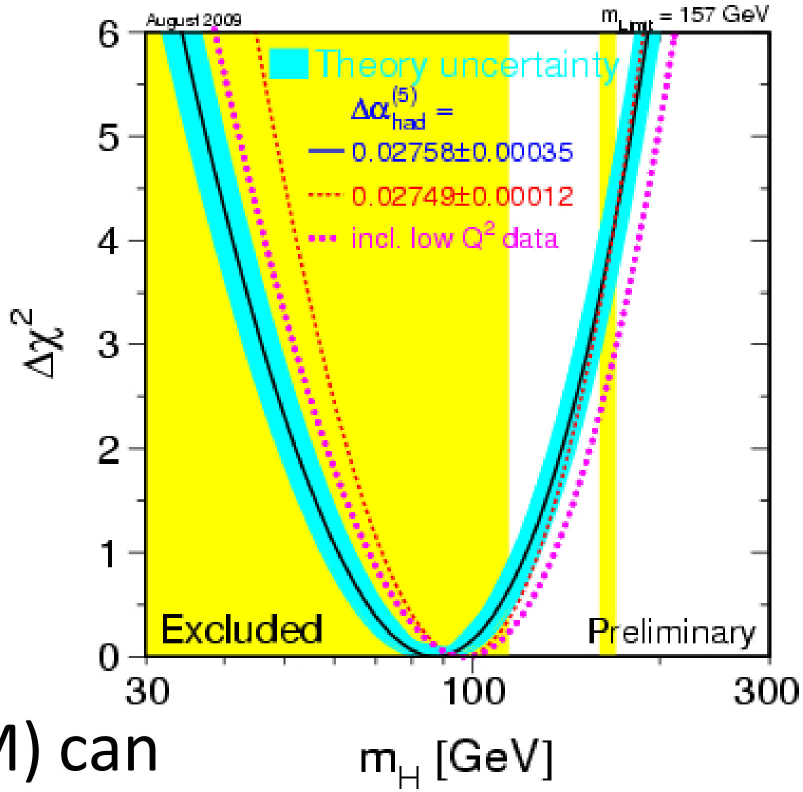
Searches for Higgs Boson at the Tevatron

Alexei Safonov
(Texas A&M University)
for CDF and D0 Collaborations

Higgs Today

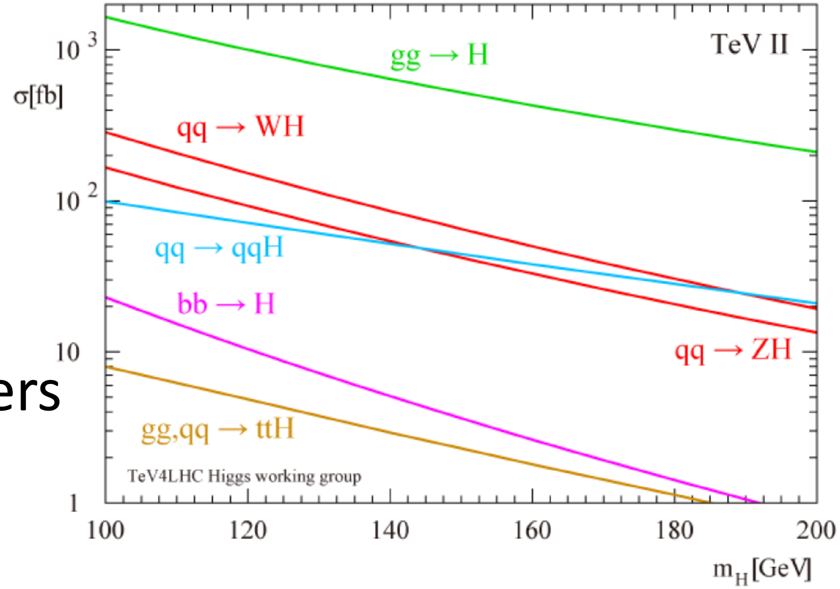
- At least one SM-like Higgs is required in most models
  - Use SM Higgs for benchmarking, but keep in mind that it can be something more complex
- Direct exclusions:
  - LEP: m>114 GeV
- Indirect:
  - LEP, Tevatron (W/top mass)
  - 95% C.L. m<158 GeV

