Higgs Boson Searches at the Tevatron

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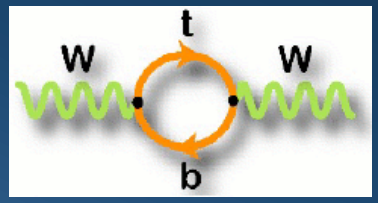
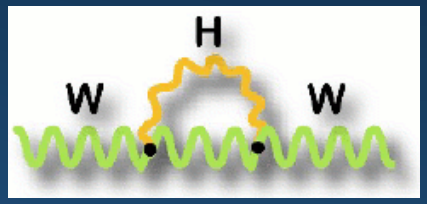
Constraints on the Higgs

M_H not predicted by the SM, but can be inferred

1) Electroweak constraints

E.g. $\ln M_H \propto \Delta M_W \propto M_t^2$





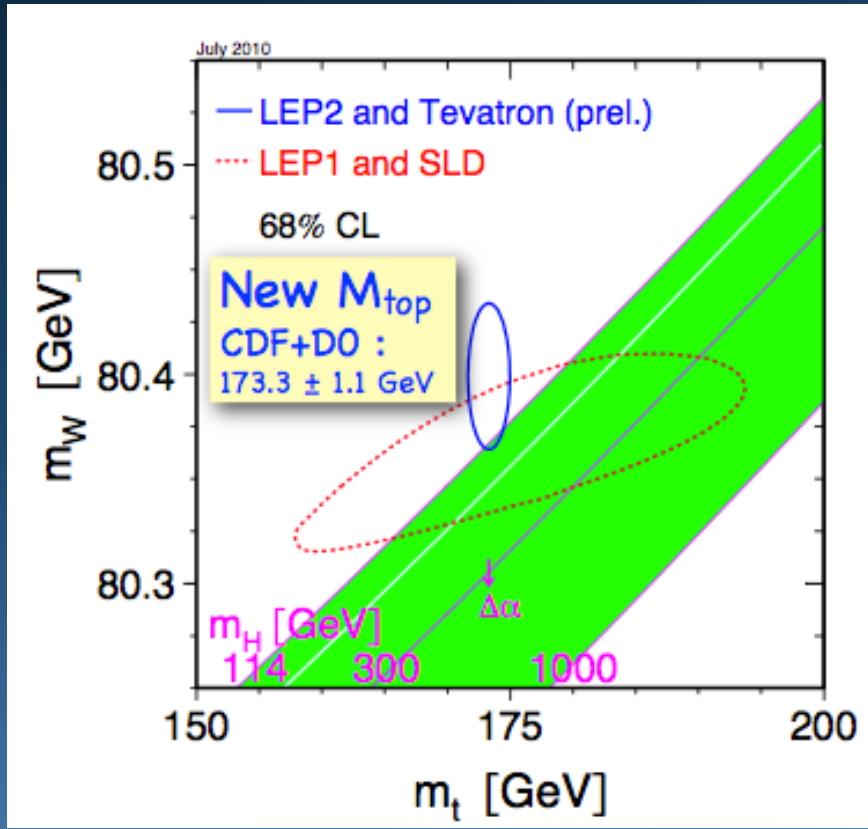
and other precision measurements of electroweak observables

2) Direct searches @ LEP

LEP: $M_H > 114.4$ GeV @ 95% C.L.

3) Direct searches @ Tevatron

4) Direct searches @ LHC (coming soon to a colloquium near you)



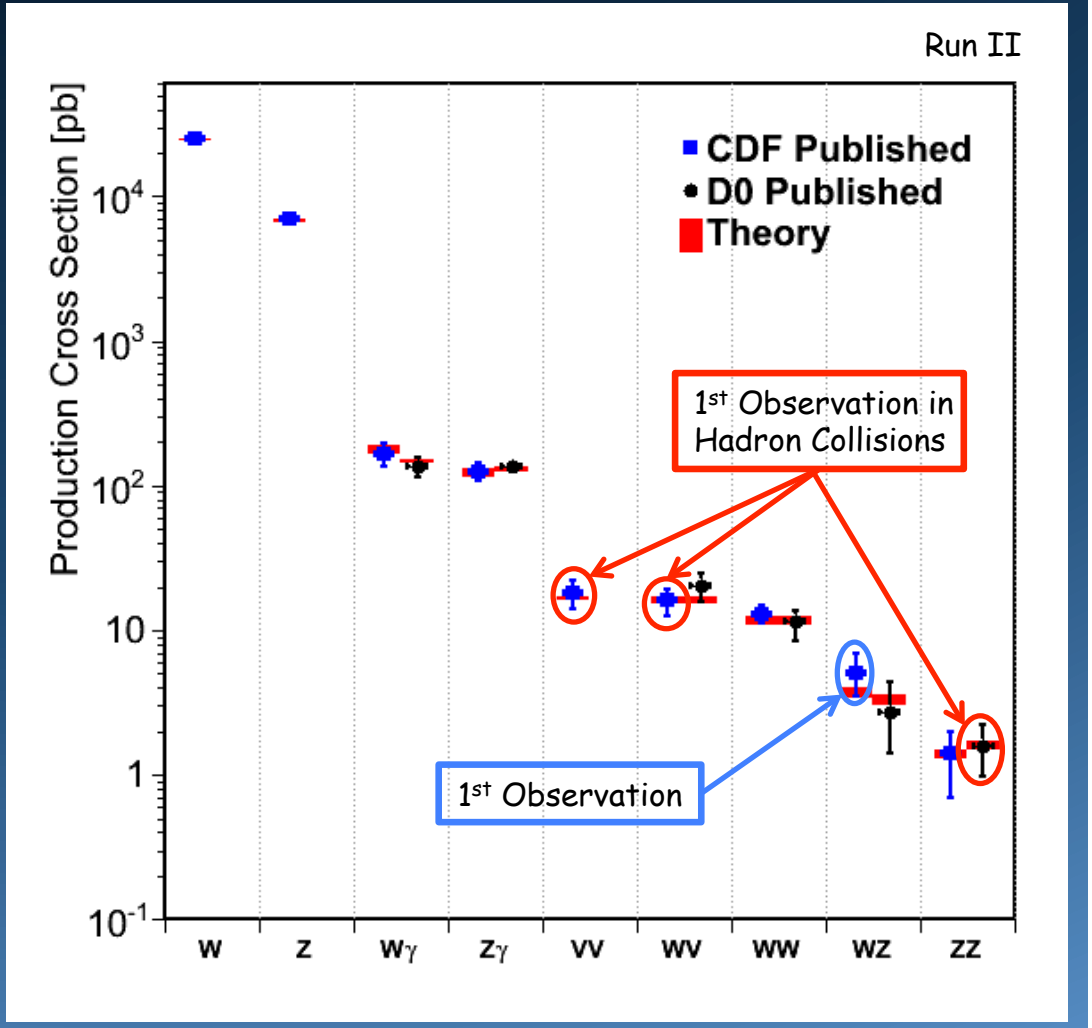
Precision Fit finds

$m_H = 89.0\ ^{+35}_{-26}$ GeV

$m_H < 158$ GeV @ 95% CL

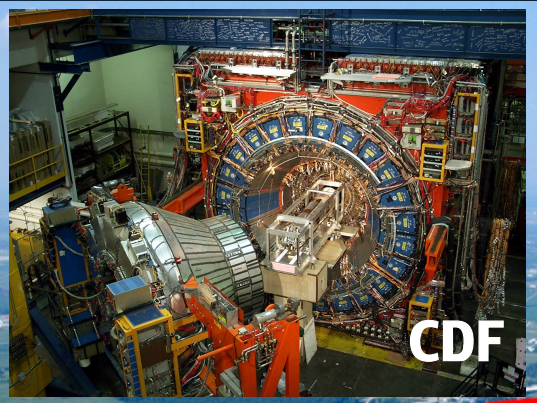
Pushing the Envelope of Smash n' Grab

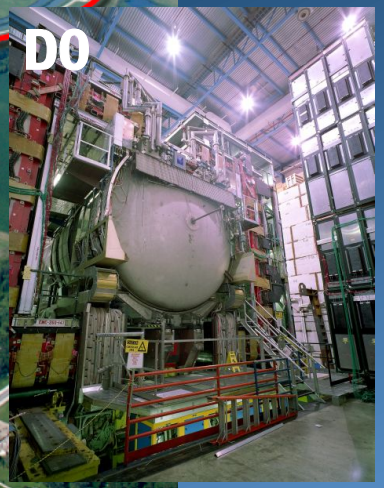
- Tevatron experiments probe production processes covering many orders of magnitude in cross section



- Many firsts during Run II (e.g. WZ, ZZ, single top)
- Now reached sub-picobarn cross section sensitivity

Tevatron, CDF, D0

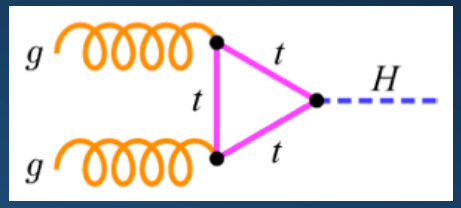




≈9.3 fb^{-1} of data delivered
More than 8 fb^{-1} acquired per experiment
Results presented today use up to 6.7 fb^{-1}

