Light SM Higgs Hunting In Challenging Channels at The Tevatron

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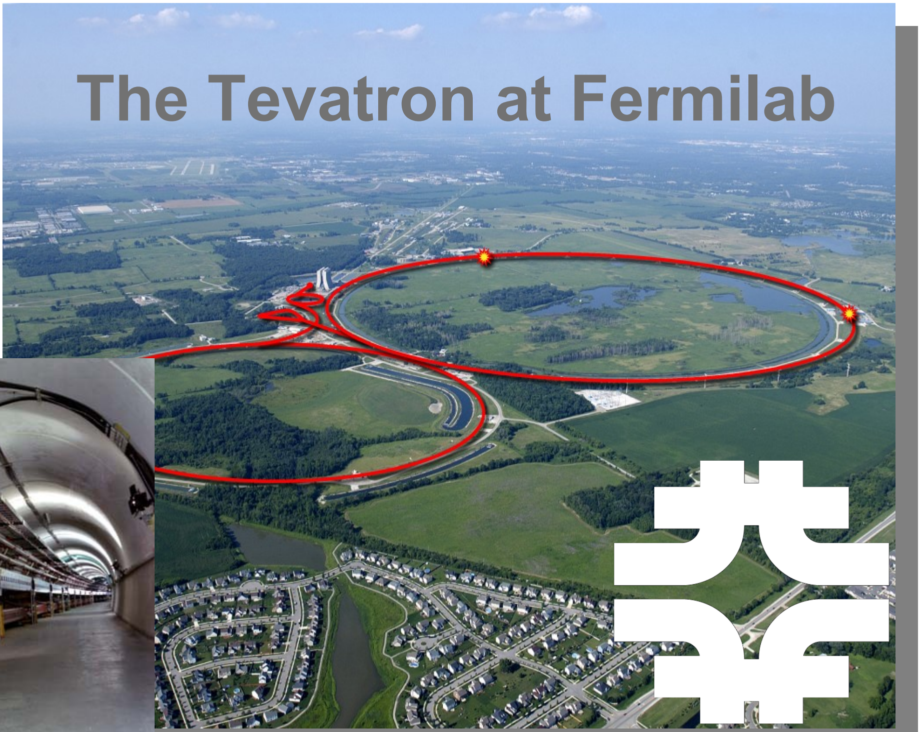
Overview

- The Tevatron Collider, CDF and DØ
- SM Higgs production at the Tevatron
- All jets search
- Searches with taus
- Diphoton searches
- Summary



The Tevatron

- Provides $p\bar{p}$ collisions at 1.98 TeV to CDF/DØ

Tevatron It seems we just *smashed* our peak luminosity record set just earlier today! Store 7747 initial luminosity = 402 ub^-1/s! WOW!

April 16 at 8:46pm via Selective Tweets · Comment · Unlike

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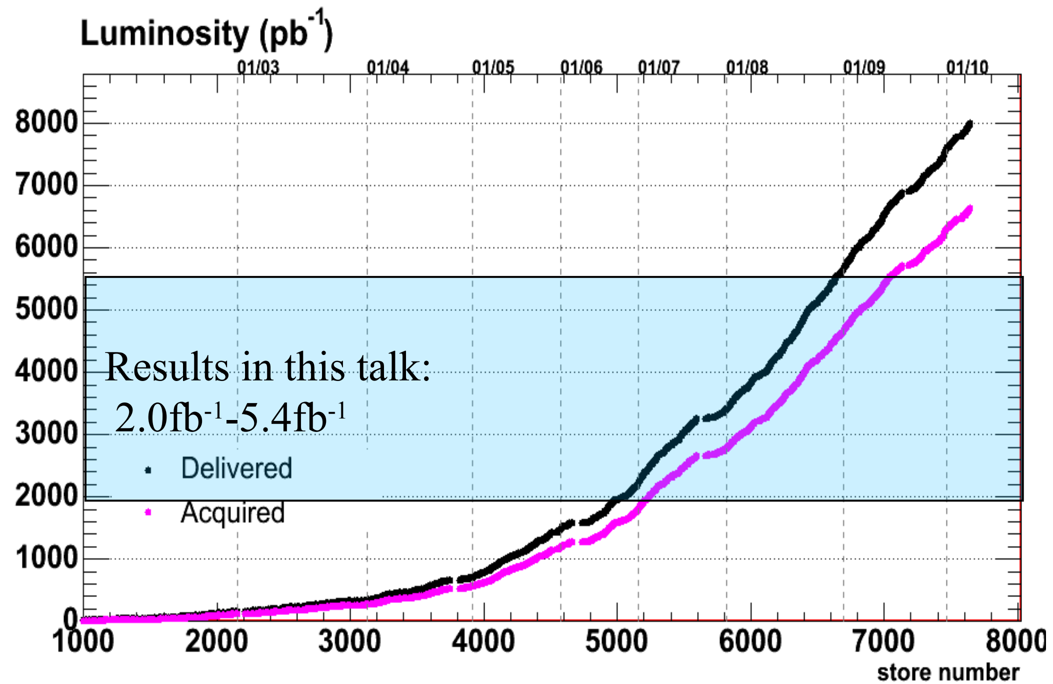
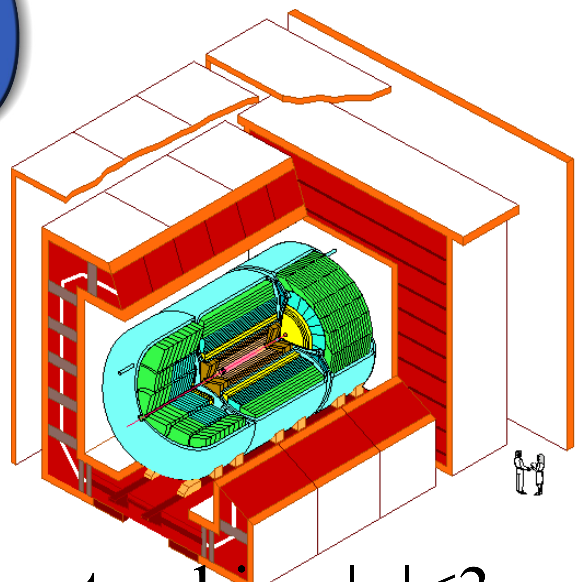
- **Setting new luminosity records each week!**
  - Peak inst. L : >400 e-30 $cm^{-2}s^{-1}$ (402 on Apr 16, 2010)

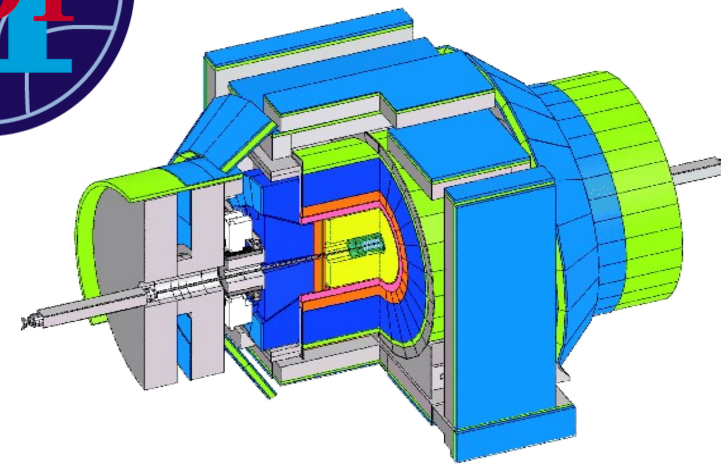


- >8 fb^{-1} Delivered/Exp.
- >7 fb^{-1} Acquired/Exp.