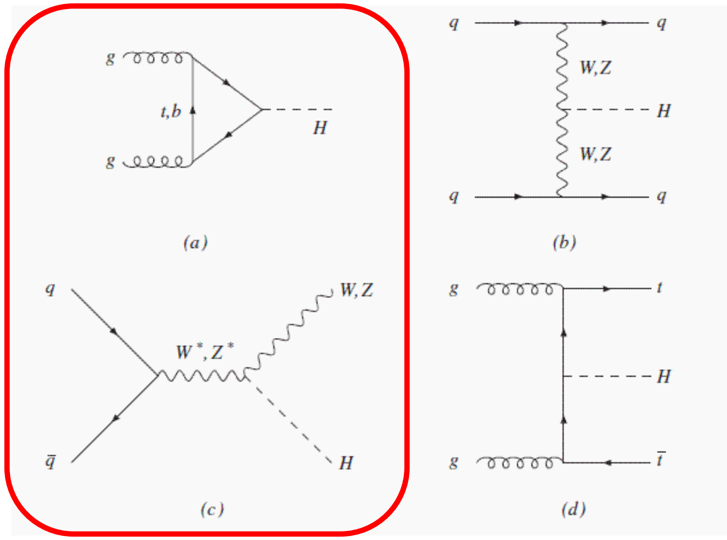


- Non-SM scenarios (e.g. NMSSM) can weaken both direct and indirect limits

Higgs Production at the Tevatron

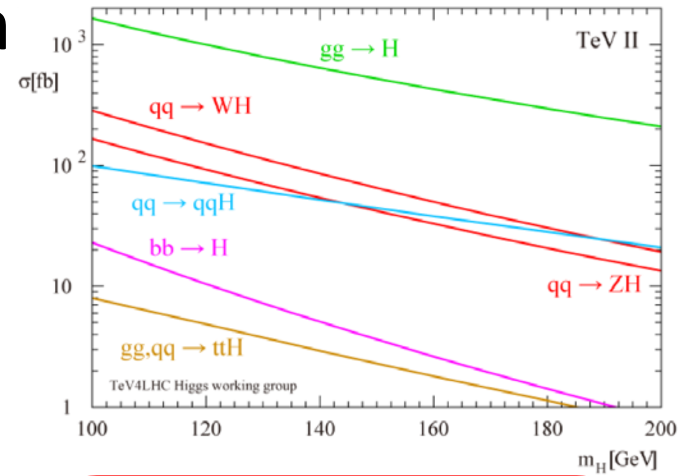
- Dominated by gluon fusion
  - But large decay modes often come with large backgrounds
- Associated Production
  - While smaller cross section, offers cleaner final states
- Vector Boson Fusion (VBF)
  - Even smaller cross-section, but can help increase the overall sensitivity
- Have to be inventive and use all accessible modes and many decay channels
  - Improving analysis techniques

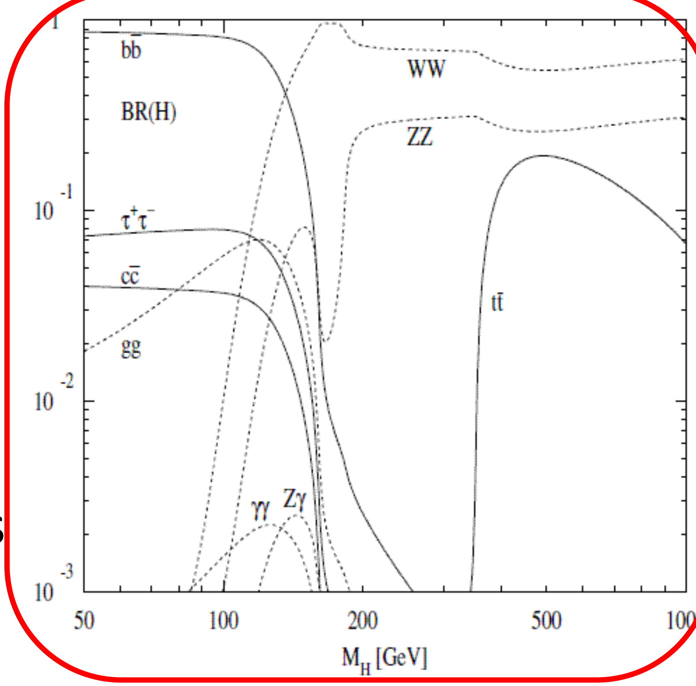




Higgs Search Strategies

- Sensitivity strongly depends on backgrounds for a specific decay channel:
- "High mass" m > ~135 GeV:
  - WW (and ZZ) decay modes
    - Clean final states with leptons, any production mode will do
- "Low mass" m < ~135 GeV:
  - Associated production:
    - Rely on leptons/neutrinos to reduce background, go after all decay modes (but bb dominates)
  - Gluon fusion:
    - H→bb dominated by backgrounds
    - H→ττ: ok but small BR



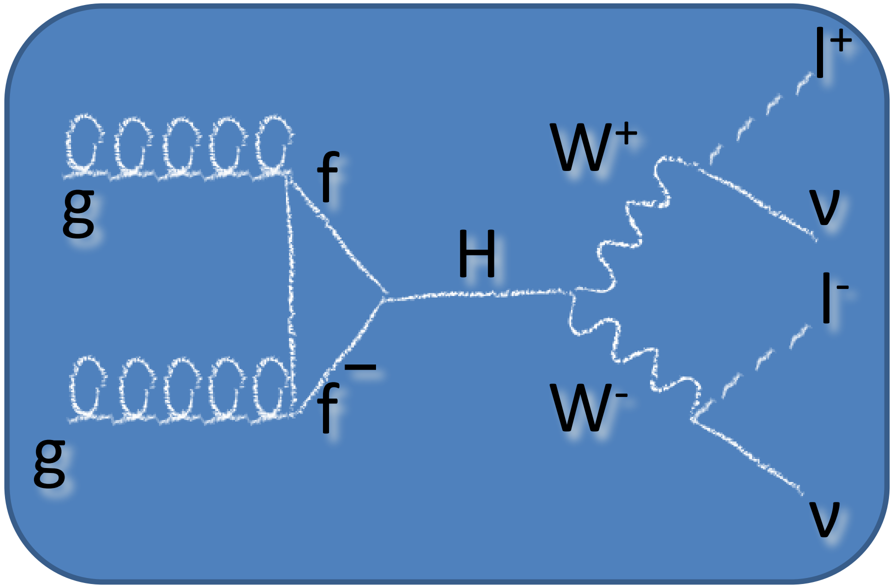


Higgs Searches at the Tevatron

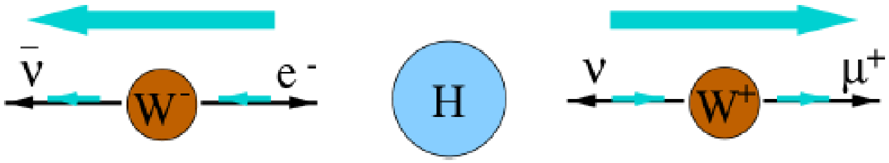
HIGH MASS HIGGS

High Mass Searches

- WW is the best channel
  - Large BR, can use all production modes
- Both experiments rely on advanced techniques and categorizations
  - Neural Net (NN), Matrix Element (ME), Decision Trees (DT)
- Backgrounds:
  - DY, diboson, W+jets
- Selections:
  - 2 OS leptons, MET
  - Leptons+jets
  - LS leptons (WH->WWW)

