Low mass secondary channels at the Tevatron

Azeddine Kasmi
Baylor University
On behalf of the CDF and D0 collaborations

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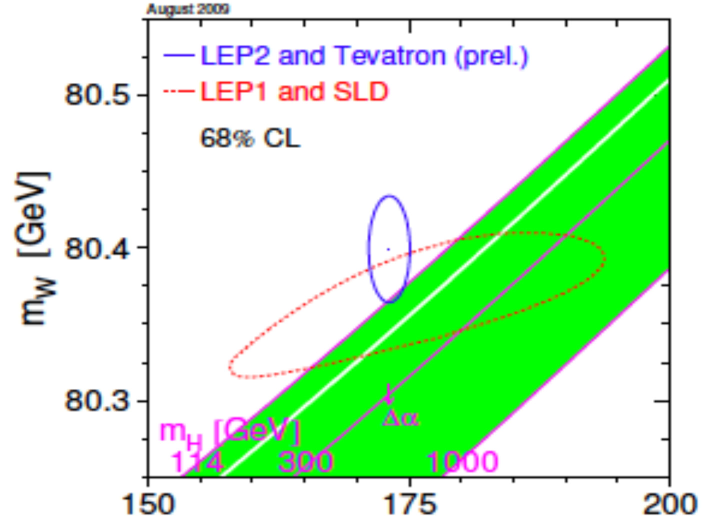
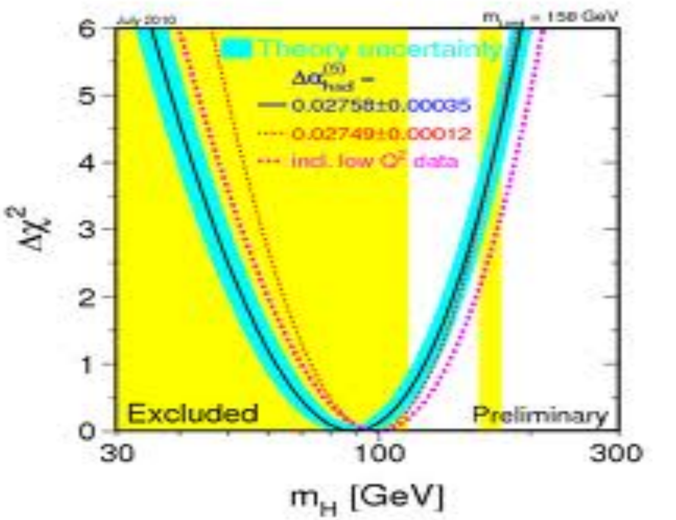
Introduction

- ElectroWeak Symmetry Breaking
  - SM allows for Higgs mechanism
  - Manifests itself as a heavy spin-0 boson
- SM predicts most properties and decay modes of Higgs but not its mass
- Experimental evidence so far:
  - Direct searches at LEP exclude **m_H**< 114 GeV
  - Direct searches at Tevatron exclude a window around m_H=160 GeV
  - Indirect constraints from precision measurements (**m_W** and **m_t**) favor a low mass Higgs: m_H<157 GeV
- CDF and D0 are pursuing direct searches for the SM Higgs over a wide range 100 GeV < m_H <200 GeV

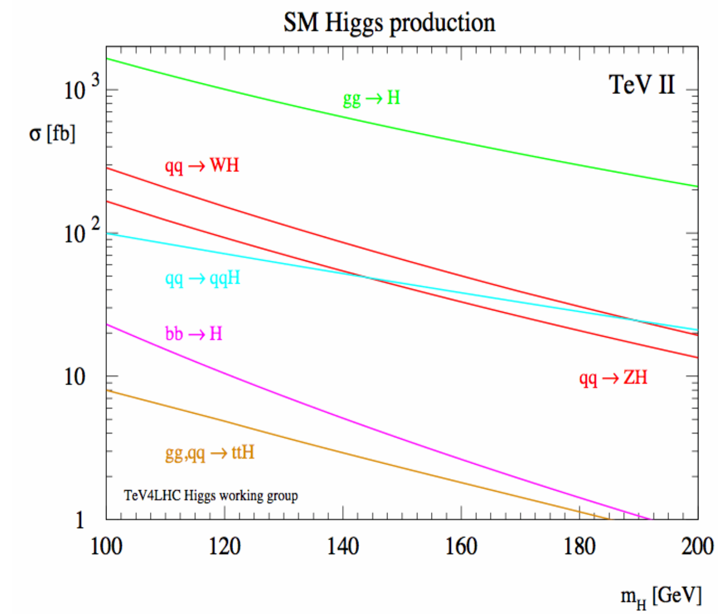
From LEPEWWG

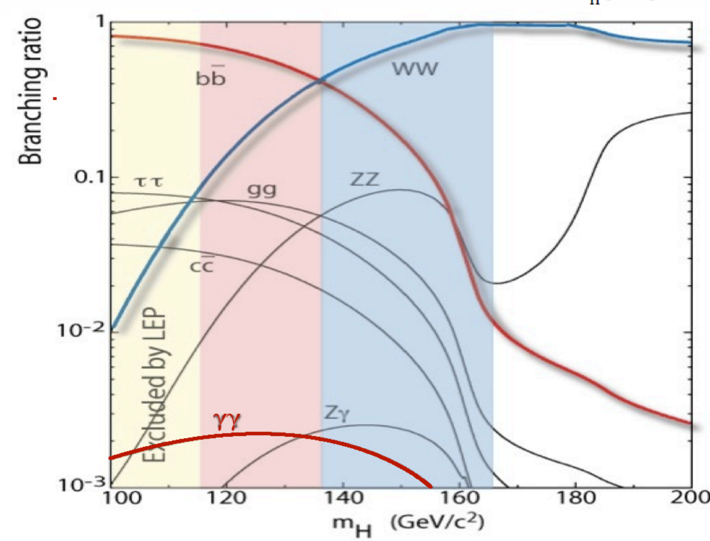




Tevatron Higgs Searches Strategy

- At Tevatron Higgs boson production is a very rare process
- The search strategy is driven by the Higgs boson dominant decay modes:
  - H → bb for M_H < 135 GeV:
    - gg → H not possible due to over-whelming multi-jet background
    - Associated production provides cleaner experimental signature
- H → WW* for M_H > 135 GeV:
  - Since the leptonic W decays provide clean final states, can take advantage of higher gluon fusion production cross section.
- **No channel left behind**

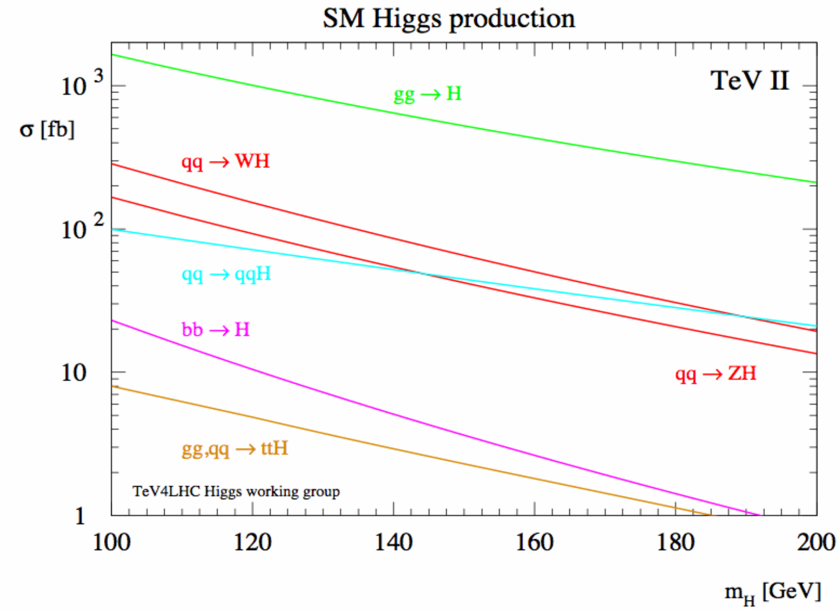


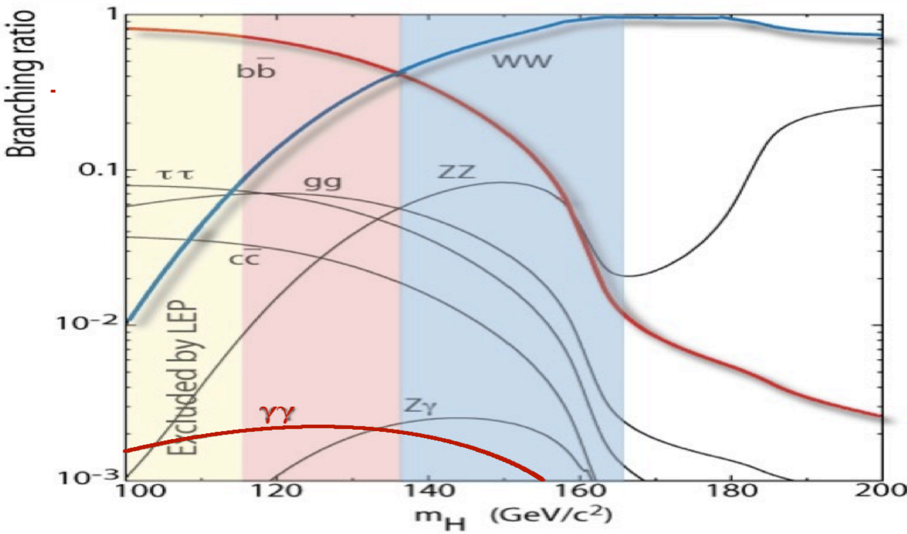


Secondary Channels

Secondary channels

- Di-photon channel
  - Low backgrounds
  - Good reconstruction efficiency
  - High mass resolution
- Di-tau channel
  - Higher branching ratio
  - Enhanced in MSSM
- Each channel alone has no great sensitivity
  - However, their combination is equivalent to a primary channel