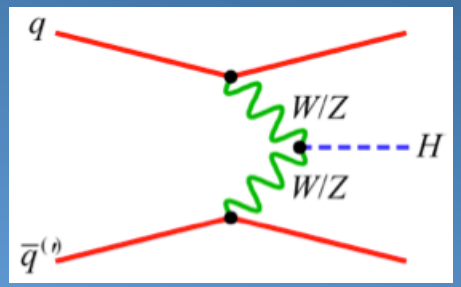
SM Higgs Production & Decay at Tevatron

$\sigma(gg \to H) = 0.2 - 1$ pb

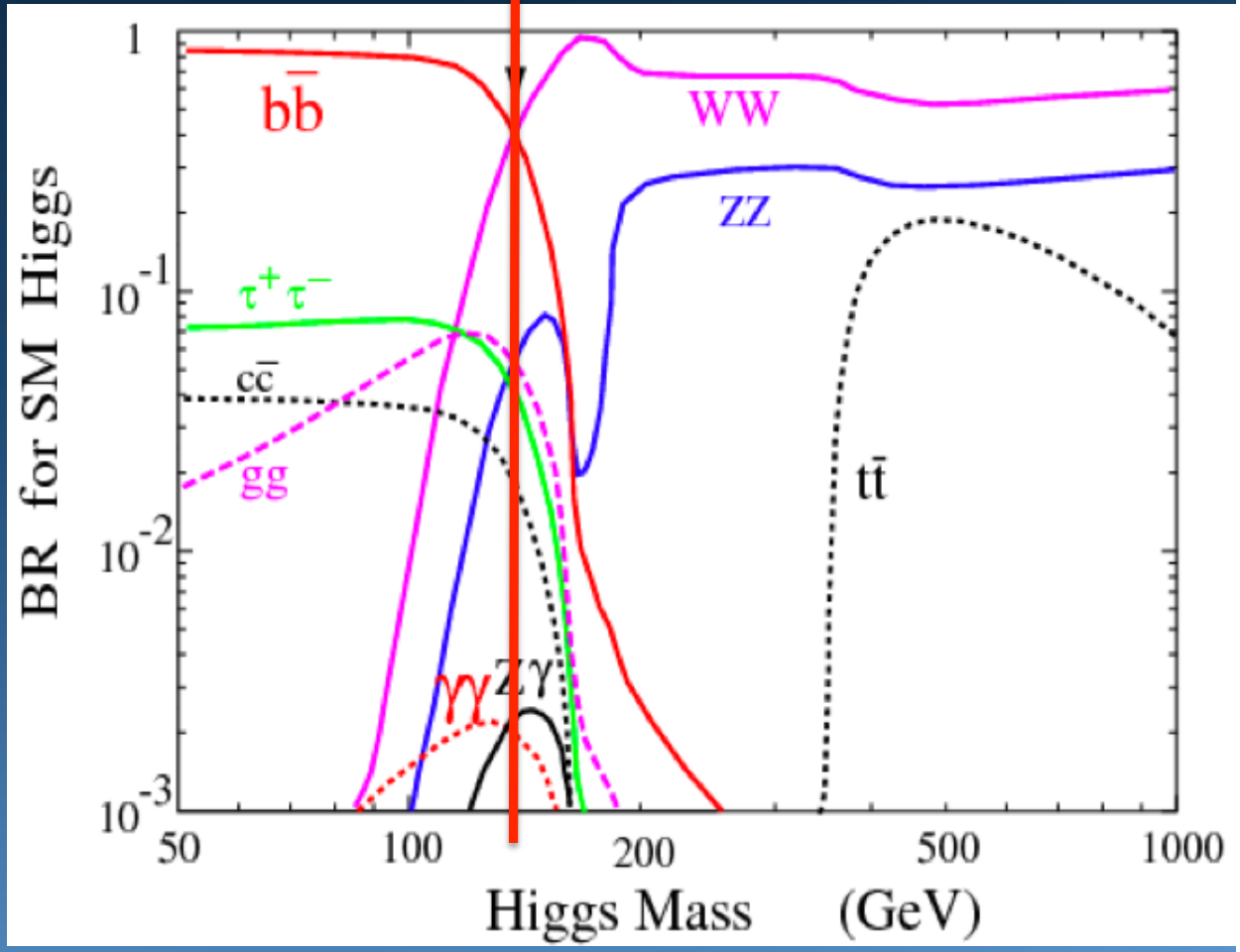


$\sigma(q\bar{q}^{(\prime)} \to HV) = 0.01 - 0.3$ pb

$\sigma(q\bar{q}^{(\prime)} \to Hq\bar{q}^{(\prime)}) = 0.02 - 0.1$ pb

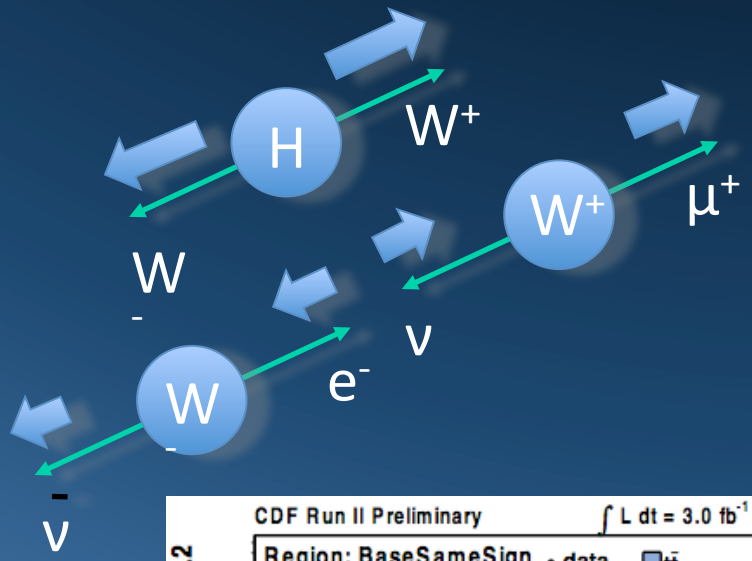


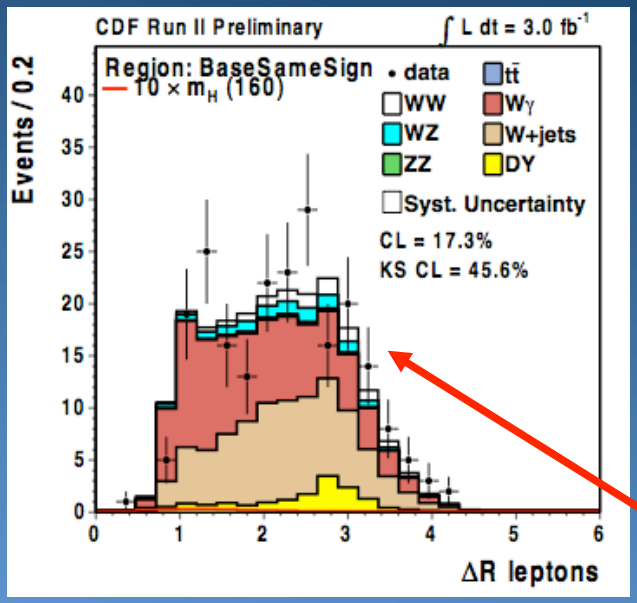
Low Mass | High Mass

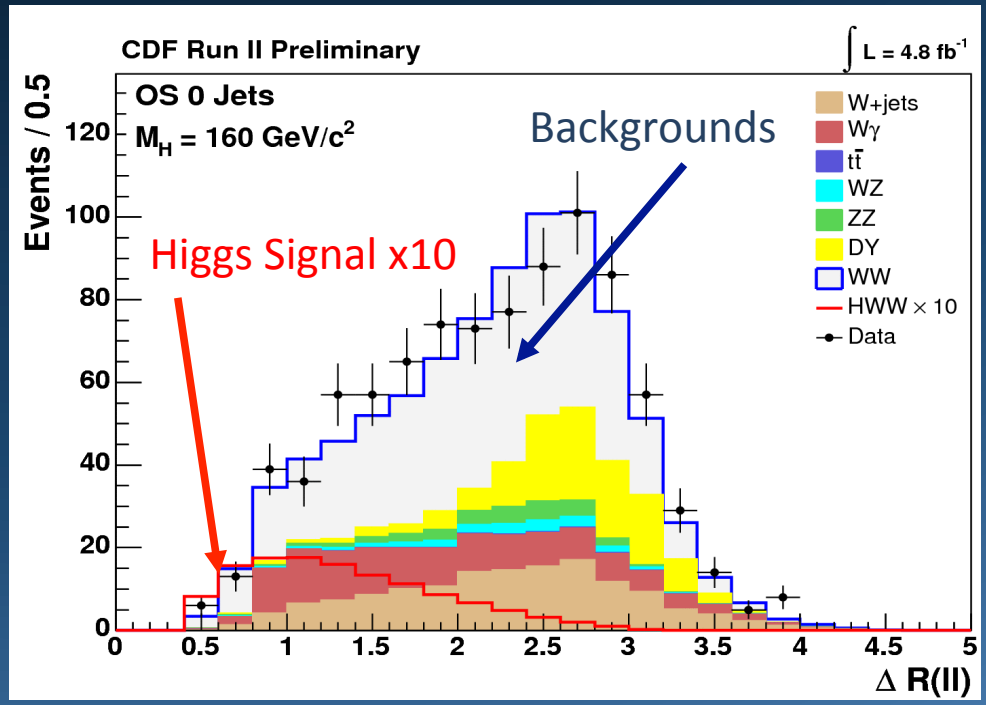


High Mass Higgs Search (WW)

Main challenge: to distinguish signal from direct WW production



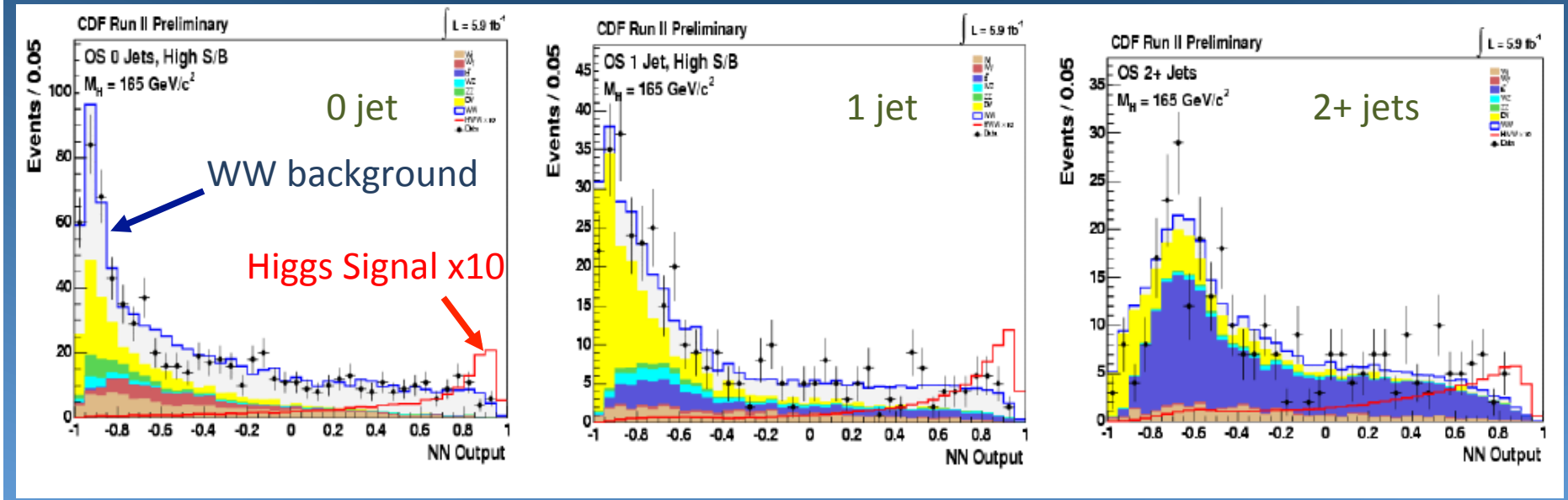




Background modeling validated using selections outside of signal region

High Mass Higgs Search (WW): Strategy

- Simple event counting is not good enough (S/√B too low): Use MVA techniques to discriminate between signal and background:
  - Matrix Elements (ME), Neural Networks (NN), Boosted Decision Trees (BDT)
  - Each channel and M_H hypothesis has its own MVA template
- Separate analysis into channels by S/B ratio in lepton purity and jet multiplicity: 0, 1 and 2+ jets
  - Consider how ggF, WH, ZH, and WBF can feed these channels



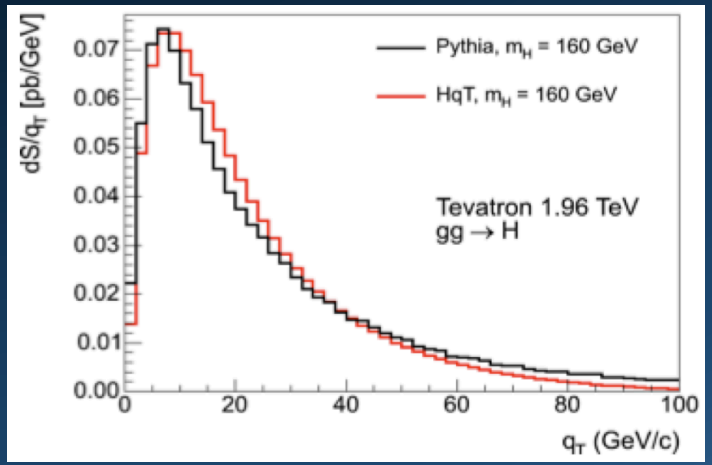
Theory & Uncertainty (High Mass Higgs)

We make use of well-motivated and state-of-the-art gluon fusion cross-section calculations and uncertainties

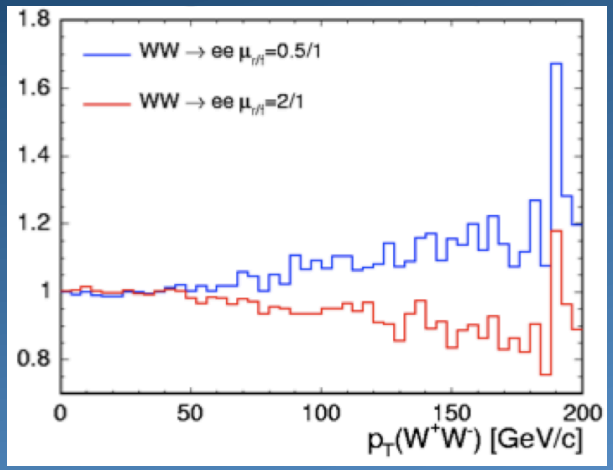
- gg → H uses NNLL + NNLO calculations "Next to Next to Leading Log/Order" de Florian & Grazzini (Phys.Lett.B674:291-294, 2009)
  - Soft-gluon resummation treatment
  - MSTW2008 Parton Density Function
- Anastasiou, Boughezal, Petriello (JHEP: 0904:003, 2009)
  - Proper treatment of *b*-quarks at NLO
  - Inclusion of two-loop electroweak effects

