Search for the SM Scalar Boson at low mass with secondary channels at the Tevatron

Nicolas Osman
Centre de Physique des Particules de Marseille

On behalf of the CDF and DØ Collaborations

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Aix*Marseille université

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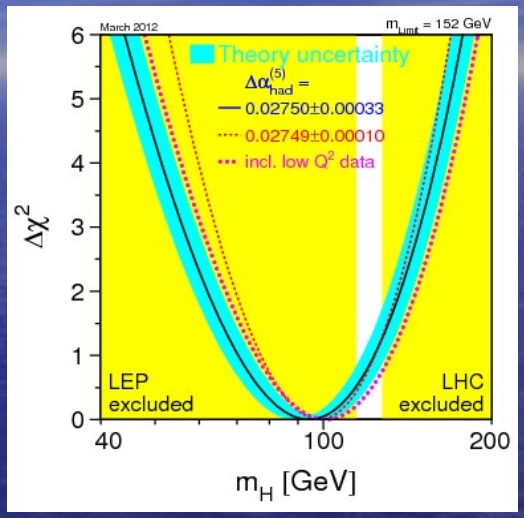
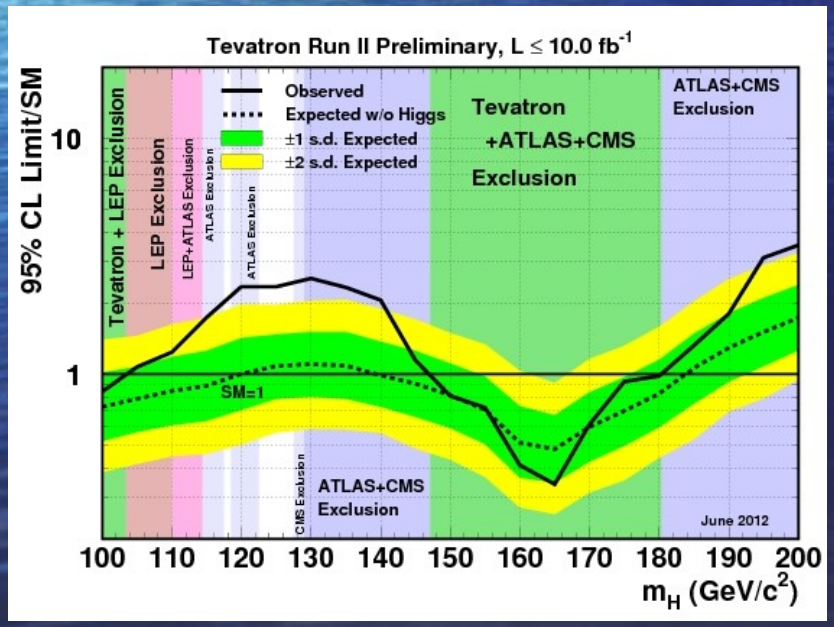
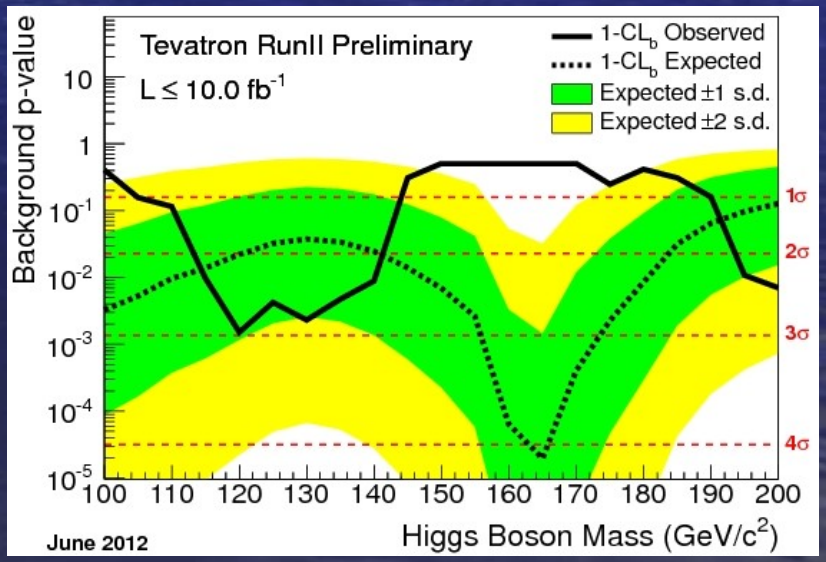
CPPM

Low Mass Higgs Boson

- EW fits predict $m_H < 152$ GeV
- ~5 s.d. excess at 125 GeV at LHC
- 2.9 s.d. excess at Tevatron

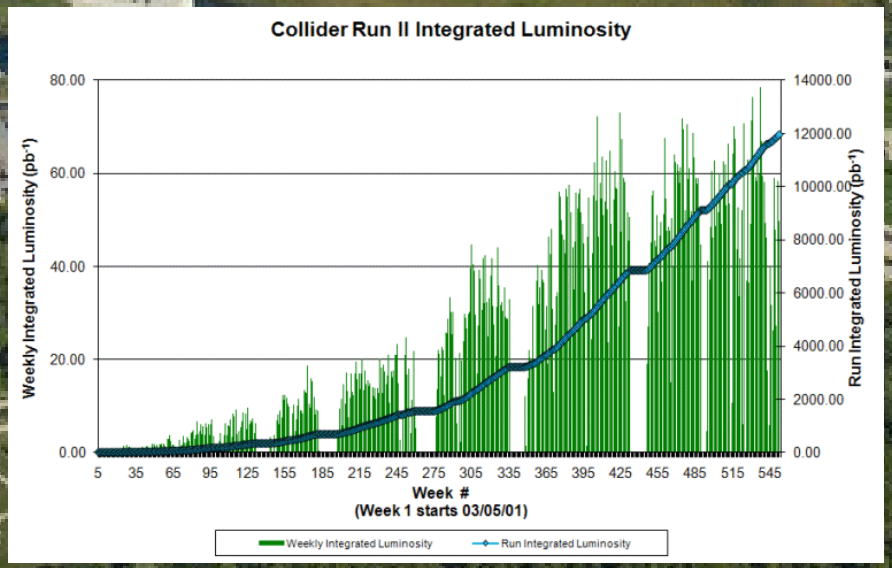






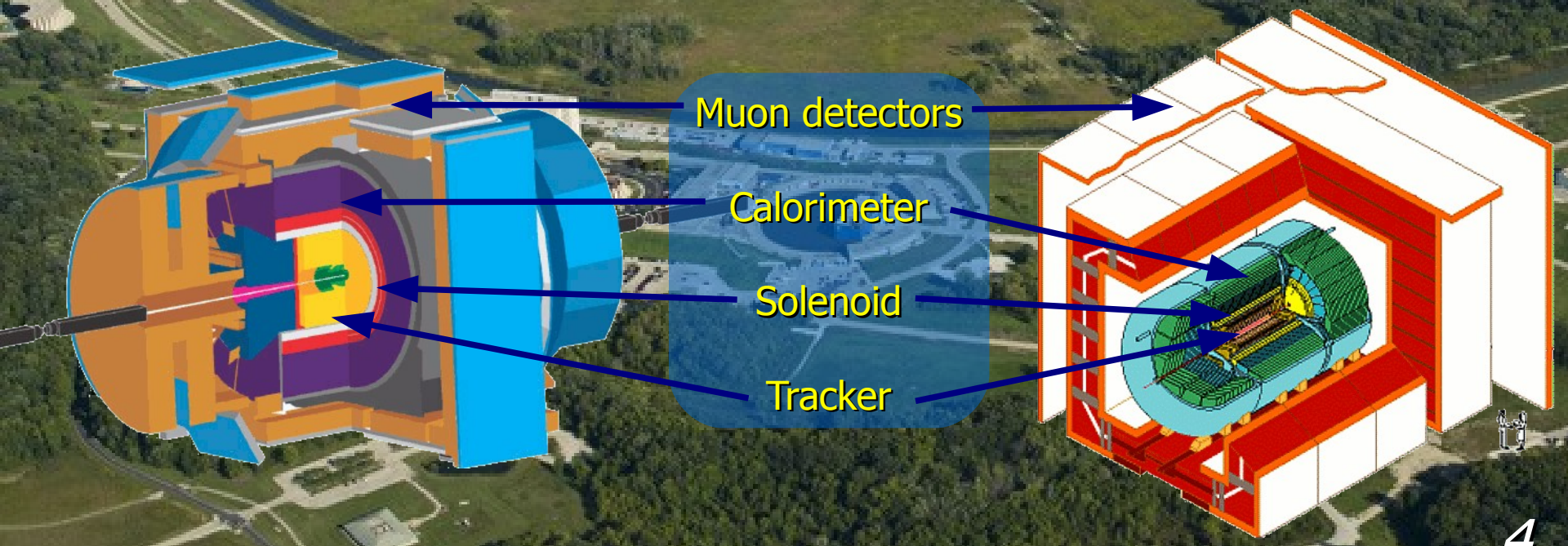
The Tevatron

- Shut down in September 2011
- $p\bar{p}$ collider with 1.96 TeV c.o.m. energy
- Peak Luminosity 4×10^{32} $cm^{-2}s^{-1}$
- Delivered 12 fb^{-1} to each experiment

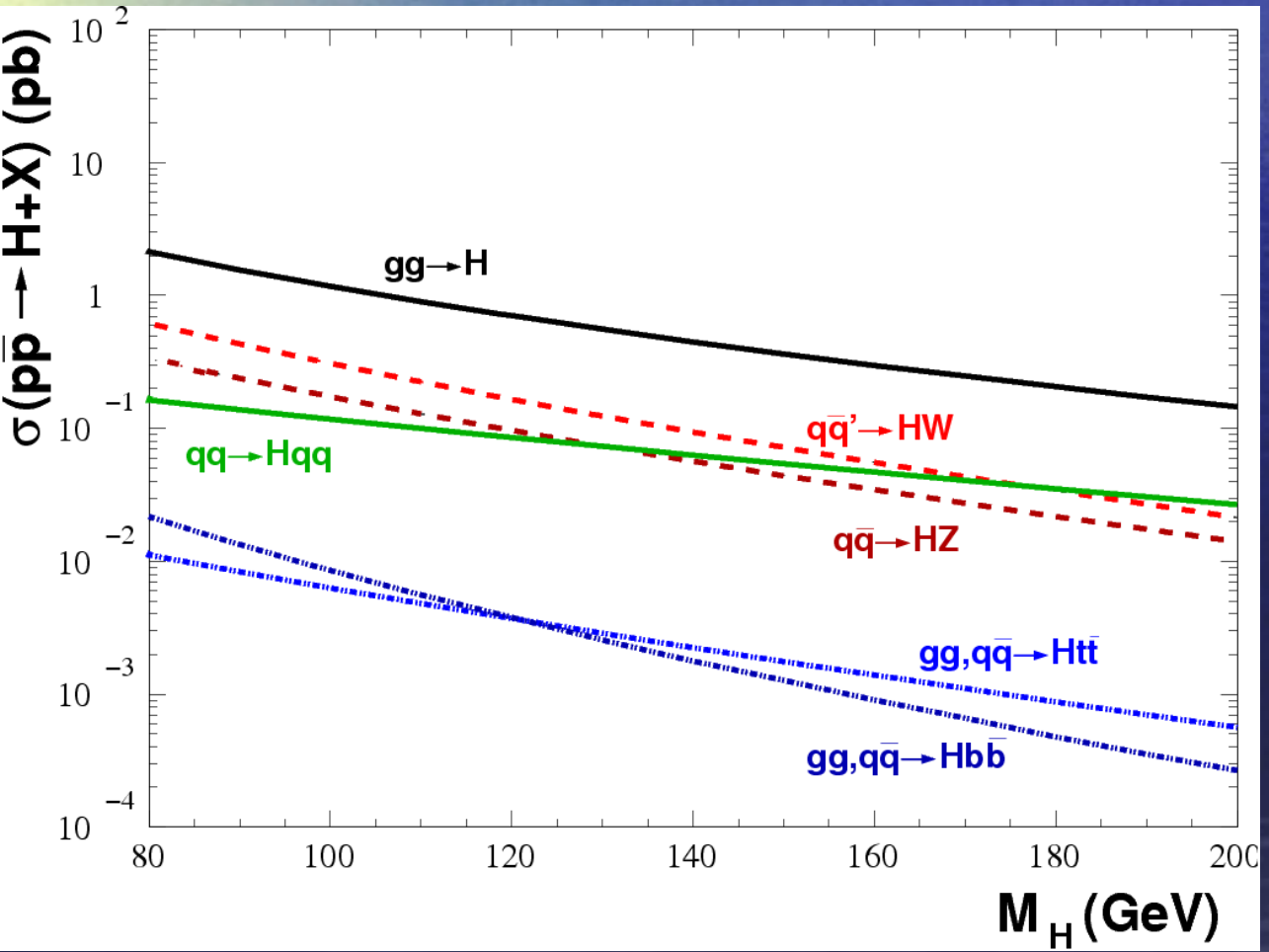


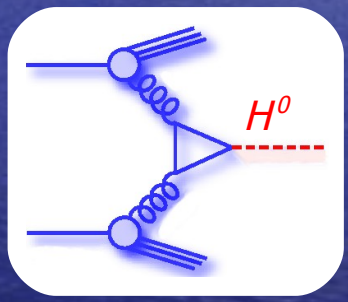
The Tevatron

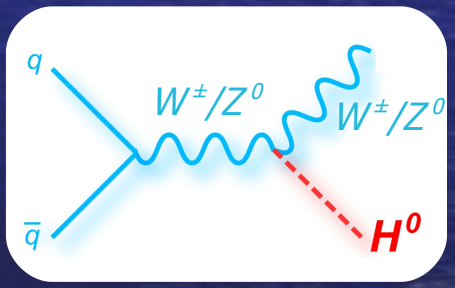
- Both detectors operated at >90% efficiency
  - Each recorded over 10 fb^{-1} of data