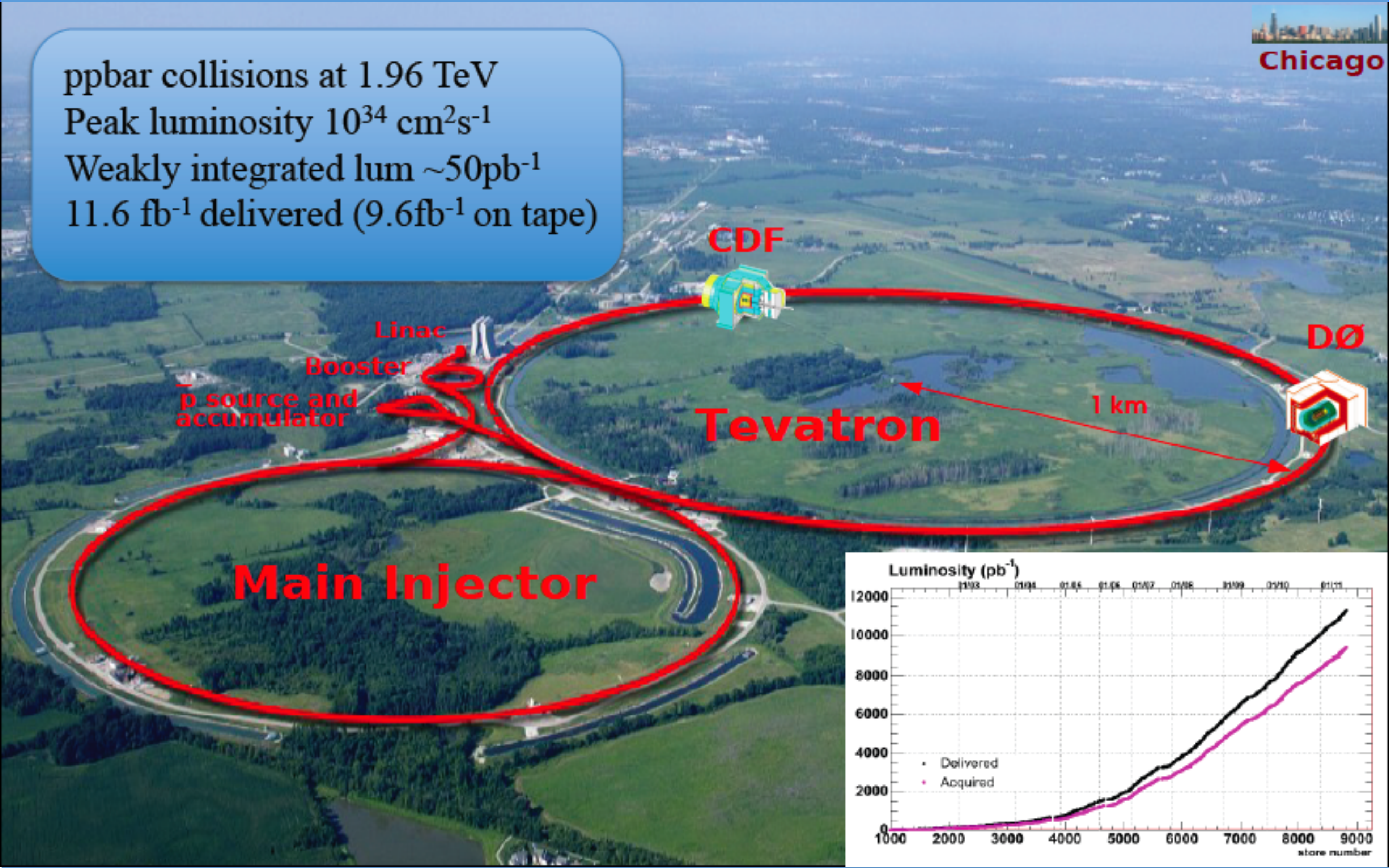
Tevatron

ppbar collisions at 1.96 TeV

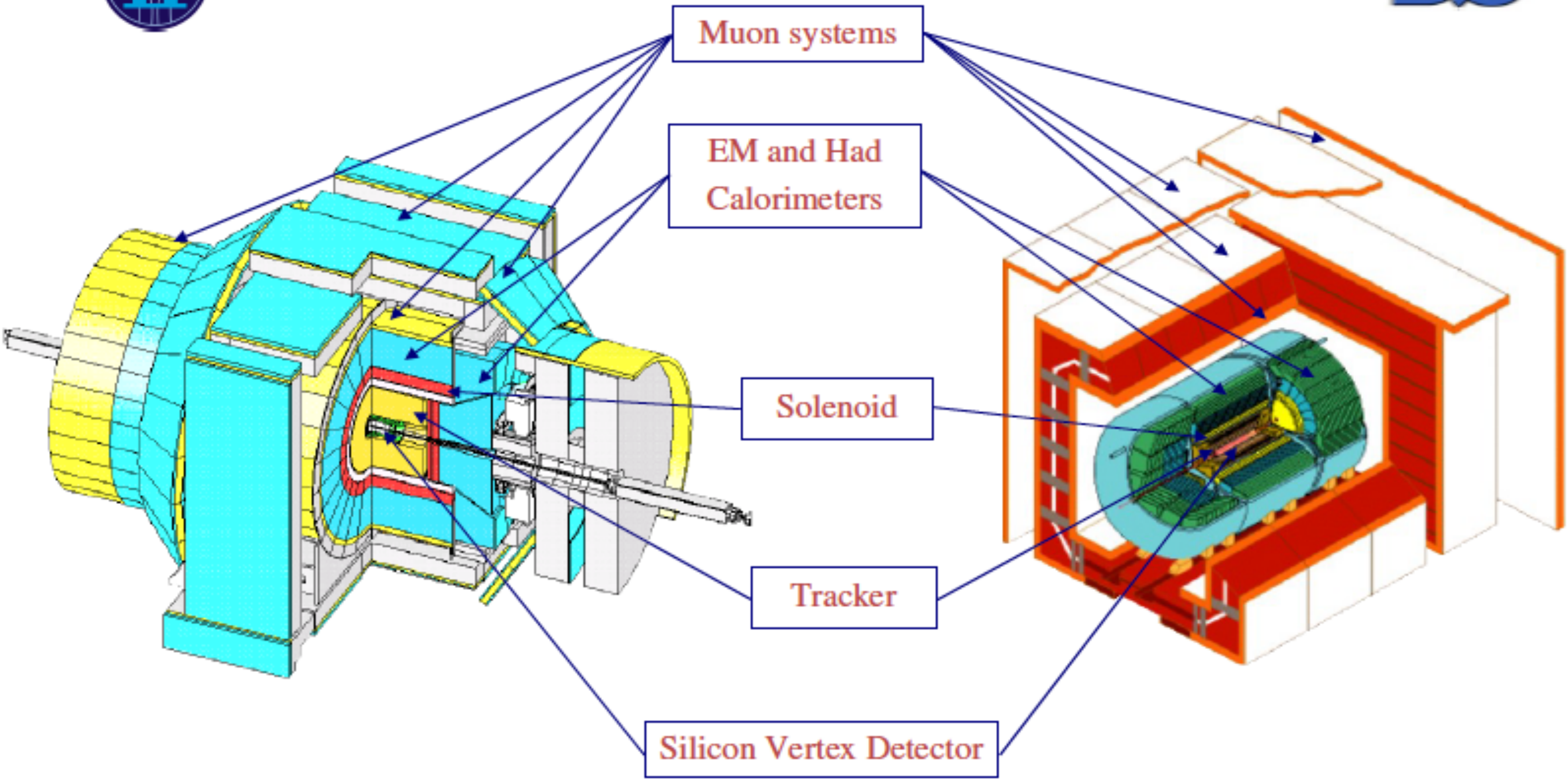
Peak luminosity 10^{34} cm^2s^{-1}

Weakly integrated lum ~50pb^{-1}

11.6 fb^{-1} delivered (9.6fb^{-1} on tape)

