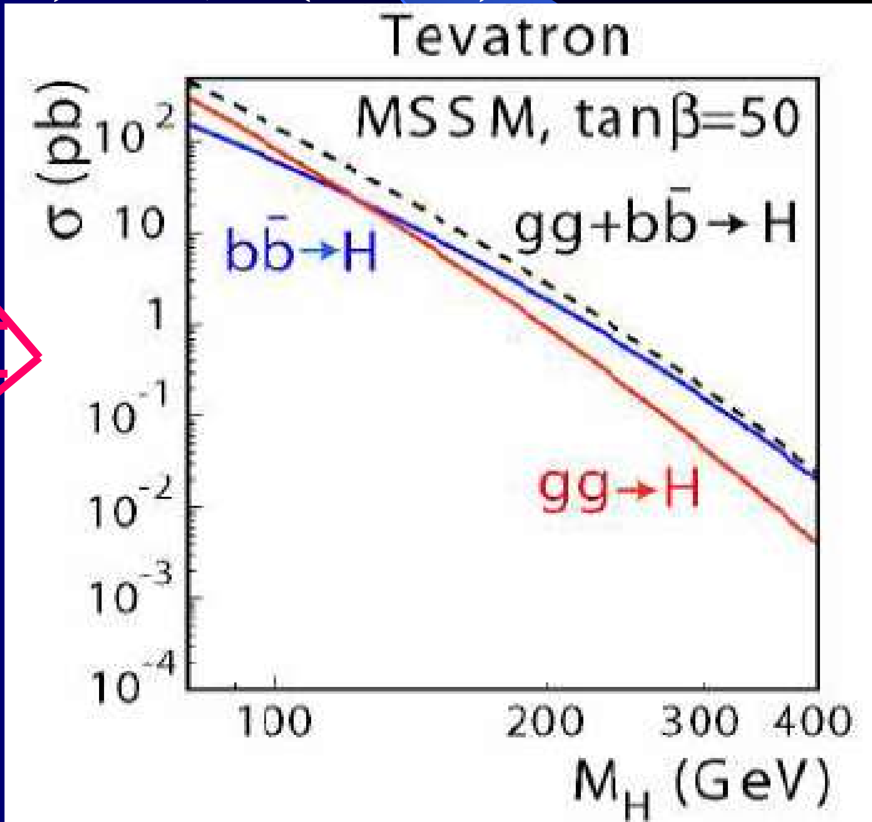
- **Tevatron will deliver about 8.5 fb^{-1} if running in 2010**
- **There is a good chance to see 3σ evidence of Higgs…**

Higgs in the MSSM

- **Extending SM to have two higgs doublets for up- and down-type quarks with different coupling to the higgs, $\tan\beta = v_2/v_1$ of vev's**
- **After EWSB: 4 scalars (h, H, H^{+-}) and a pseudoscalar (A) Higgs**
- **If $\tan\beta$ is large, the Higgs production is enhanced as $\tan\beta^2$ and H/h and A nearly degenerate in mass as called H**
- **For intermediate masses: $Br(H \to bb) = 0.9$, $Br(H \to \tau\tau) = 0.1$**