Higgs Boson Production at the Tevatron







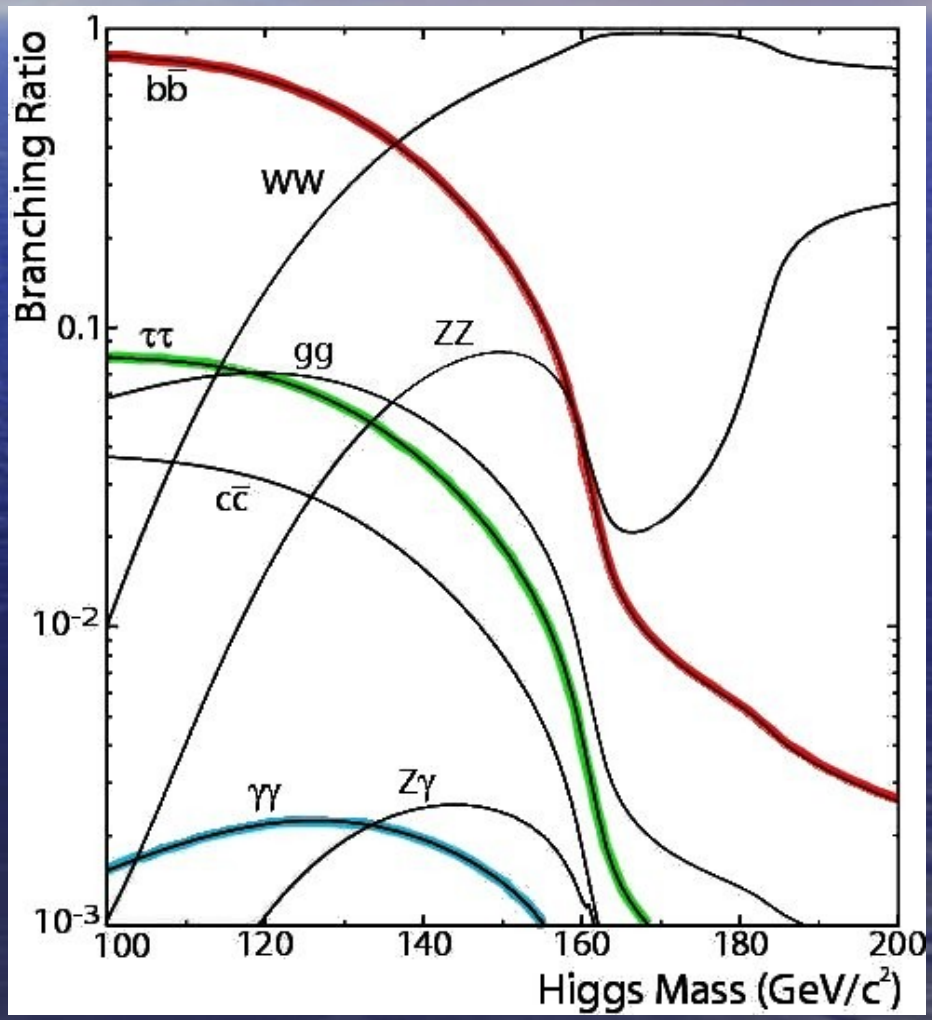
Low Mass Higgs Boson Decays

Primary

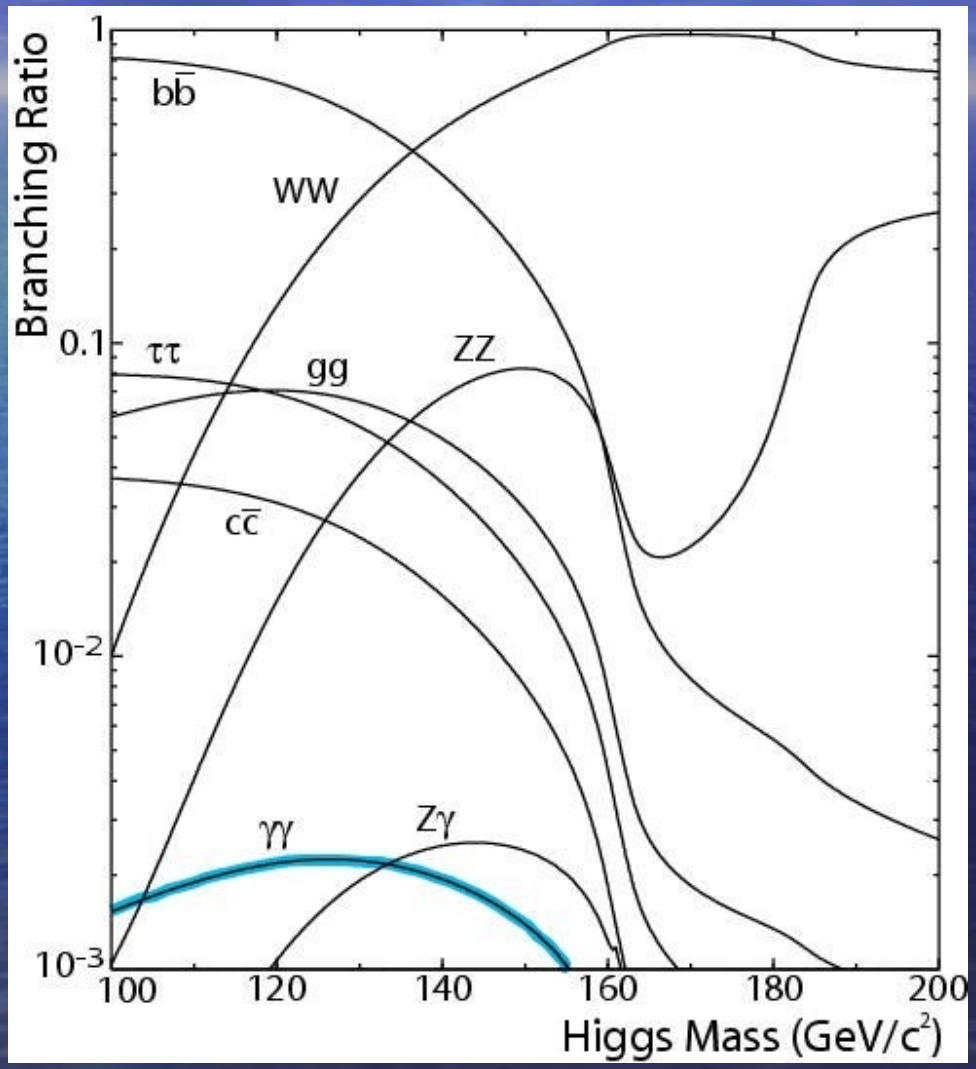
- $WH \rightarrow \ell\nu bb$
- $ZH \rightarrow \nu\nu bb$
- $ZH \rightarrow \ell\ell bb$

Secondary

- $VH \rightarrow qqbb$
- $Htt \rightarrow bb$ + jets
- $H \rightarrow \tau\tau$ + jets
- $H \rightarrow \tau\tau$ + leptons
- $XH \rightarrow \mu\tau\tau$
- $H \rightarrow \gamma\gamma$ + jets

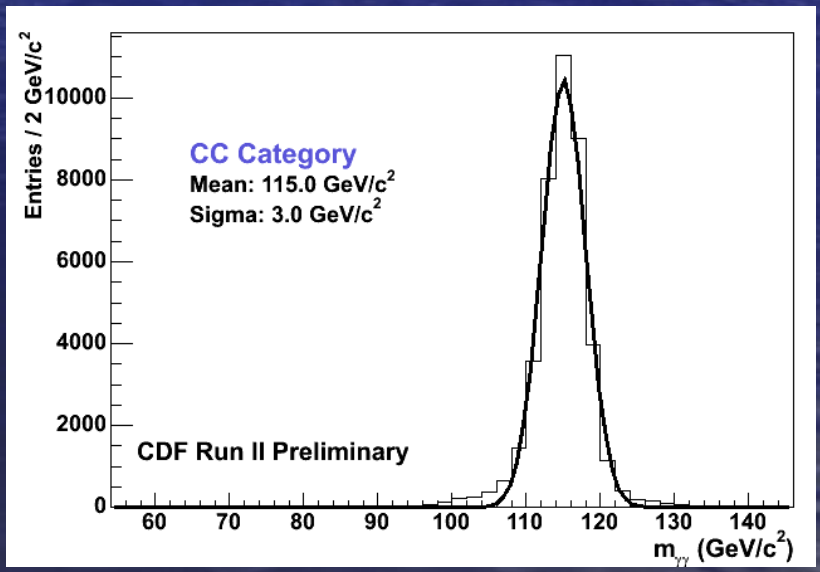


$H \rightarrow \gamma\gamma$



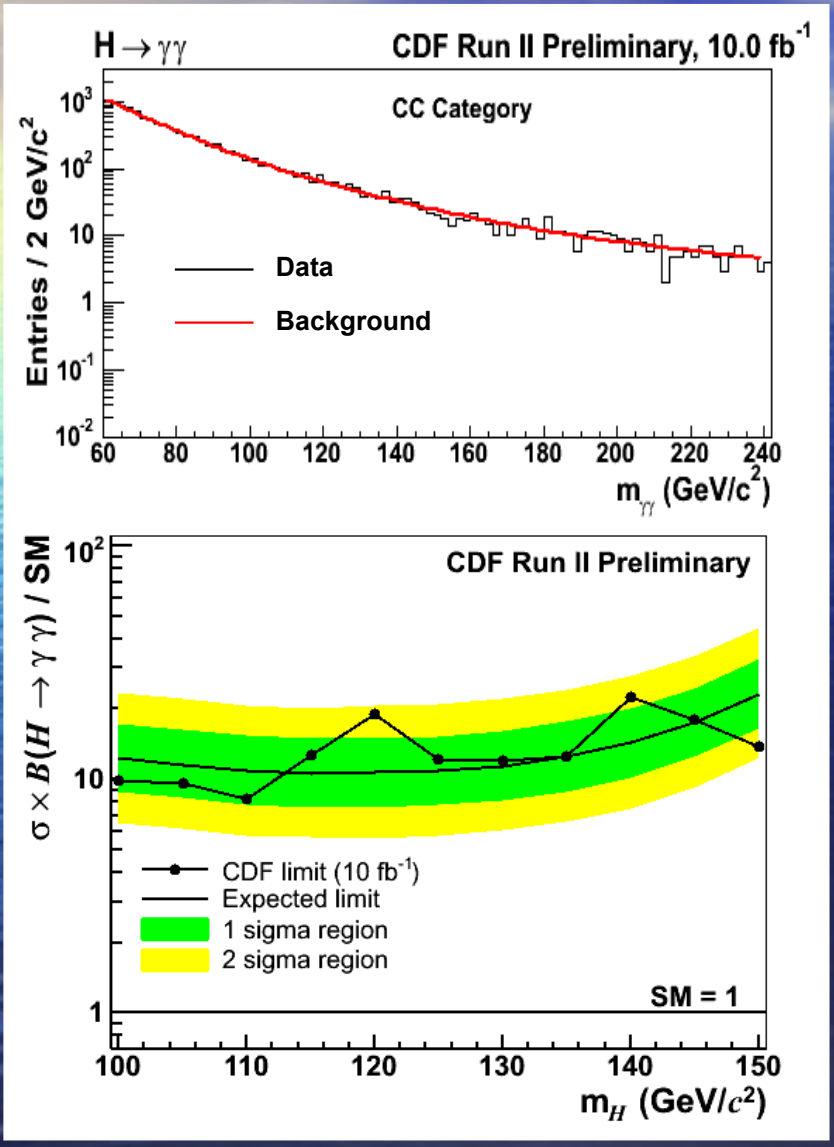
CDF H→γγ

- Scan γγ mass spectrum in 10 fb^{-1} of data
- Require 2 photons – at least 1 in central region
  - Include γ→ee candidates in sub-channels
- Identify central (plug) photons with NN (cuts)
- Simulated Higgs boson mass resolution of 3 GeV



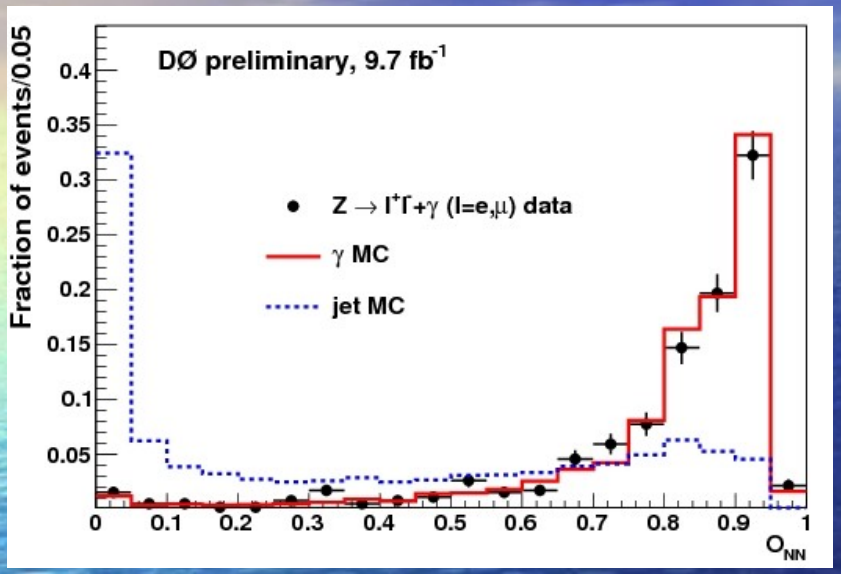
10 fb^{-1}

CDF H→γγ

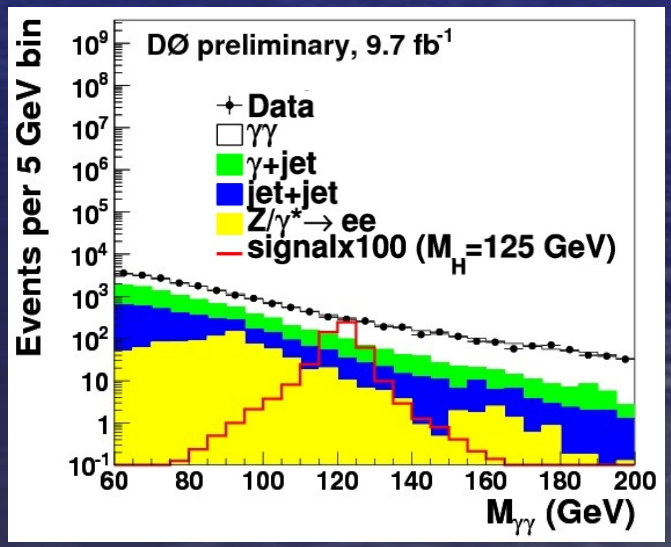


- Di-photon mass is final discriminant
- Estimate background by fitting to data
  - Remove 12 GeV mass window around each mass hypothesis for fit
- Observed (expected) confidence limit at 125 GeV: 12.2 (10.8) x SM σ