A detailed explanation of our procedures and arguments can be found at:

http://tevnphwg.fnal.gov/results/SM_Higgs_Summer_10/addendumresponse_oct2010.html

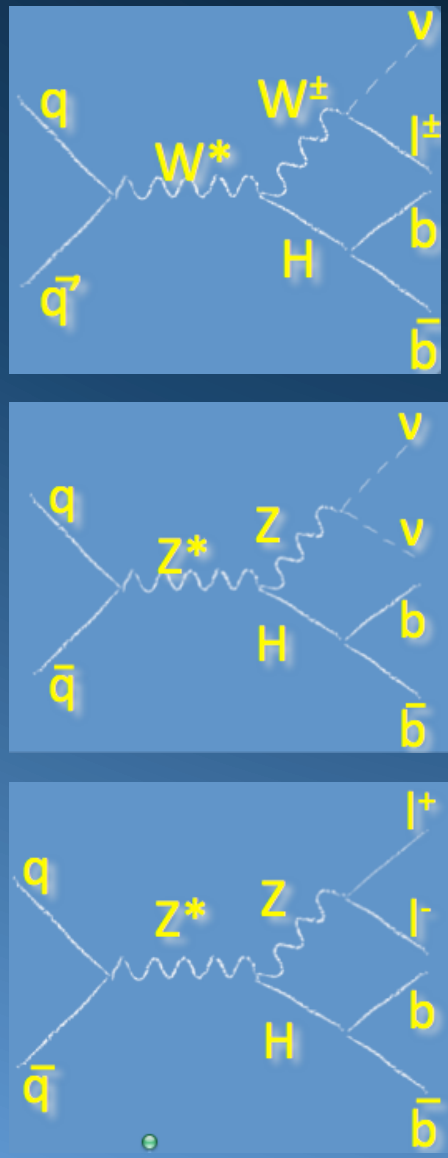


Reweight PYTHIA Higgs kinematics to full NNLL calculation



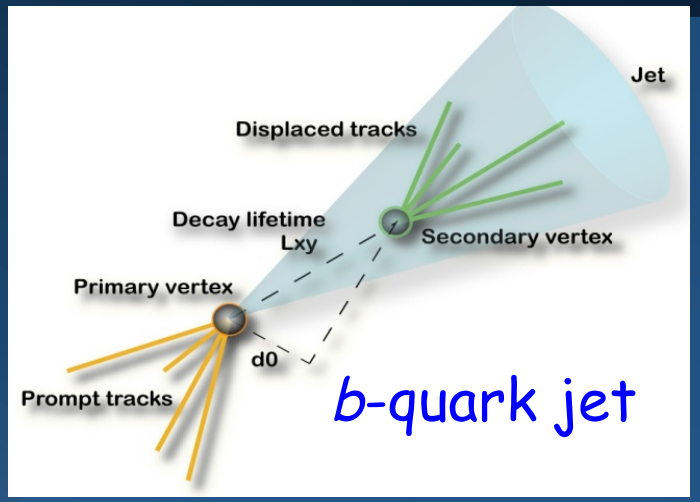
Consider same variations for dominant WW background

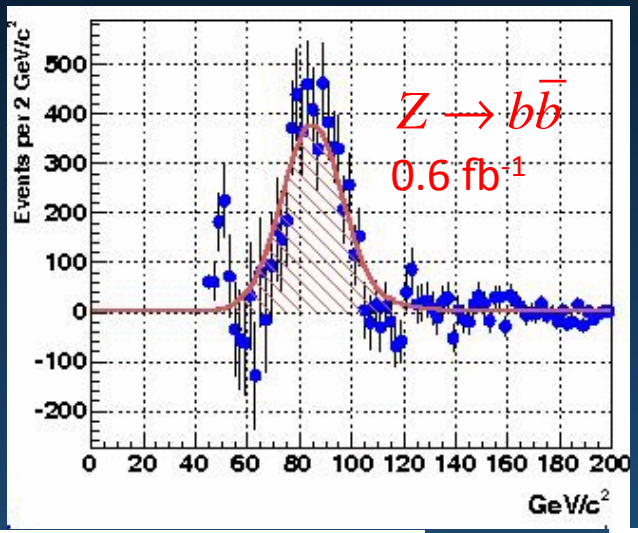
Low Mass Higgs: Associated Production

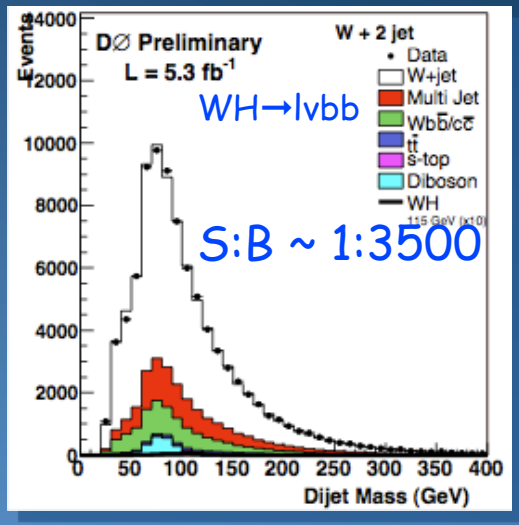


- While smaller cross-section (than gluon fusion), final states are much cleaner
- Main ingredients:
  - Leptons or MET allow large reduction in backgrounds to go after dominant *bb* decay channel
  - *b*-tagging dramatically reduces W/Z + light jet and QCD backgrounds
- Analyses look for a bump in the dijet mass spectrum
  - Good understanding of *bb* mass resolution is critical

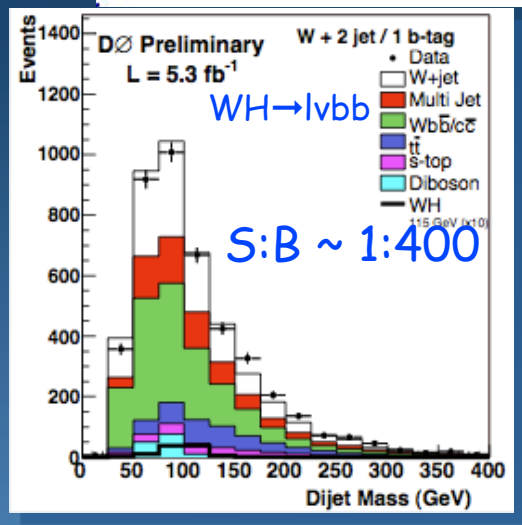
Backgrounds and Resolution



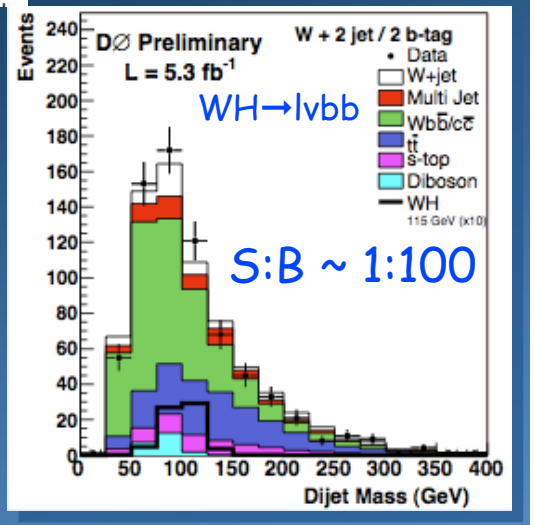




1 *b*-tag



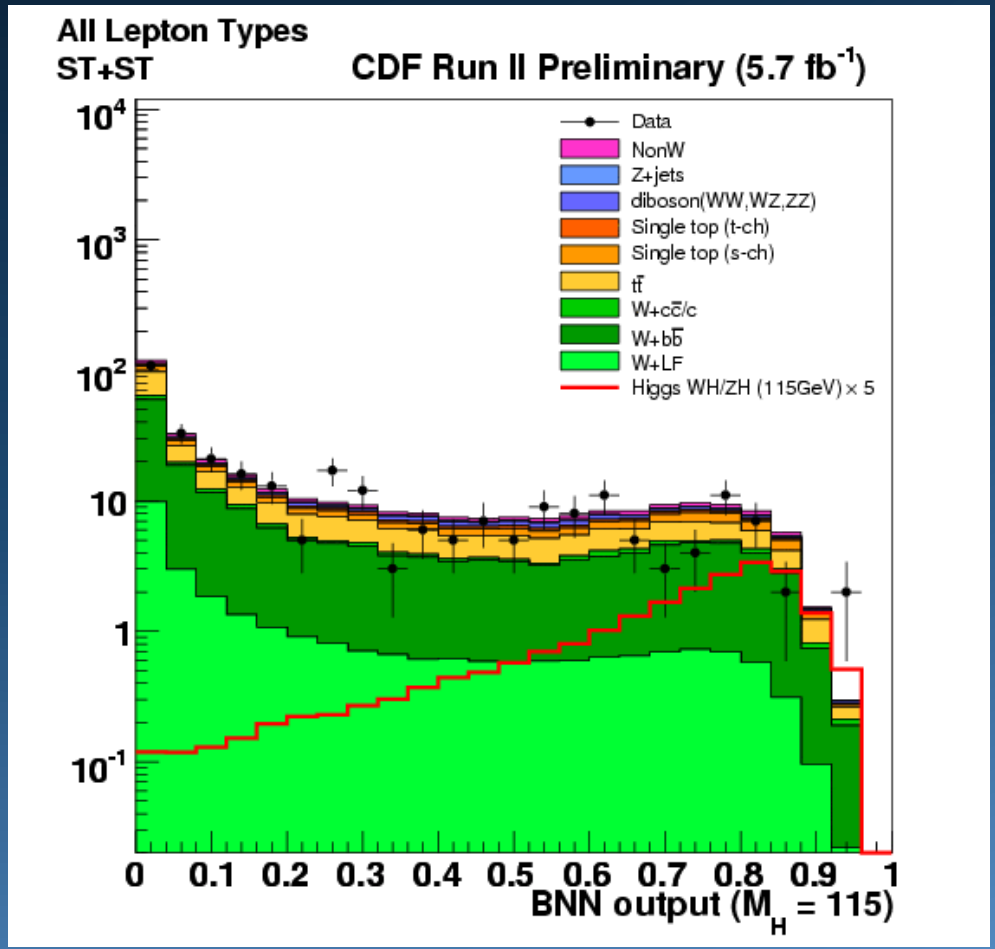
2 *b*-tag



- After 1 or 2 b-tags
- Signal region with enhanced signal / background

Multivariate Techniques for Low Mass Higgs

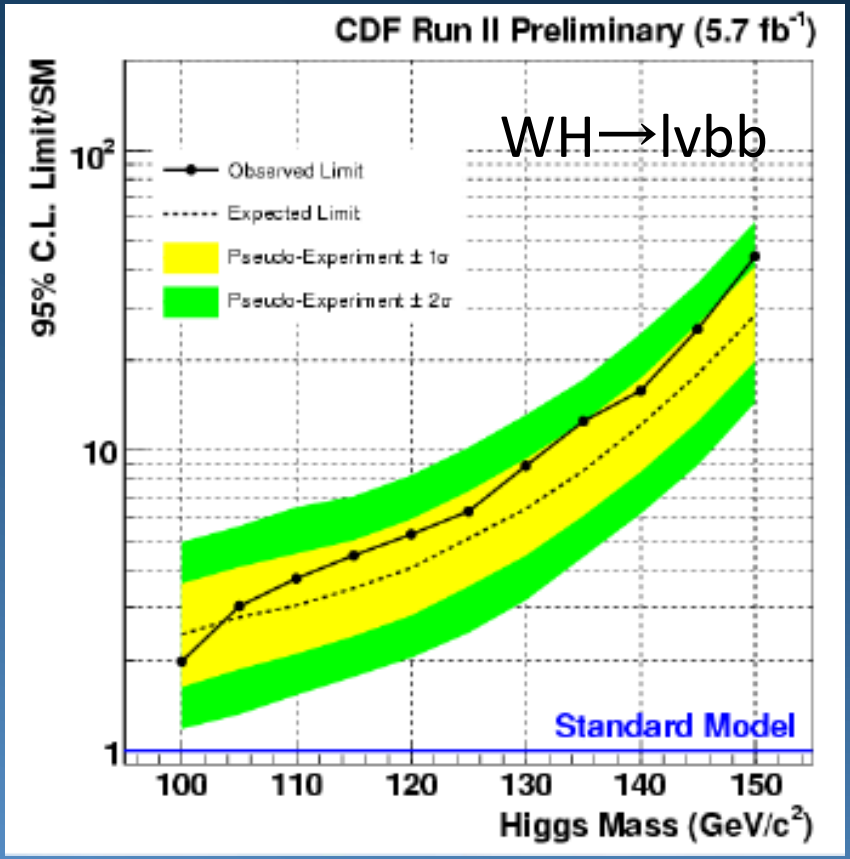
- Both experiments rely on advanced techniques
  - NN, ME, BDT
    - Validated in other analyses, requires excellent understanding of the detectors
  - Extensive categorization to improve sensitivity
    - E.g. 4 *b*-taggers (displaced vertex, track impact parameter, NN)
    - Multiple lepton categories including lose ones to increase acceptance