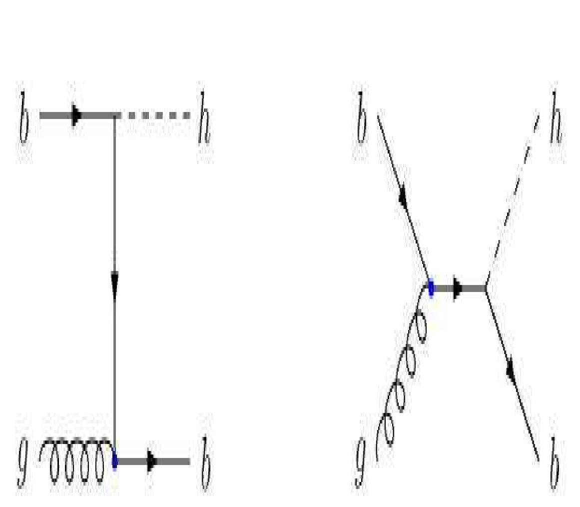


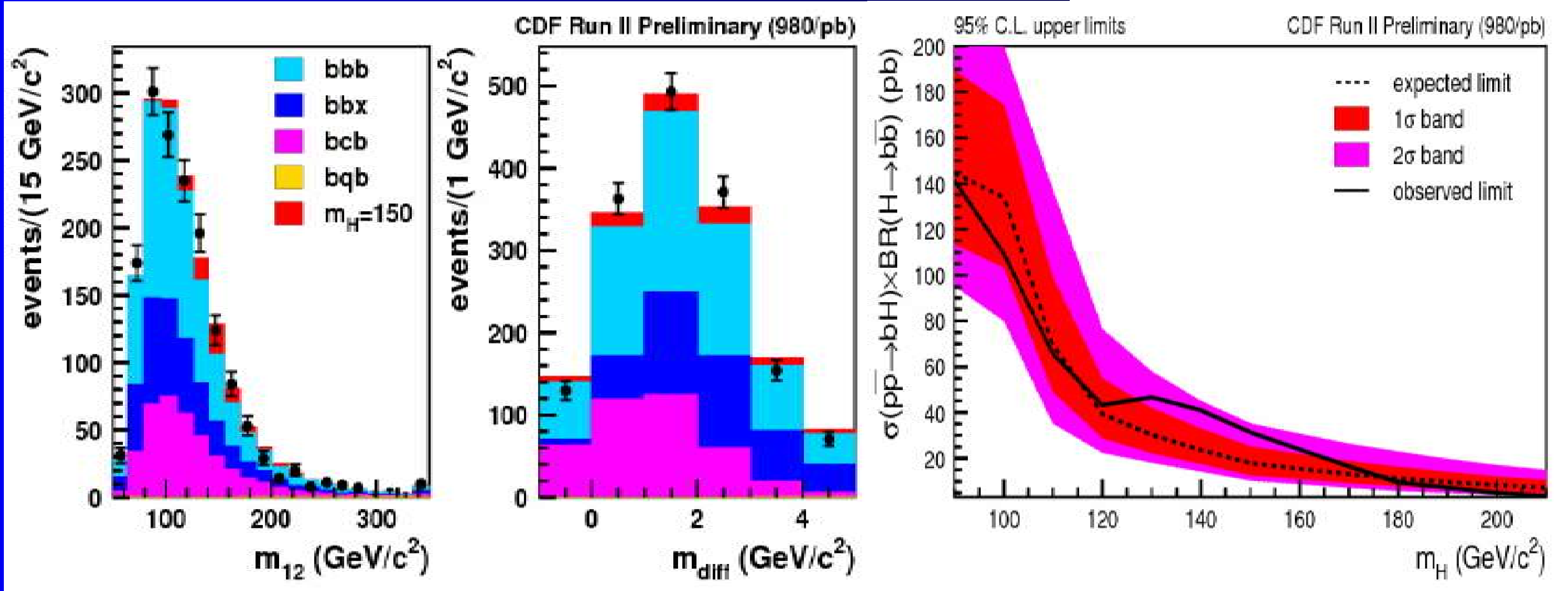
$\Rightarrow$



Search for gb→Hb→bbb

- Trigger in three jets with SVT
- Requireing 3 b-tag jets (Et>20,|η|<2)
- Look for a bump in mass of jet 1, 2
- **Background:** modeling tag mass($m_{diff}= m_{tag1}+m_{tag2}-m_{tag3}$) to understand b/c/q from jets data
- 2D fit to m_{12} and m_{diff} and extract limit