DØ H→γγ



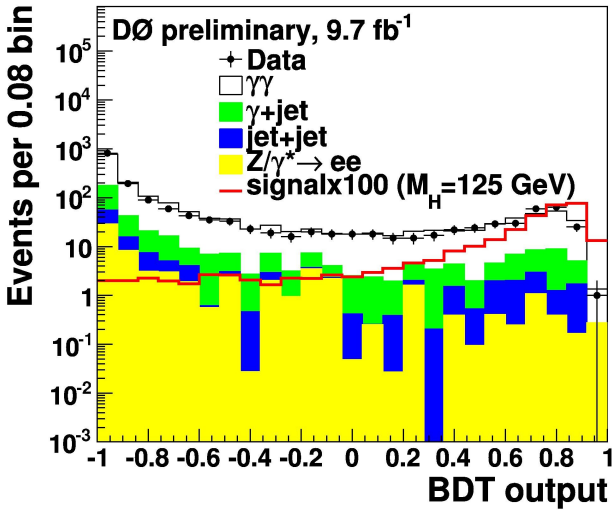
- Require 2 central photons
  - Identified using NN and selection cuts
  - Use central preshower detector to verify vertex
- Drell-Yan, γ-jet/jet-jet and direct γγ backgrounds
  - Simulate Drell-Yan
  - Data driven method for other backgrounds

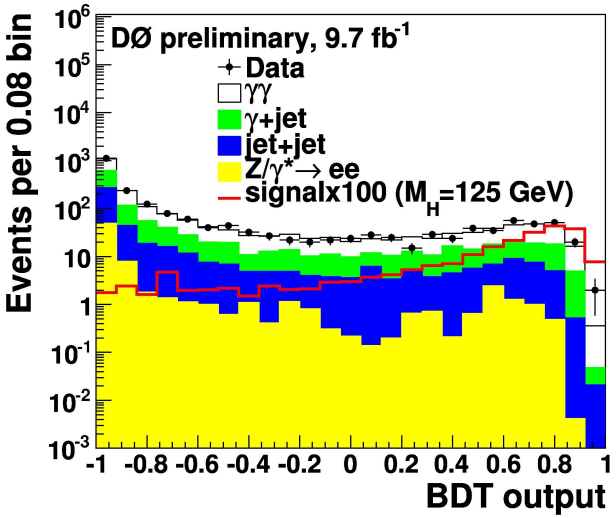


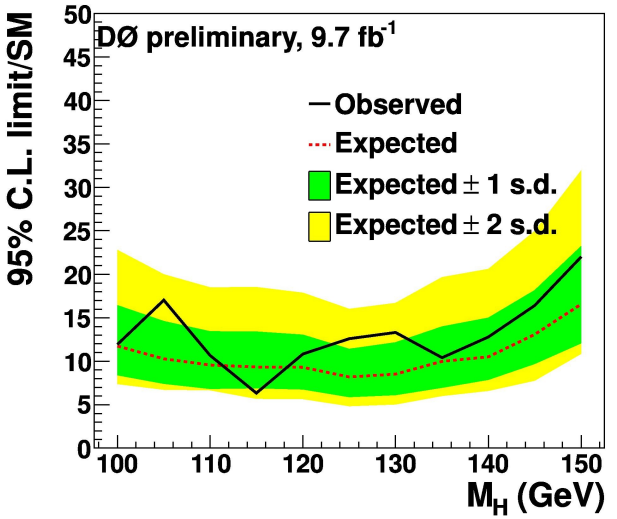
9.7 fb-1

DØ H→γγ

- Divide into γ- and j-dominated regions
- BDT trained to identify signal-like events



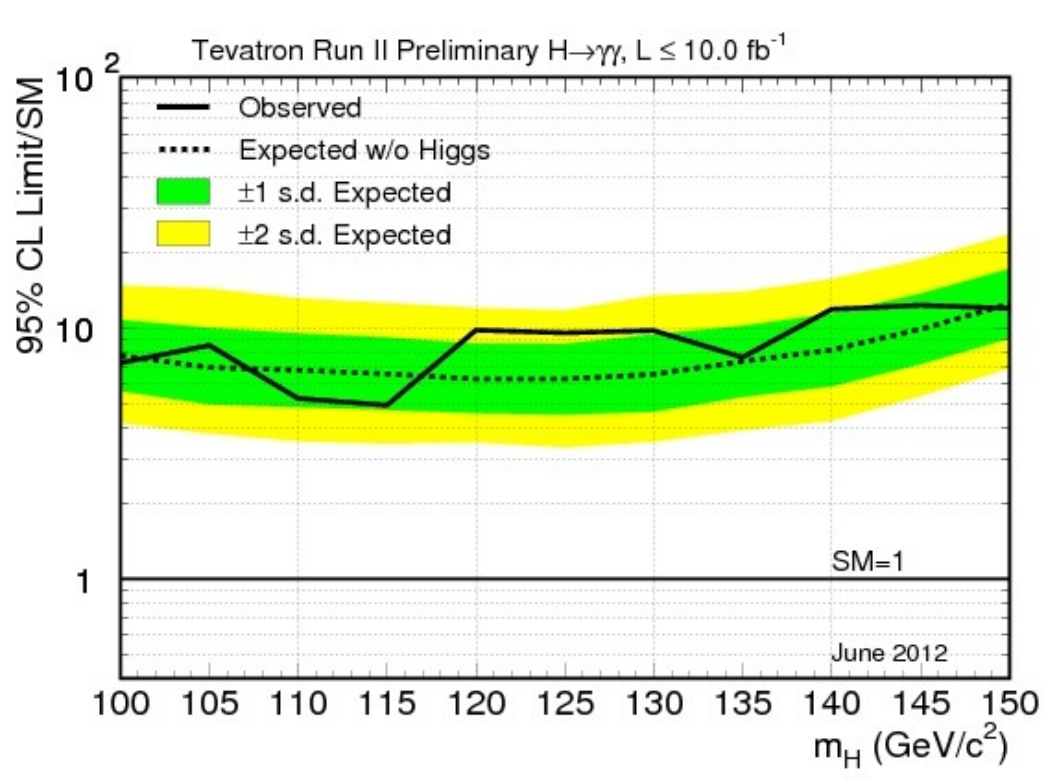




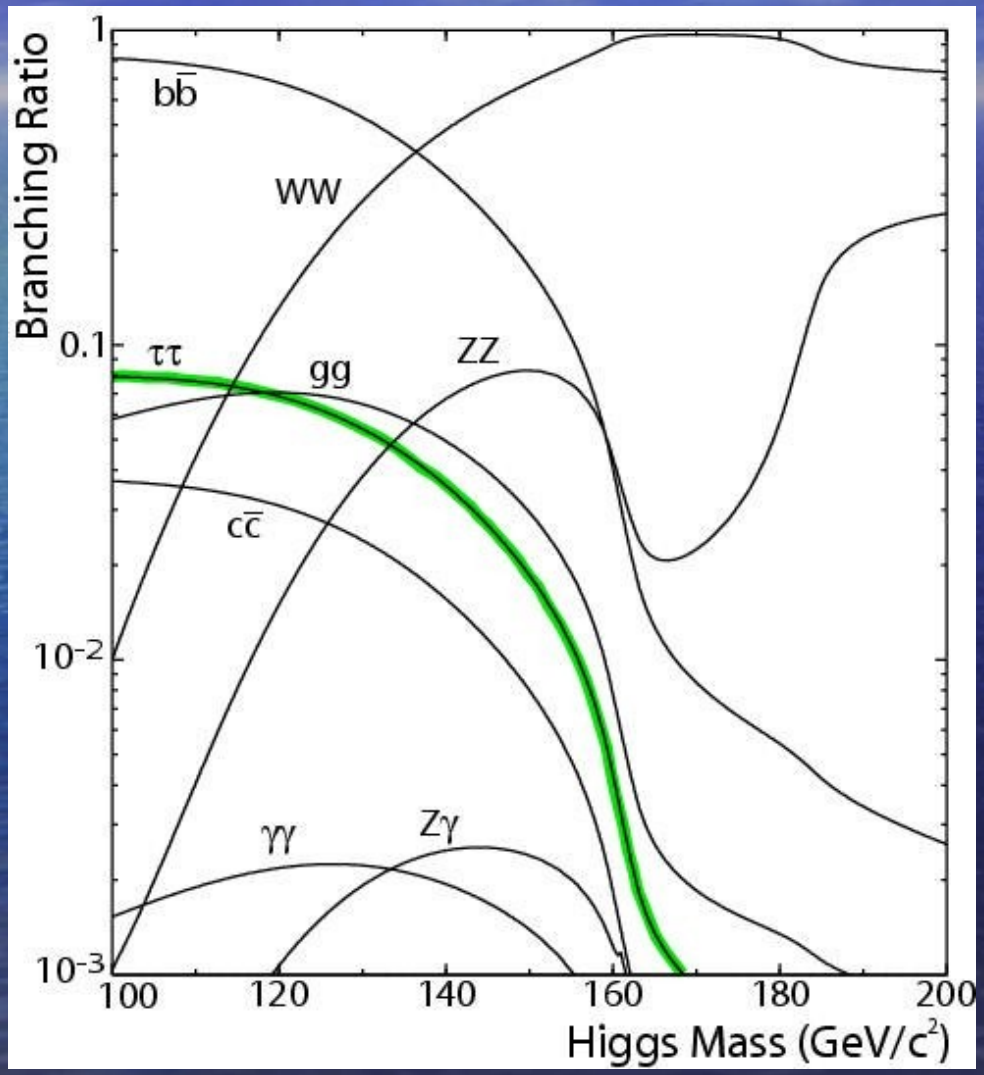
- Observed (expected) confidence limit is 12.9 (8.2) x SM σ at 125 GeV

Tevatron H→γγ Combination

- Combined limit ~10 x SM σ at 125 GeV
- Expected limit is ~6 x SM σ



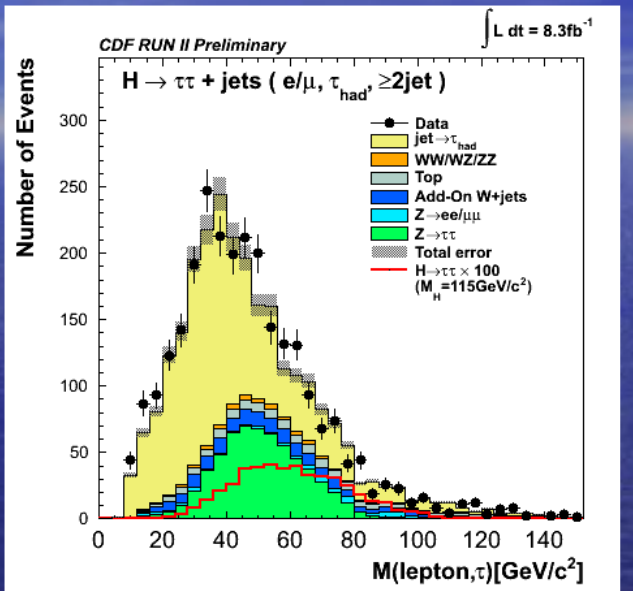
$H \rightarrow \tau\tau$

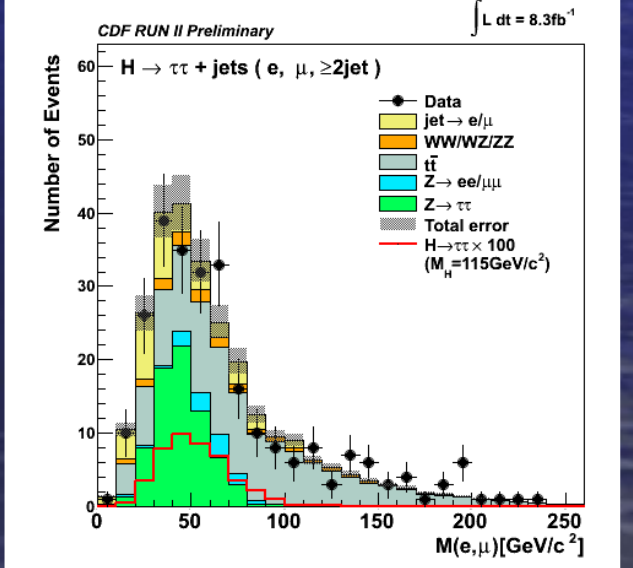


CDF H→ττ + Jets

- Search for Higgs bosons from four processes: WH, ZH, VBF and GF
  - Majority of signal events include 1 or more jets
- Final states τ_h+e/μ or e+μ, +1 or more jet
- Major backgrounds: jet →τ, Z→ττ, tt