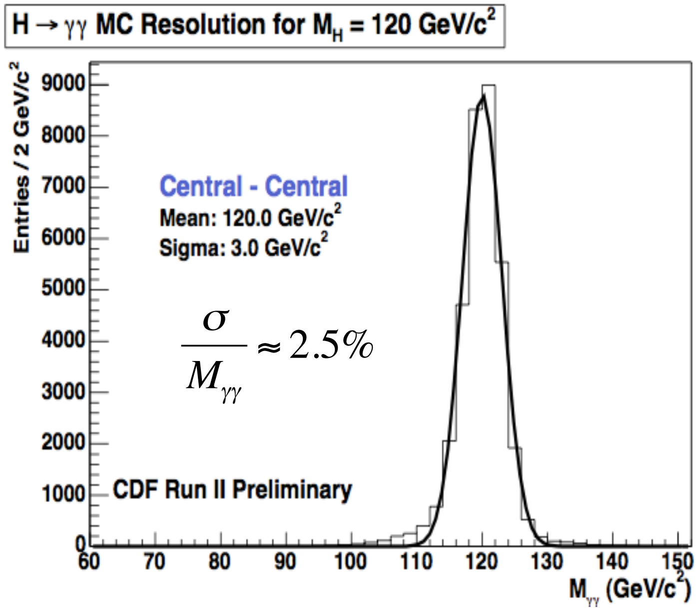


The CDF and the D0 Detectors



SM Higgs to diphoton

- Advantages
  - Clean signature compared to *H → bb*
  - Mass resolution limited only by EM calorimeter (1σ diphoton width ~3 GeV compared to 1σ bbar width ~16 GeV)
  - Sideband fits can be used to estimate background
  - Contributes sensitivity in M_H range less accessible to primary searches



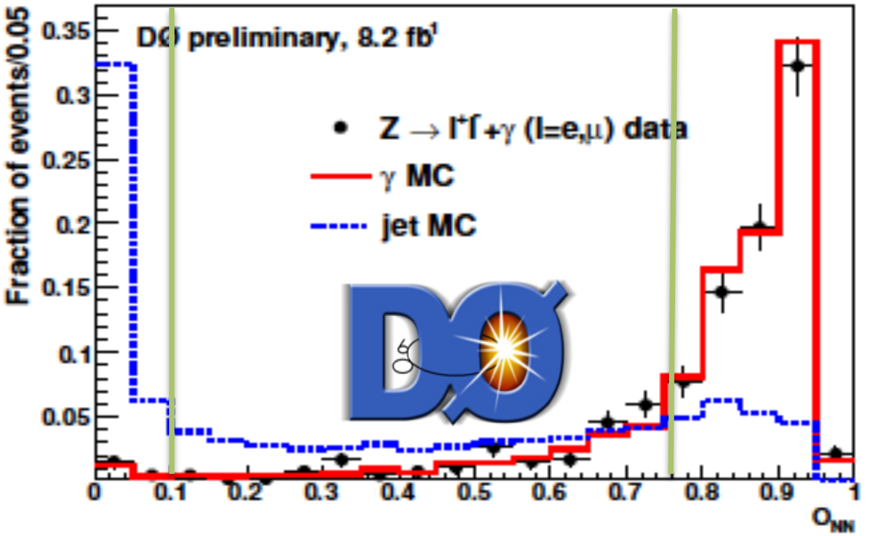
- The Challenge
  - Small branching ratio

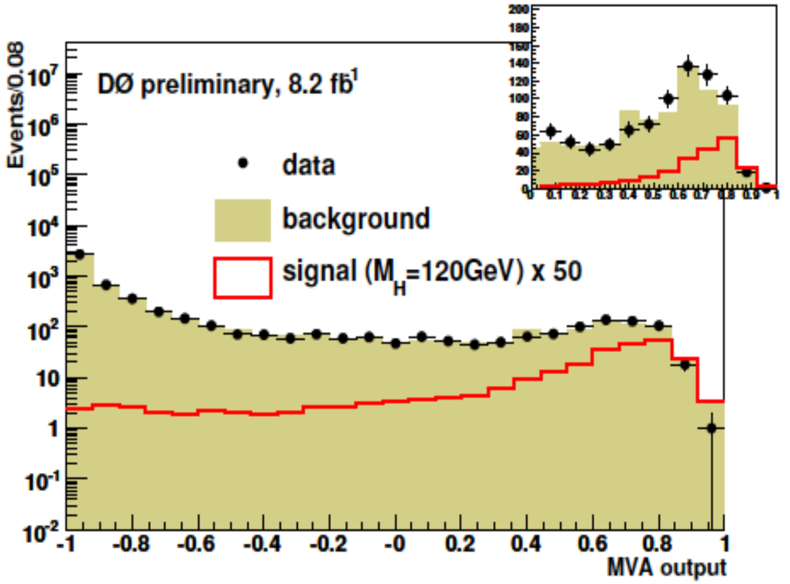
Event Selection

Use a Neural Network for ID

- trained on Jet vs. Photon MC
- validated with Z→ ll+ γ data
- Reject candidates with low NN output
- Separate candidates between NN in midrange and high
    - Categorize events into 4 categories
    - Pass, Fail x2 candidates
    - Using 4x4 efficiency matrix, derive the number of events from γγ,γj,jγ,jj
- Shape from low NN score data sample

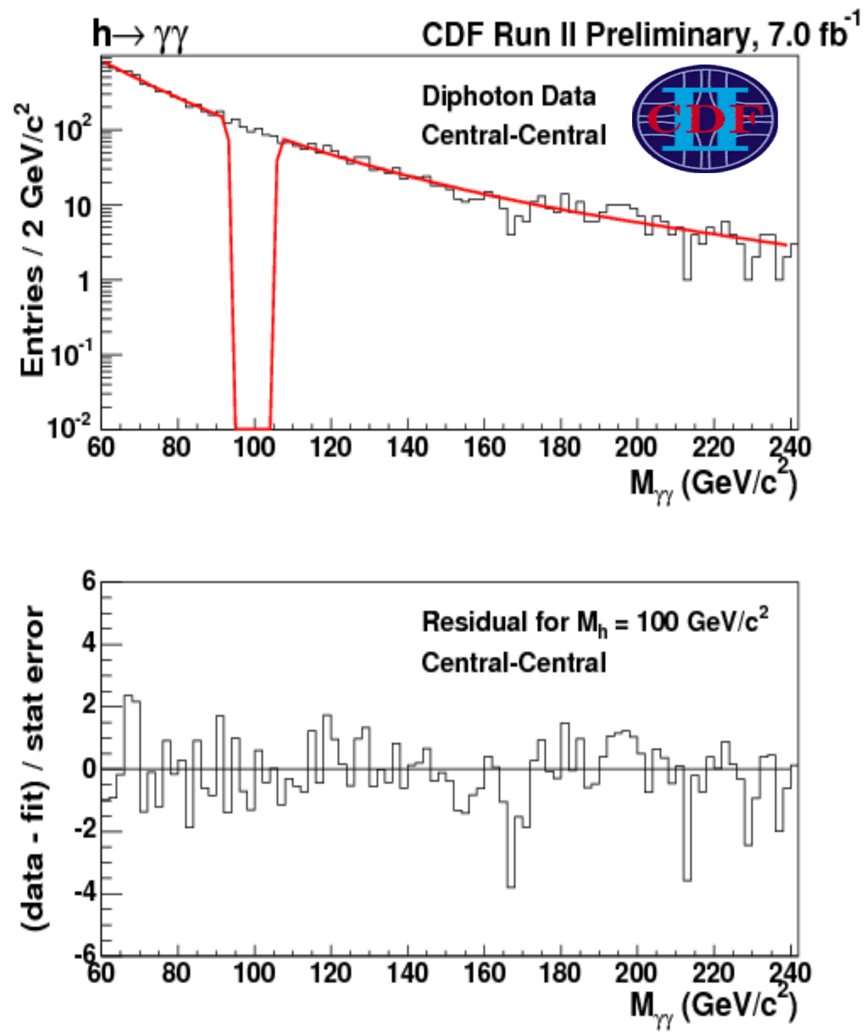
$$\begin{pmatrix} N_{ff} \\ N_{fp} \\ N_{pf} \\ N_{pp} \end{pmatrix} = E \times \begin{pmatrix} N_{jj} \\ N_{j\gamma} \\ N_{\gamma j} \\ N_{\gamma\gamma} \end{pmatrix}$$





Background Modeling

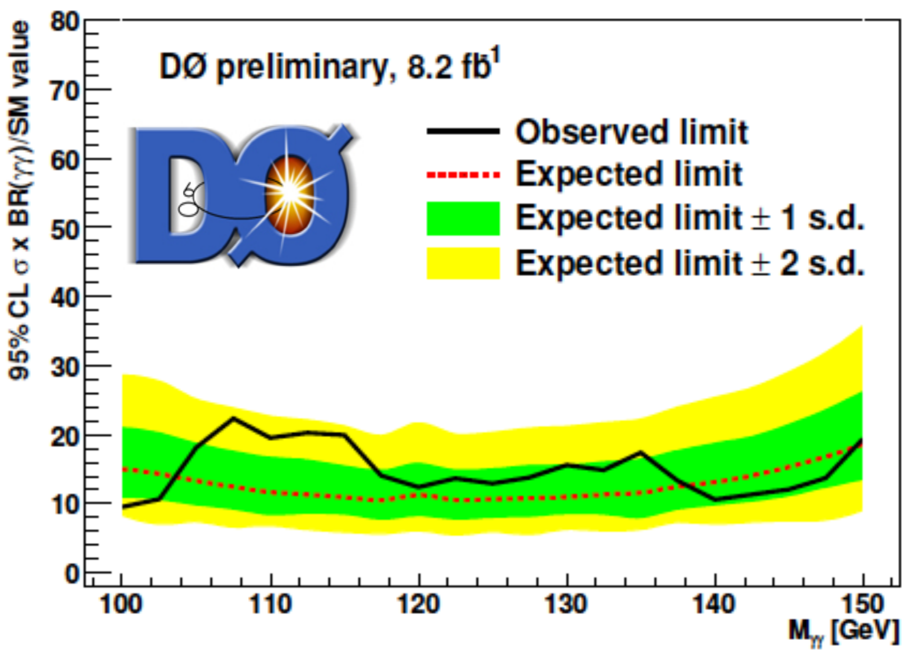
- Fit made to sideband regions of $M_{\gamma\gamma}$ distribution
- Use a six parameter polynomial times exponential to model smooth QCD diphoton background contribution
- Fit is then interpolated into the 12 GeV signal region