DØ and CDF



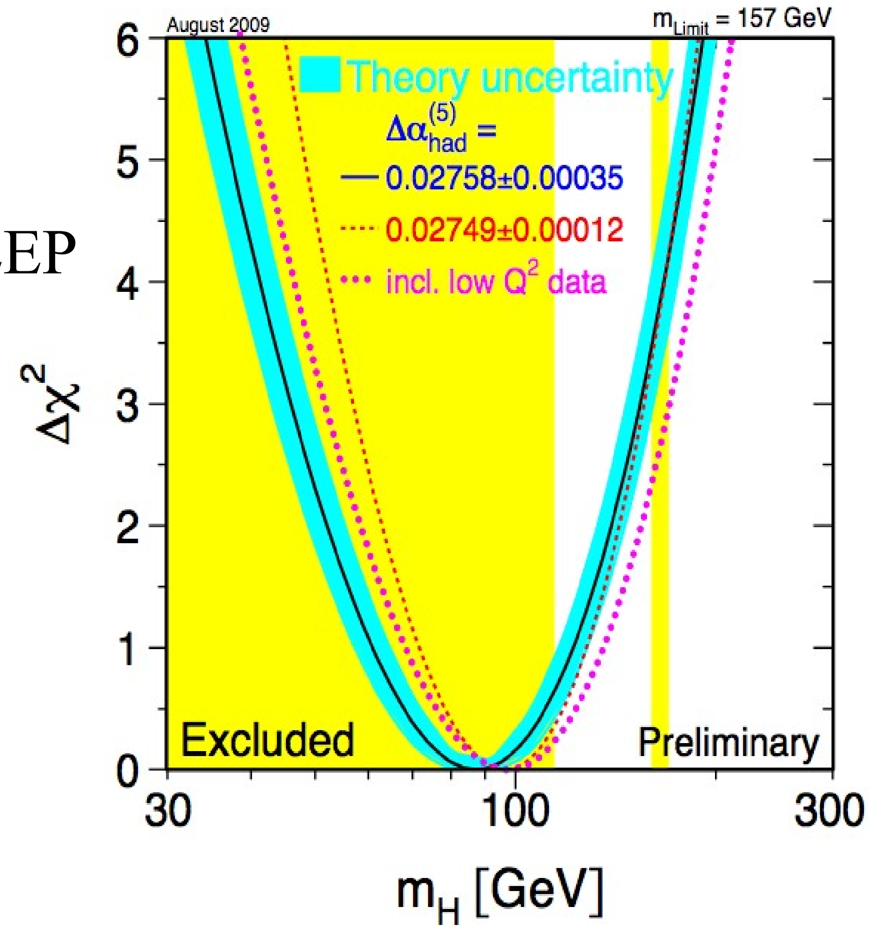
- Silicon tracking $|\eta|<3$
- Fiber tracker
  1.9 T, $|\eta|<1.7$
- LAr/DU calor. $|\eta|<4$
- Muons: $|\eta|<2$



- Silicon Tracking $|\eta|<2$-2.5
- Drift cell Tracker
  1.4 T, $|\eta|<1.1$
- Scintillator Cal. $|\eta|<3.2$
- Muons: $|\eta|<1.5$

Producing the SM Higgs at The Tevatron

- Indirect measurements show the SM favors a light Higgs with **M_H < ~154 GeV** @ 95% CL
  114 < M_H from direct searches at LEP

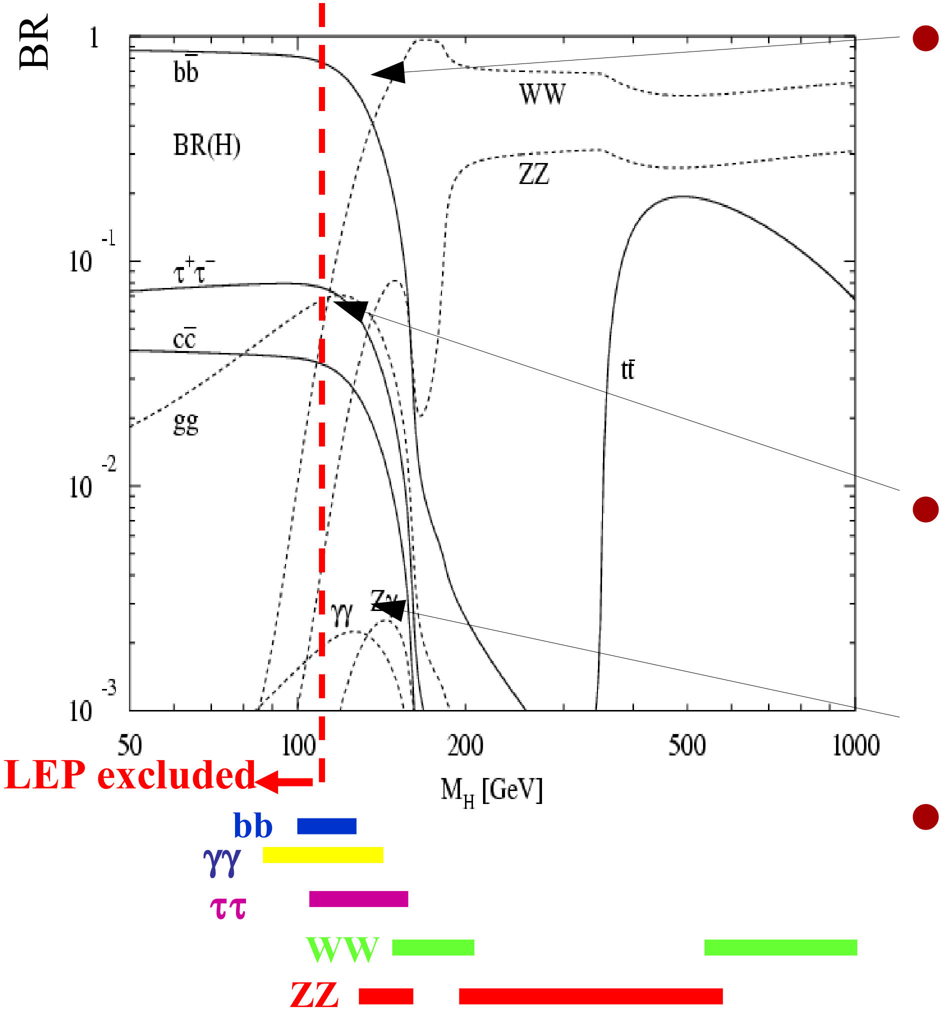


- SM(M_H = **120 GeV**) predicts
  ~2 SM Higgs bosons produced each week at the Tevatron.

- Production largest via:
  - gluon-gluon fusion ~1.2pb
  - Associated production with a W or Z boson. ~0.2pb

- Total inelastic: ~ 1 barn: **Difficult to isolate signal from SM backgrounds**

Dominant Decay Modes



Graphic lifted B. Heinemann

- $b\bar{b}$
  - •VH with e, mu in final state (previous talk)
  - •Will discuss all-jets, W→τυ
  - •BG, reco challenging at LHC
- **Ditau**
  - •Many different decay states
  - •Important for MSSM Higgs search
- **Diphotons**
  - •Low backgrounds, good reconstruction efficiency
  - •One of most likely modes for first SM Higgs evidence at LHC

Challenging channels for the light SM Higgs search at The Tevatron

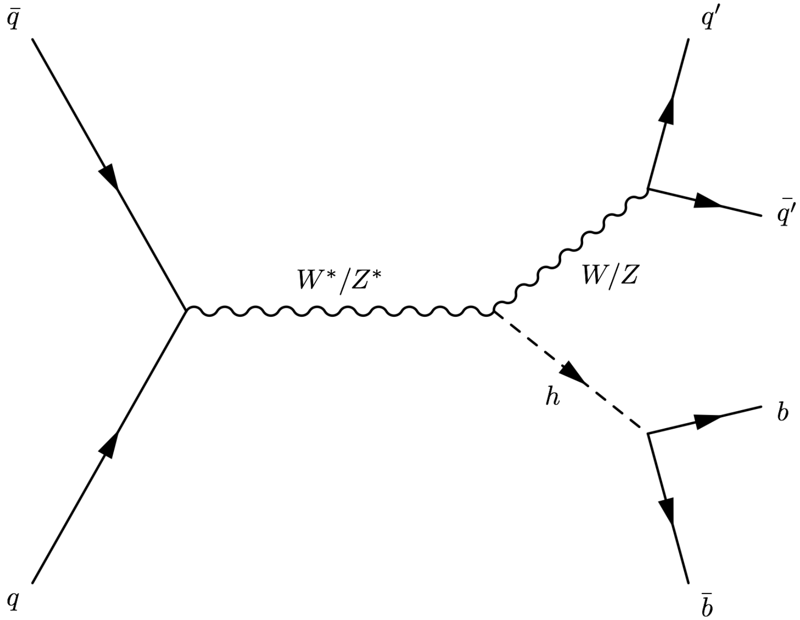
- **All Channels Discussed Here have sensetivities ~20 >> Combo**
  - •Individually don't contribute much (add as ~inverse S^2)
  - •Sum: 20/√6 ~ 8.2xSM
    - **•Together like a primary channel!**
- They create a challenging environment for developing experimental techniques
  - •Can be applied to LHC, other channels