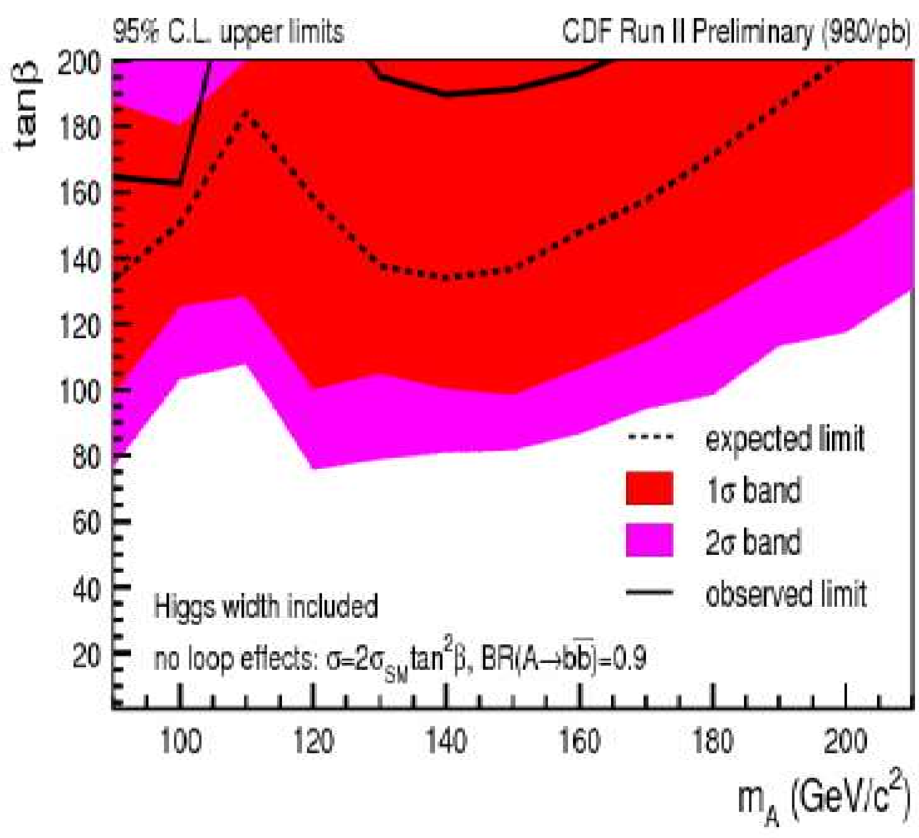


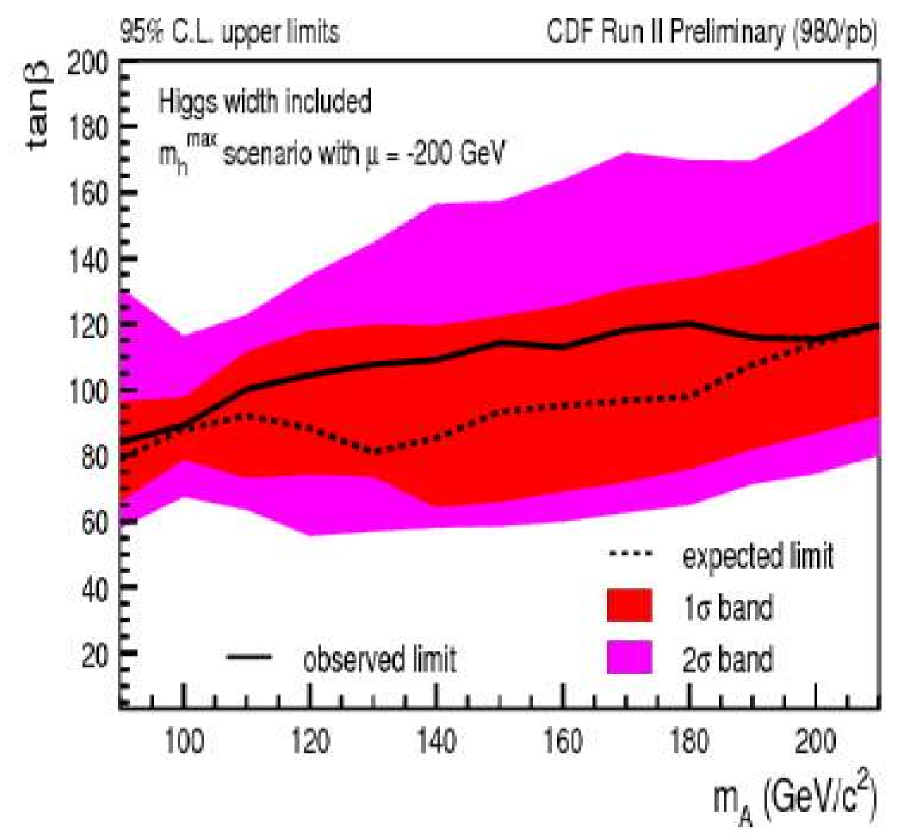


Limits on tanβ

- **Interpret these limits as upper limit on tanβ vs m_H**
- **Depend on loop correction and Higgs width**
- **Use two benchmark scenarios(hep-ph/0511023):**

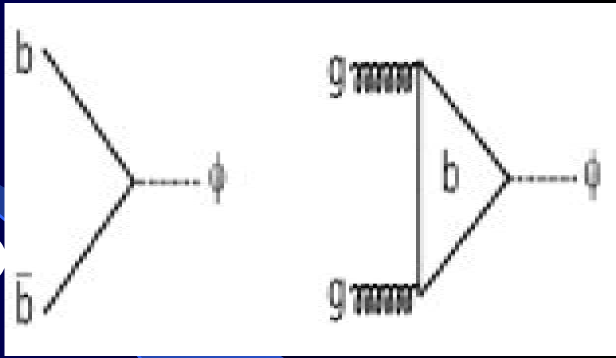
Constrained $m_H^{max}(\Delta b=0)$ **m_H^{max} scenario with $\mu<0$**