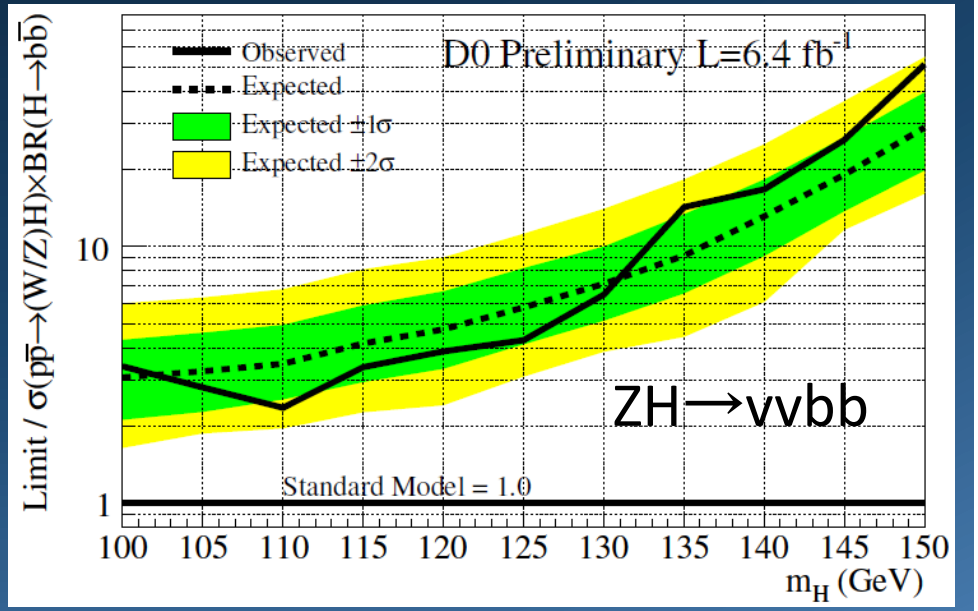


- Bayesian NN output in WH→lν*bb* analysis

Low Mass Higgs Limits

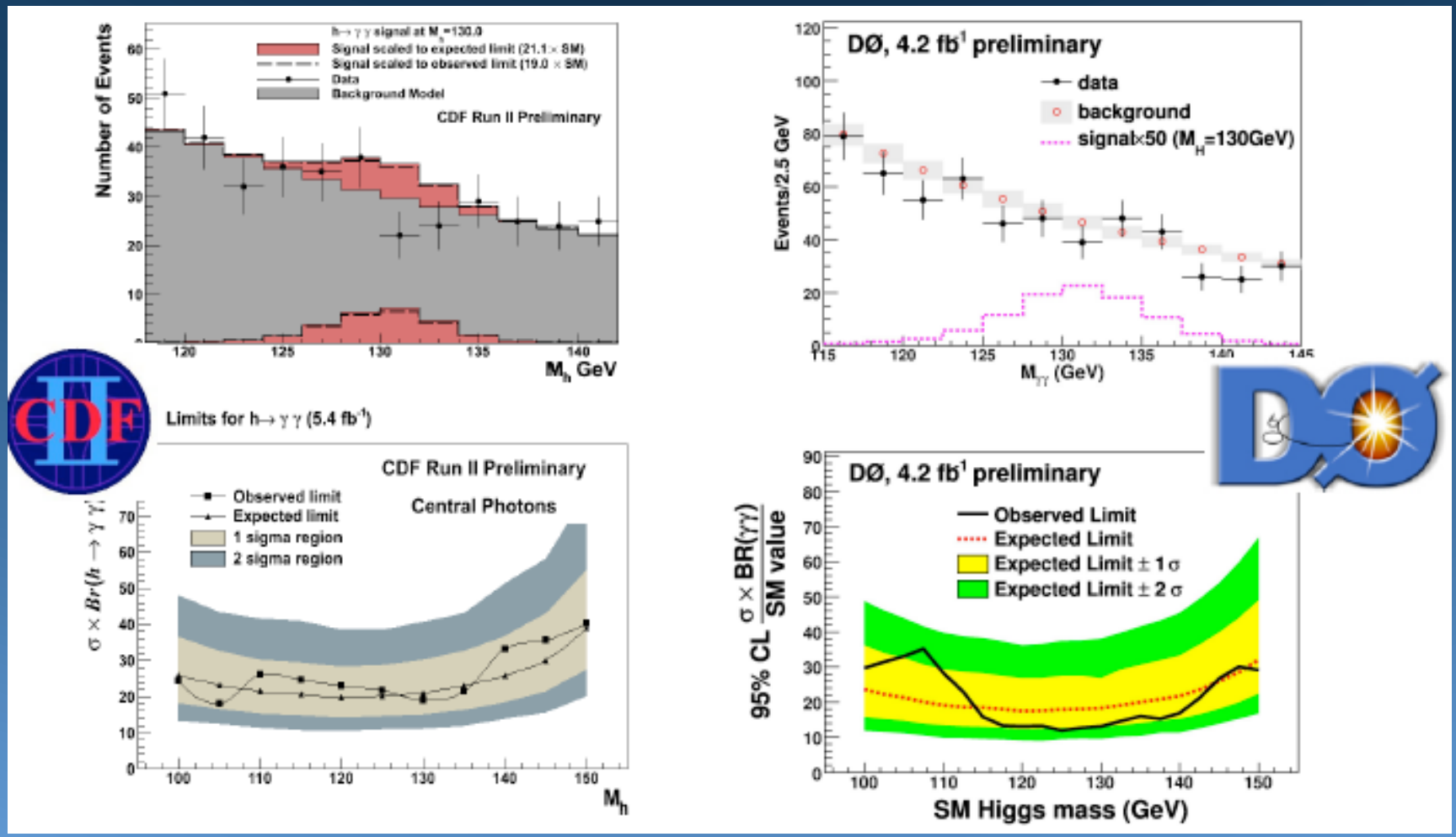
Data consistent with expectations



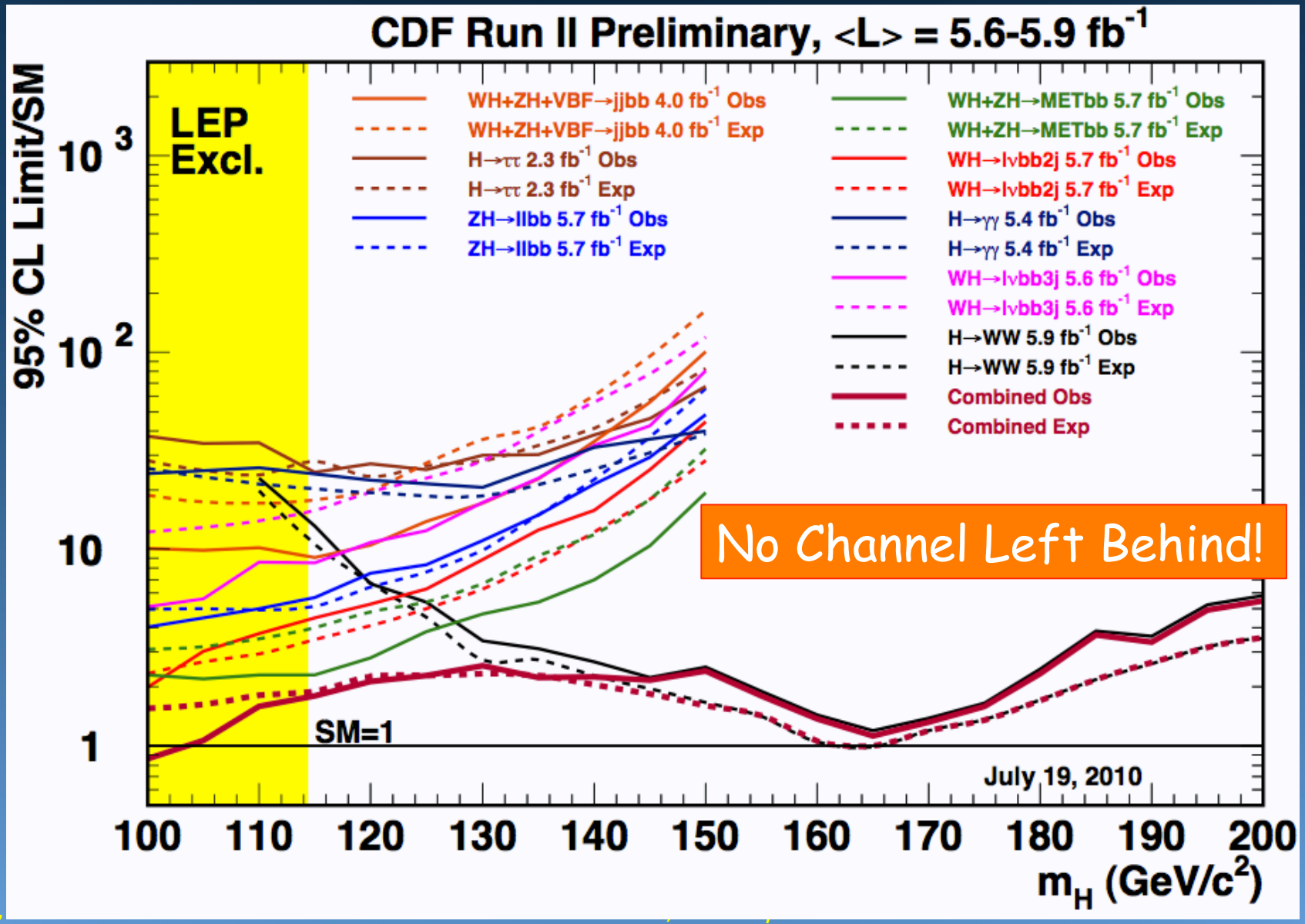


"New" Low Mass Search Channel: H->γγ

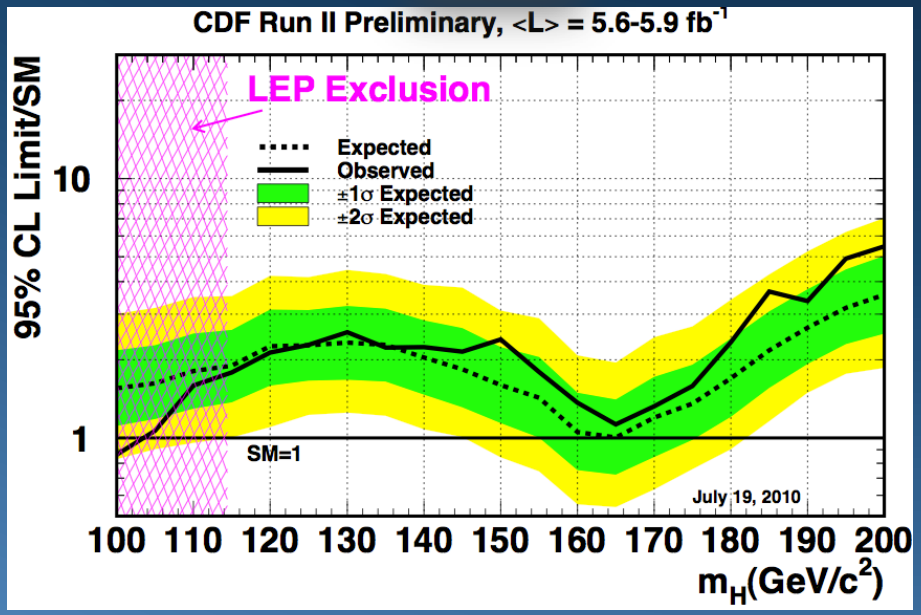
- Small BR~0.2%, but a narrow bump
  - Sensitivity is a strong function of EM calorimeter resolution