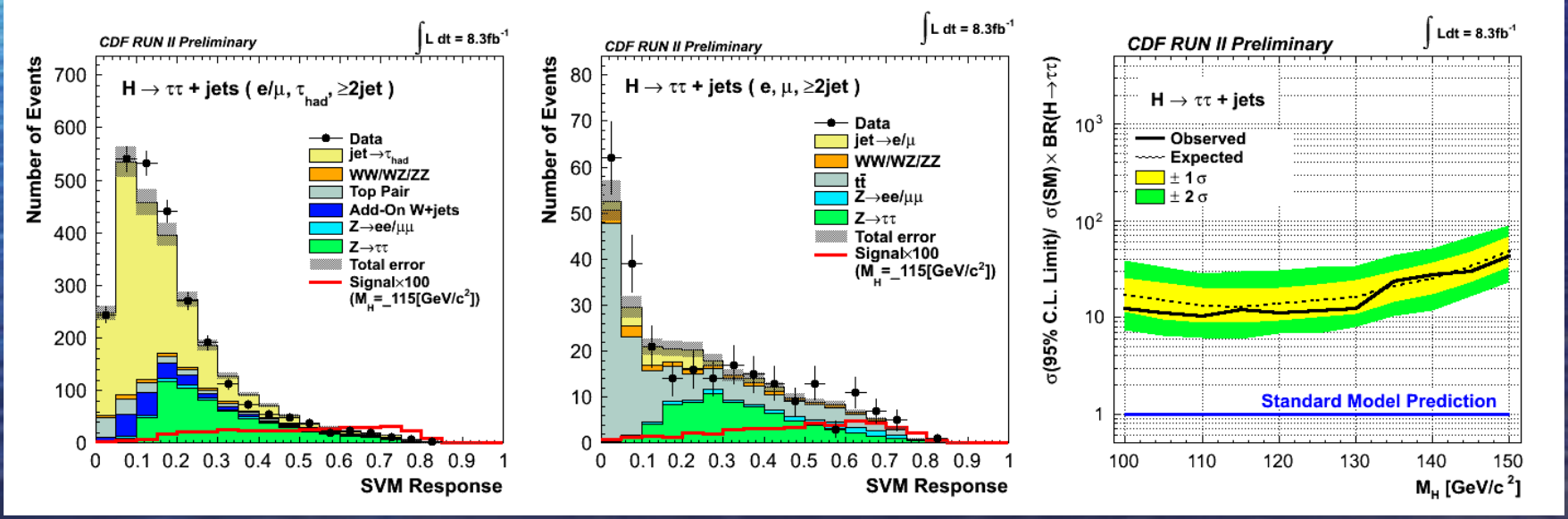
8.3 fb^{-1}



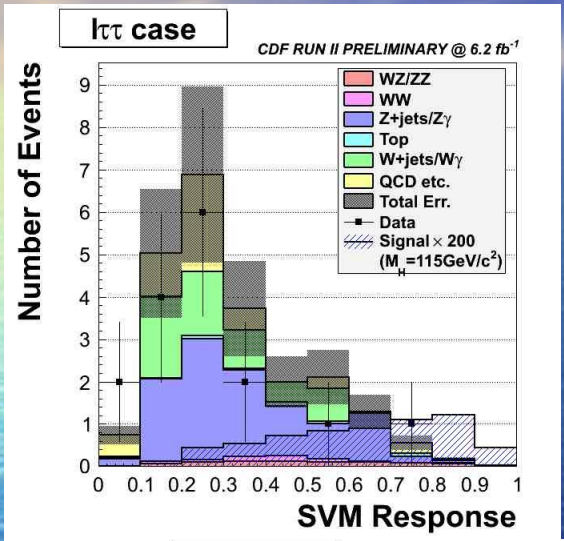


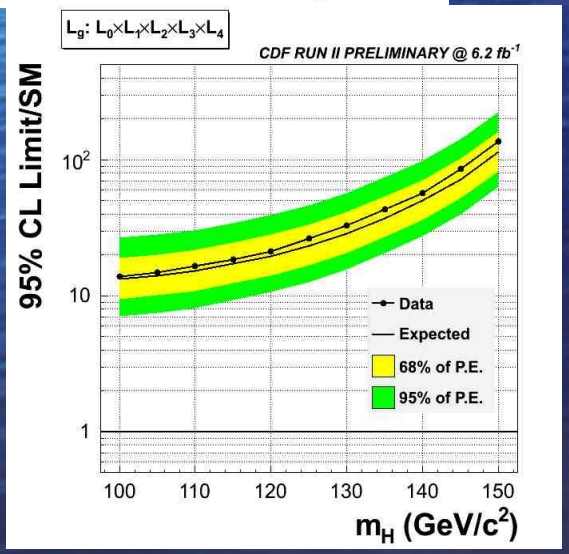
CDF H→ττ + Jets

- Use Support Vector Machine (SVM) to boost sensitivity (one SVM per bkgd. per channel)
- Observed (expected) cross section limit is 11.7 (14.8) times SM at 125 GeV



CDF H→ττ + Leptons



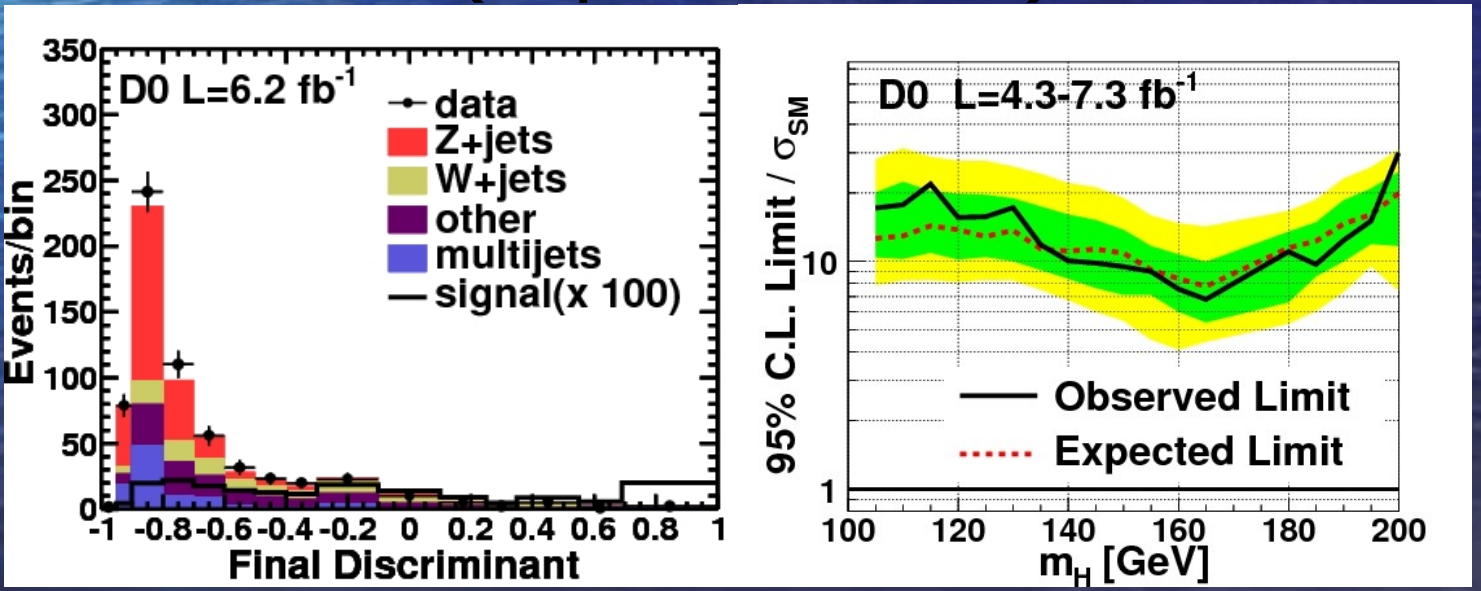


- Complement H->ττ+jets search
  - VH→ℓℓ ττ is main signal
- Large Drell-Yan background suppressed using SVM
- Exclude cross section 26.5 x SM prediction (exp. 23.3) at 125 GeV

6.2 fb^{-1}

DØ $H \rightarrow \tau\tau$

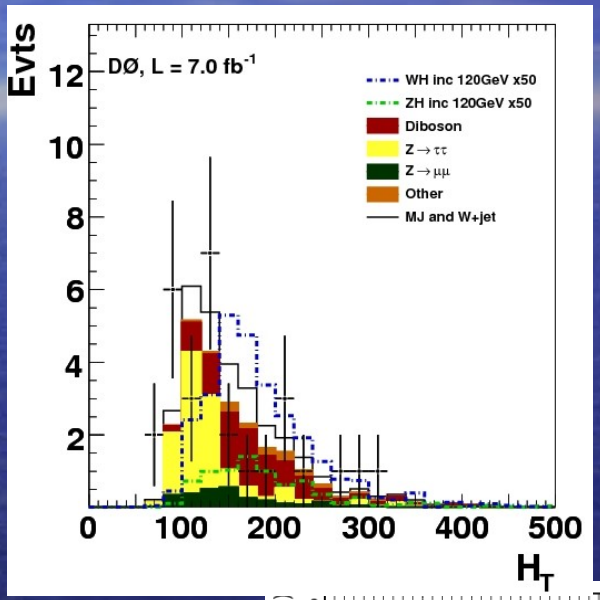
- Search for τ_h+e/μ+jets, and τ_h+μ
- Separate MVA for each channel
- Observed limit 15.7 x SM prediction for m_H = 125 GeV (exp. limit 12.8)

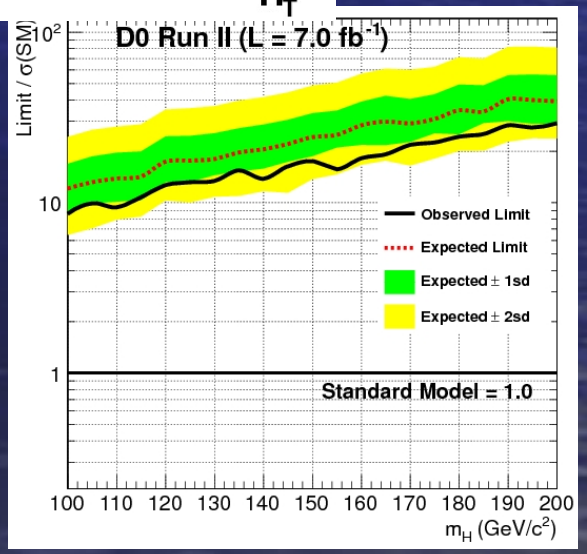


4.3 – 7.3 fb-1

DØ μττ + jets

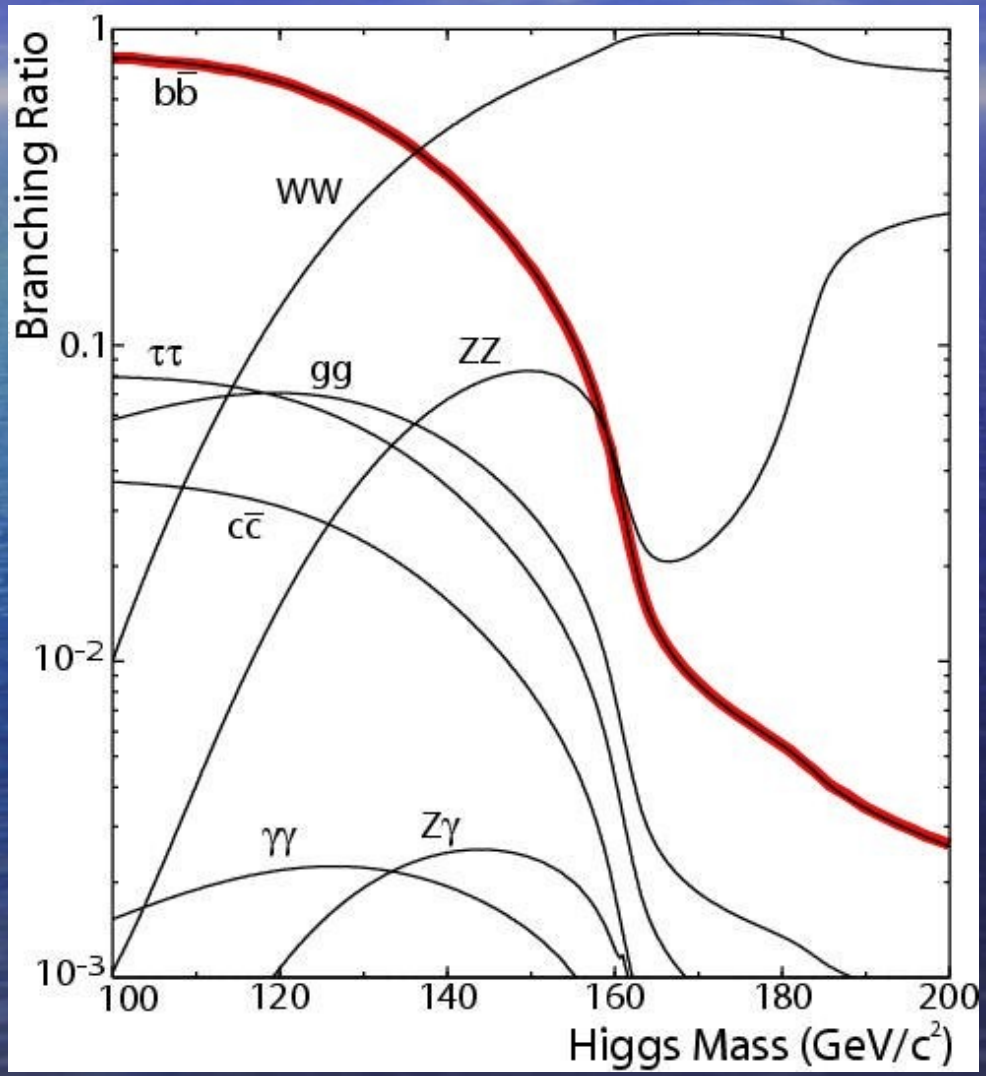
- Sensitive to H→V V, H→ττ, H→μμ
- Backgrounds: Z→ℓℓ, diboson, multi-jet
- Use reconstructed Higgs p_T as final variable
- Observed limit is 13.1 x SM σ (17.6 expected)