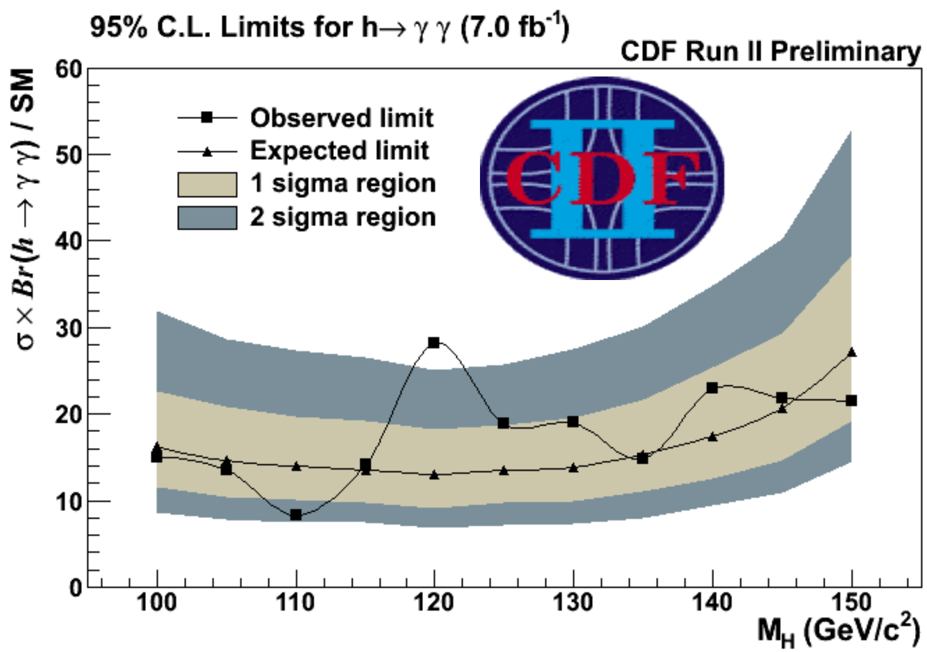


Event selection

- NN for Central region
- Converted photon are recovered

Results





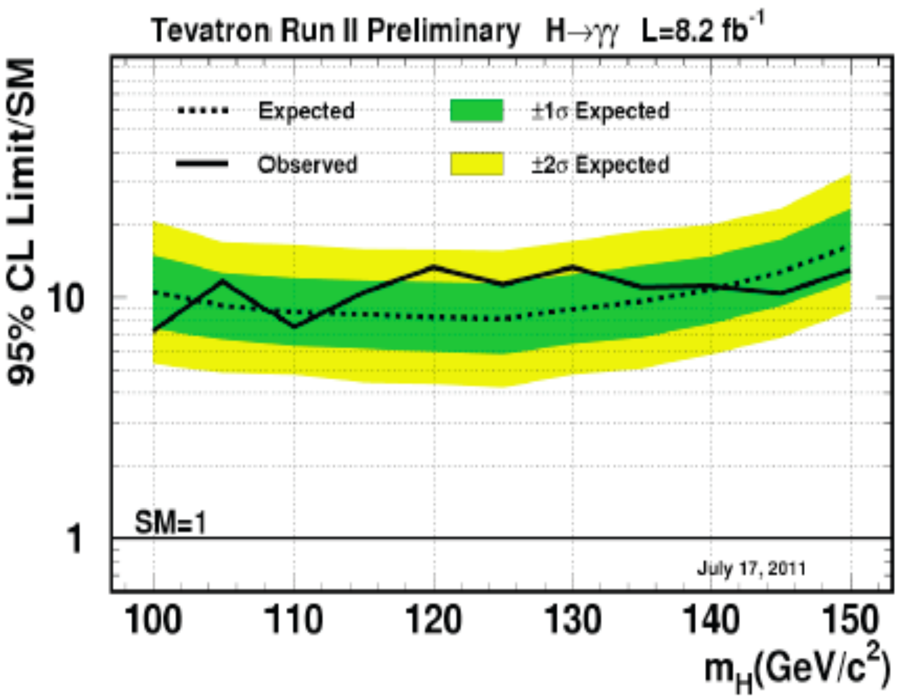
Limits @ 120 GeV
Expected limit: 11.3
Observed limit: 12.4

- Expected limit @120 GeV 13.0xSM
- Observed limit outside 2σ band @ 120 GeV, but reduced to < 2σ after trial factor taken into account

Combination Results

- Observed @ 120: 13.4xSM
- Expected @ 120: 8.3xSM
- This is deepest existing investigation into this channel – a channel that's very different from H→ bb

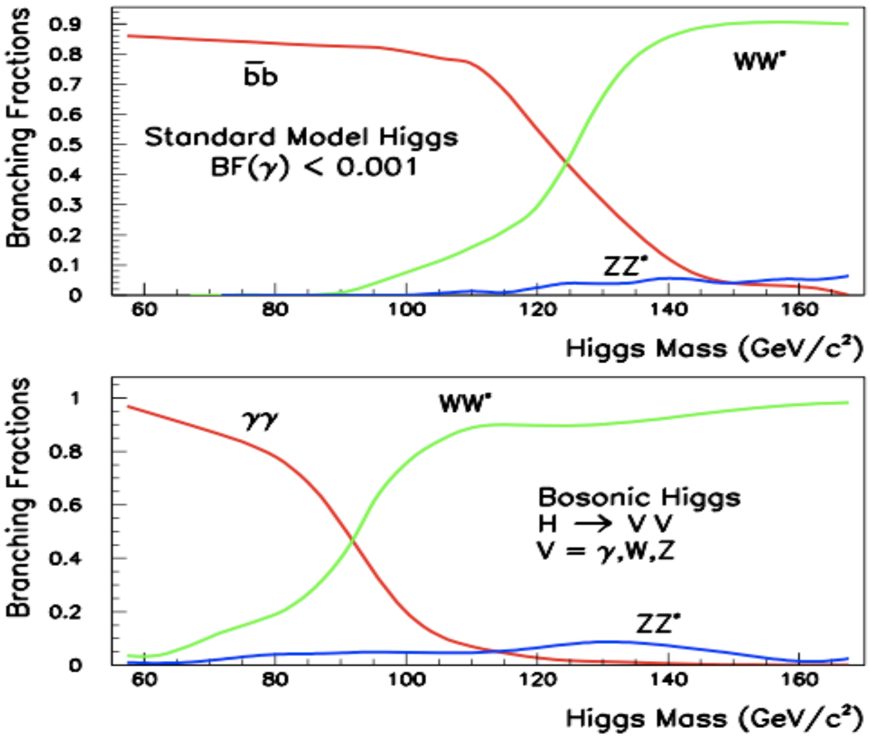
- Reaching within one order of magnitude of SM prediction!



BSM Higgs (Fermiophobic)

- We also consider a "benchmark" fermiophobic model
- A two-Higgs doublet model extension to the SM

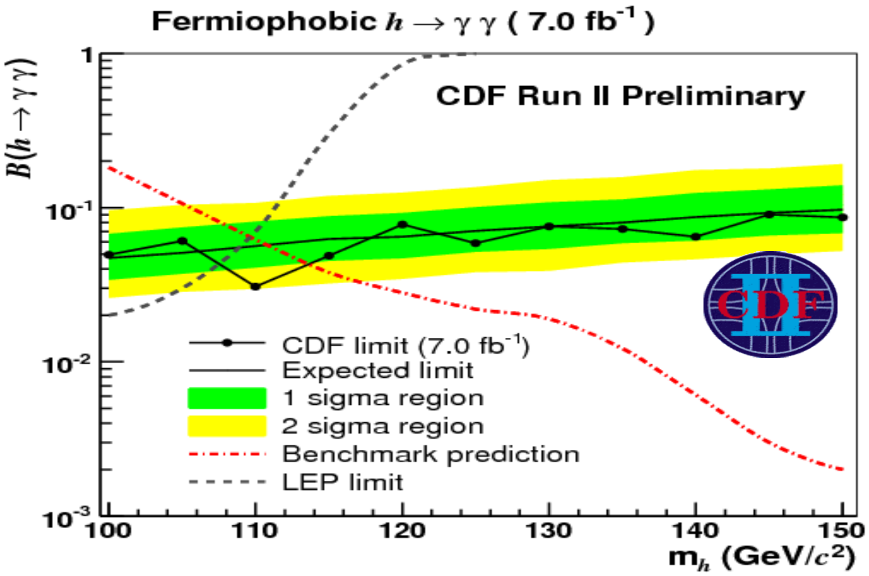
- No gluon fusion production
- Only VH and VBF
- Assume SM cross sections
- Branching ratio is enhanced significantly