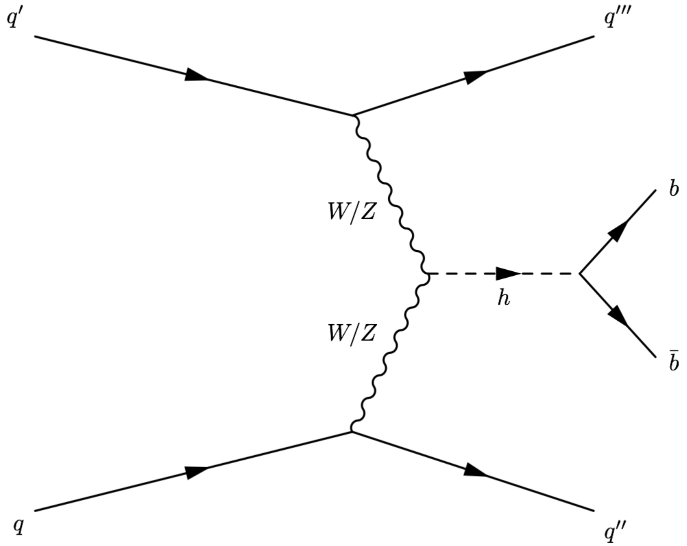
Analysis	L (fb^{-1}) Analyzed	Expected Sensitivity @MH =115 (xSM)
Tevatron Combo	2.0-5.4	1.78
CDF qqbb	4.0	18
CDF $H\rightarrow\tau\tau$	2.3	25
DØ $H\rightarrow\tau\tau qq$	4.9	18.8
DØ $WH\rightarrow\tau\upsilon bb$	4.0	22.4
DØ $H\rightarrow\gamma\gamma$	4.2	18.5
CDF $H\rightarrow\gamma\gamma$	5.4	19.4 (@120)

Why Are These Channels Interesting?

- In this talk, we'll avoid the details of the analyses, and focus on **particular techniques** of each which **can be applied to other modes, BSM or to the LHC.**
  - All-jets search
    - Modeling large QCD backgrounds
  - Searches with τs
    - ID techniques for complicated objects (hadronic τ decays)
  - Higgs decaying to photons
    - Small signal: expand acceptance
    - Descriptions of QCD background

The All-Hadronic SM-Higgs search at CDF

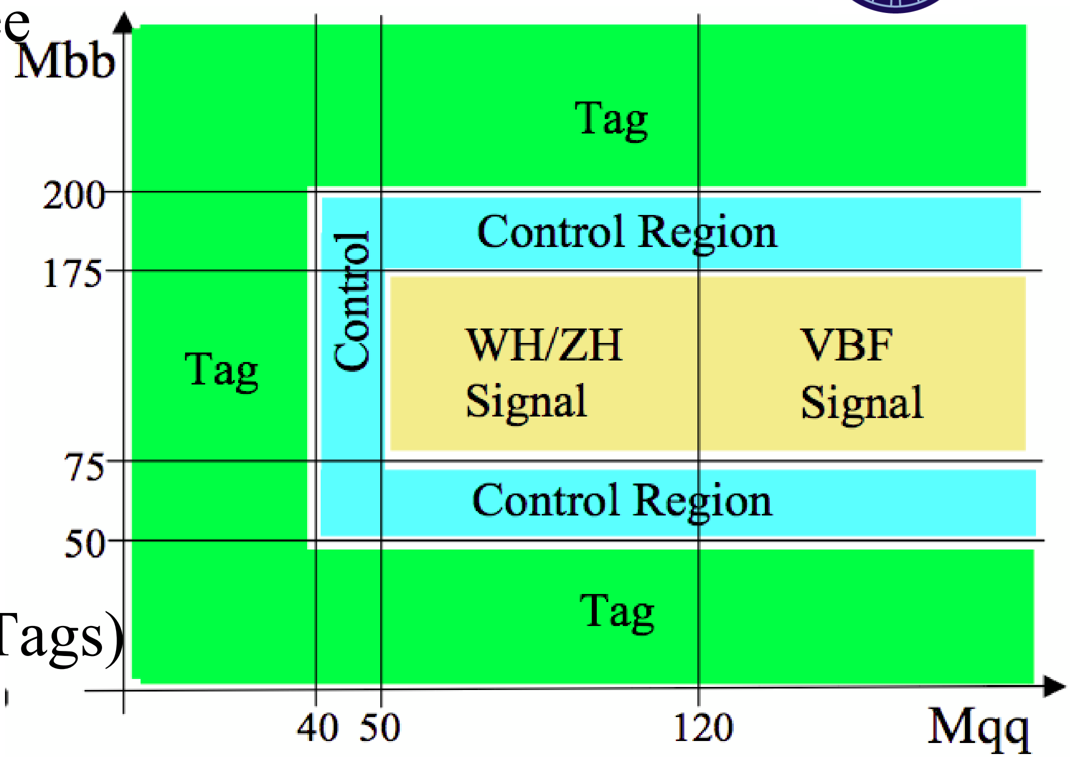




- **The Channel**
  - H→bb,
  - two additional **<u>quark</u>** jets
  - VH, VBF
  - 4 or 5 jets ET>15 GeV
  - **<u>exactly two</u>** jets are b-tagged
- **The Challenge**
  - Huge QCD backgrounds
  - Hard to model b-tags
- **Basic Tools**
  - Reduce Ditop
    - Reject events with leptons
    - Reject events with MET
  - Reduce QCD
    - Require Sum ET > 220 GeV

Estimation of the Double Tag Rate in The All-Hadronic SM-Higgs search at CDF

- Large (98% of total) QCD background requires data-based model
- **Tag rate function (TRF)** parameterizes the probability of a double b-tag assuming a single tag
    - 3D matrix: TRF(Et,eta, dR) = #2Tags/#1Tags
- TRF is measured in signal-free TAG region
    - Alternate in CONTROL for systematic estimate
- Separate TRFs used for the two b-jet tagging categories
- Validation
    - Compare Shape of Signal region 2Tags with TRF(1Tags)

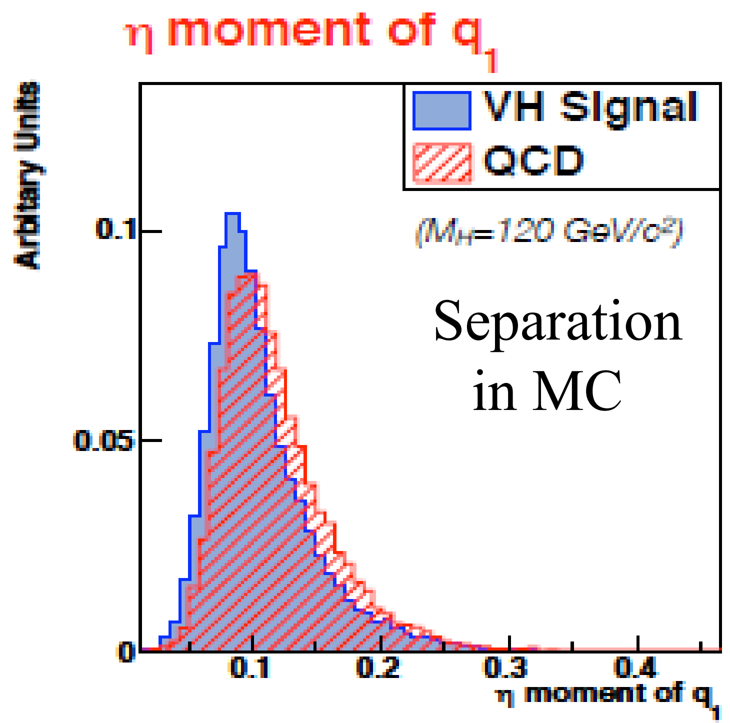


Suppression of QCD with Jet Shapes in the All-Hadronic SM-Higgs search at CDF

$$\eta\text{-moment}(<\eta>) = \sqrt{\sum_{\text{towers}} \left(\left(\frac{E_t^{\text{tower}}}{E_t^{\text{jet}}} \eta_{\text{tower}} \right)^2 - \eta_{\text{jet}}^2 \right)}$$

$$\phi\text{-moment}(<\phi>) = \sqrt{\sum_{\text{towers}} \left(\left(\frac{E_t^{\text{tower}}}{E_t^{\text{jet}}} \phi_{\text{tower}} \right)^2 - \phi_{\text{jet}}^2 \right)}$$