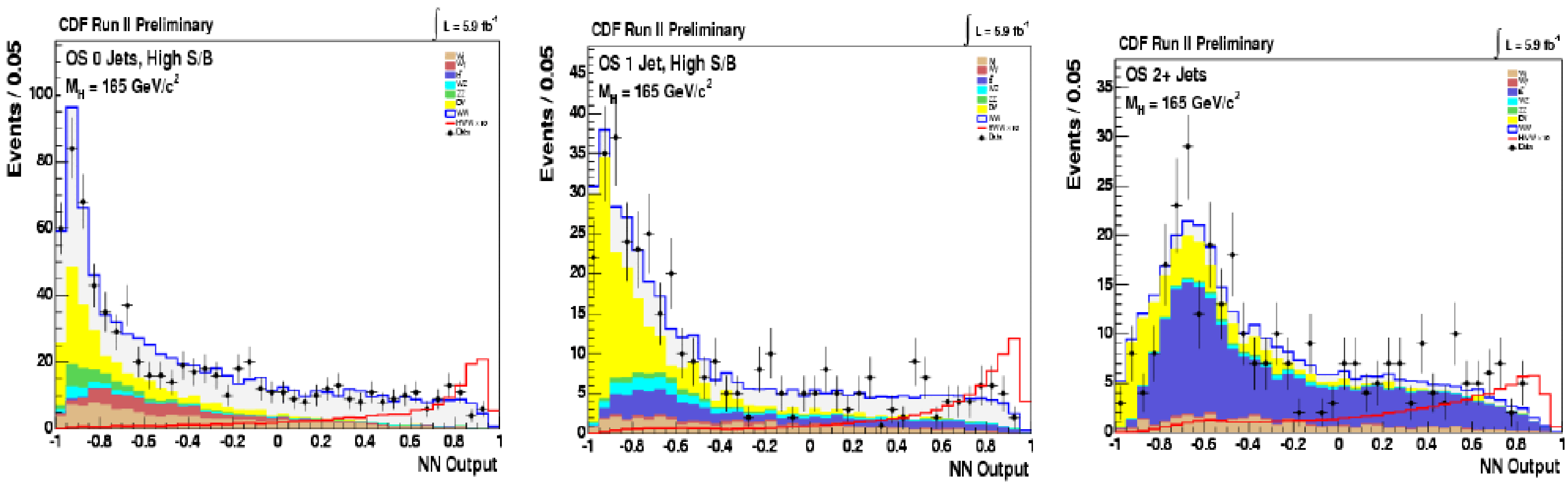


- Helicity conservation:
  - Leptons tend to go in the same directions



Signal Extraction

- Categorize according to N_{jet}=0, 1, 2 in $ll+N_{jets}$
  - Adds VBF and associated production with H→WW
- CDF uses NNs, DO - BDTs
  - Trained on each category separately
  - Inputs: event topology (lepton kinematics, lepton and MET, jets and MET) and quality of leptons

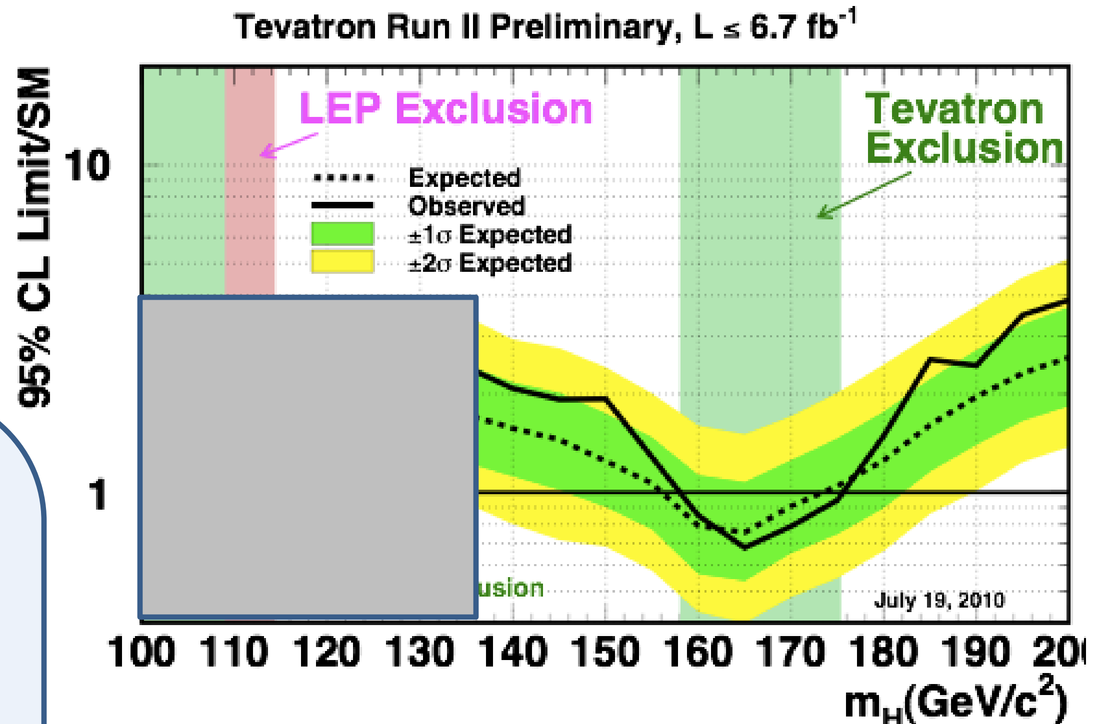


High Mass: Results

- Combine together multiple analysis channels
  - CDF example shows importance of different contributions