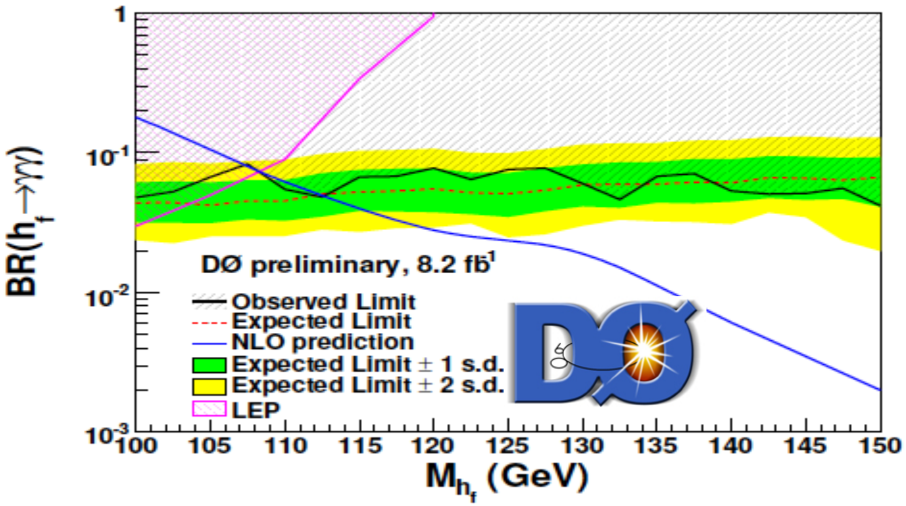


Fermiophobic Higgs Results

- For comparison:
  - LEP Limit: 109.7 GeV
- CDF
  - Expected limit 111 GeV
  - Observed limit 114 GeV
- *DØ*
  - Expected limit 112 GeV
  - Observed limit 112 GeV

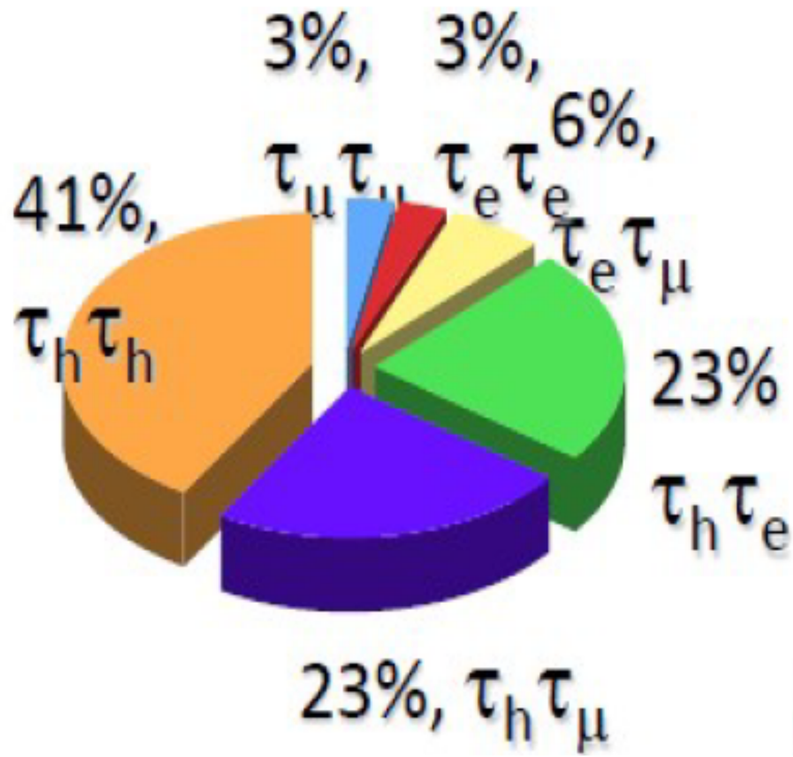
CDF limit of 114 GeV is currently world's best limit on h_f pending Tevatron combination





SM Higgs Searches with τ leptons

- Channels:
  - $H \rightarrow \tau\tau$
- The Challenge
  - Difficult ID
    - Multiple decay modes
    - Type 1: τ+/- $\rightarrow \pi^{+/-}\ \nu$
      - CAL + TRK and no EM subcluster
    - Type 2: $\tau^{+/-} \rightarrow \pi^{+/-}\ \pi^{0}\ \nu$
      - CAL + TRK + EM subcluster
    - Hadronic τ are jets, but narrow with mostly 1, 3 Tracks
  - QCD jet fake estimates hard
- Difficult reconstruction
  - Only part of energy visible

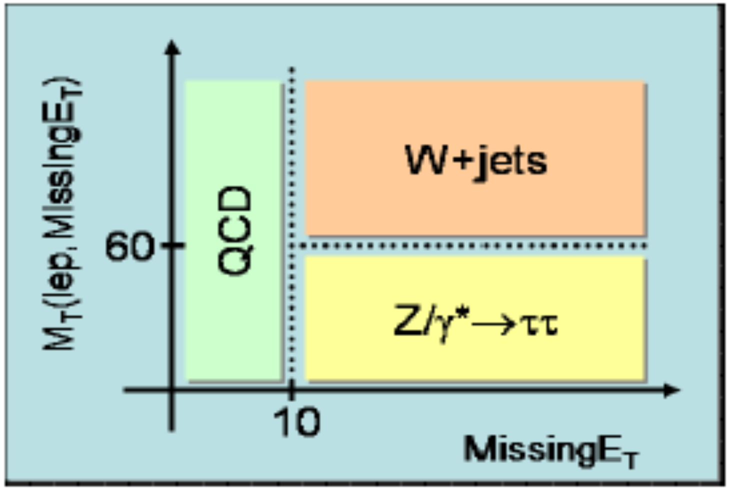


$\tau^- \rightarrow \pi^- + N\pi^0$ (1 prong)

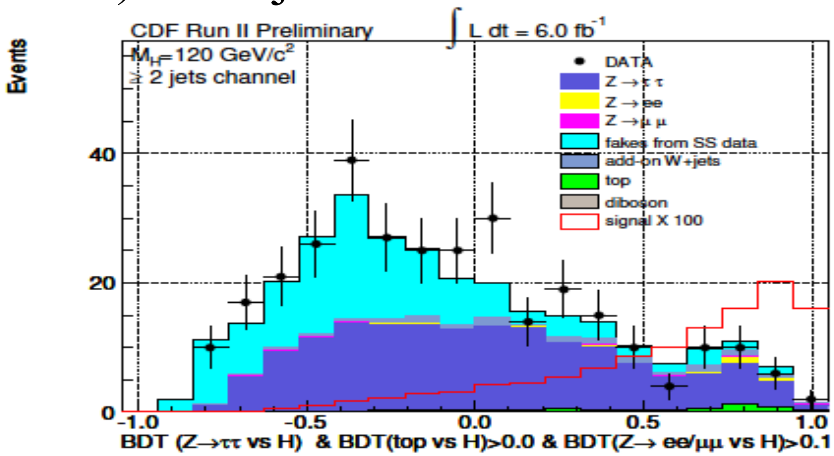
$\tau^- \rightarrow \pi^-\pi^+\pi^- + N\pi^0$ (3 prong)

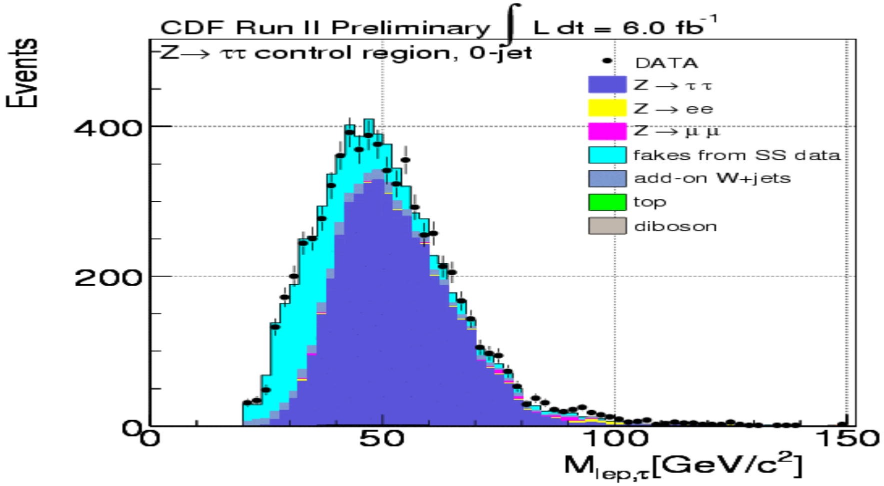
CDF H→ ττ (1 τ leptonic and 2nd hadronic)

- Search for H → $\tau^+\tau^-$ in VH, VBF, and gluon-gluon τ_e τ_h and τ_μ τ_h (BR 46%)
- Control regions:
  a) Z→ττ enriched
  b) W +Jets enriched
  c) QCD enriched
- Signal regions
  a) 1 jet in the final state
  b) >= 2 jets in the final state