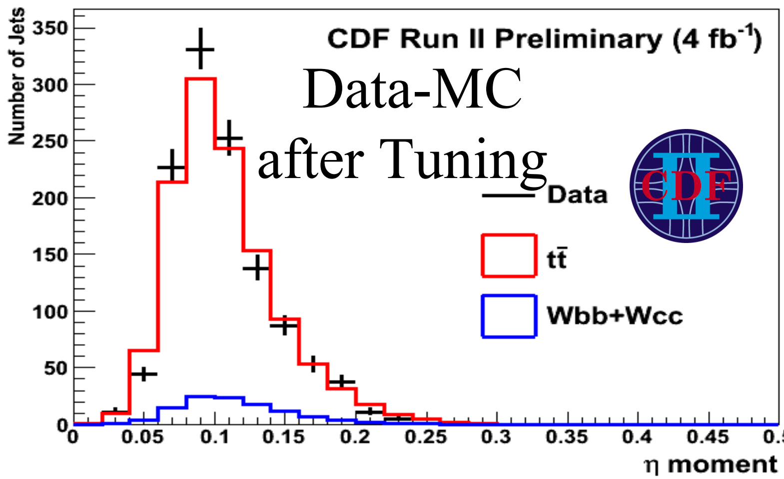
- QCD Multi-jet background:
  - Mixture of gluon & quark jets
- **Higgs signal: Only quark jets**
- **Gluon jets** tend to be **broader** than light flavored quark jets
- Use jet-width to separate gluon & quark jets
- Dependencies upon jet-ET, jet-η and number of reconstructed vertices are removed.



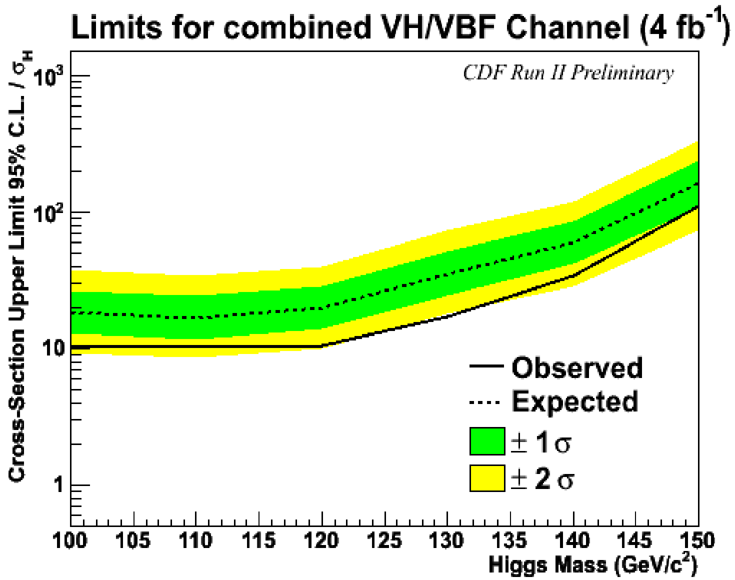
Tuning MC Jet Shapes in the All-Hadronic SM-Higgs search at CDF

Tune MC using q-enriched events tt→bbWW→bblνjj

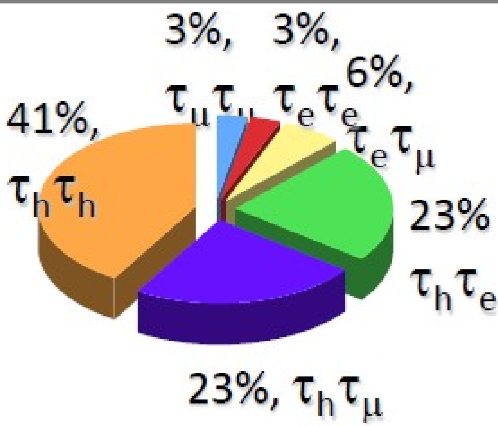
- Selected tt data events are:
  - ~86% tt
  - ~14% Wbb+Wcc+others
- Non b-jets are quark jets from W decay
- After performing corrections to the MC, the two agree well

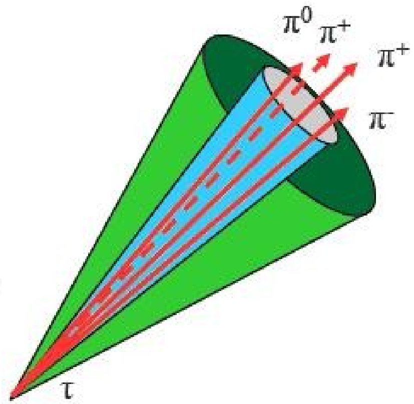


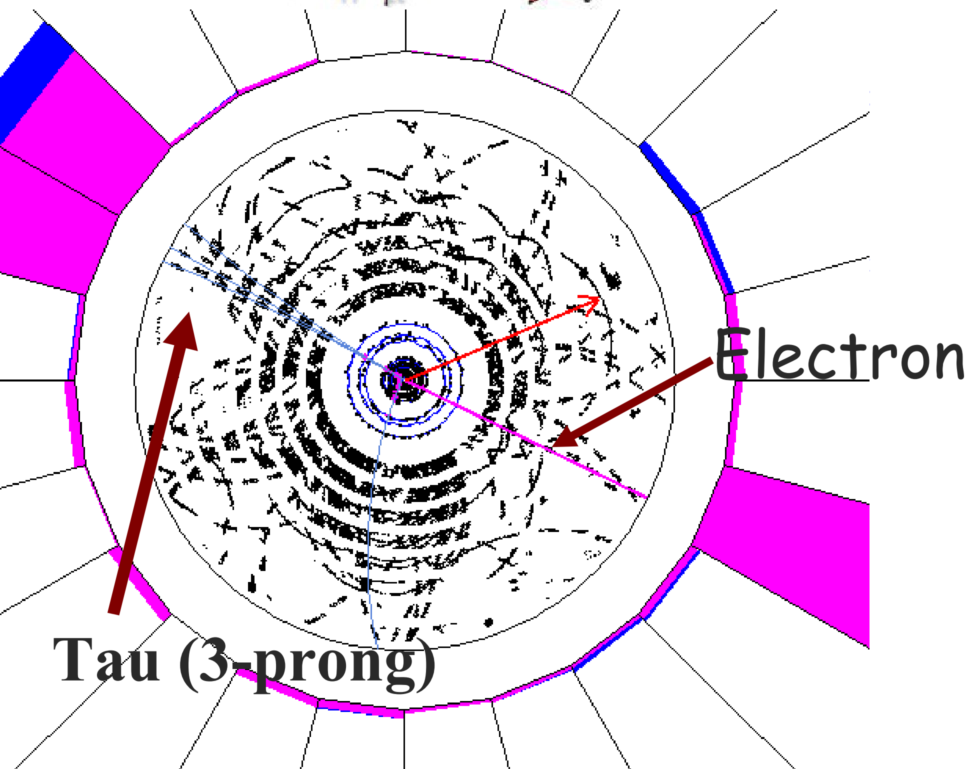
Moments become inputs to discriminant NNs