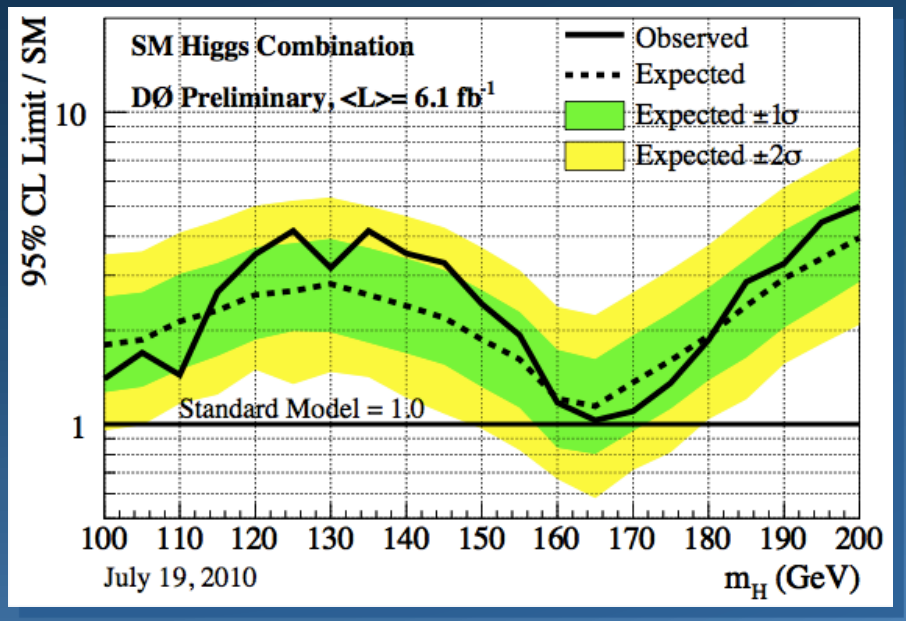


Searches in Combination (CDF)



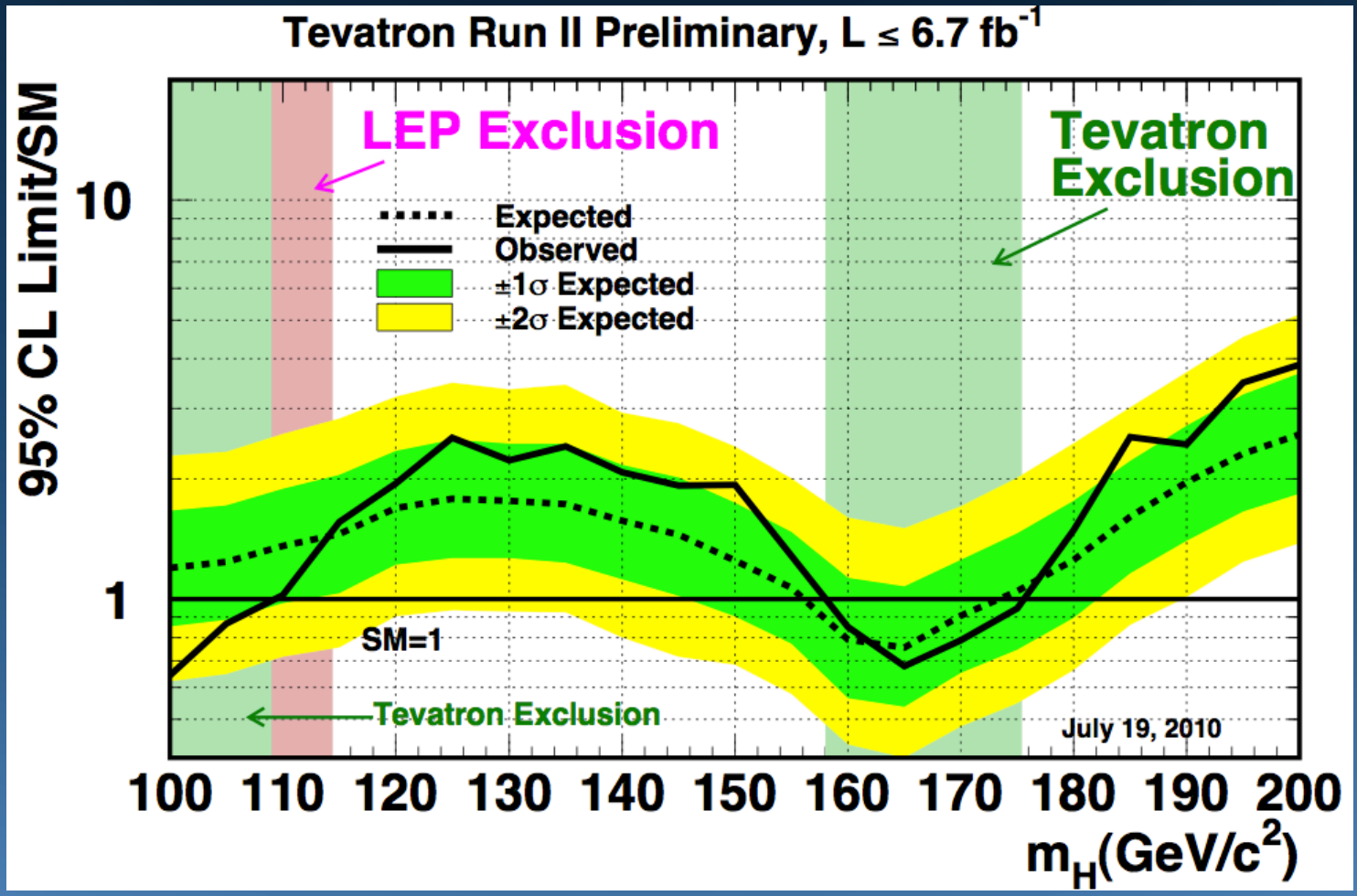
CDF & DO Individual Combinations





@ m_H = 100 GeV, both set observed limits below expectation
Closing in on low mass LEP exclusion

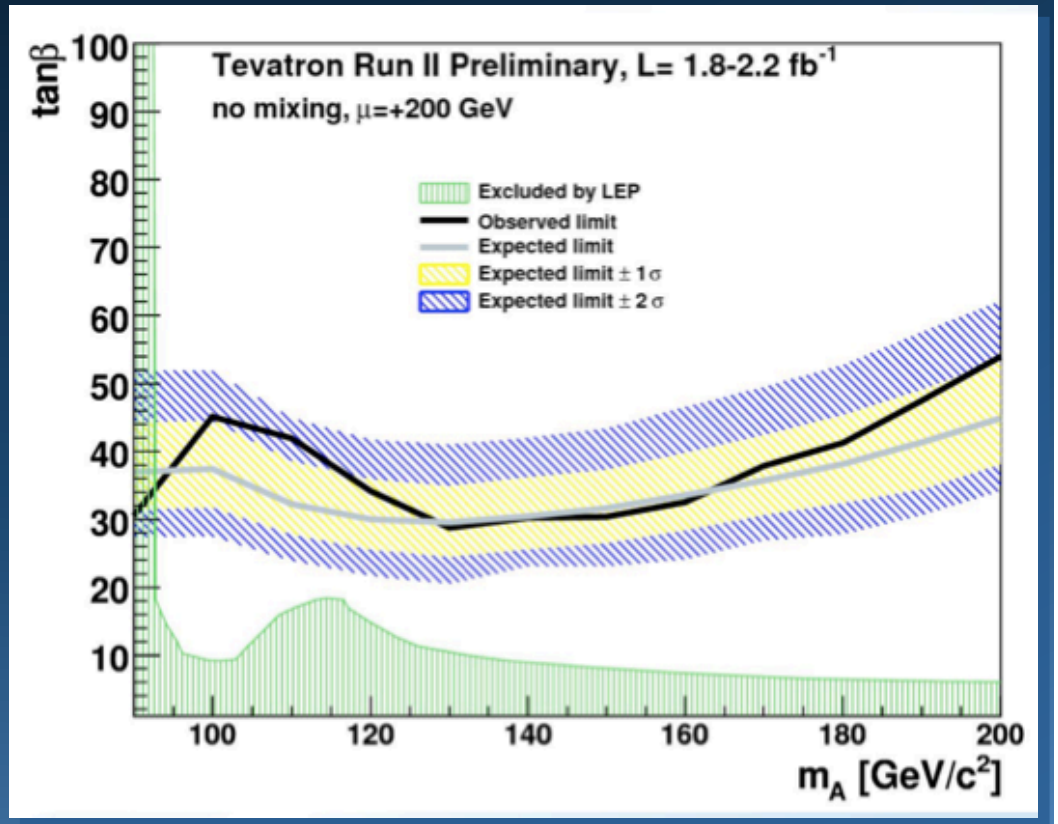
Tevatron Combination



- Low mass sensitivity approaching LEP exclusion:
  - Expected 1.45*SM @ 115 GeV
  - Expected 1.24*SM @ 105 GeV
- High mass 95% CL exclusion :
- 158 < m_H < 175 GeV
  - Expected (156 < m_H < 175 GeV)

MSSM Higgs Search

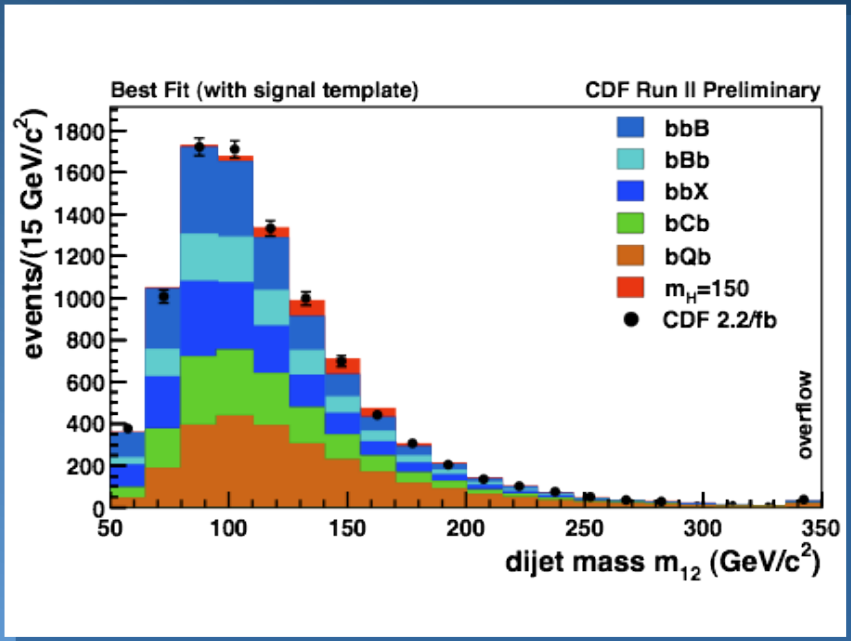
- Extended Higgs sector in SUSY models
  - $\Phi = (H^0, A^0, h^0)$ and $H^{\pm}$
- Higgs coupling enhancement at large tanβ:
  - Large increase in cross-sections compared to SM
    - E.g. $gg \rightarrow \Phi$, $gb \rightarrow b\Phi$
  - Dominant $gg \rightarrow \Phi \rightarrow bb$ is still difficult, but new final states:
    - $\Phi \rightarrow \tau\tau$
    - $\Phi b \rightarrow bbb$, $b\tau\tau$
    - $\Phi bb \rightarrow bbbb$, $bb\tau\tau$