M_H=165 CDF Run II	Expected limit	Observed limit
0 jets	1.67	2.39
1 jet	2.35	2.46
2+ jets	3.16	6.14
SS 1+jet	4.86	5.92
Tri-lep. NoZ	7.37	7.85
Tri-lep. Z1J	31.8	36.4
Tri-lep. Z2+J	9.16	10.4
Hadr. Tau	14.5	23.5
Low Mll	11.2	7.21
Combined	1.00	1.08

Ratio σ(excluded)/σ(SM)

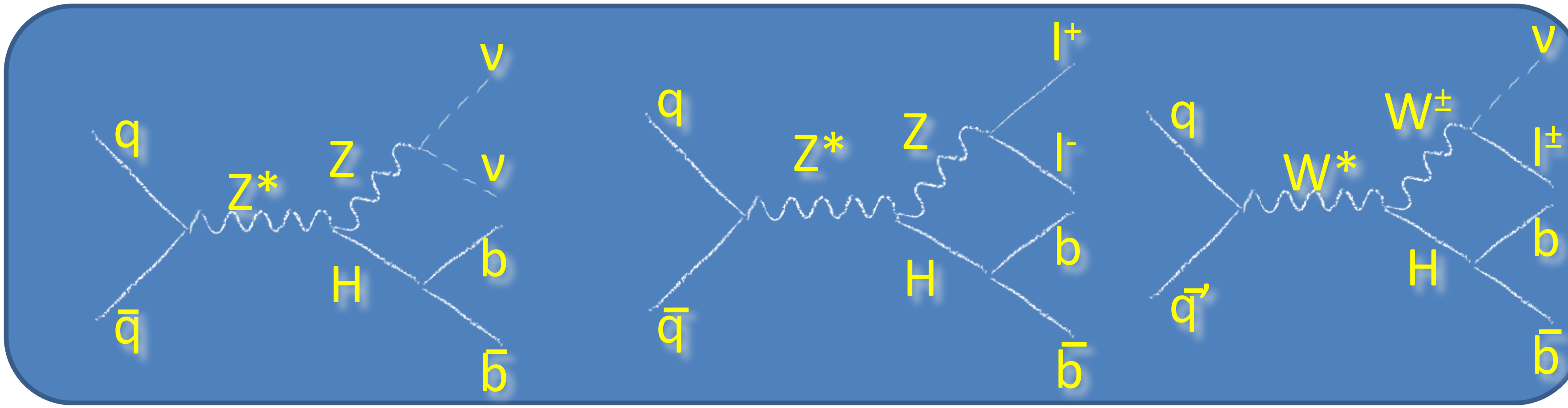


- Combine CDF and D0
- Excluded mass range:
  - 158-175 GeV/c^2

Higgs Searches at the Tevatron

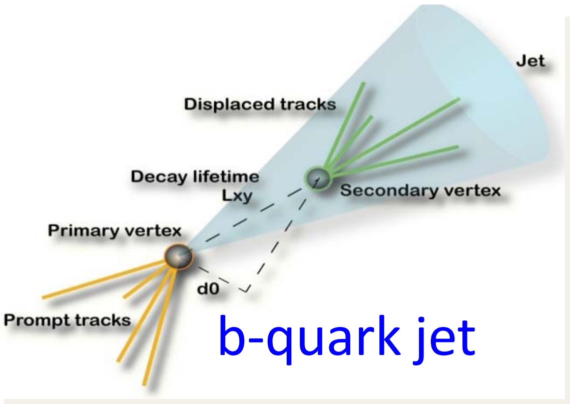
LOW MASS HIGGS

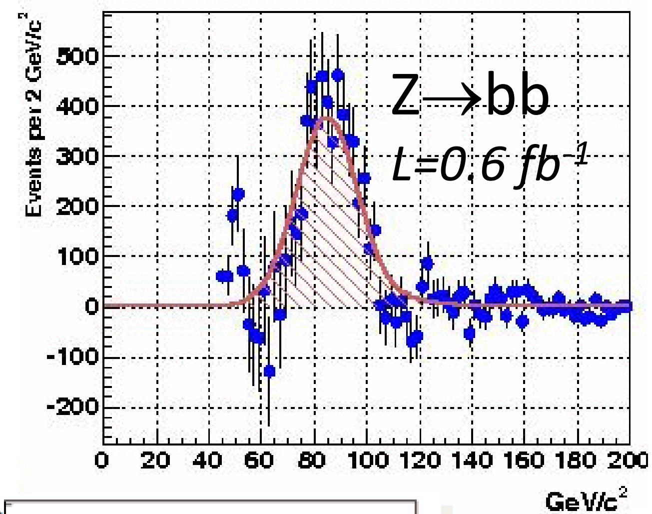
Associated Production Channels

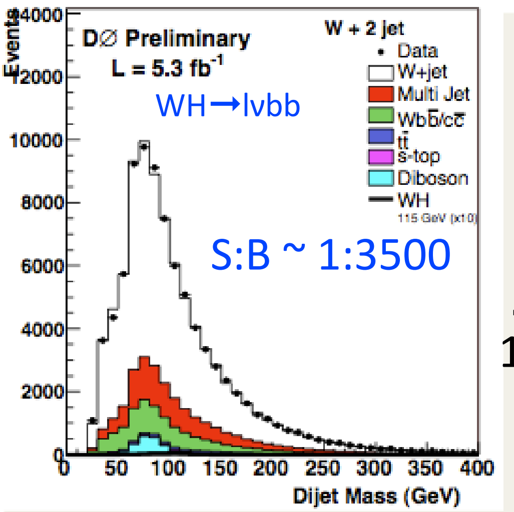


- While smaller cross-section, final states are much cleaner
- Main ingredients:
  - Leptons or MET allow large reduction in backgrounds to go after dominant bb decay channel
  - b-tagging dramatically reduces W/Z+light jet and QCD backgrounds
- Analyses look for a bump in the dijet spectrum
  - Good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