SM Higgs searches with τ leptons

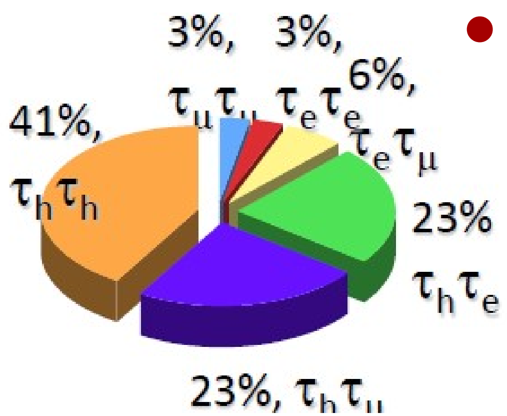


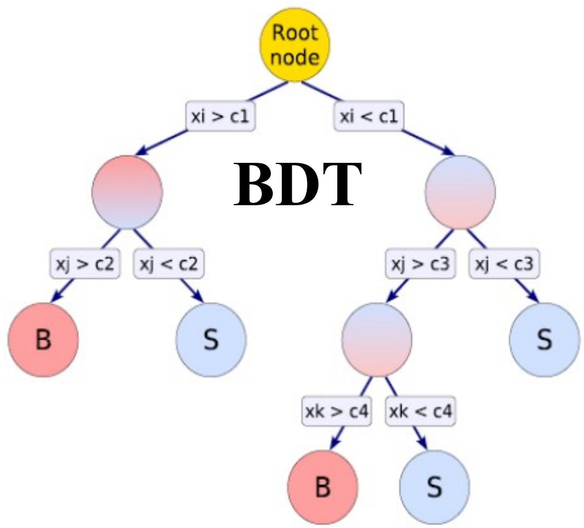




- **The Channels**
  - H→ττ, ZH(Z or H→ττ)
  - WH(W→τυ)
- **The Challenge**
  - Difficult ID
    - Multiple decay modes
    - Hadronic taus **<u>are</u>** jets, albeit narrow ones with mostly 1,3 tracks
    - Complicated definition → QCD jet fake estimates hard
  - Difficult reconstruction
    - Only part of energy visible

SM H→ττ search at CDF: Boosted Decision Tree ID



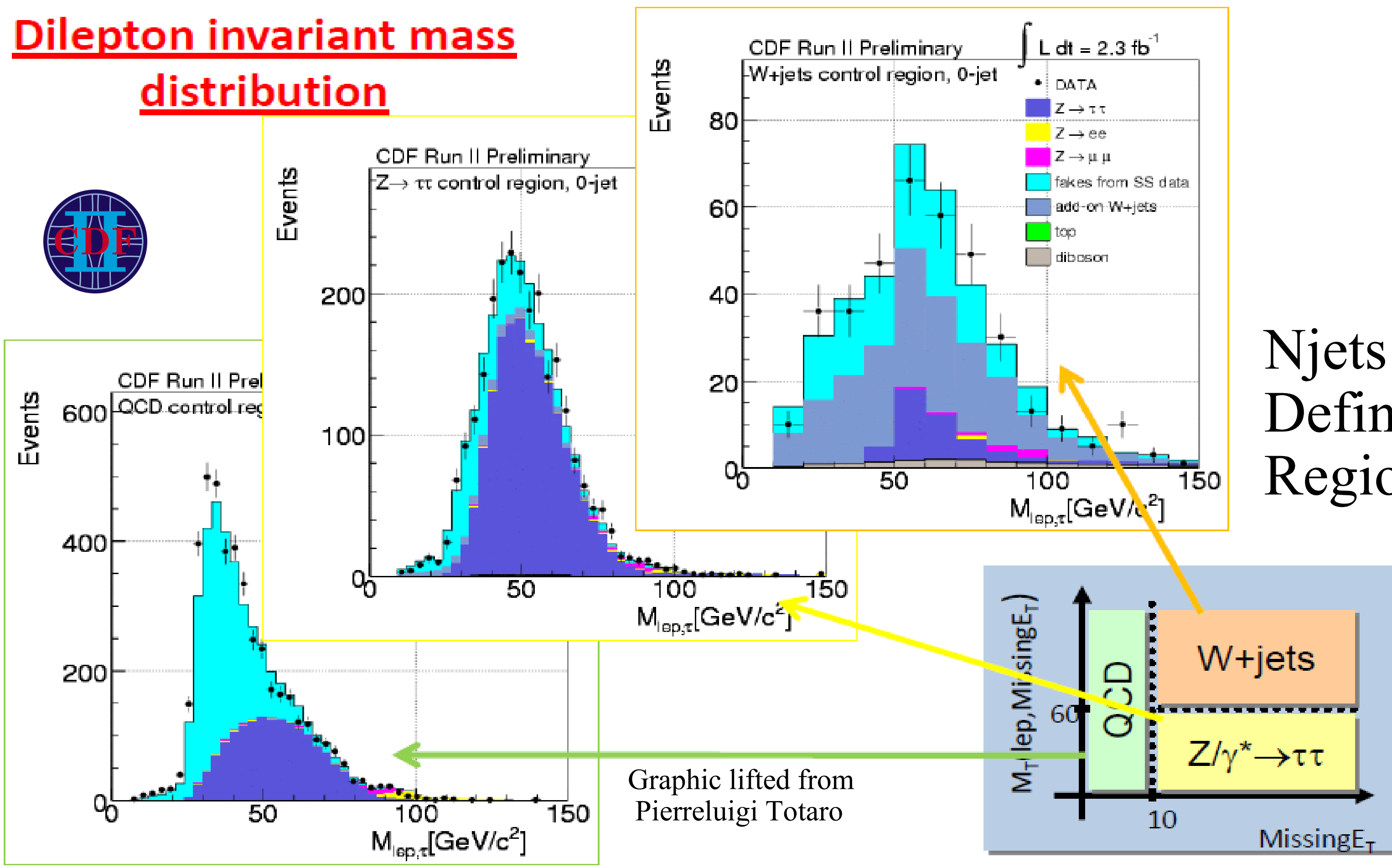


- Require
  - •1 leptonic tau, 1 hadronic tau (~46%) total
  - • 1 or 2 additional jets
    - •0 jets is enriched w/DY → control region
- Identify hadronically decaying taus using a BDT
  - •Trained: loose tau-cut samples of MC signal, jet data
  - •Sub-select training samples to flatten visible En dist.
  - •Estimate signal acceptance uncertainty by selecting subranges in visible transverse energy
  - •**Analysis with ID BDT adds 10-40% sensitivity with same lumi!**

ID BDT Acceptance Uncertainty in SM H→ττ search at CDF

- Njet Signal, sideband definition allows control of DY, Fakes, but causes reliance on JES-> Dominant systematic