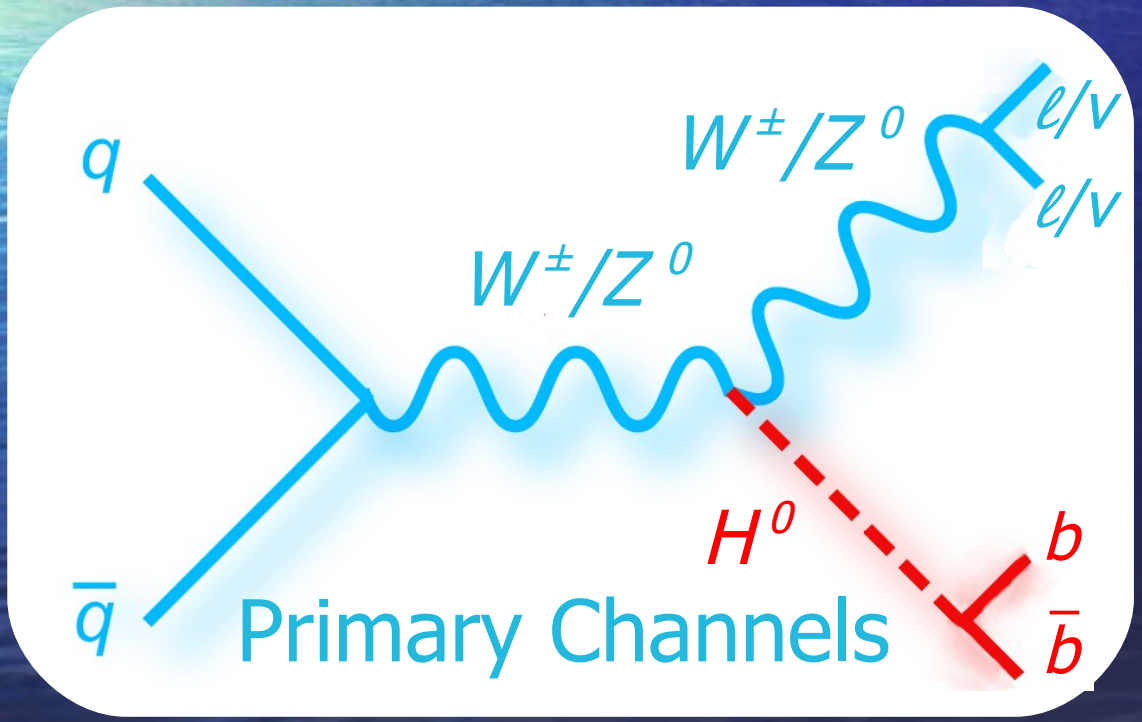
7.0 fb^{-1}

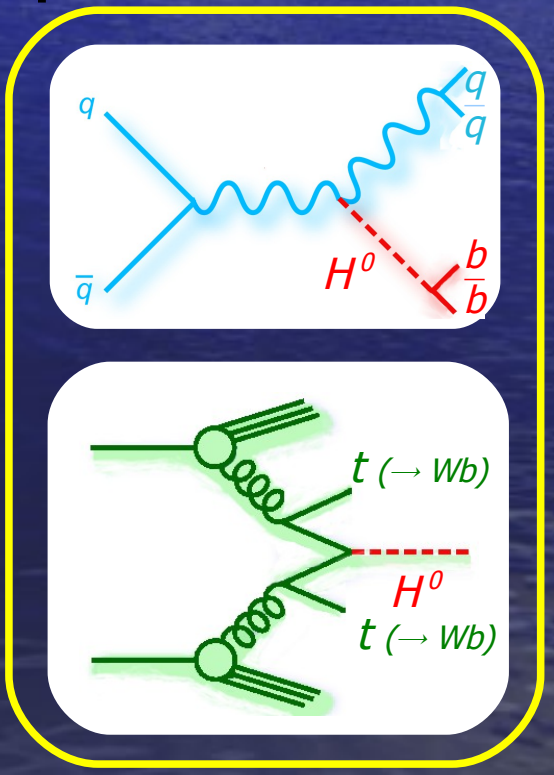
H→bb


Branching Ratio
1
0.1
10^{-2}
10^{-3}
$b\bar{b}$
WW
ZZ
$\tau\tau$
gg
$c\bar{c}$
$\gamma\gamma$
$Z\gamma$
100
120
140
160
180
200
Higgs Mass (GeV/c^2)

H→bb

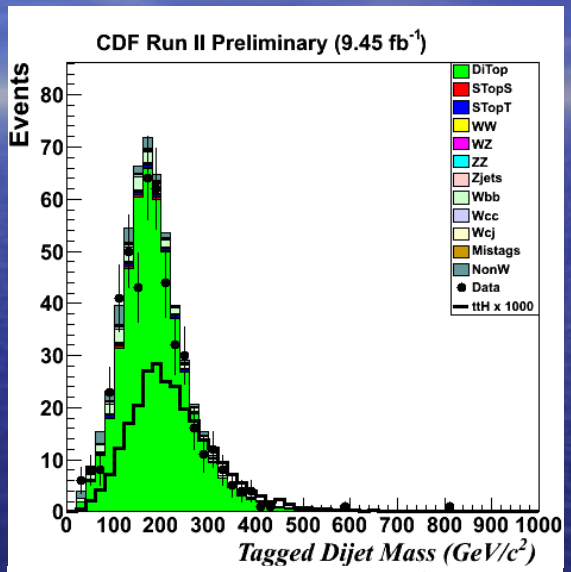
- Extremely rewarding – and challenging – analysis channel
- Use associated products to suppress MJ

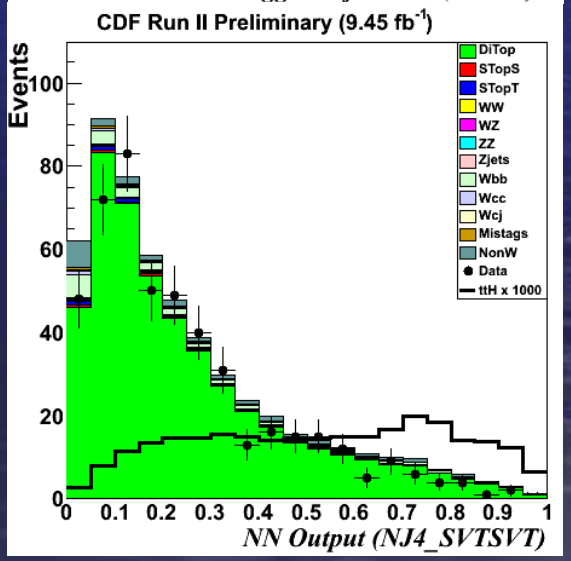




CDF Htt→bb + jets + X

- Search for two b-jets + top decay products
- Very large tt background: train NN to identify signal events
- Multiple jet pairs: combine di-jet masses in NN

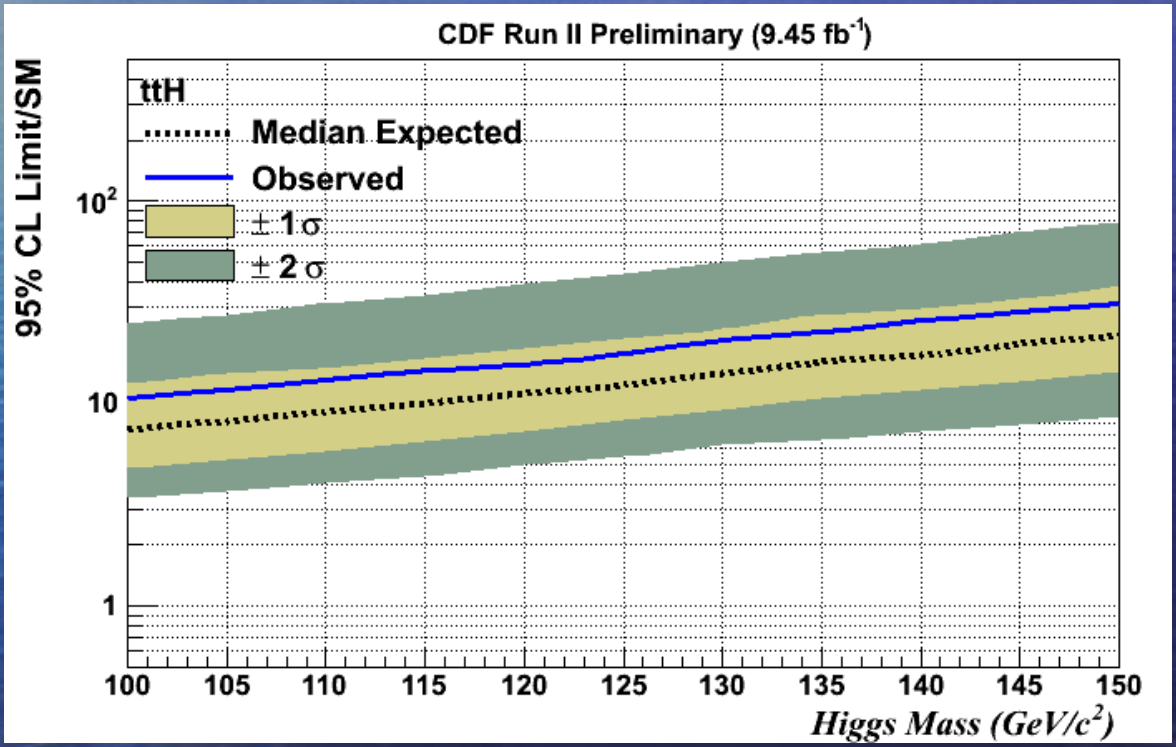




9.45 fb^{-1}

CDF Htt→bb + jets + X

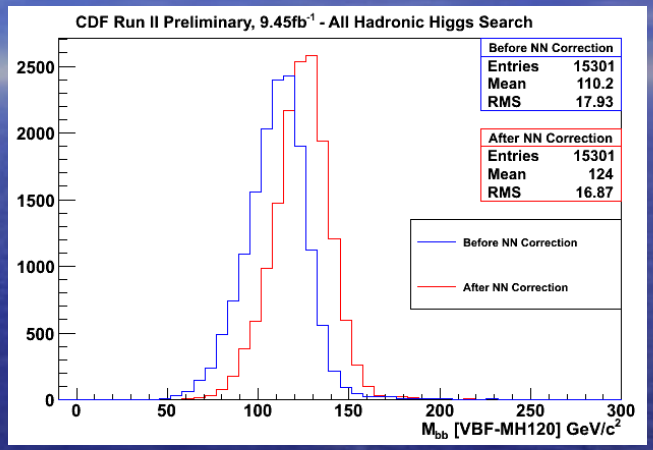
- NN response used to set cross-section limits

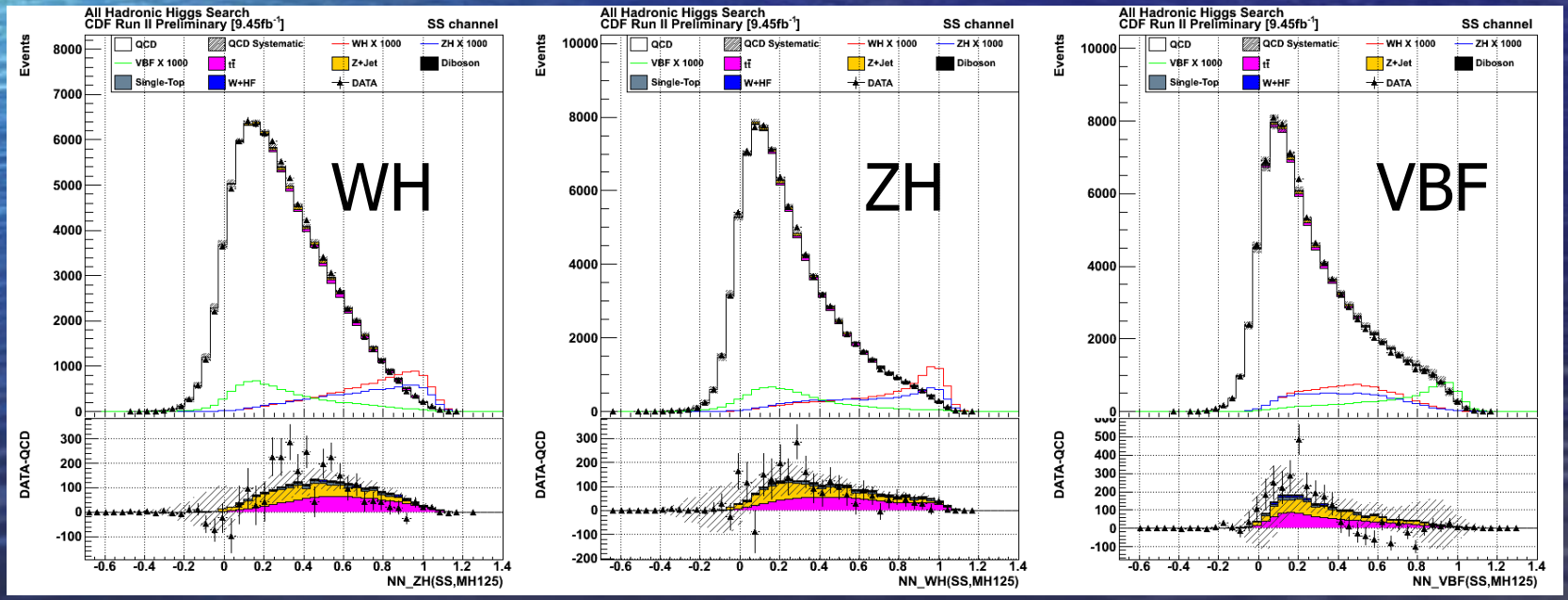


- Observed limit is 17.6 times SM Higgs cross section at 125 GeV (12.36 expected)

CDF (V/qq) H→qqbb

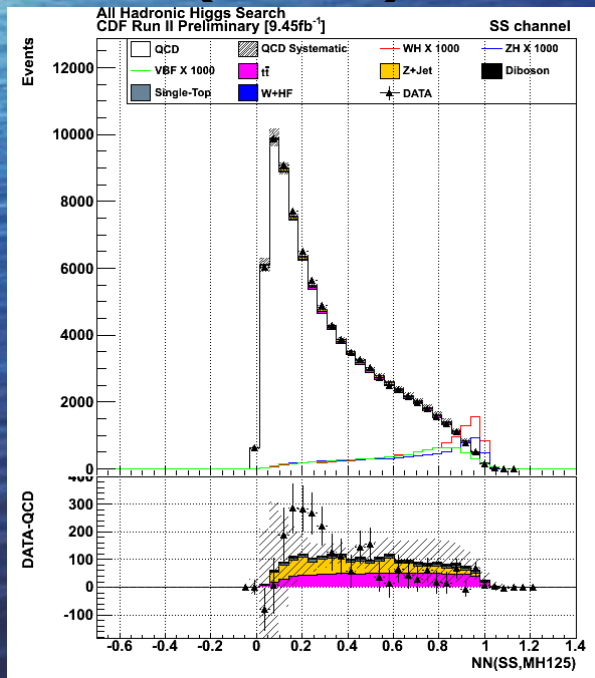
- All-hadronic final state
  - b-tagging and jet width measurement reduce bkg.
- NN's suppress background