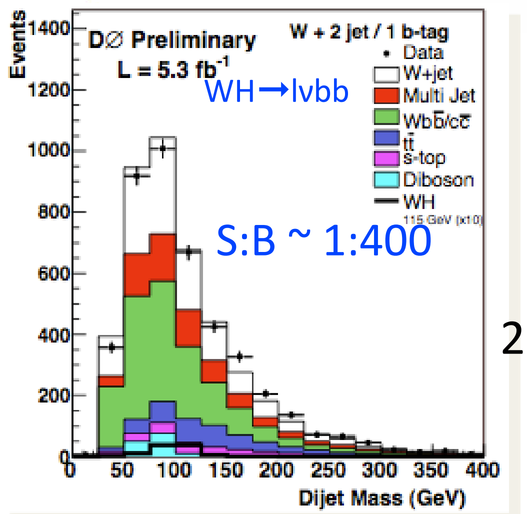
Backgrounds and Resolution



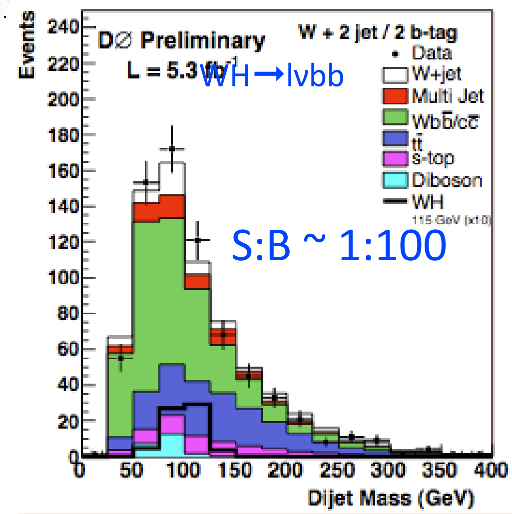




1 b-tag →



2 b-tags →

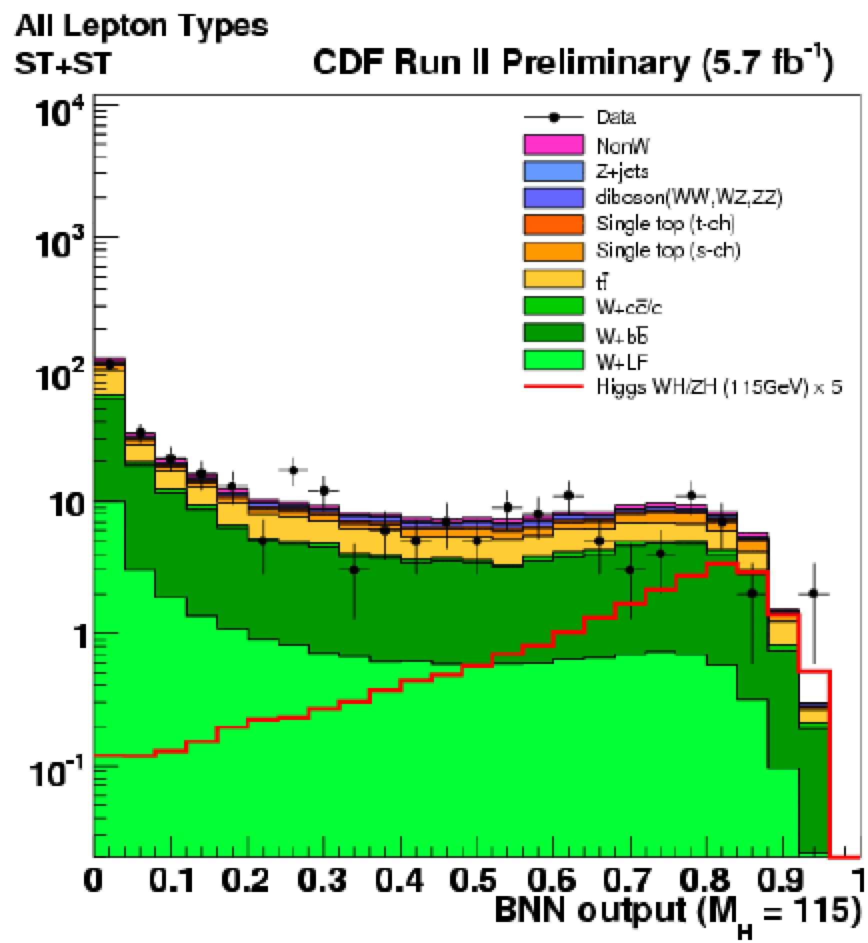


- After 1 or 2 b-tags

  Signal region with enhanced signal / background

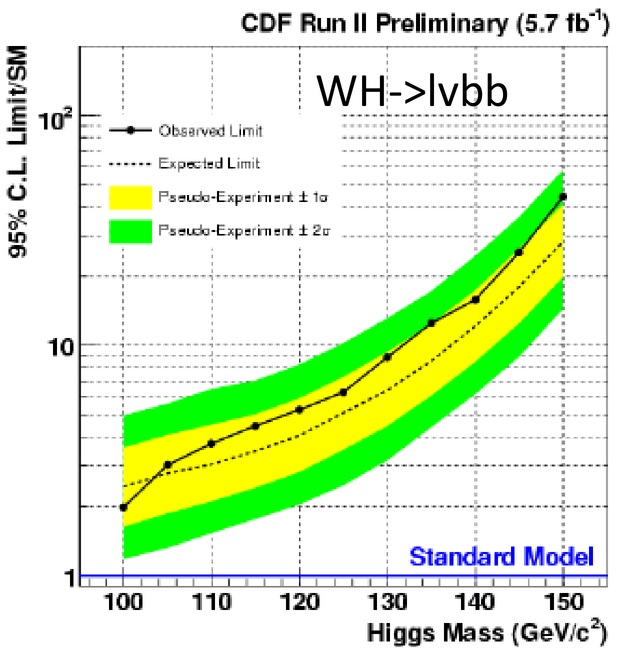
Multivariate Techniques

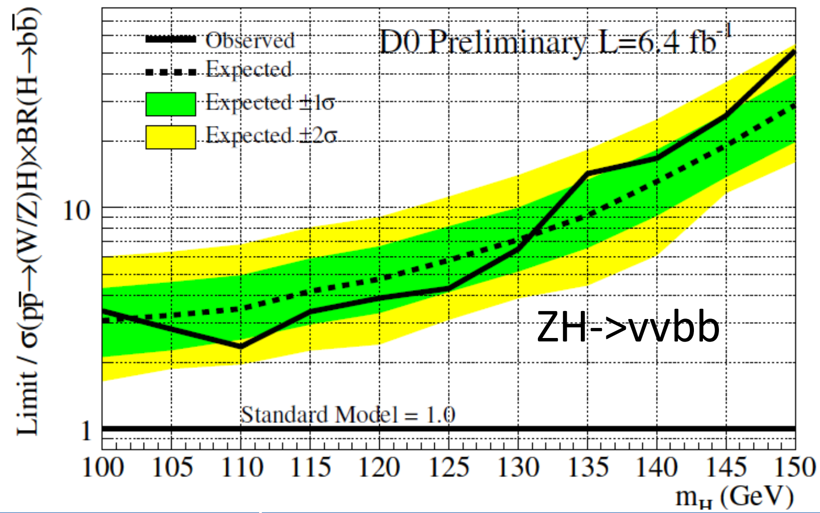
- Both experiments rely on advanced techniques
  - NN, ME, DT
    - Validated in other analyses, requires excellent understanding of the detectors
  - Extensive categorization to improve sensitivity
    - E.g. 4 b-taggers (displaced vertex, track impact parameter, NN)
    - Multiple lepton categories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