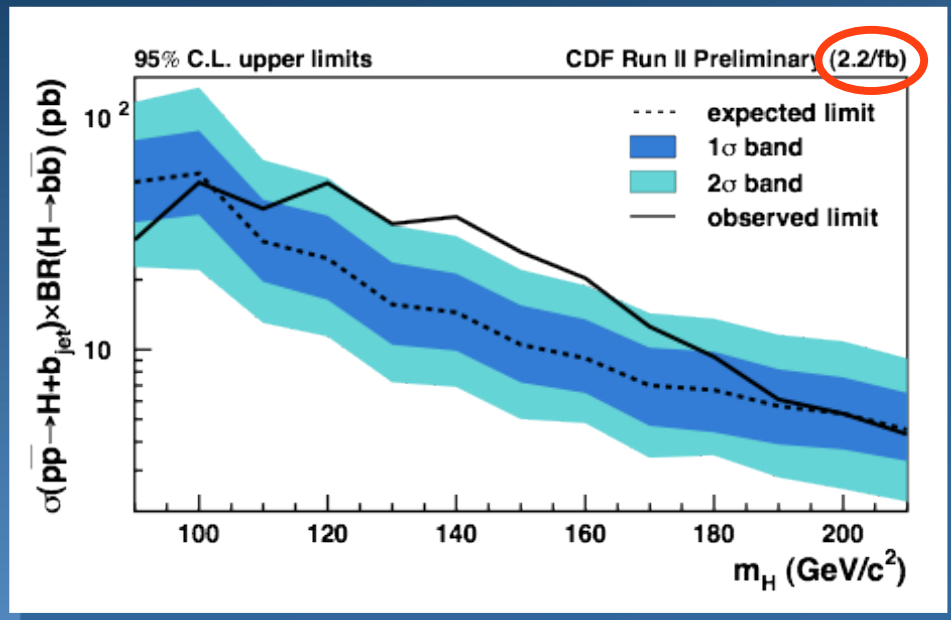


- CDF and D0 combined search for $\Phi \rightarrow \tau\tau$ with 2 fb^{-1}

MSSM Higgs Search

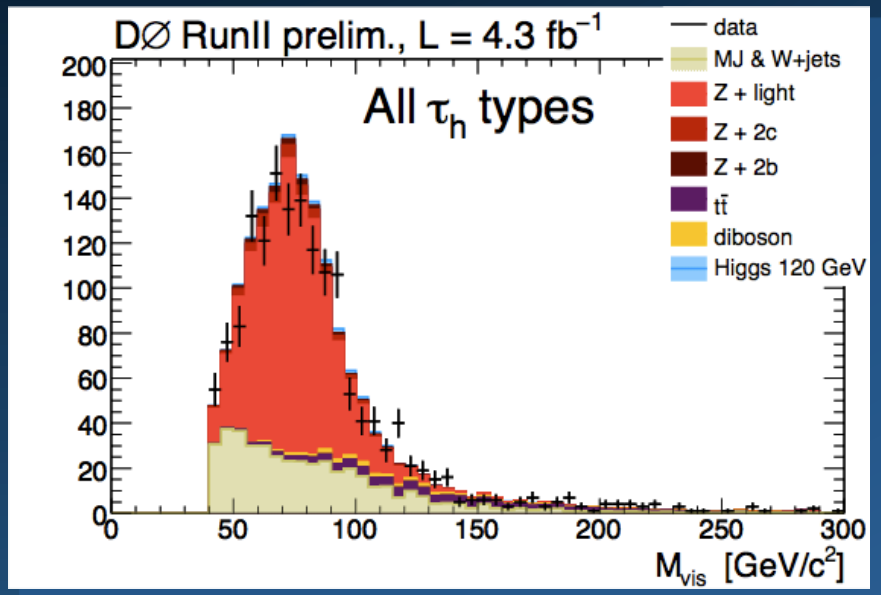
- MSSM Higgs 3*b* search ($\Phi + b \rightarrow bb + b$)
  - Complements MSSM H → ττ search
  - Relies on CDF's trigger-level *b*-tagging used in *b* physics
  - New version of analysis 2x more acceptance
    - m_H = 140 GeV most significant excess

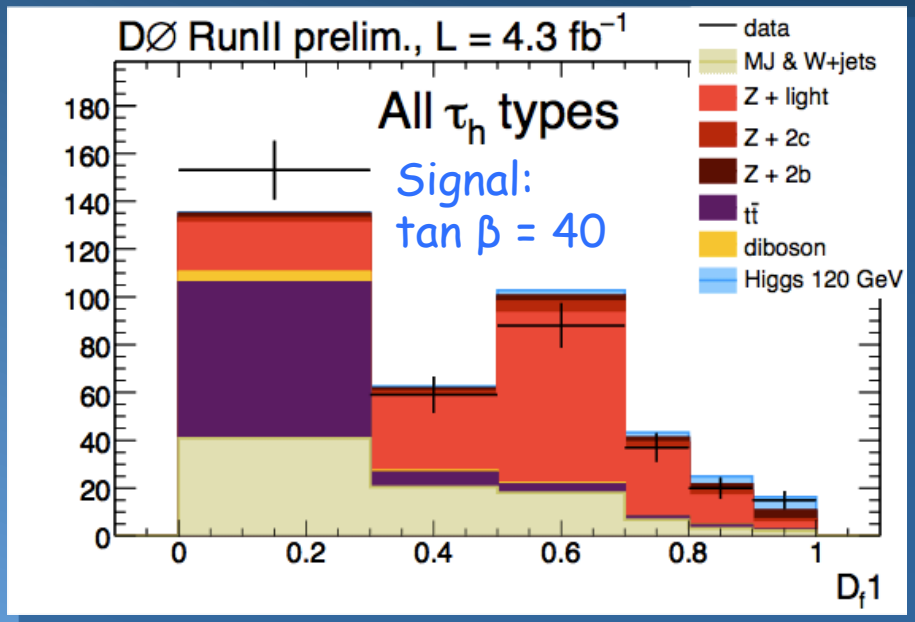


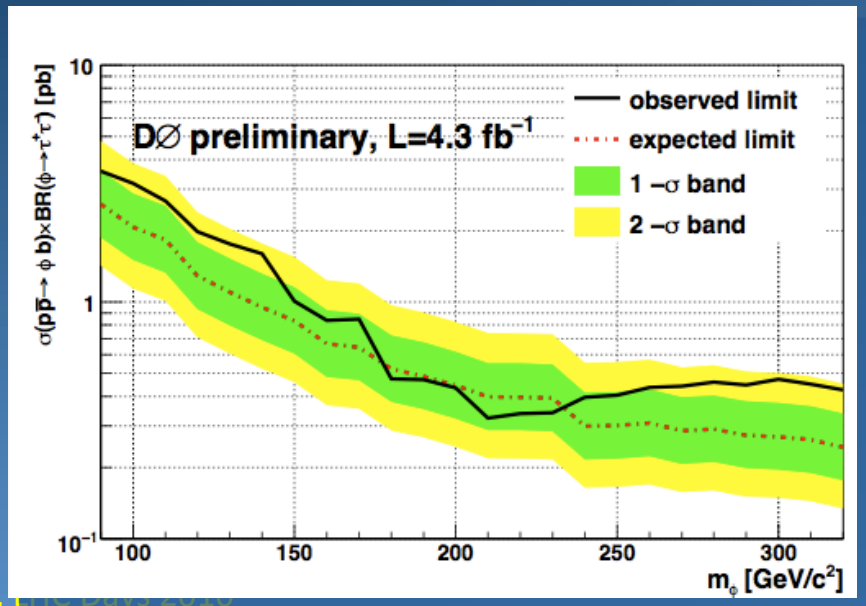


"New" MSSM Higgs Search

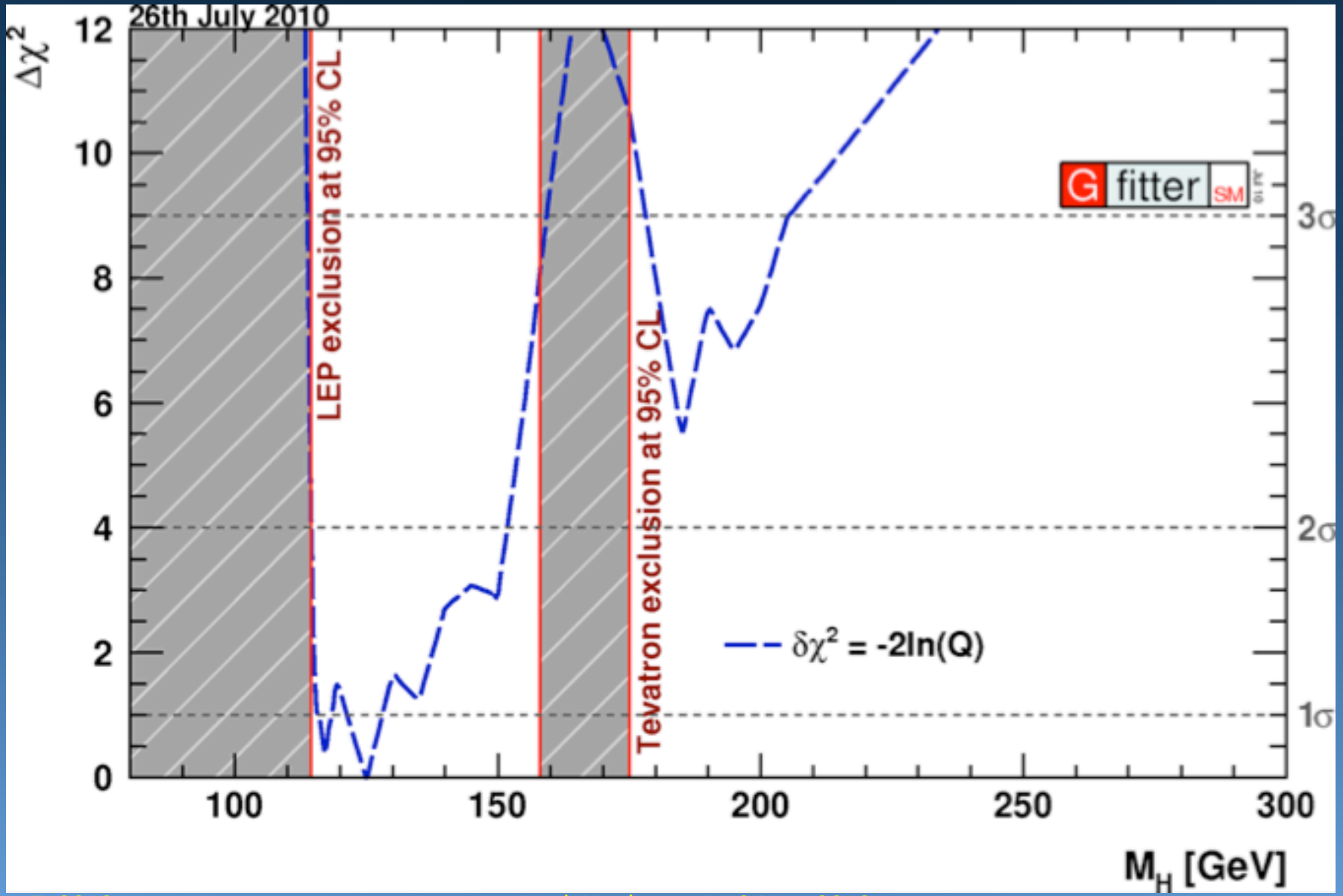
- D0's $\Phi \rightarrow \tau\tau + b$
  - Does not suffer from radiative corrections increasing Higgs width in $\Phi \rightarrow bb + b$
  - Exclusive from $\Phi \rightarrow \tau\tau$
    - Provides similar sensitivity







Combined SM Higgs Constraints (Gfitter)