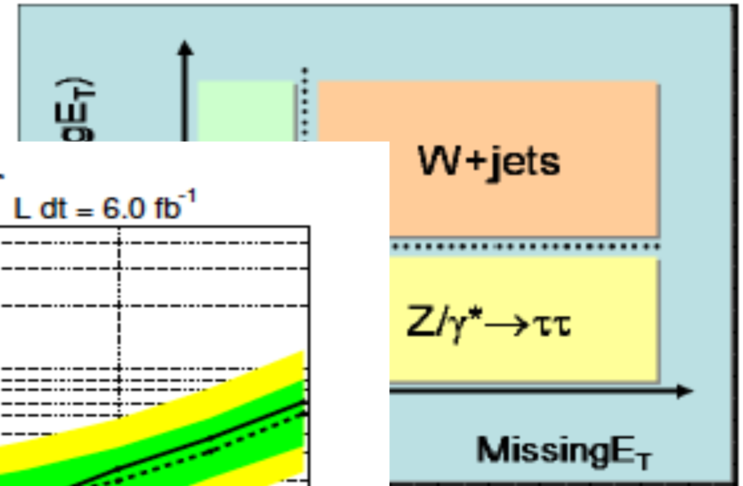
Control Region Njets = 0



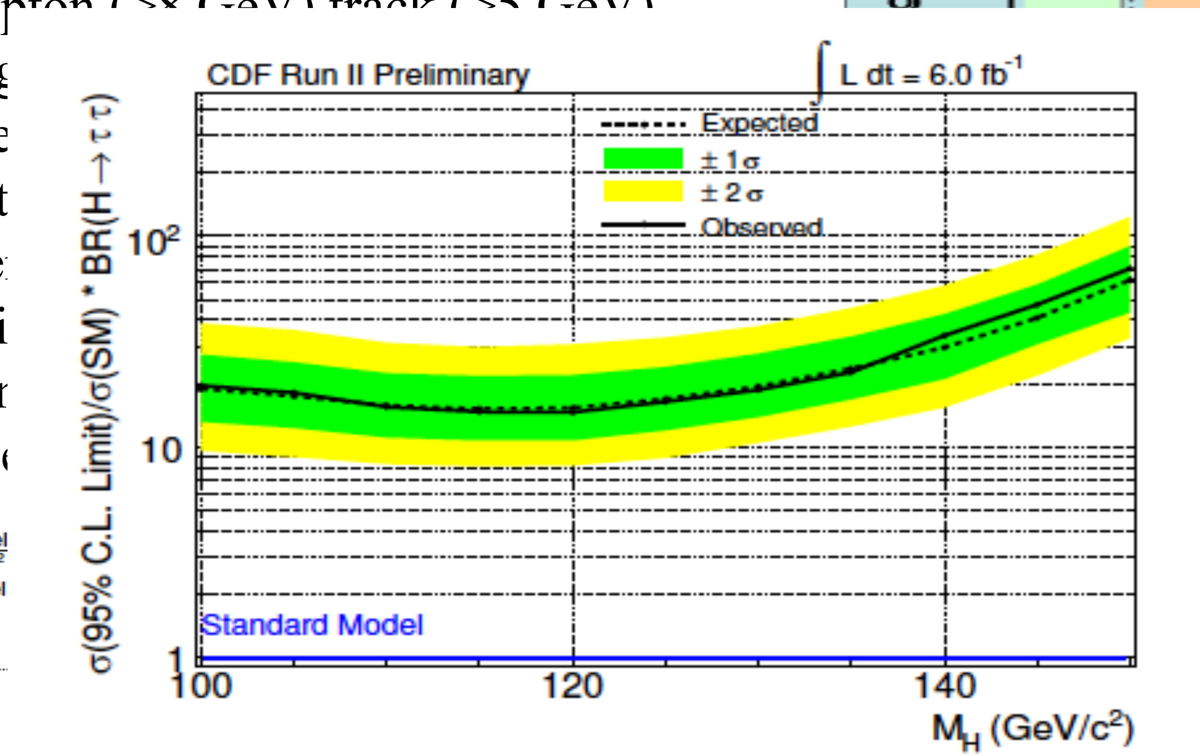


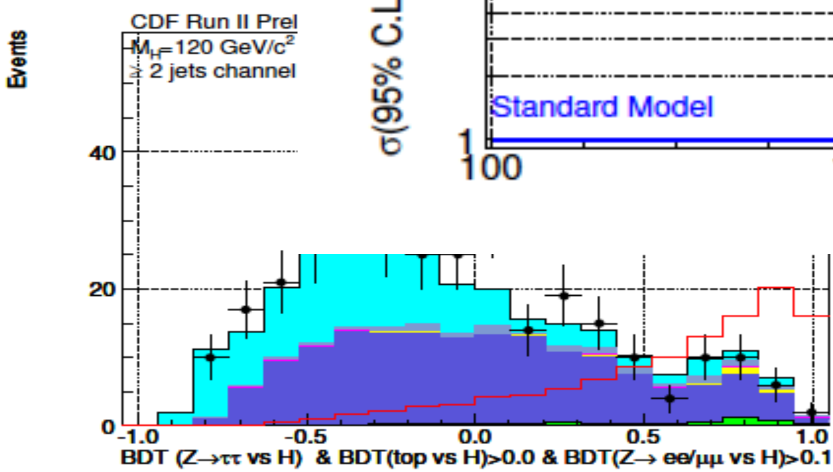
CDF H→ ττ (1 τ leptonic and 2nd hadronic)

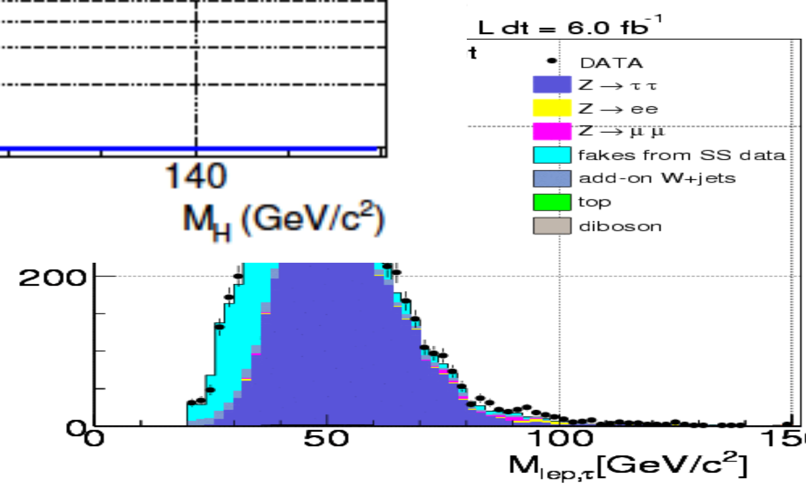
- Search for H → $\tau^+\tau^-$ in VH, VBF, and gluon-gluon τ_e τ_h and τ_μ τ_h (BR 46%)
- Trigger: lepton (>8 GeV) track (>5 GeV)
- Control reg
  - a) Z→ττ e
  - b) W +Jet
  - c) QCD e
- Signal regi
  - a) 1 jet ir
  - b) >= 2 je



n Njets = 0

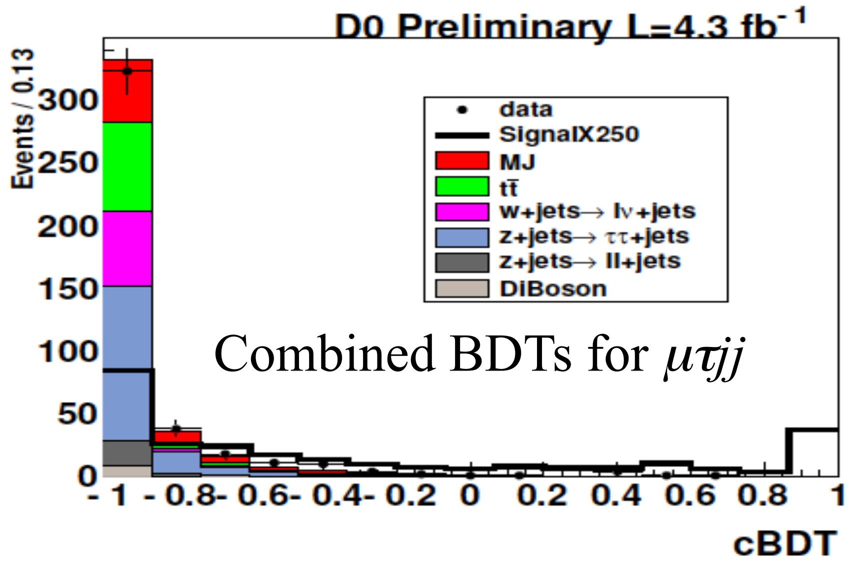


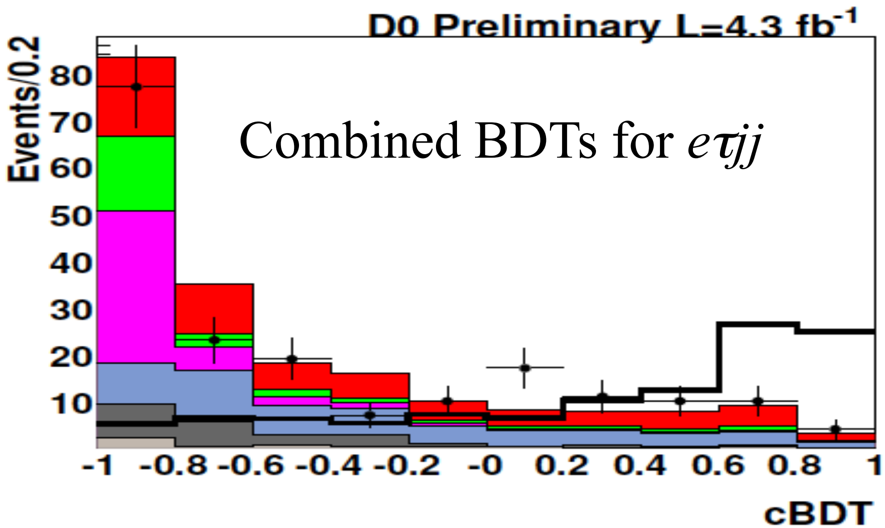




SM Higgs boson in the $\tau^+\tau^-$ + 2 jets final state

- NNs are used to select tau candidates
- BDTs are used to characterize differences between events originating from specific signal and background processes
- Information from the individual trees are combined into a final BDT to obtain the best possible overall discrimination