Dilepton invariant mass distribution

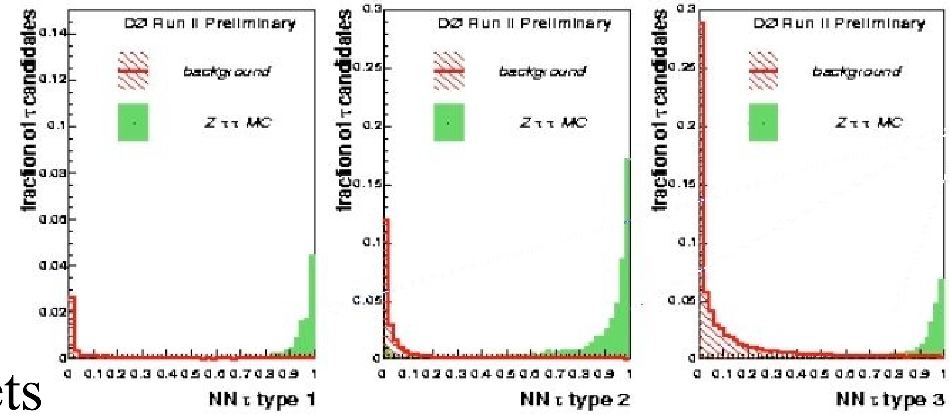


Njets = 0 Defines Control Region

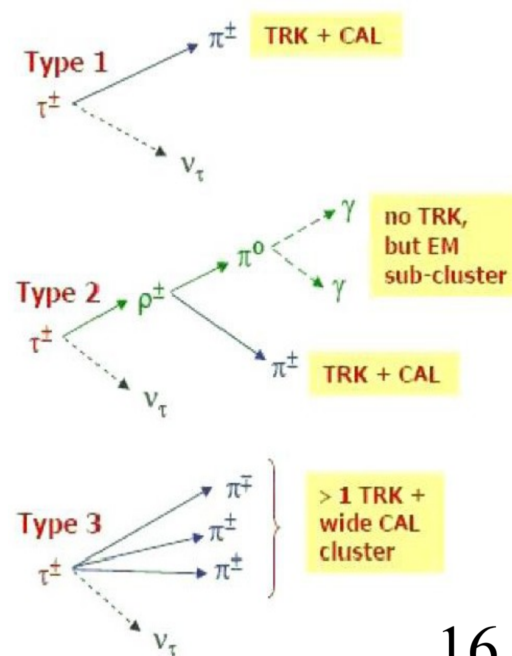
Graphic lifted from Pierreluigi Totaro

NN ID Background Acceptance SM $H\rightarrow\tau\tau$ searches at DØ

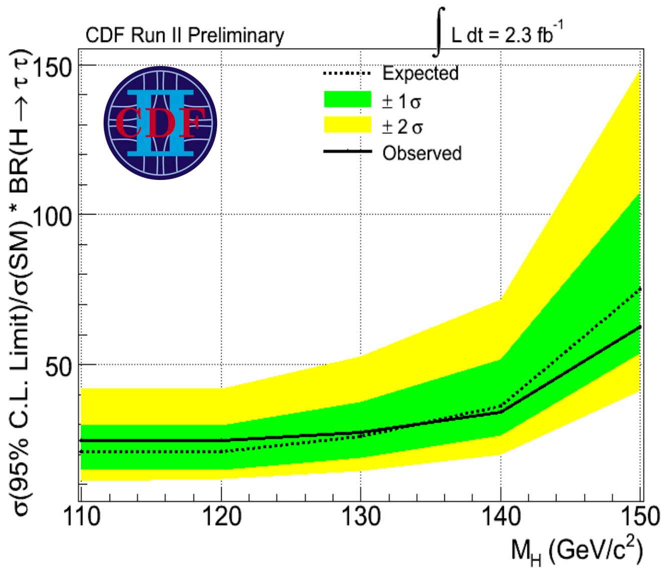
- Search in the $\tau\tau qq$ final state:
  - ZH, $Z\rightarrow\tau^+\tau^-$, $H\rightarrow qq$
  - HZ, $H\rightarrow\tau^+\tau^-$, $Z\rightarrow qq$
  - HW, $H\rightarrow\tau^+\tau^-$, $W\rightarrow qq$
  - $qq\rightarrow Hqq$, $H\rightarrow\tau^+\tau^-$
  - $gg\rightarrow H$, $H\rightarrow\tau^+\tau^-$, additional 2jets

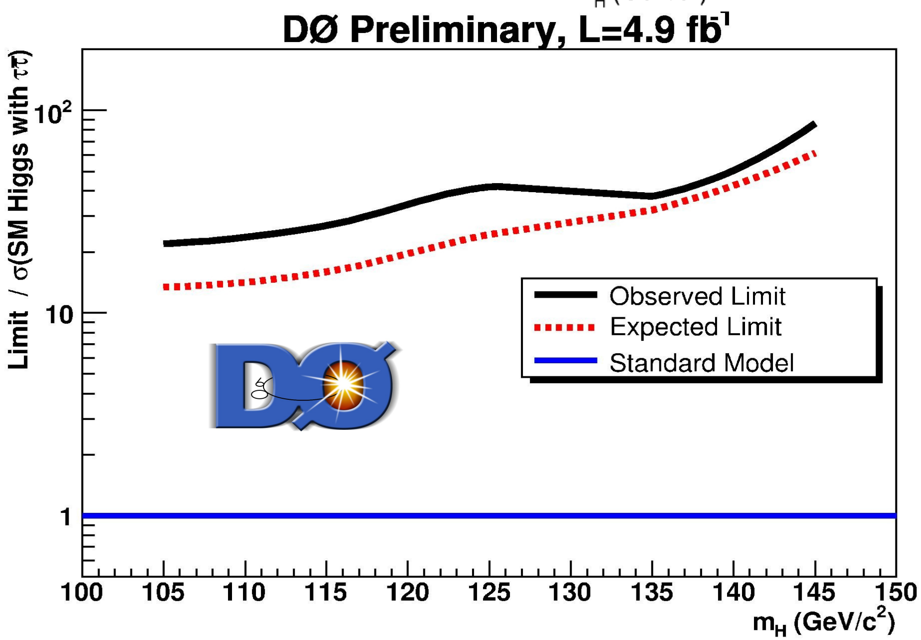


- One tau required to decay into a μ, the other hadronically
  - 3 decay modes, each treated separately
- NN trained on DY OS vs SS $\tau\mu$ candidates
  - Selection requirement for high NN output
- QCD sample selected requiring muon anti-isolated and tau NN output is in mid-range ~95% QCD, the rest largely non-tau SM
  - Additionally Measure N(OS)/N(SS) in this sample, apply to signal region SS for alternative description



Resultant Limits from SM H→ττ searches at The Tevatron

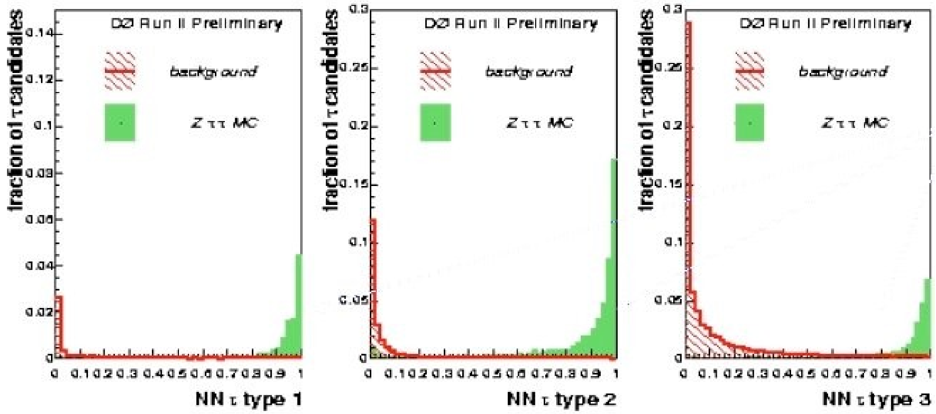


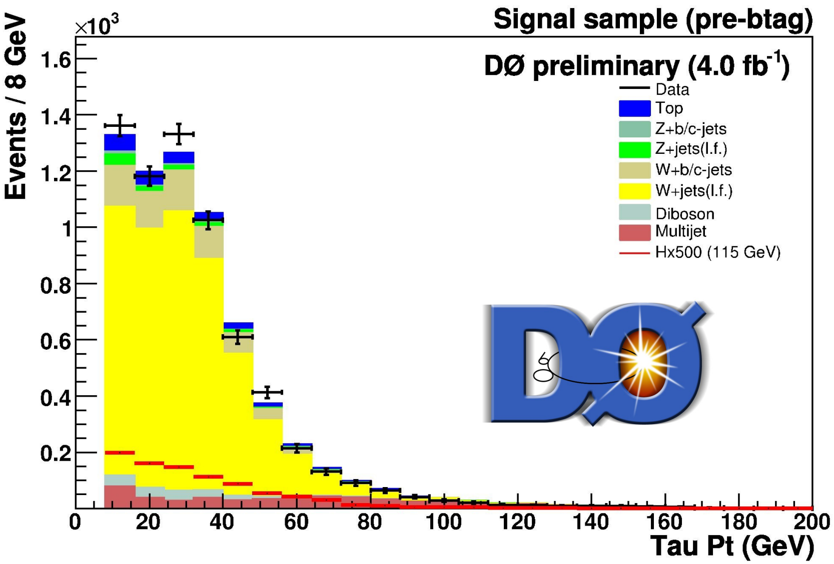


- Both Analyses use multiple specialized BDTs for signal discriminant
  - trained signal vs. different BG types (CDF)
  - trained background vs different MC signal types (DØ)

- Expected Limits:
  - CDF: 21-75 (2.3fb-1)
  - DØ: 15-71 (4.9 fb-1)