Prospects for SM Higgs from the Tevatron

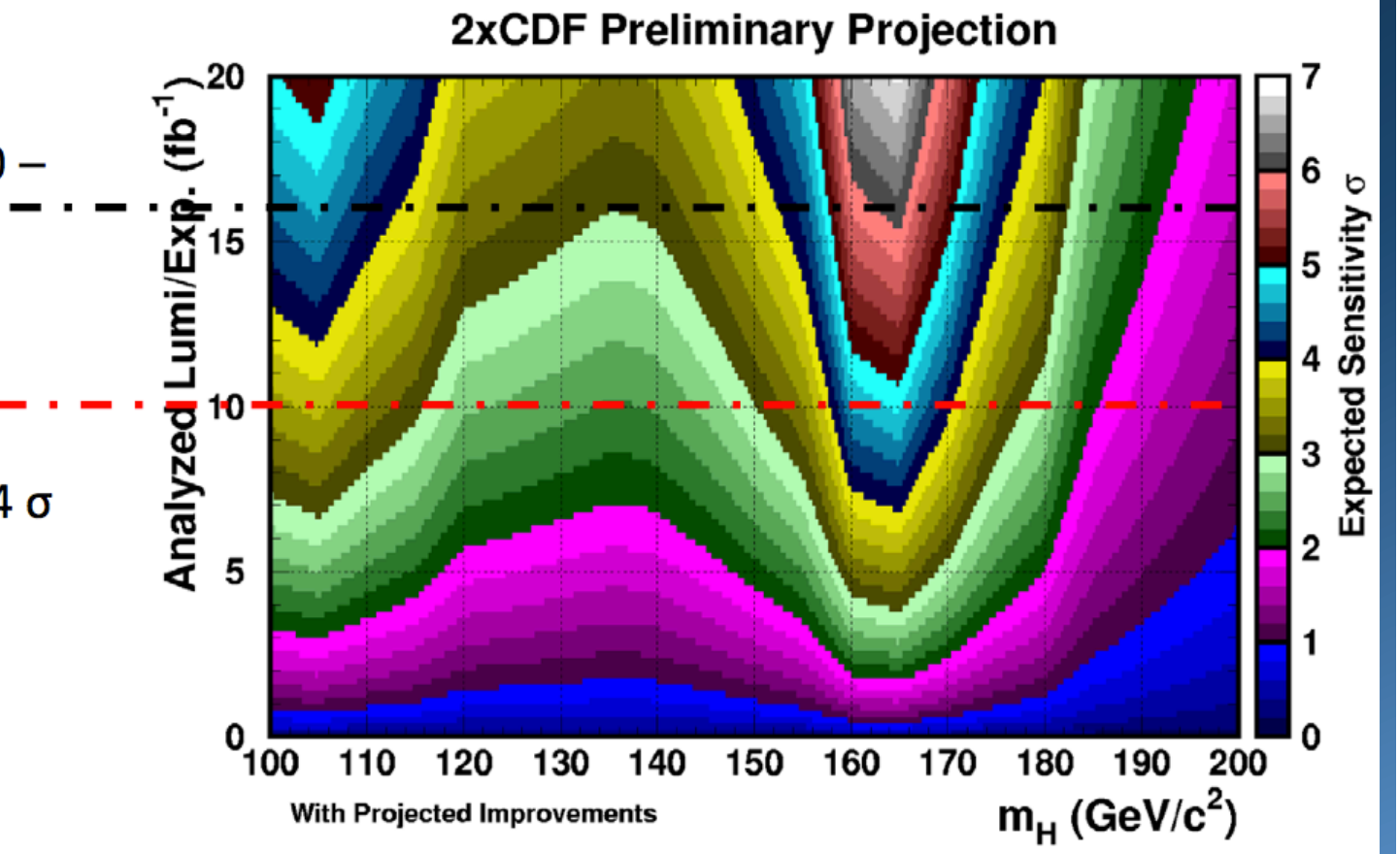
~16 fb^{-1} :*

> 3 σ expected sensitivity from 100 – 185 GeV

4 σ @ 115 GeV

End of 2011: > 2.4 σ expected sensitivity across mass range

3 σ at 115 GeV



* 16 fb^{-1} : based on "Run III" proposal to run 3 more years

Conclusions

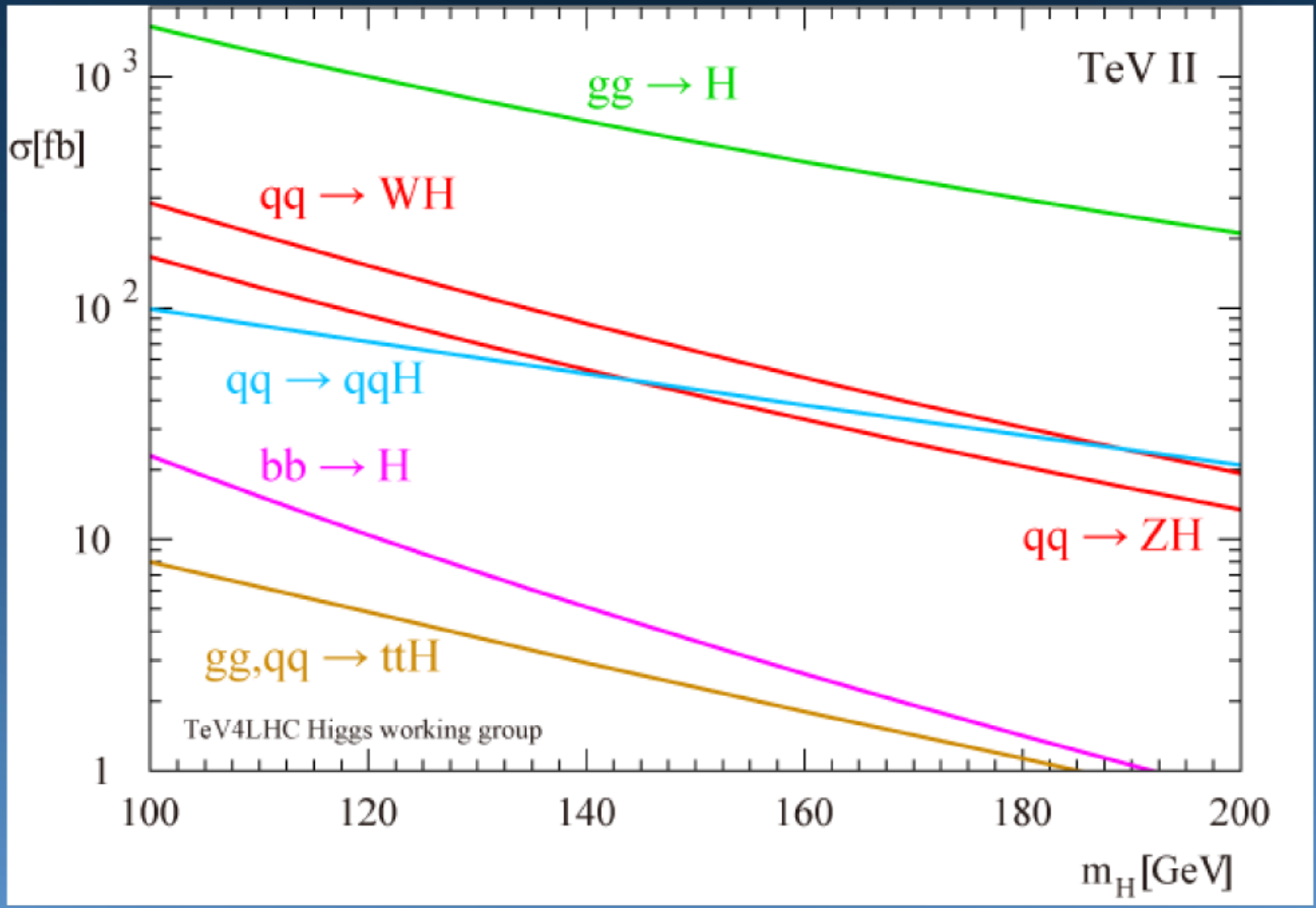
- Direct searches for the SM Higgs at the Tevatron are squeezing the allowed M_H range from both low and high
  - 95% C.L. exclusion for $158 < M_H < 175$ GeV
  - Limit 1.5*SM @ 115 GeV
- BSM searches: consistent with SM
  - 2σ in CDF MSSM $\Phi \rightarrow bb$ largest discrepancy (thus far)
- Higgs search over the next few years will be interesting

"There are two mistakes one can make along the road to truth…
not going all the way, and not starting"

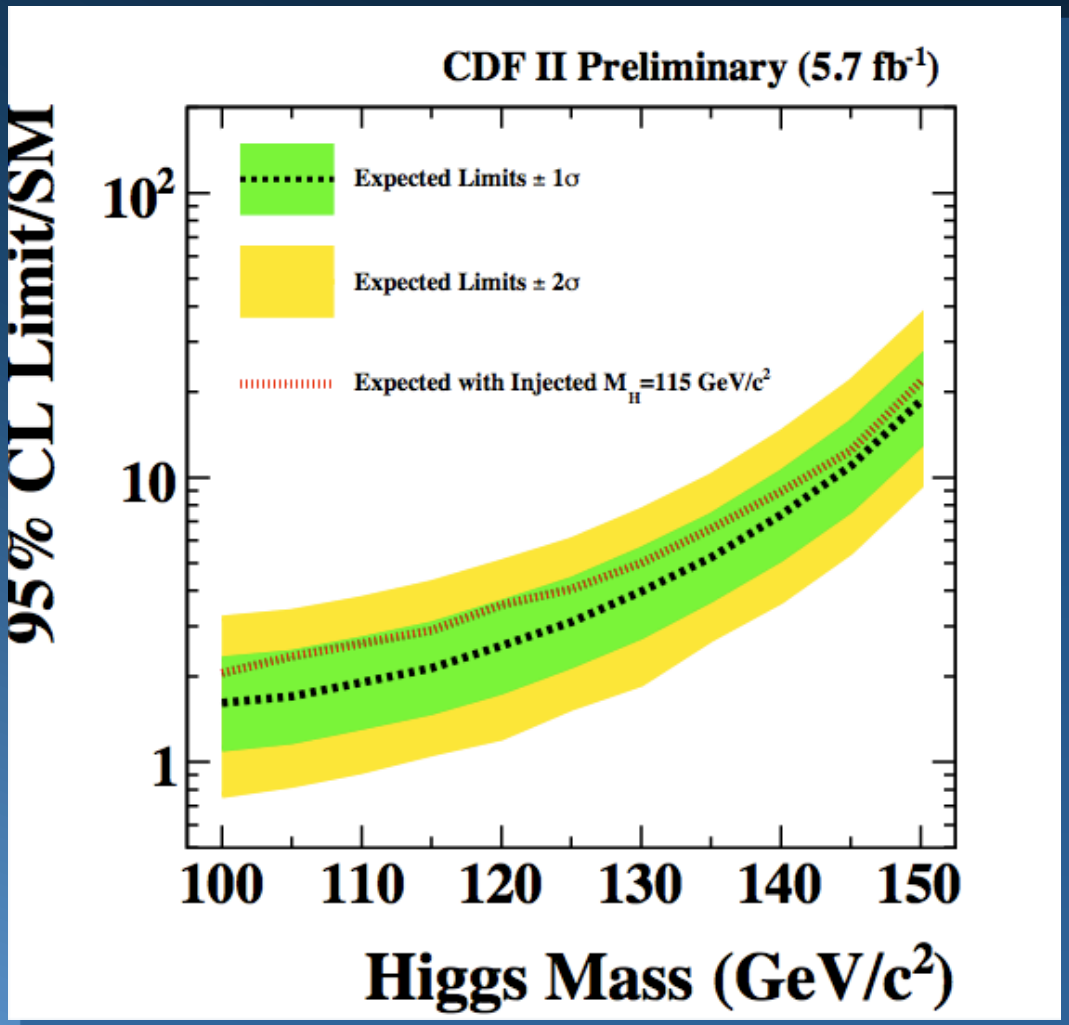
Siddharta Gautama, the founder of Buddhism, 563-483 B.C

Extras

Higgs Production



What might a signal look like?