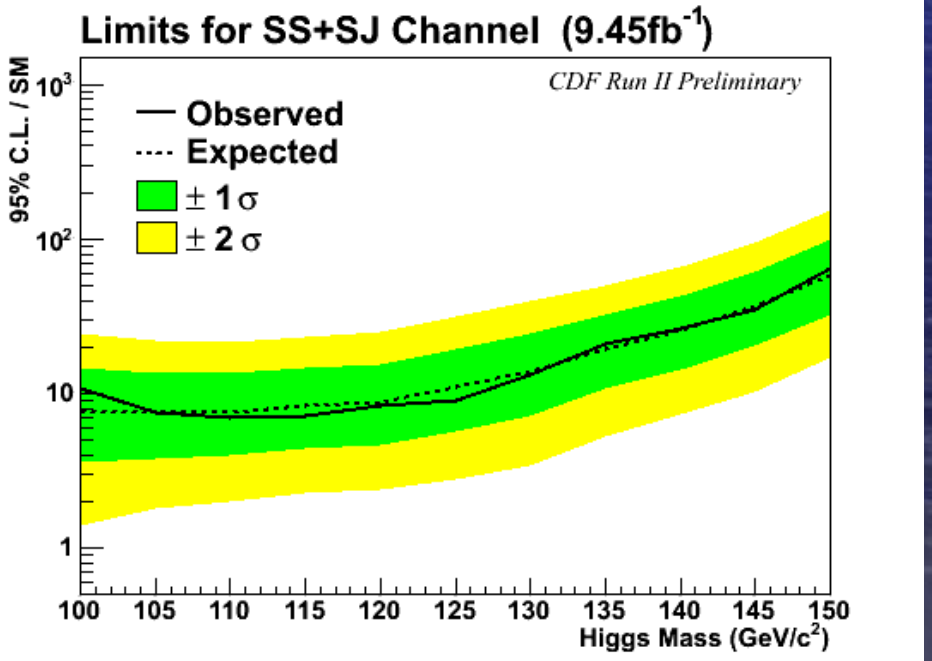




CDF (V/qq) H→qqbb

- Super-Discriminant trained on response of WH, ZH and VBF NN's
- Observed (expected) cross section limit is 9.0 (11.0) x SM





Summary of Results

Channel	Limit at 115 GeV		Limit at 125 GeV		Data Analysed
	Obs.	Exp.	Obs.	Exp.	
CDF $H\to\gamma\gamma$	12.7	10.6	12.2	10.8	10.0 fb^{-1}
DØ $H\to\gamma\gamma$	7.9	9.7	12.9	8.2	9.7 fb^{-1}
CDF $H\to \tau\tau$+jets	12.2	12.6	11.7	14.8	8.3 fb^{-1}
CDF $H\to\tau\tau$+ll	18.5	17.3	26.5	23.3	6.2 fb^{-1}
DØ $H\to\tau\tau$	21.8	14.3	15.7	12.8	4.3 – 7.3 fb^{-1}
DØ $\mu\tau\tau$	10.7	14.2	13.1	17.6	7.0 fb^{-1}
CDF $ttH\to ttbb$	14.5	10.1	17.6	12.4	9.5 fb^{-1}
CDF $VH\to qqbb$	7.2	8.3	9.0	11.0	9.5 fb^{-1}

Conclusion

- Secondary channels sensitive to ~10 x SM σ
  - Included in Tevatron Higgs combination
  - Provide comparison with LHC
- Many thanks to everyone at Fermilab for the great results!

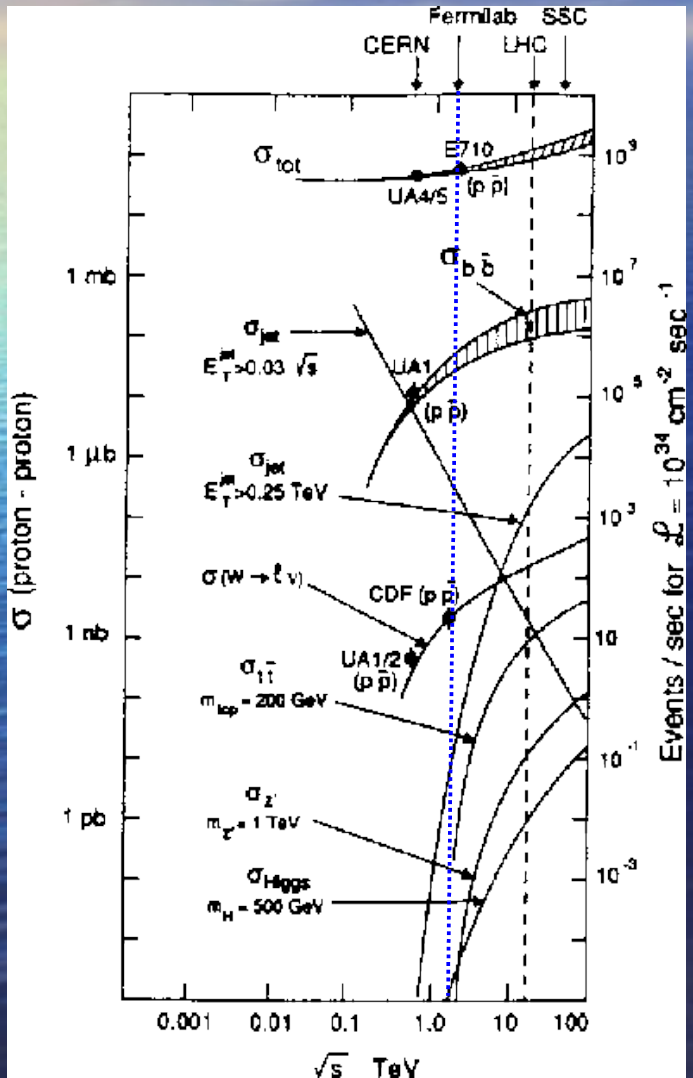
Primary channels VH $\ell\ell$bb, $\ell\nu$bb, $\nu\nu$bb coming next – stay tuned!

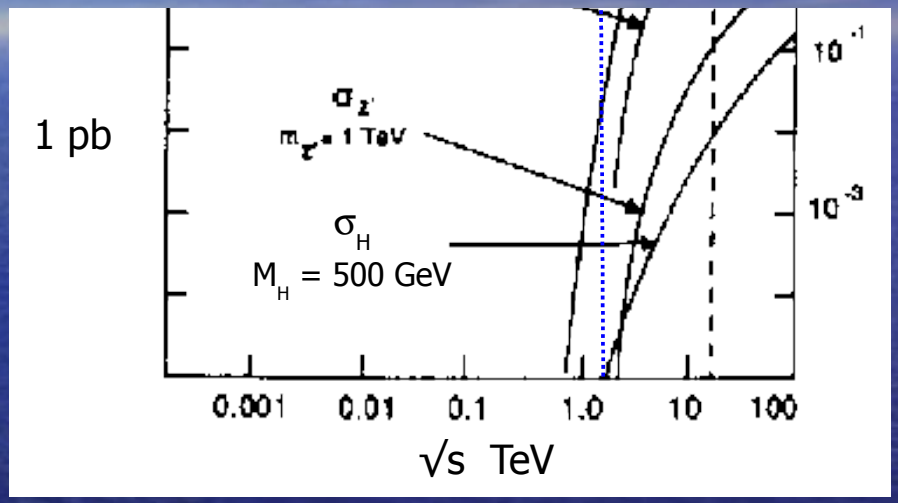
Additional Slides

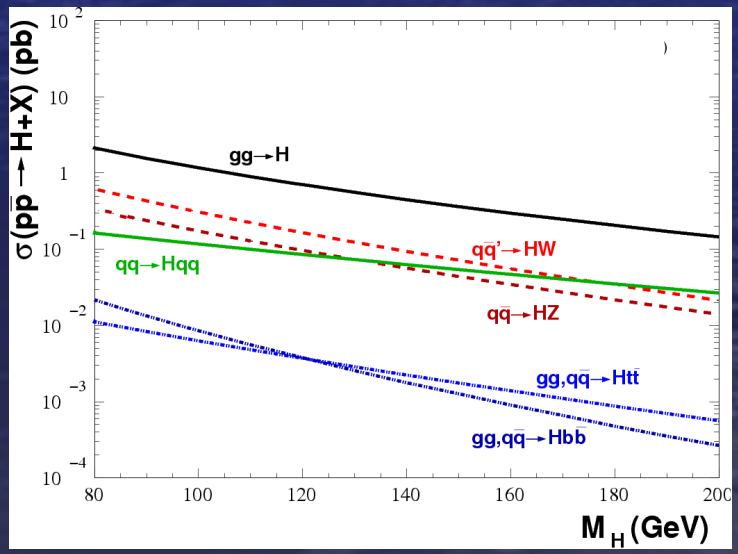
Further Information:

- CDF Higgs Results:
  - www-cdf.fnal.gov/physics/new/hdg/Results.html
- DØ Higgs Results:
  - www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm
- Tevatron New Phenomena & Higgs Working Group:
  - http://tevnphwg.fnal.gov/