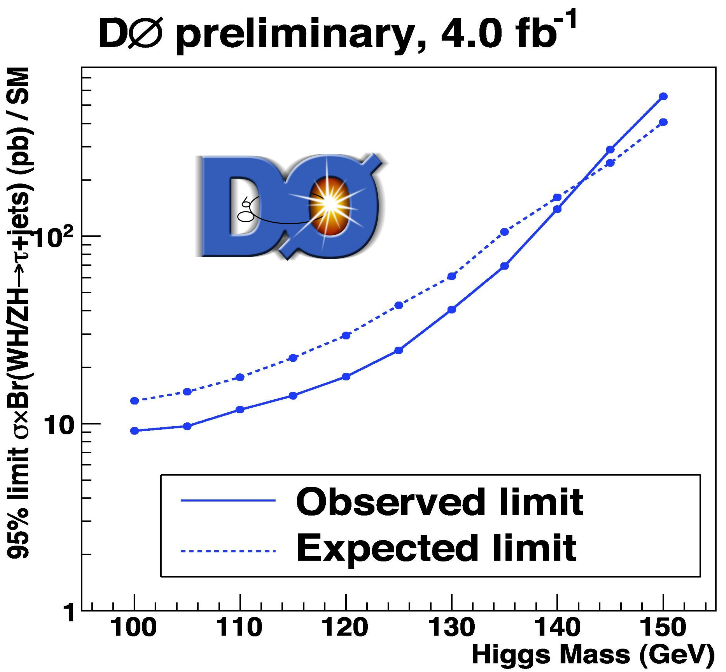
WH→τυbb search at DØ



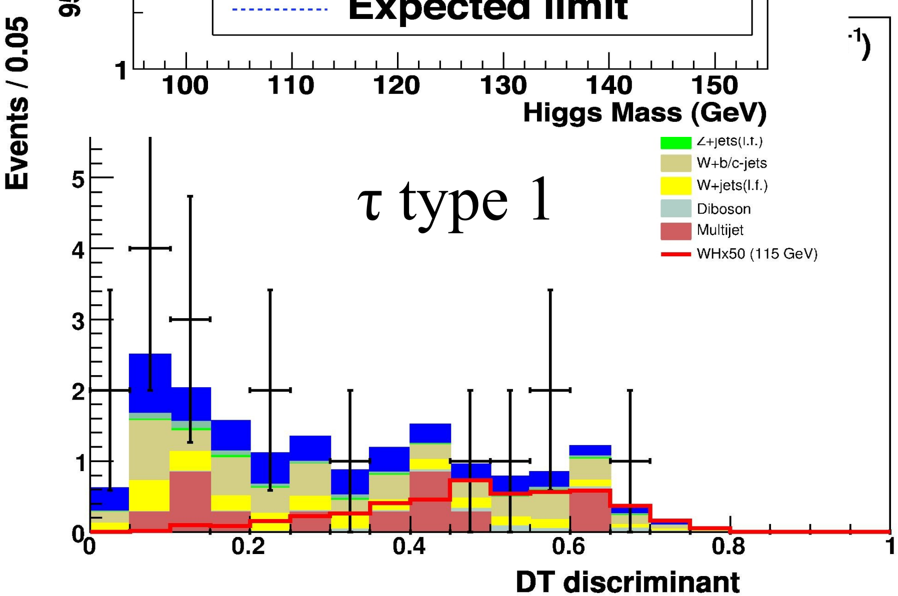


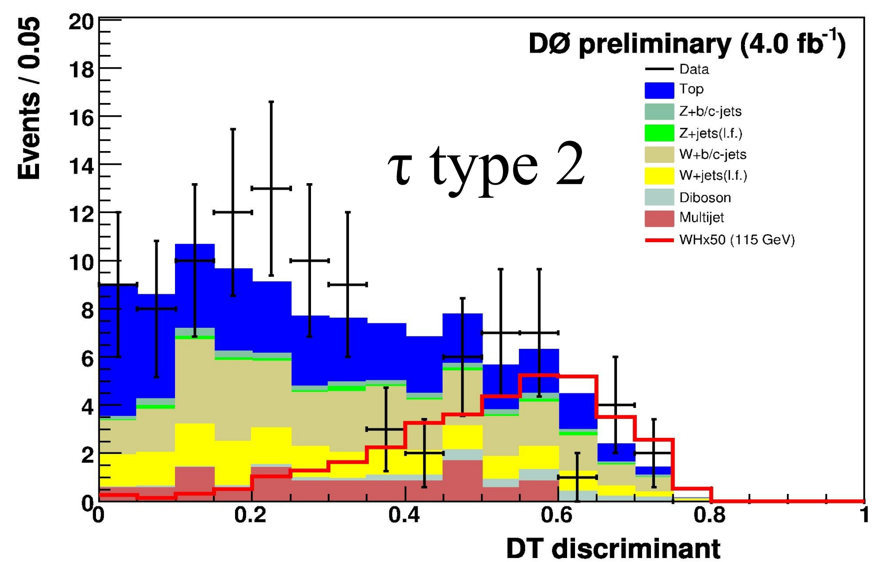
- Require one hadronic tau, two jets, MET > 15 GeV
- Similar to DØ H→ττ search, a NN is used to identify hadronically decaying taus of two decay categories
  - Signal ONN "high"
    - ~65% efficient
- Orthogonal Data samples used to reweight MC
  - A QCD sample is also selected using ONN in "medium score", +low MET significance
  - A QCD depleted sample is selected by requiring MET>80, simulates SM backgrounds

WH→τνbb search at DØ

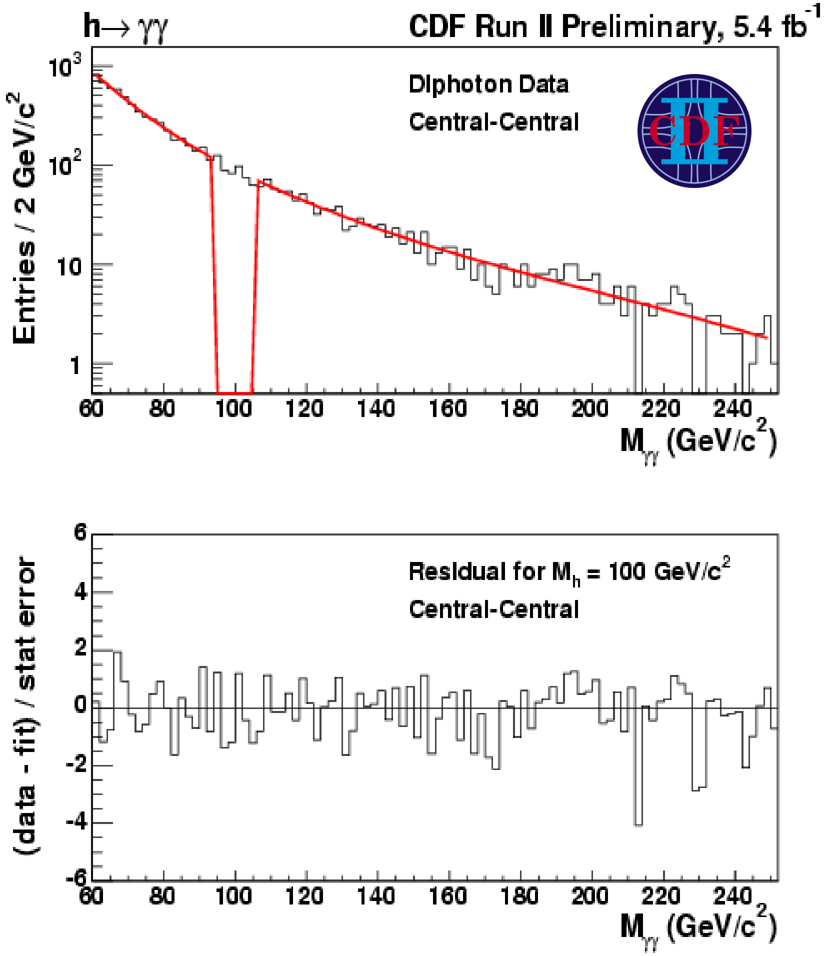


- Additionally improve s/b by requiring either one very tight b-tag, or one tight and one loose tag of the two jets in the event
- A BDT is trained to separate signal from all MC backgrounds (not QCD)



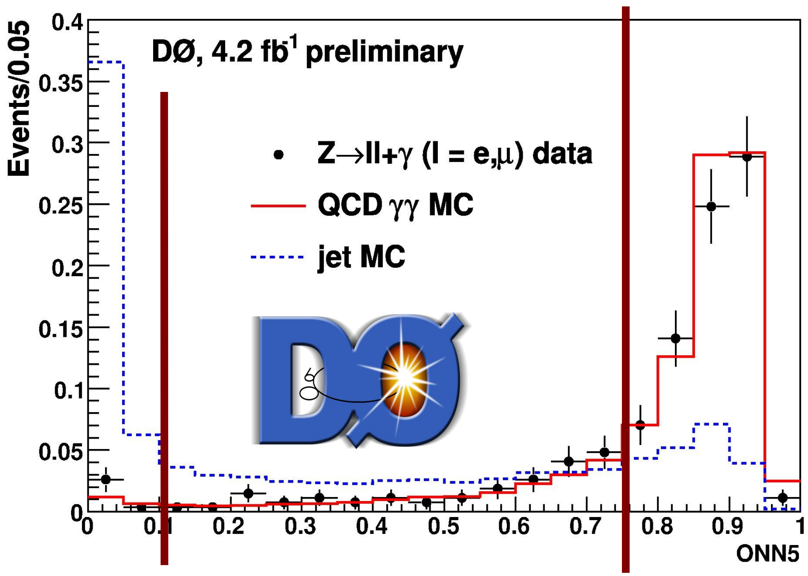


Light Higgs Searches to Diphotons



- The Channel
  - •Sample of inclusive diphotons
- General Strategy
  - •Parameterize or subtract reducible/irreducible background, excluding a signal window (s/b ~.2%)
  - •Fit for a signal on top of the extrapolated background or residual in the signal window
- The Challenge
  - •Small cross section Br(h→γγ) < .25%
    - •Maximize acceptance
  - •Estimate jet fakes in signal
  - •Understanding of MC/Data Acc.