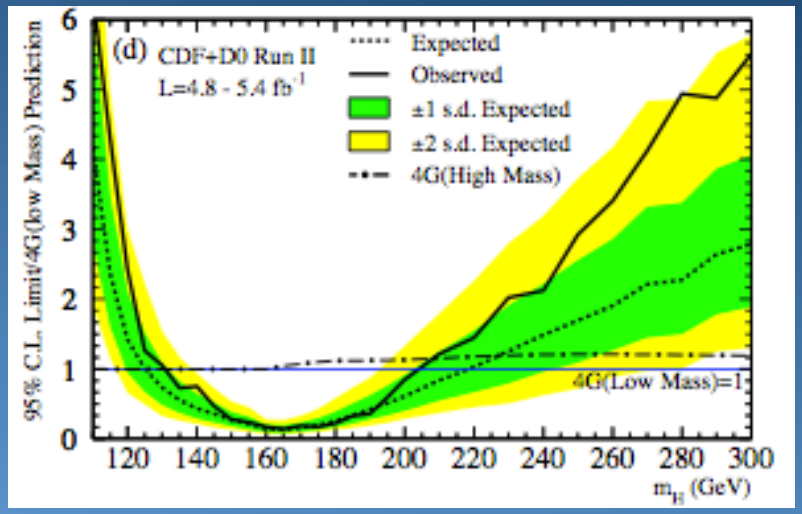
- Perform the following test:
  - –Inject signal with m_H = 115 GeV into pseudoexperiments
    - ZH→llbb, WH→lvbb, ZH→vvbb
- Result: slight excess
  - –Similar to observed limits

Search for Higgs with 4 quark Generations

4th quark generation popular theory to resolve SM discrepancies and produce new CP violation

Analysis :

- gg→H production enhanced if new 4th generation quarks more massive than top
- m_H < 300 GeV electroweak precision fits @ 68%C.L.
- Use existing H→WW analysis framework



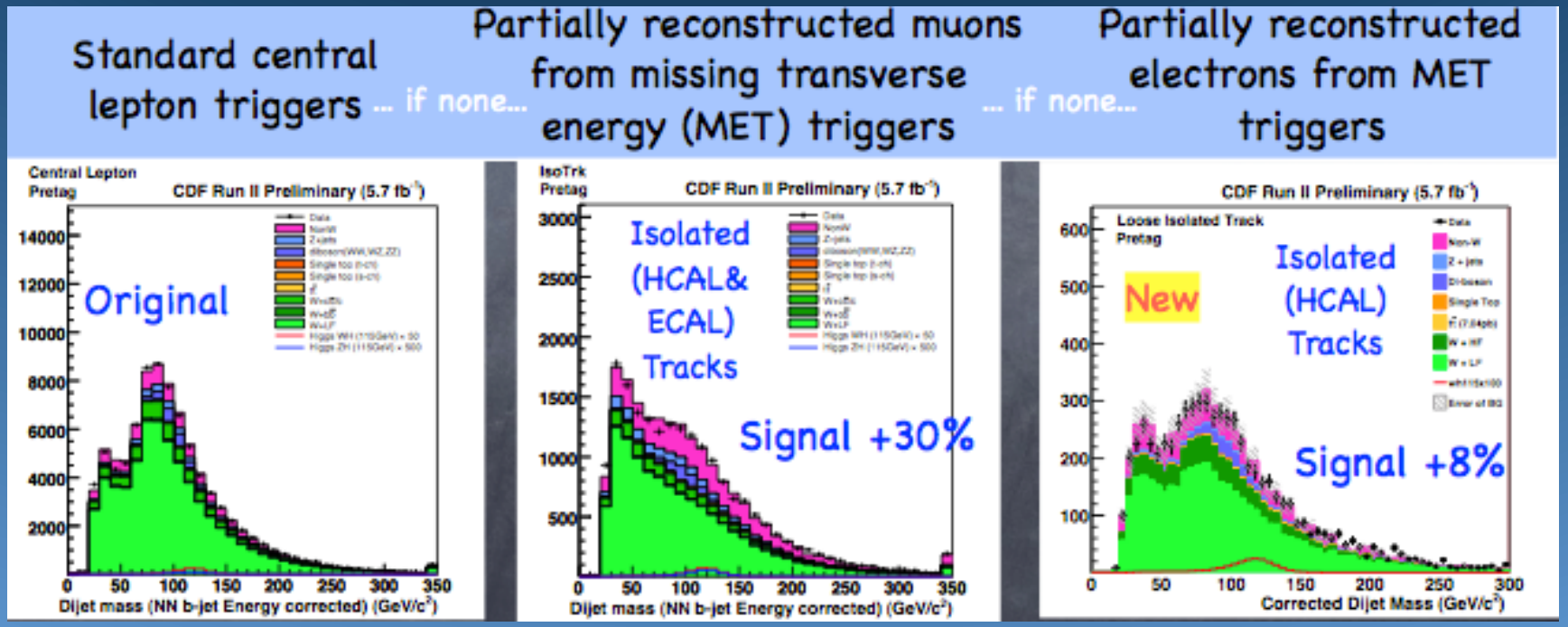
Excess could signal both evidence for Higgs boson, and evidence for 4th generation of quarks

CDF + D0 combination : 131 < m_H < 204 GeV excluded

Increasing Higgs Acceptance

Originally: tight triggers & lepton IDq Now: suite of triggers and loose lepton ID

- Challenge : Model important kinematics for increasingly poorly reconstructed events
- For instance, CDF WH→lvbb analysis :



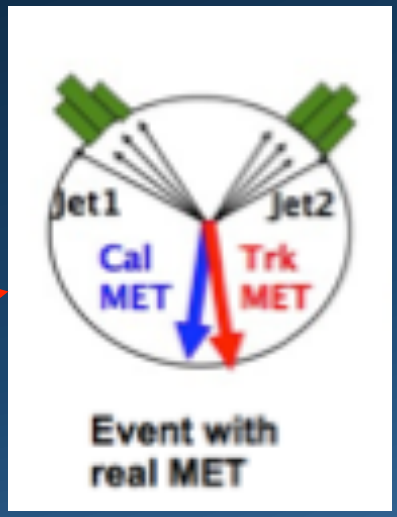
Removing Difficult Backgrounds

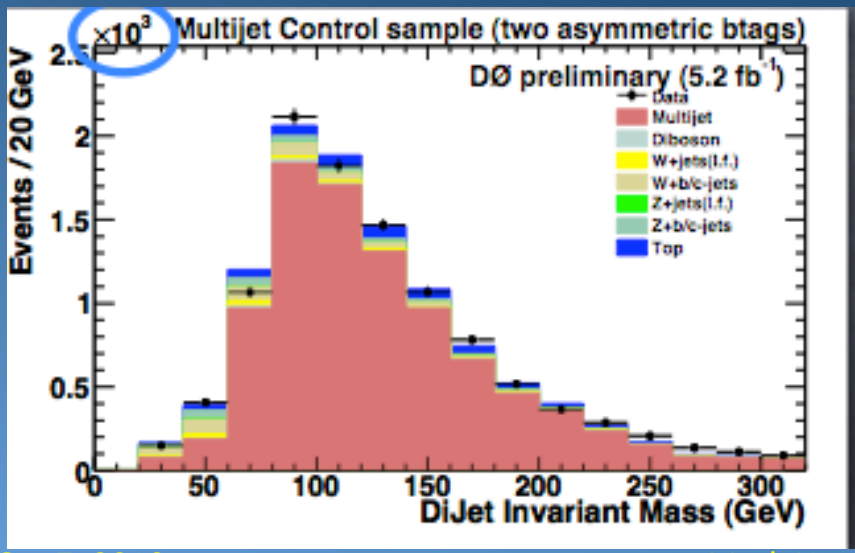
Higgs signals can have large MET

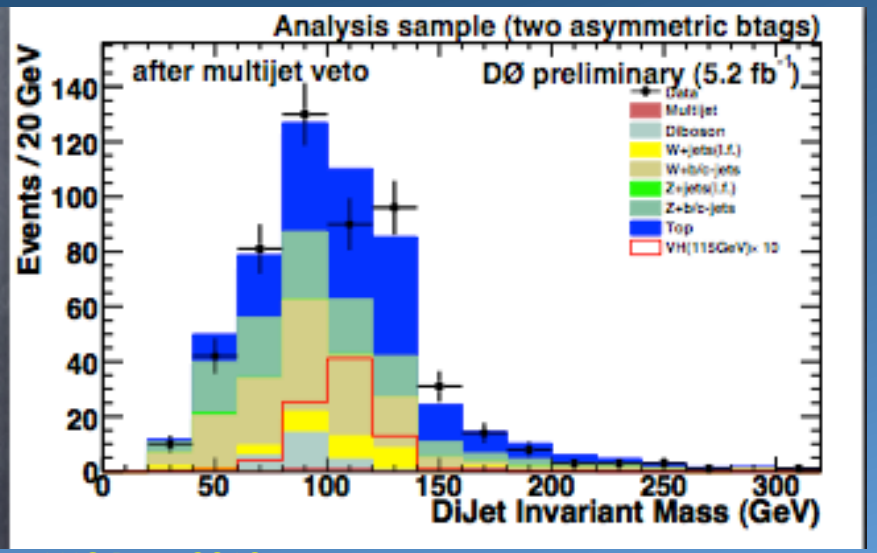
- ZH → ννbb, WH → lνbb (lepton missed)
- Large QCD multijet with mismeasured jets
- Peaks near where signal expected in Mjj

Multijet removal techniques save this channel

- MET significance
- Missing track PT (MPT)
- Topological requirements



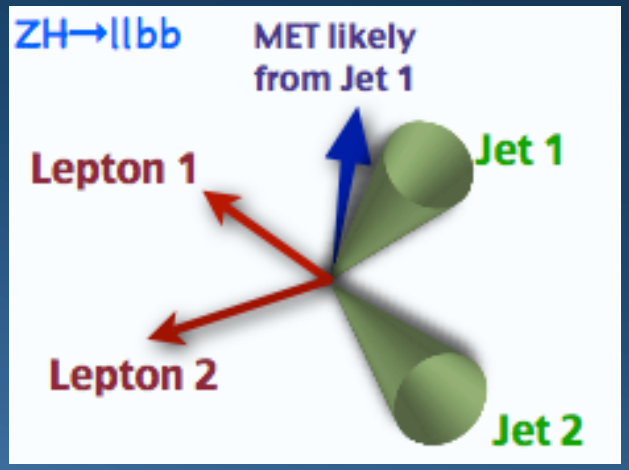


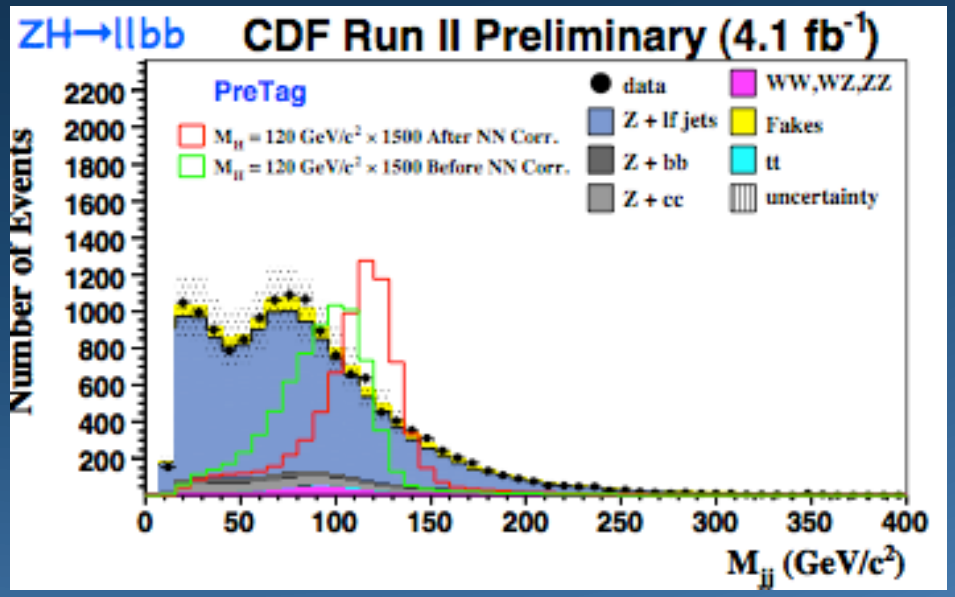


Improving M_{bb} Resolution

H → *bb* signal significance enhanced by improving M_{jj} resolution

Apply MET constraint to correct jet energies





M_{jj} resolution improvements in other analyses :

- Track momenta within jets additional constraint (~ "particle flow")
- Displaced vertex info to determine boost of *b*-hadron