- Bayesian NN output in WH->lvbb analysis

Low Mass Limits



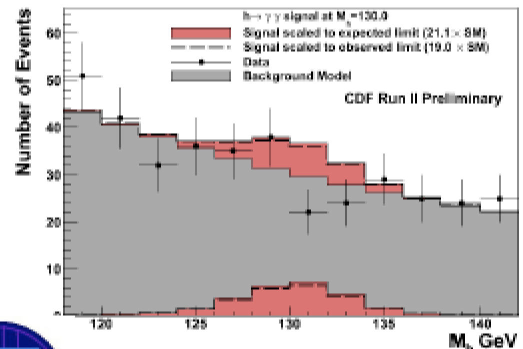


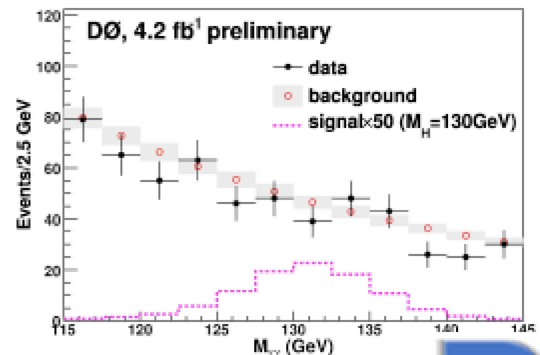
- Data consistent with expectation
- Sensitivity ranking list of channels
  - Use CDF as an example

Channel	Expected σ(excl)/σ(SM) for m=115 GeV
WH→lνbb	<3.5
VH in MET+bb	<4.0
ZH→llbb	<5.5
VH in qqbb	<18
γγ	<21
2τ+2j	<23
Combined	<1.9

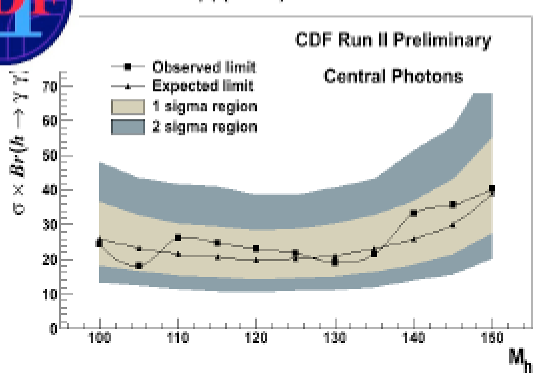
“New” Low Mass Channel: H→γγ

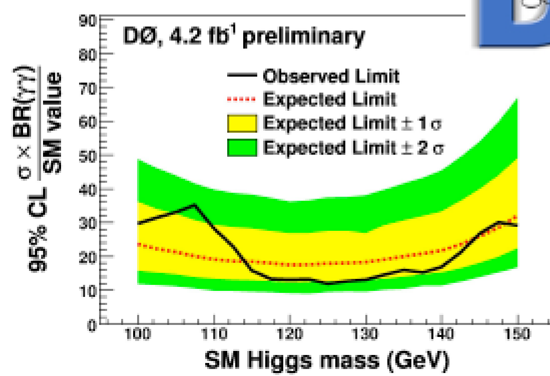
- “Discovery” mode at the LHC
  - Small BR~0.2%, but a narrow bump
    - Sensitivity is a strong function of EM calorimeter resolution





Limits for h→γγ (5.4 fb-1)