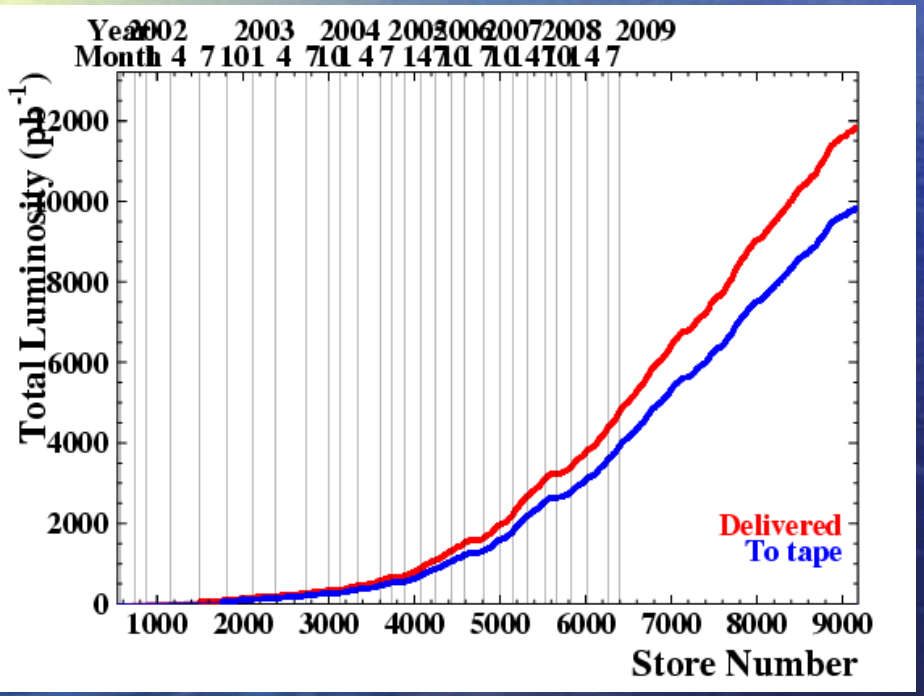
Higgs Cross-Section at Tevatron

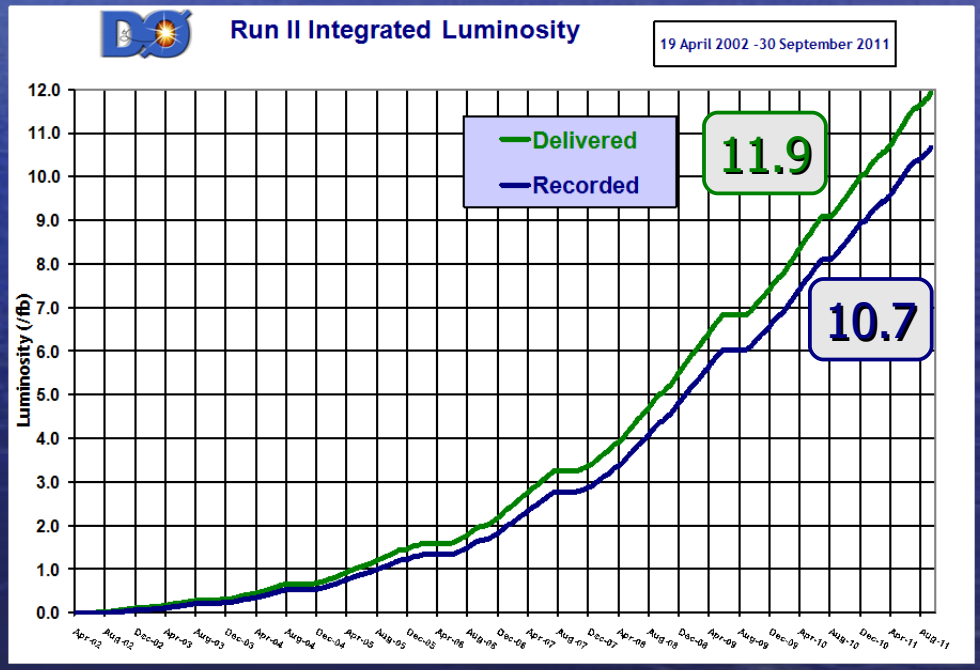




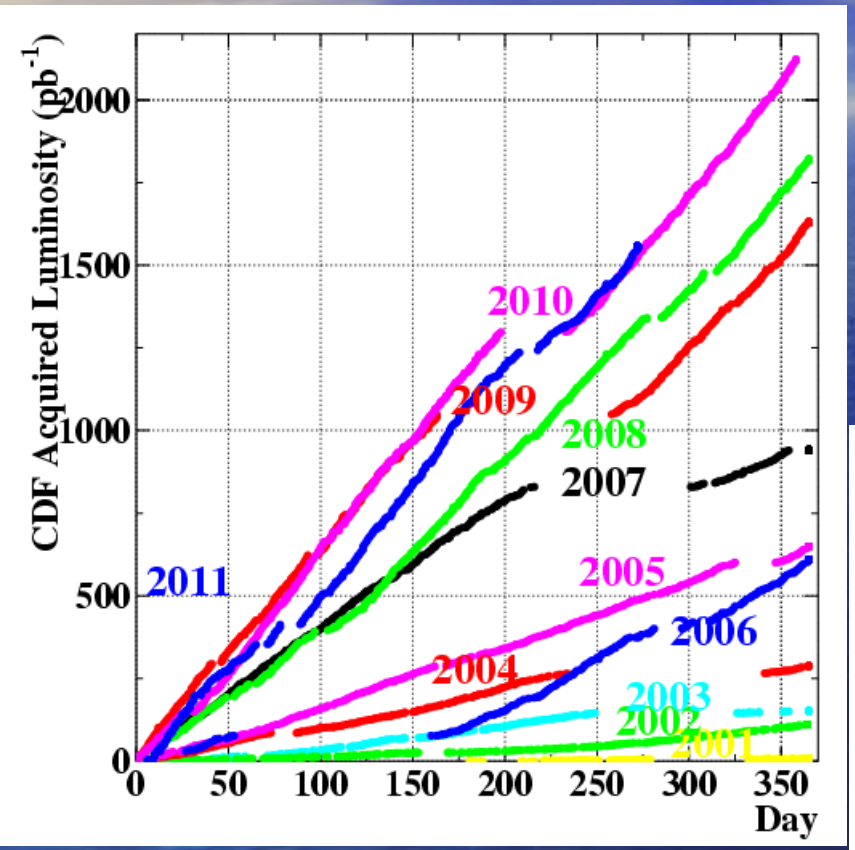


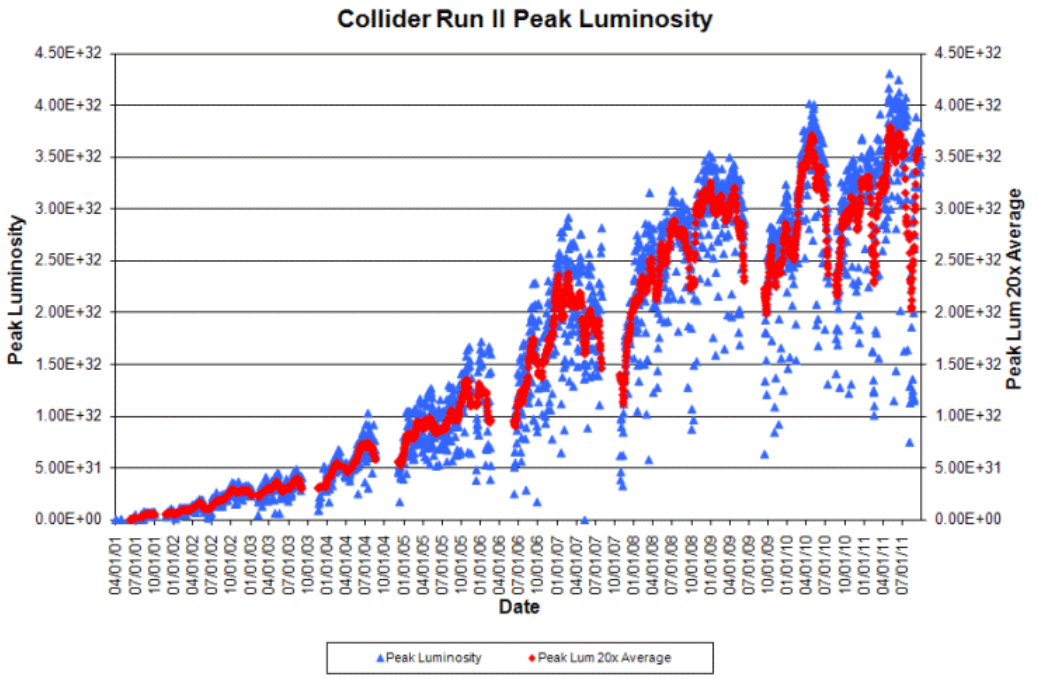
Tevatron Performance



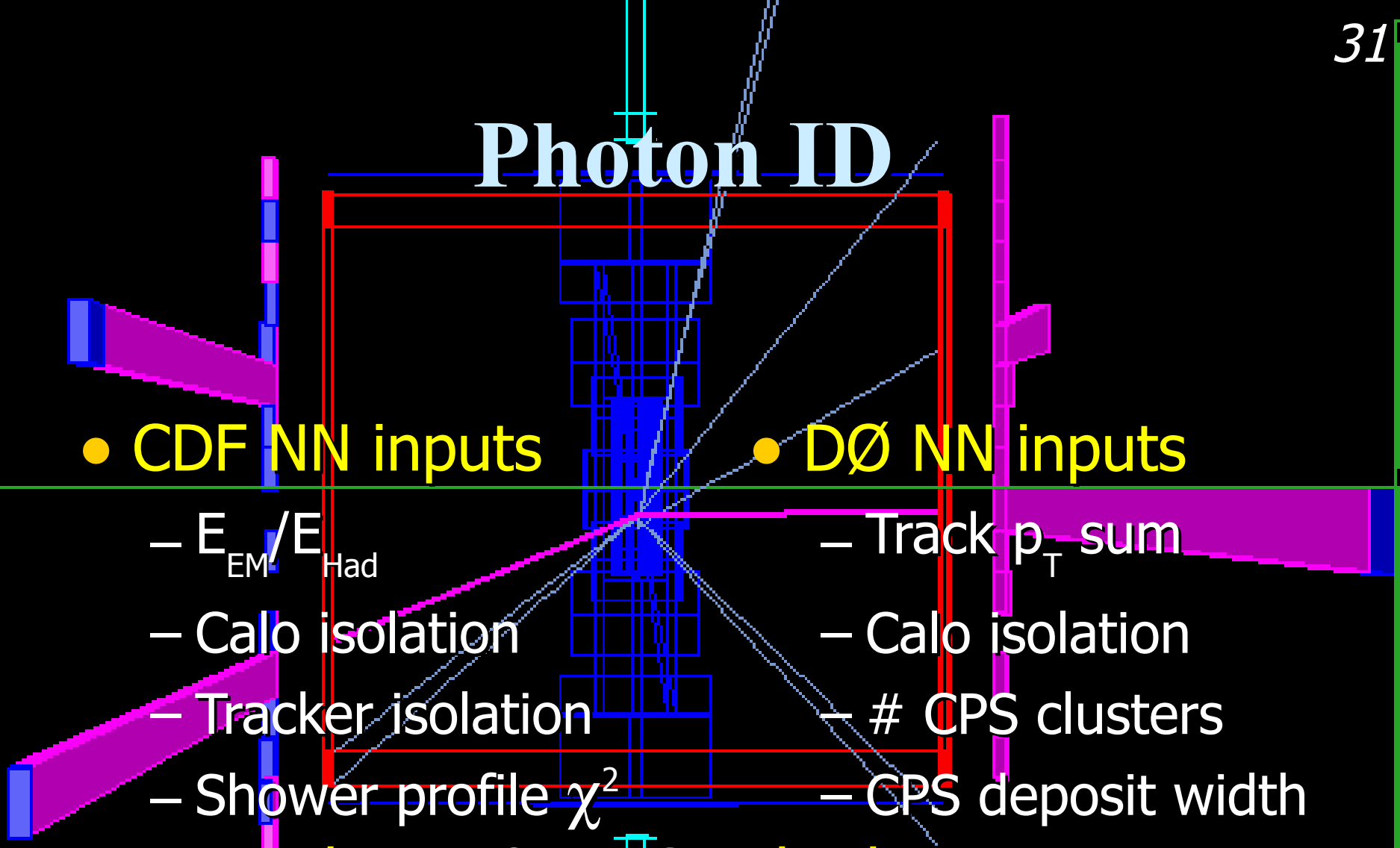


Tevatron Performance





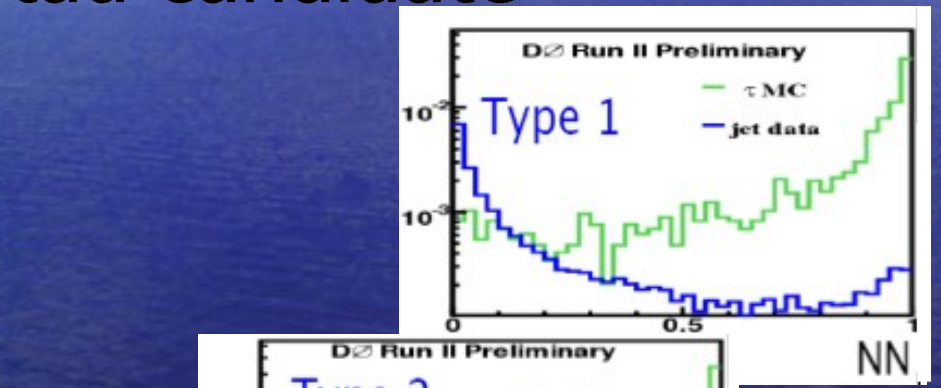
Photon ID

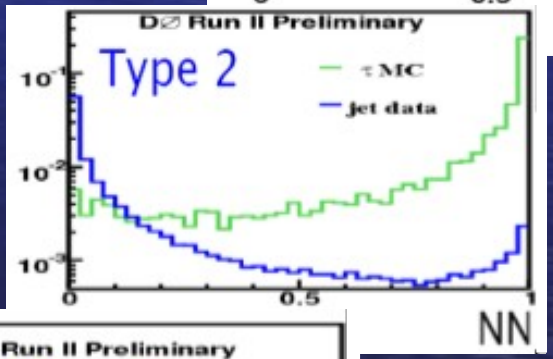


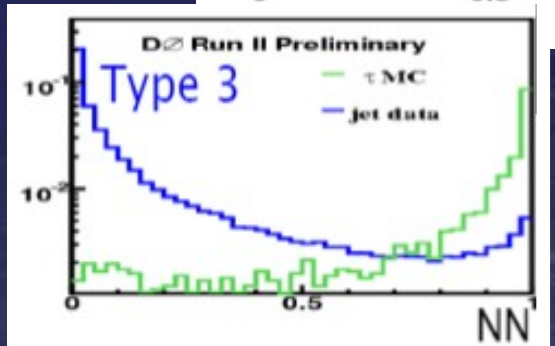
- CDF NN inputs
  - E_{EM}/E_{Had}
  - Calo isolation
  - Tracker isolation
  - Shower profile χ^2
- DØ NN inputs
  - Track p_T sum
  - Calo isolation
  - # CPS clusters
  - CPS deposit width
- Trained on γ & j MC in both cases
- Certified on $Z \rightarrow \ell\ell$+j events

Tau ID

- 3 types of Hadronic tau candidate
  - 1: $\tau \rightarrow \pi^{\pm} \nu$
  - 2: $\tau \rightarrow \pi^{\pm} \pi^{0} \nu$
  - 3: $\tau \rightarrow \pi^{\pm} \pi^{\mp} \pi^{\pm} \pi^{0} \nu$
- CDF: suite of BDTs
  - Divided by # tracks
  - And by visible P_T
- DØ: one NN for each τ type $\rightarrow$

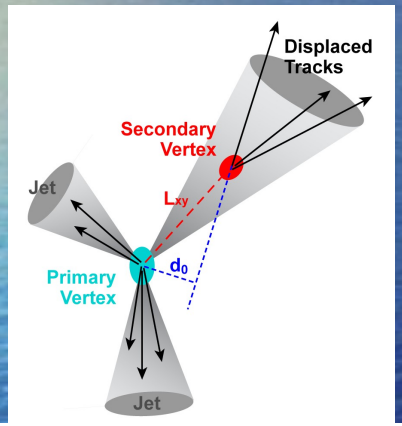


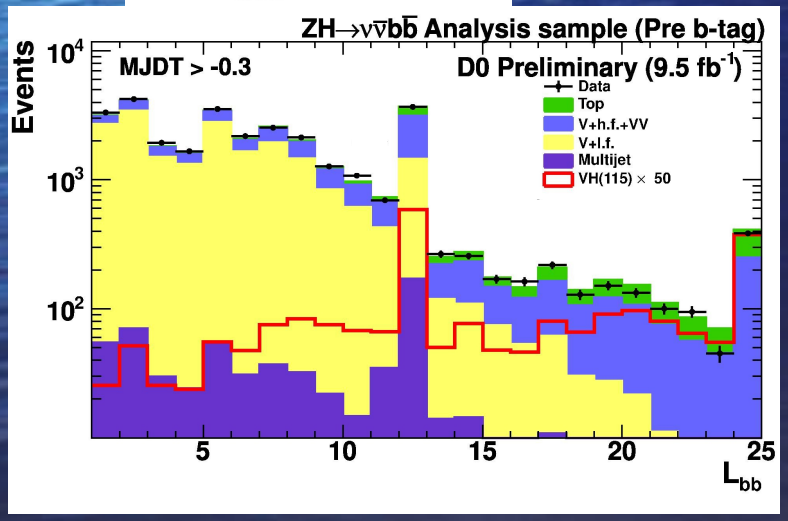




b-jet ID

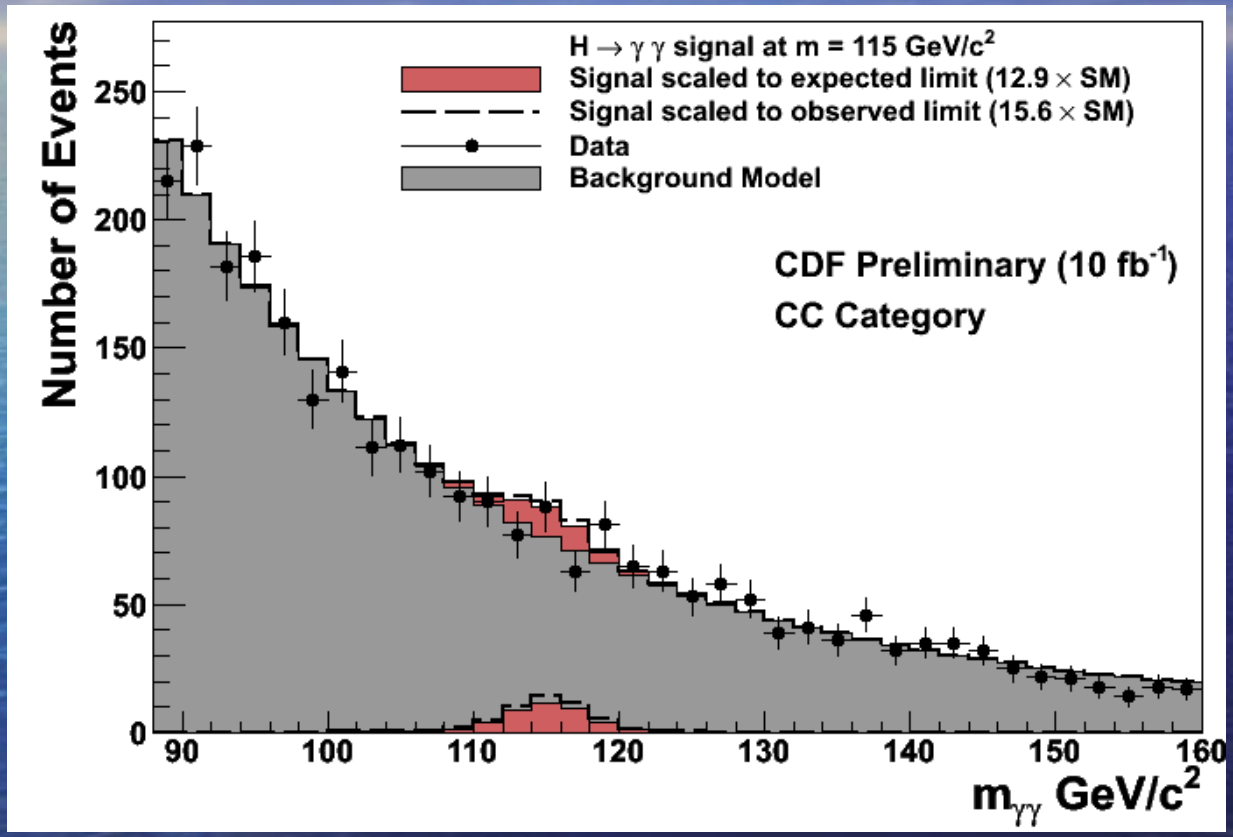
- b-jets have longer life time than light jets