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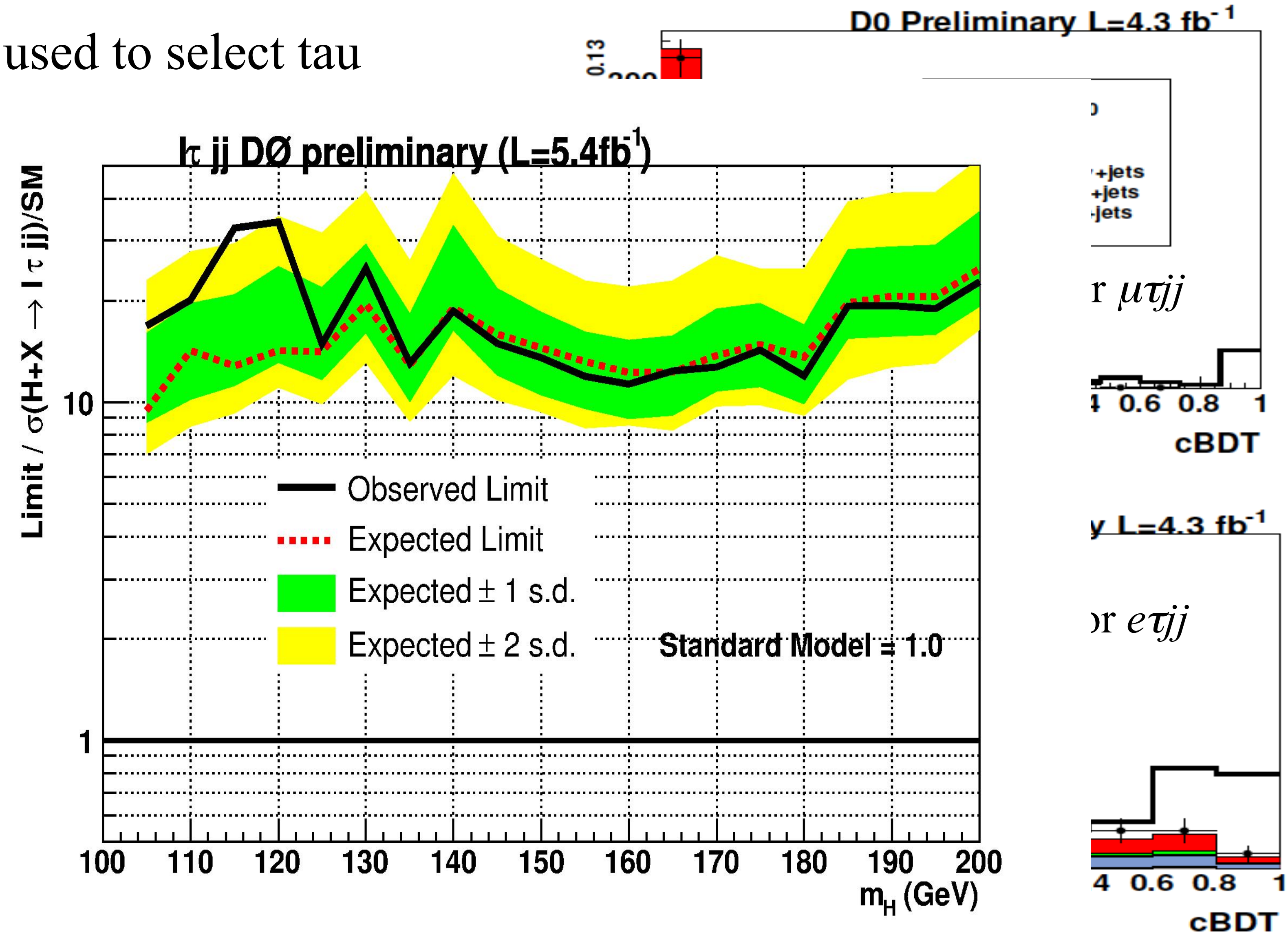
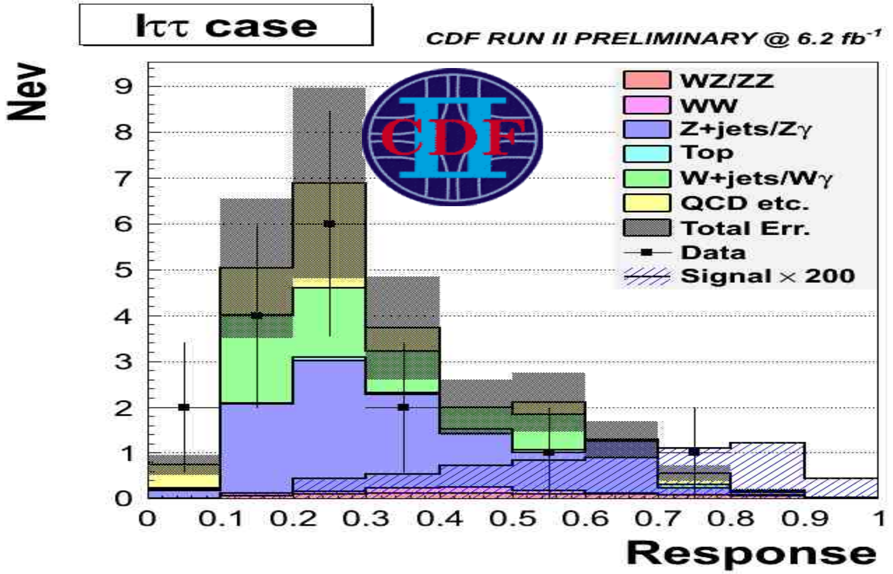
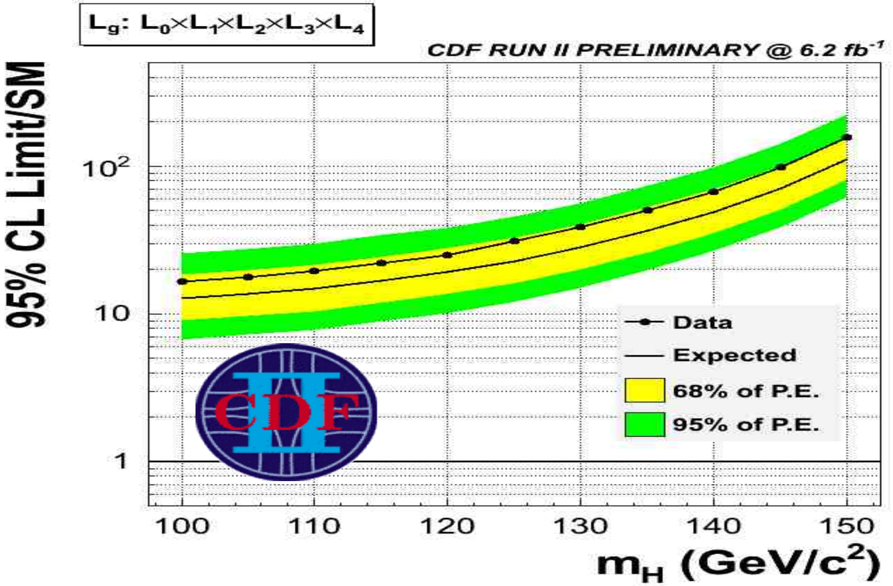


SM Higgs to ττ in VH channels

- Signal processes are:
  WH → $l\nu\tau\tau$ and ZH → $ll\tau\tau$
- Select 3 or 4 leptons including at least one hadronic tau candidate
- To improve search sensitivity, use Support Vector Machines (SVM) to discriminate signals from backgrounds.