DØ Search for Diphotons: Data Derived Estimate of Non-photon BG



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

- Employ a Neural Network for ID
  - trained on Jet vs. Photon MC
  - validated with Z→ll+γ data
- Reject all candidates w NNout low
- Separate candidates between
- ONN in midrange and high
  - Splits events into 4 categories
    - Pass, fail x2 candidates
  - Using 4x4 efficiency matrix, derive the number of events from γγ,γj,jγ,jj. (Norm only)
- Shape from data ONN low sample

Comparing Diphoton searches to Other Channels

Signal Expectation (CDF):

≈ 16 events produced with 5.4 fb^{-1} of data

≈ 2 events after acceptances and efficiencies included

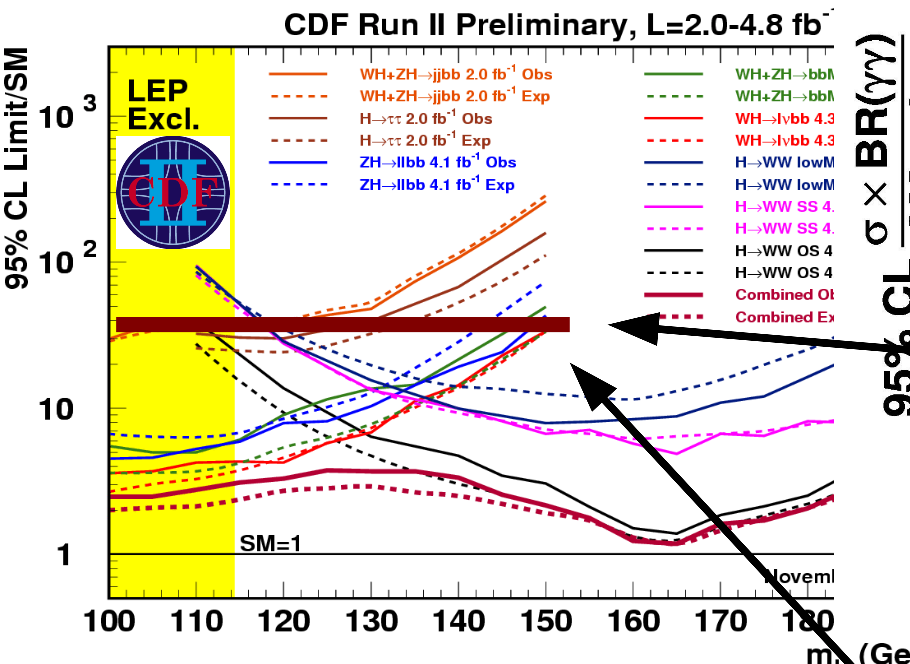
Compare at MH = 120	Lumi	s/b	Expected #Events	Expected Limit	Observed Limit
CDF (High) ZH->llbb	4.3	~0.5%	~2.5	8.49	7.89
CDF $H \rightarrow \gamma\gamma$	5.4	~0.2%	~2	19.4	22.5

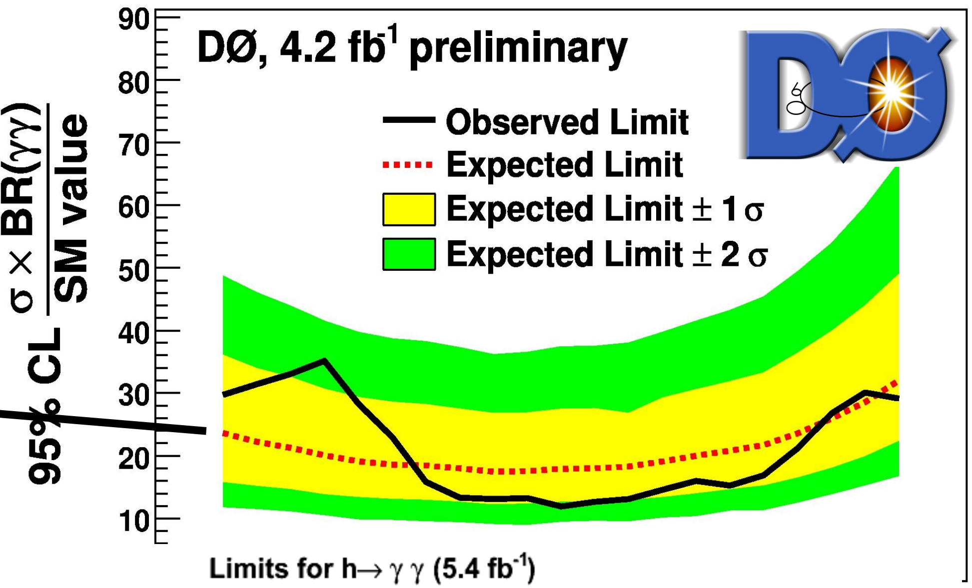
CDF (High) ZH->llbb here refers to only the "high s/b" lepton categories (all tags) of the CDF llbb analysis.

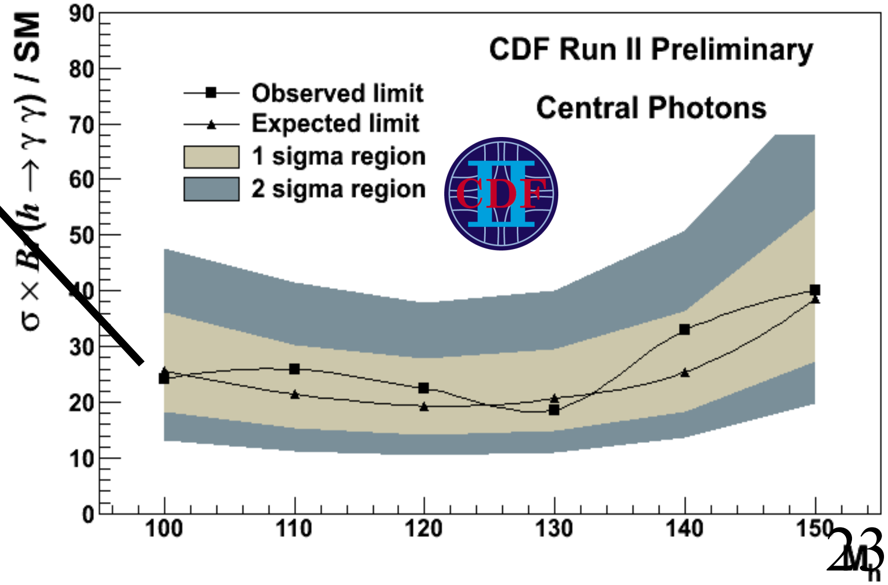
s/b refers to the total channel, s/b in the highest bins of the discriminant is far higher >20%

Expected Limits for MH:	140	150
CDF (High) ZH->llbb	19.27	73.72
CDF $H \rightarrow \gamma\gamma$	25.5	38.6

Comparing Diphoton searches to Other Channels







- **Sensitivity relatively flat!** Higher masses: as BR(bb) falls, sensitivity comparable to ZH->llbb!
  - Important role in combination!

Summary

- The Tevatron is delivering luminosity at record rates
- CDF and DØ are conducting Light SM Higgs searches in every viable channel
  - •Maximizing acceptance while managing backgrounds
  - •Developing techniques which can be used at CMS/ATLAS for
    - •Tau ID (MSSM Higgs)
    - •Photon ID (Light SM Higgs)
    - •QCD background estimates (Light SM Higgs)
- The Light SM Higgs searches at DØ/CDF are rapidly improving!

Thank You For Your Attention

Questions?