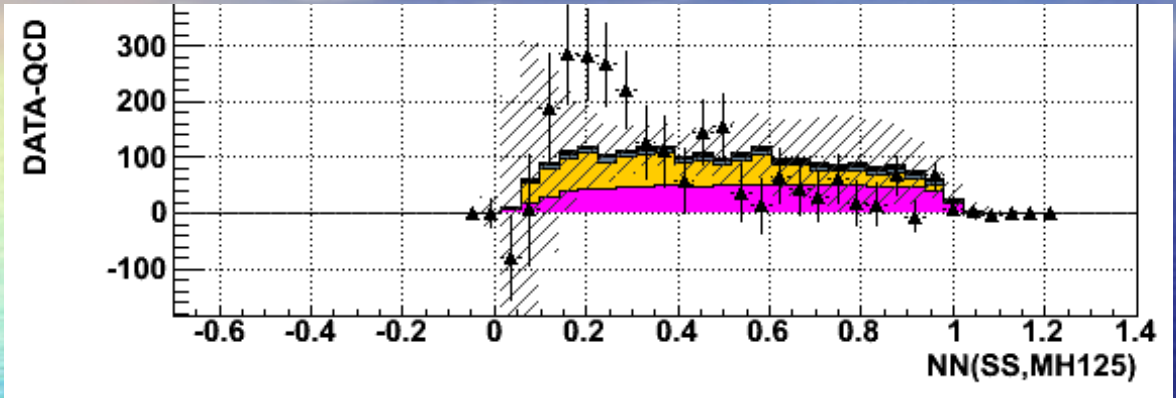
  - Several parameters indicate heavy jet:
    - Secondary vertex
    - Impact parameter
    - Soft lepton
  - CDF and DØ input these variables into MVA

CDF H→γγ: Expected Sensitivity

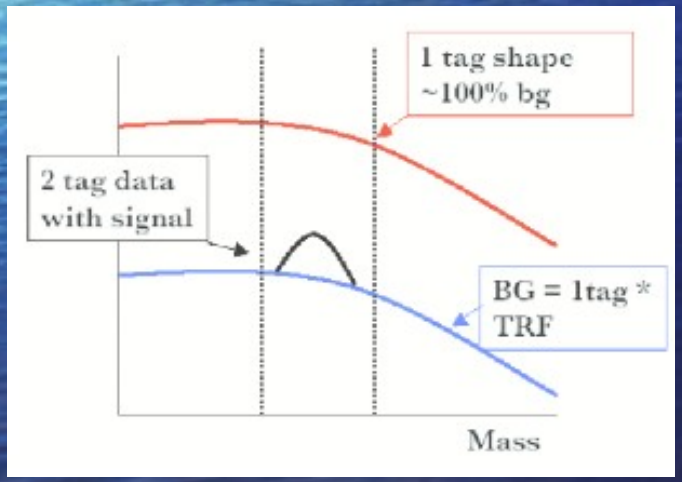


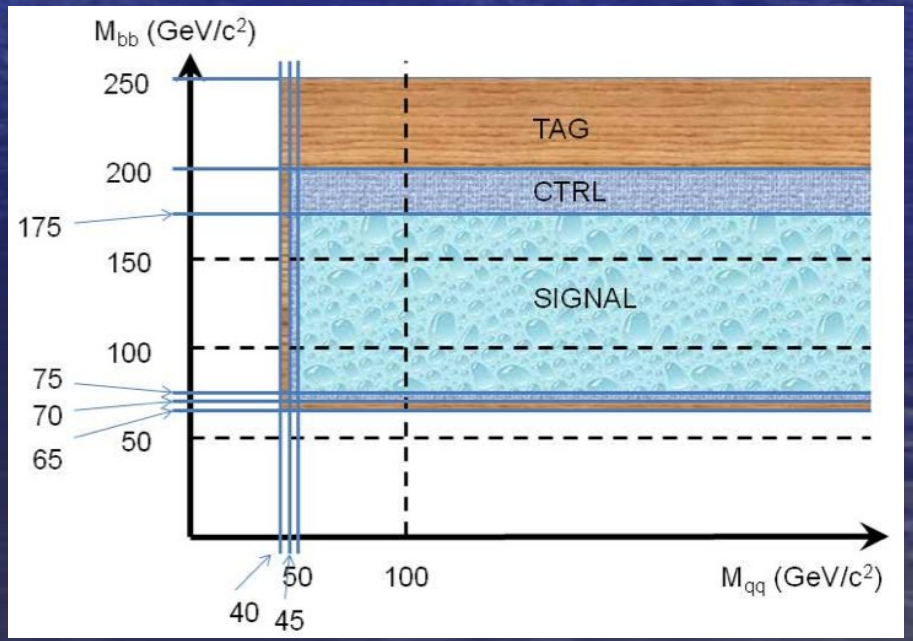
- H→γγ mass peak scaled by cross-section limit: CDF sensitive to excess this size

CDF VH→qqbb: MJ Background



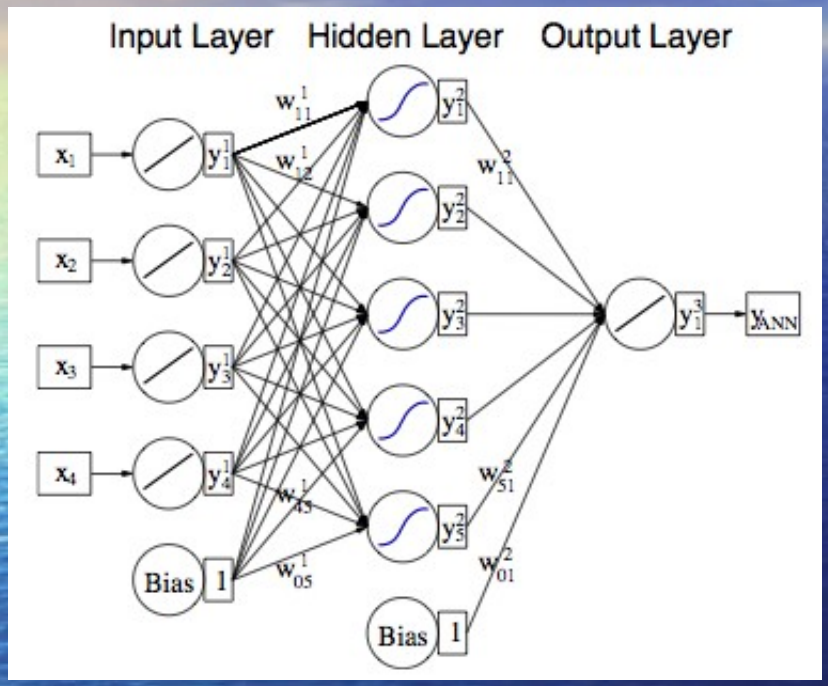
Define control regions to estimate MJ in signal region ↓



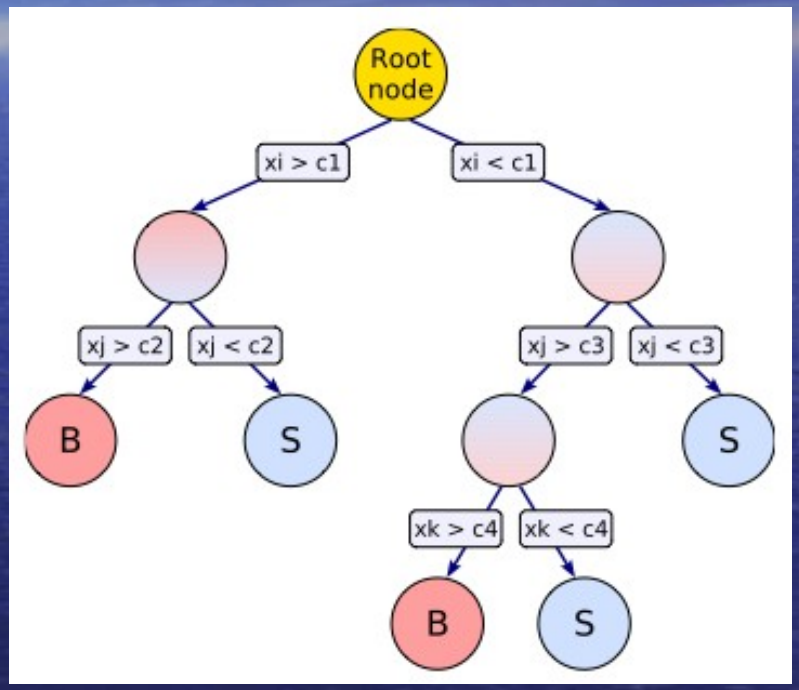


↑ MJ in 2 tag channel ~ scaled version of 1 tag channel

NN and BDT

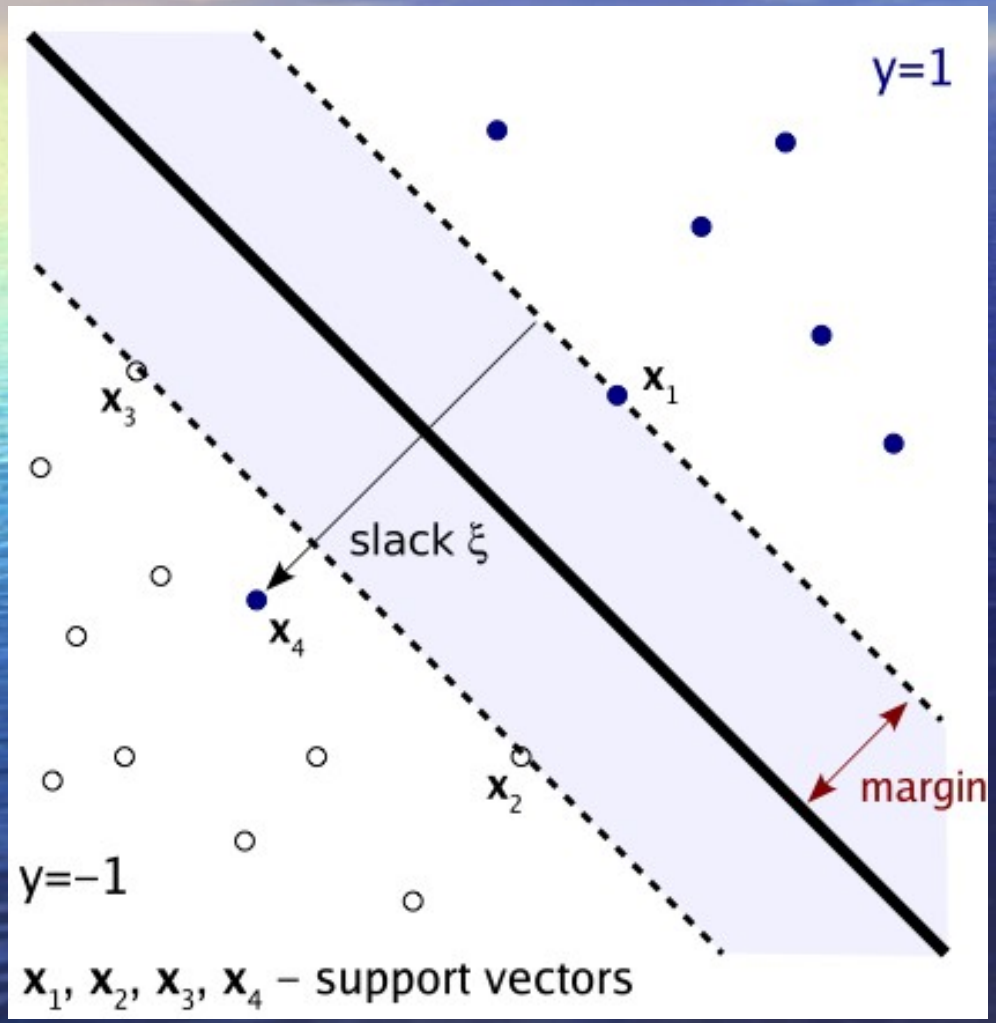


- Nodes represent linear/sigmoid functions
- Neuron weights altered to give output = target



- Cuts increase purity
- Combine many trees: weight difficult-to-identify events higher

Support Vector Machine



- Events are vectors in multi-dimensional hyperplane
- Define a separating plane using minimal set of vectors (*support vectors*)
- Move plane to maximise margin between plane and support vectors