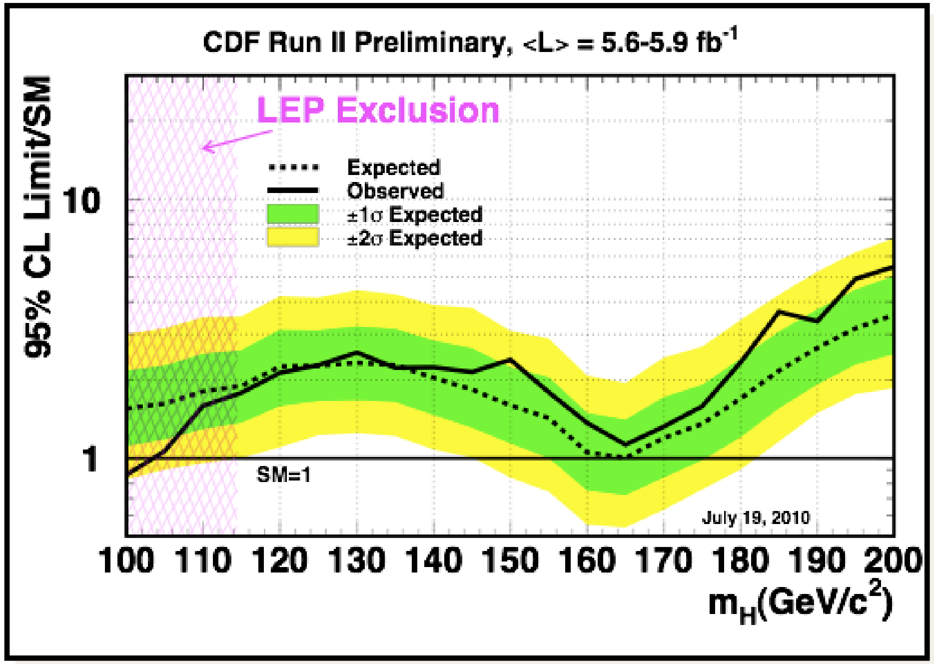


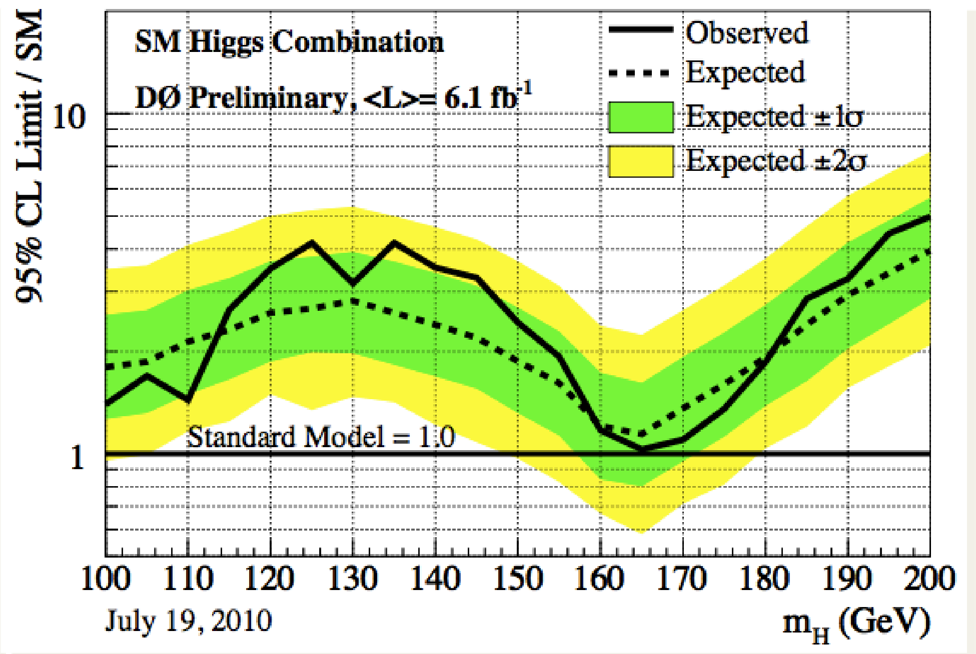


  - Useful experience in preparing for H→γγ at the LHC

CDF & D0 Combinations

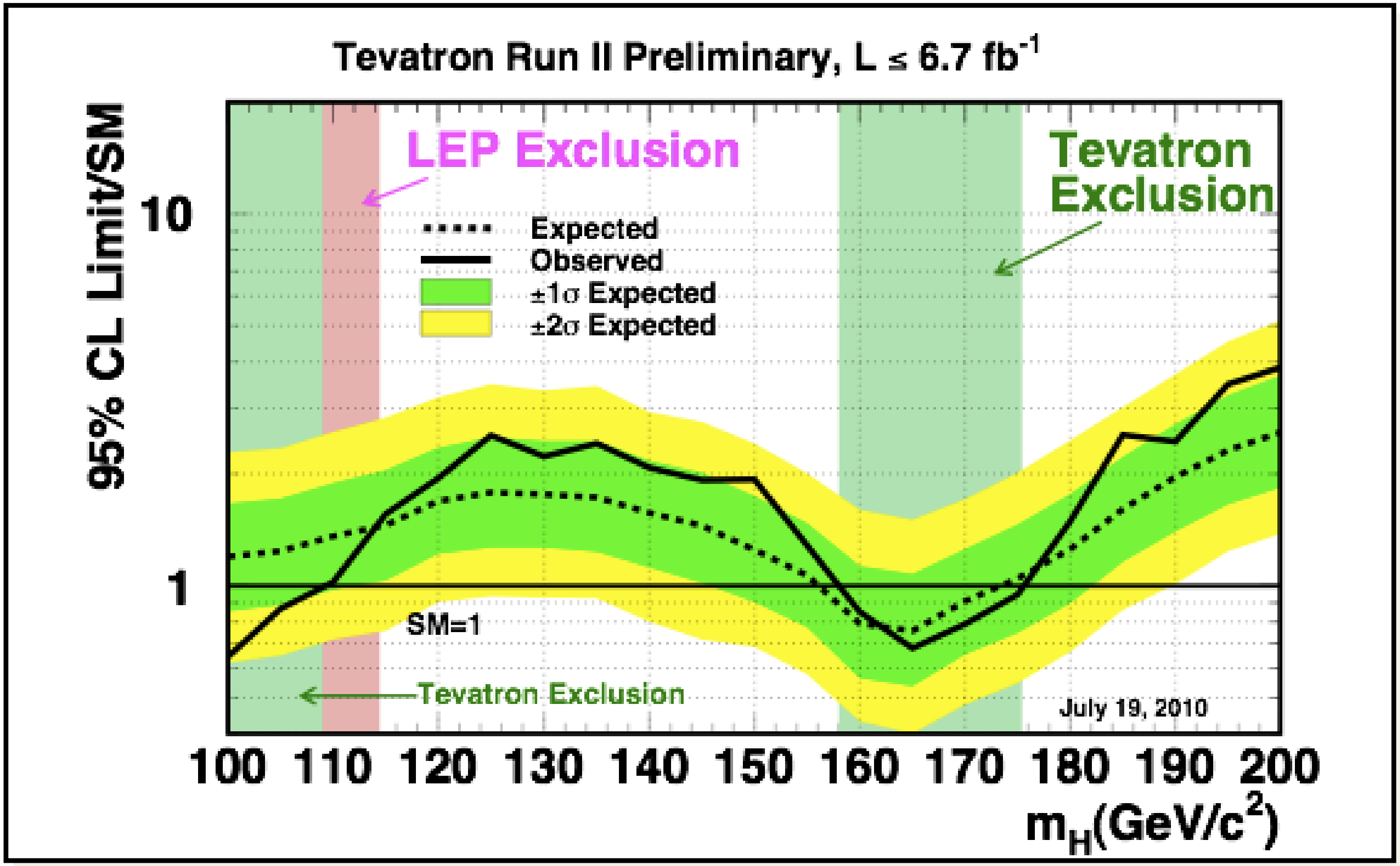
- CDF limits
- D0 limits





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