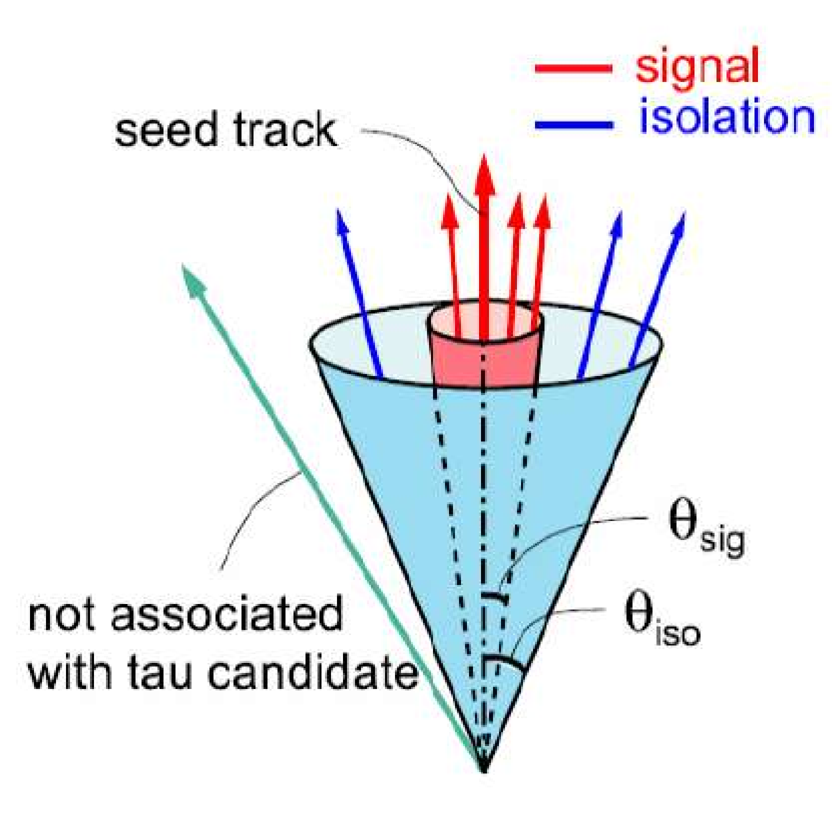


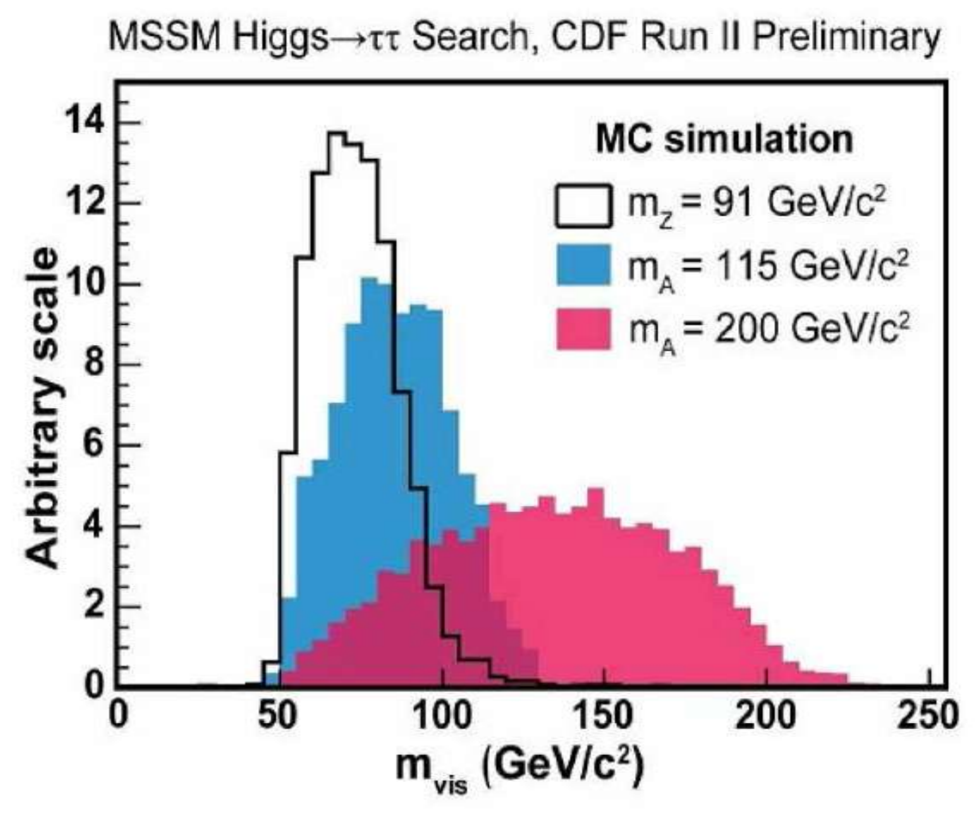


Search for gg→H→ττ

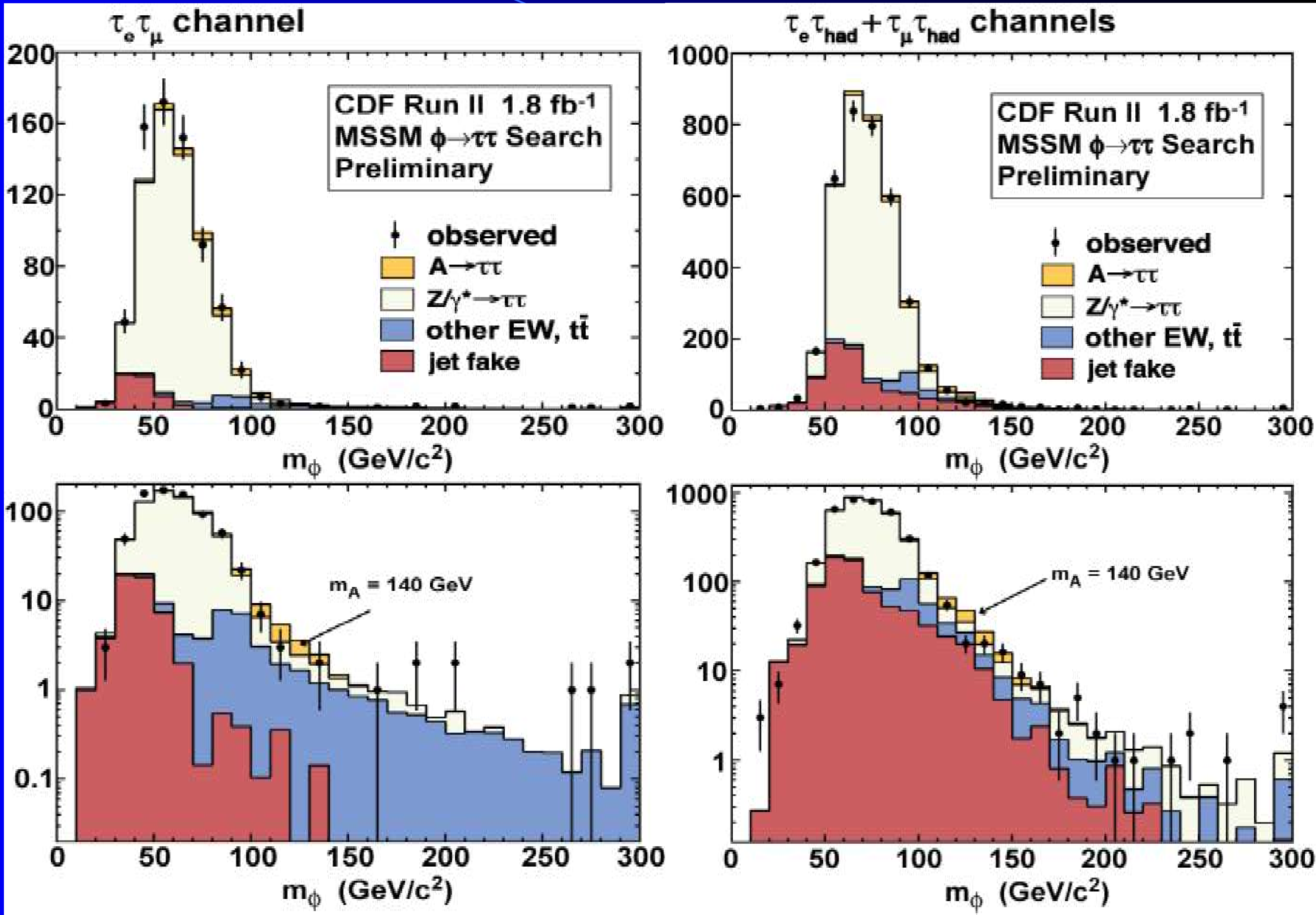
- Small σ×BR, compared to bb, but clean final states
- Select final states: e+h, μ+h, e+μ
  - Identify τ Et>15Gev(shrinking cone)
  - Lepton Pt>10 GeV, opposite charge
  - Met not recoiling against leptons (rejects w→lν)
- Use visible mass of lepton and tau as discriminant