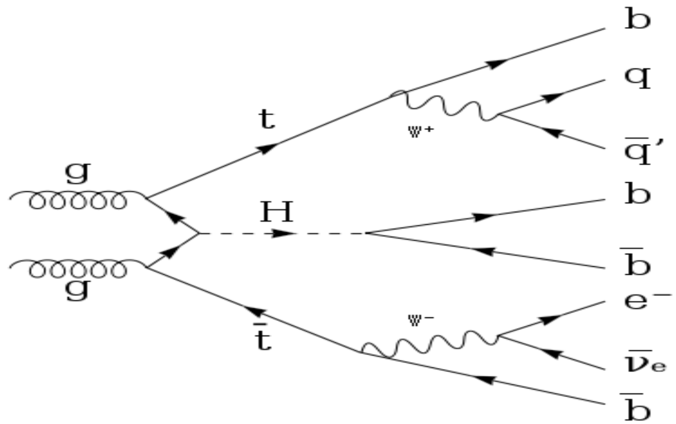


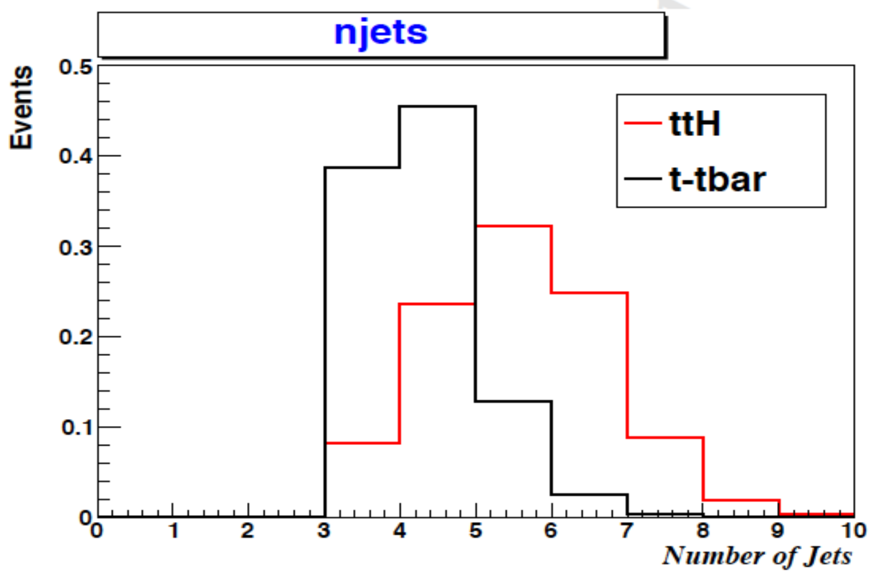


ttH Search

- Expected ttH cross section is small

  ~ 4 fb at $M_H = 120$ GeV
  - Anomalous top couplings or new physics however could enhance this cross section
- ttbar production is the main BG
- Select events with high p_T lepton and large missing E_T
- At least two 2 ***b***-jets tagged
- Sample divided into two categories
  - Four jets
  - Five or more jets

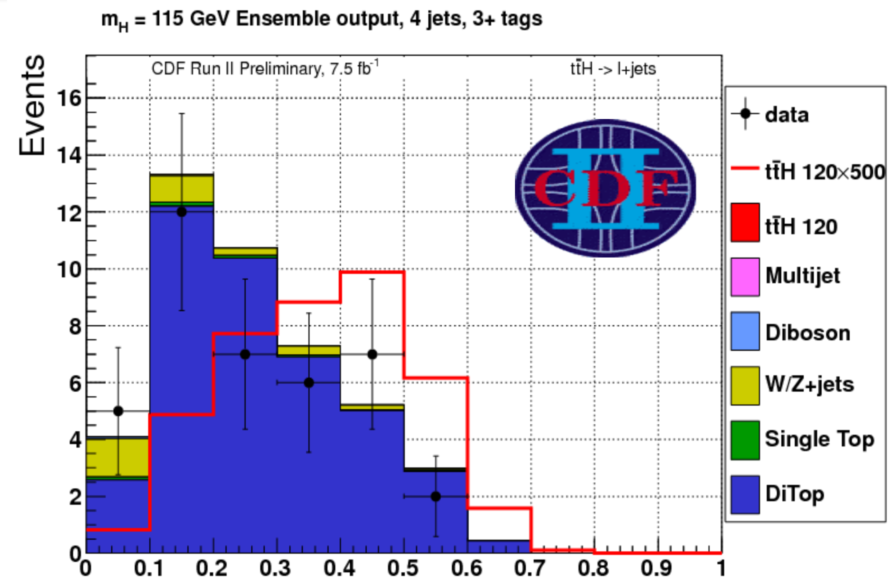


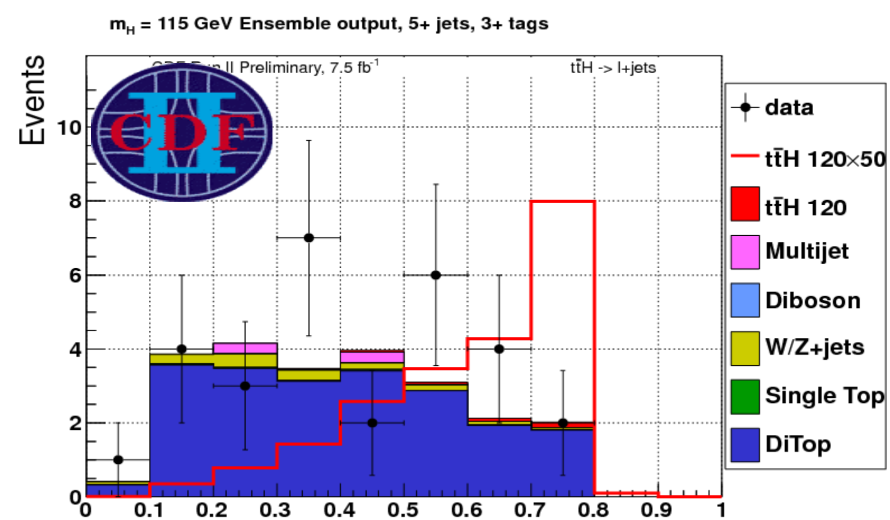


$E_T > 20$ GeV
$|\eta| < 2.0$

ttH Search

- Ensemble discriminants trained at each mass point
- Other channels which consider events without a lepton in the final state are also analyzed (not discussed here)





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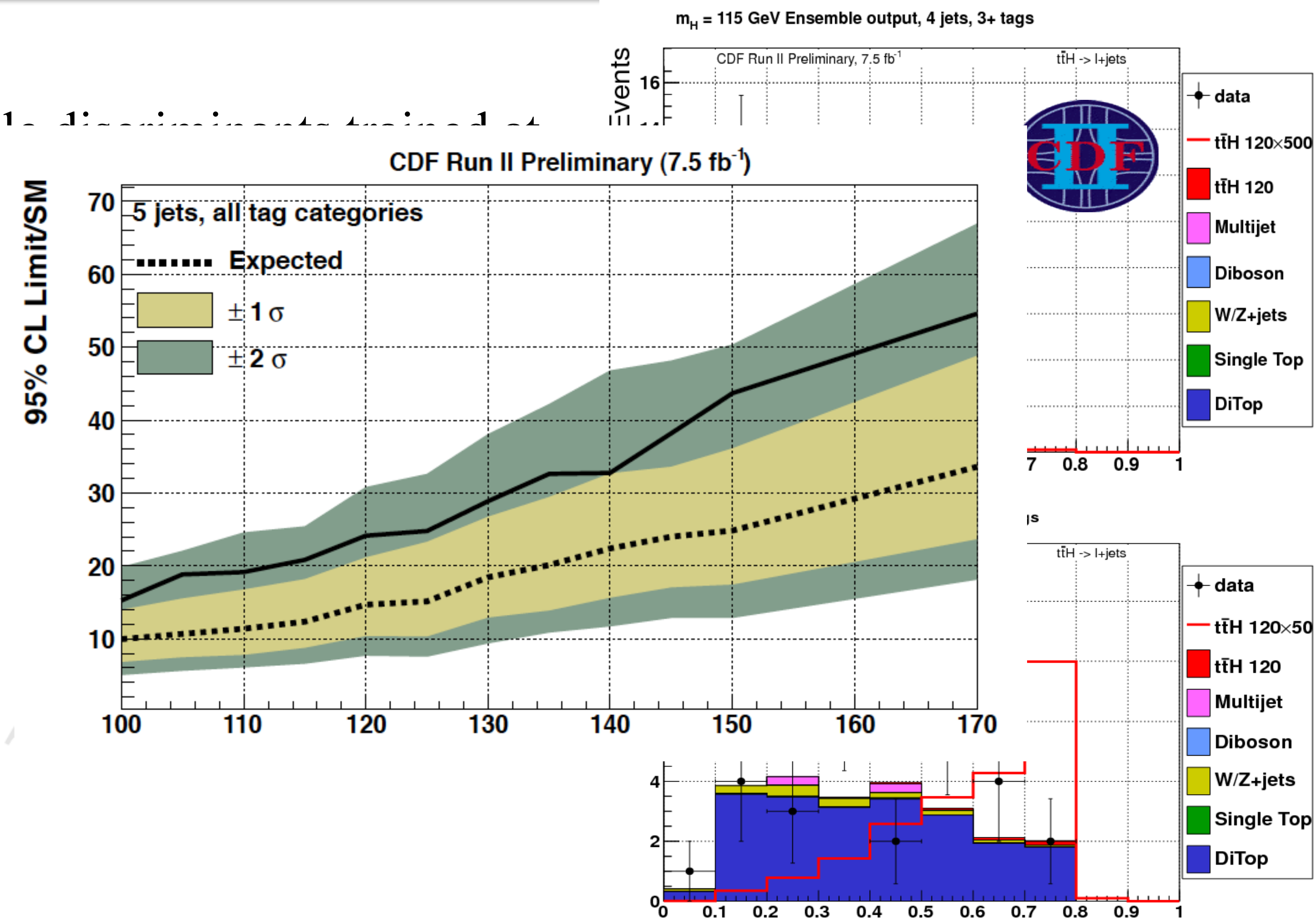

Conclusion

- Tevatron still collecting data with very high efficiencies
- Secondary channels contribute to the combination at the 5-10% level
- Light mass searches at Tevatron are improving rapidly
  - Sophisticated techniques
  - Considering more channels
    - Diphoton final state channels
    - Di-tau final state channels
    - ttH channels
    - All hadronic channels (not mentioned here)
  - Larger data sets
- Tevatron is still in the game of low mass Higgs searches
- Please check the public webpages of CDF and D0 for the details of each analysis