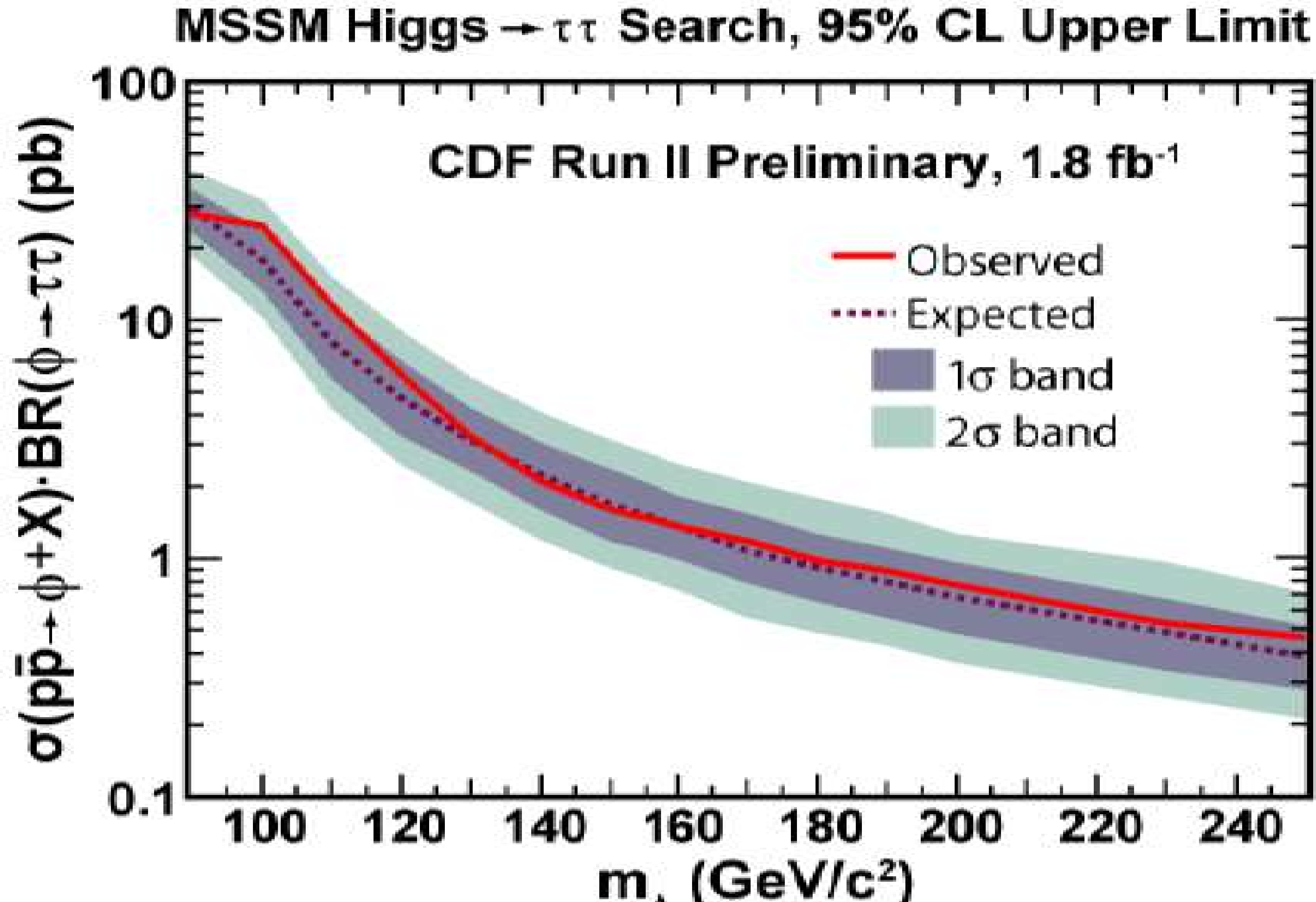




Visible Mass Distributions

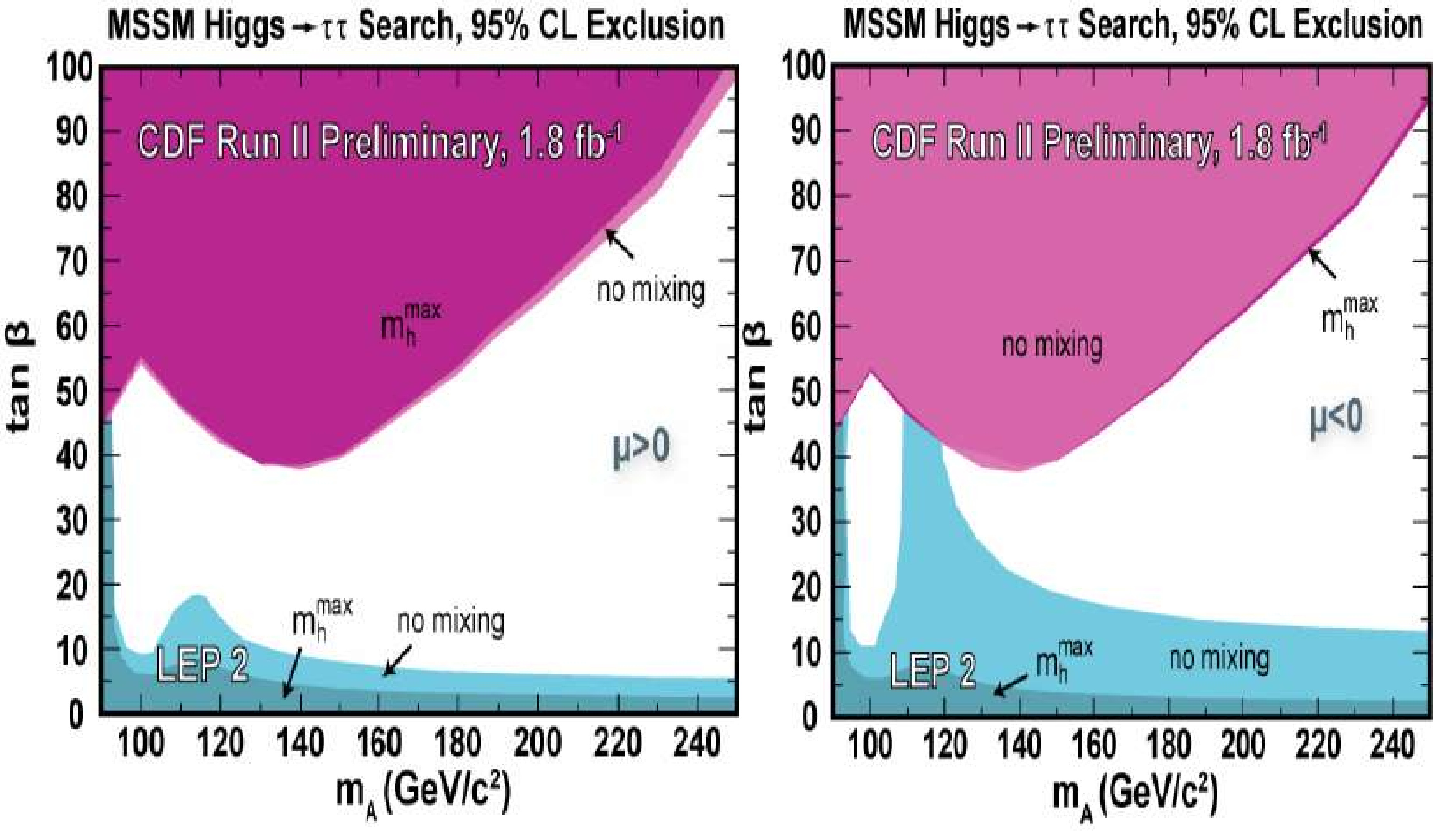


σ×BR(H→τ τ) Limits



Limit on tanβ

- **Interpret these cross section limits in MSSM**
- **Exclusion insensitive to different scencarios or μ**



Conclusions

- **We are closing in sensitivity towards unknown territory (SM Higgs, Technicolor, SUSY…)**
- **There is no magic bullet, 10% effects matter most and no stone is left unturned.**
- **The bands of possibility shown here are achieveable based on real studies and ideas that we have and will have.**
- **This is very exciting time for Higgs search at Tevatron**