Tevatron combination



Low mass sensitivity approaching LEP exclusion m_H>109 GeV:

Expected 1.45*SM @ 115 GeV

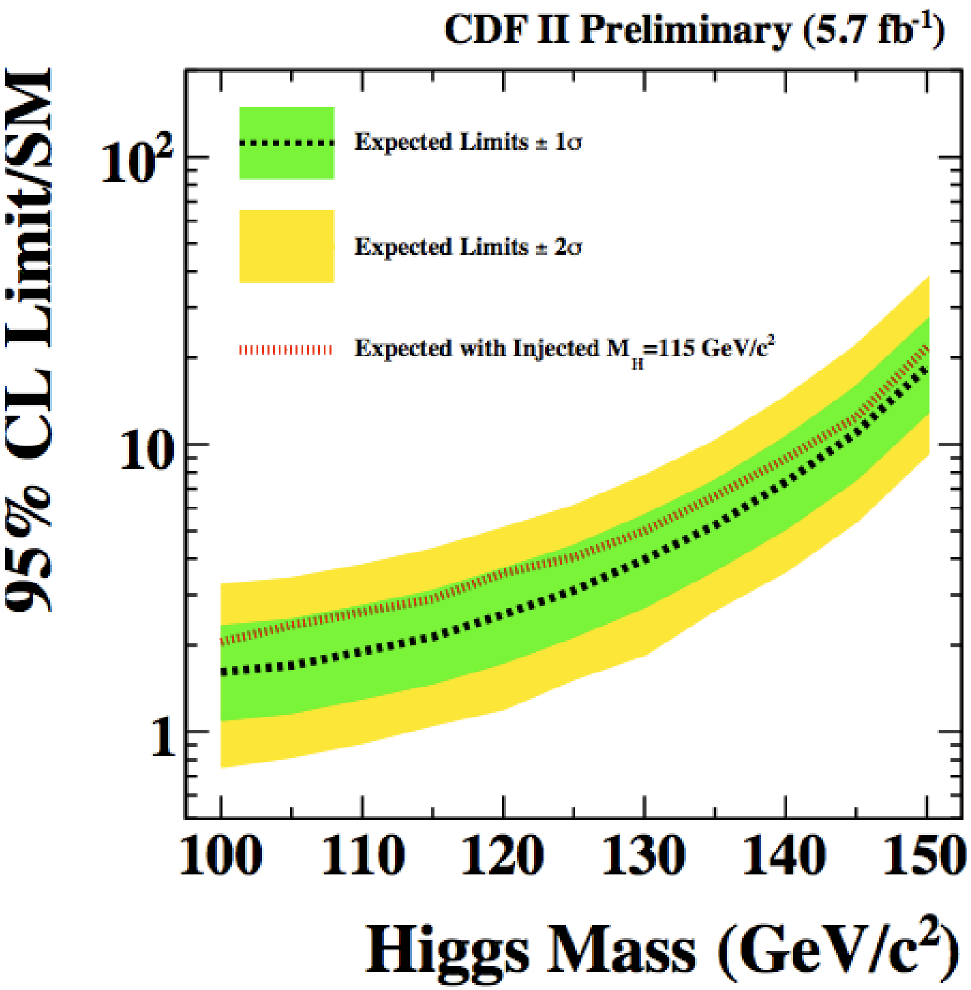
Expected 1.24*SM @ 105 GeV

High mass 95% CL exclusion :

158 < m_H < 175 GeV

Expected (156 < m_H < 175 GeV)

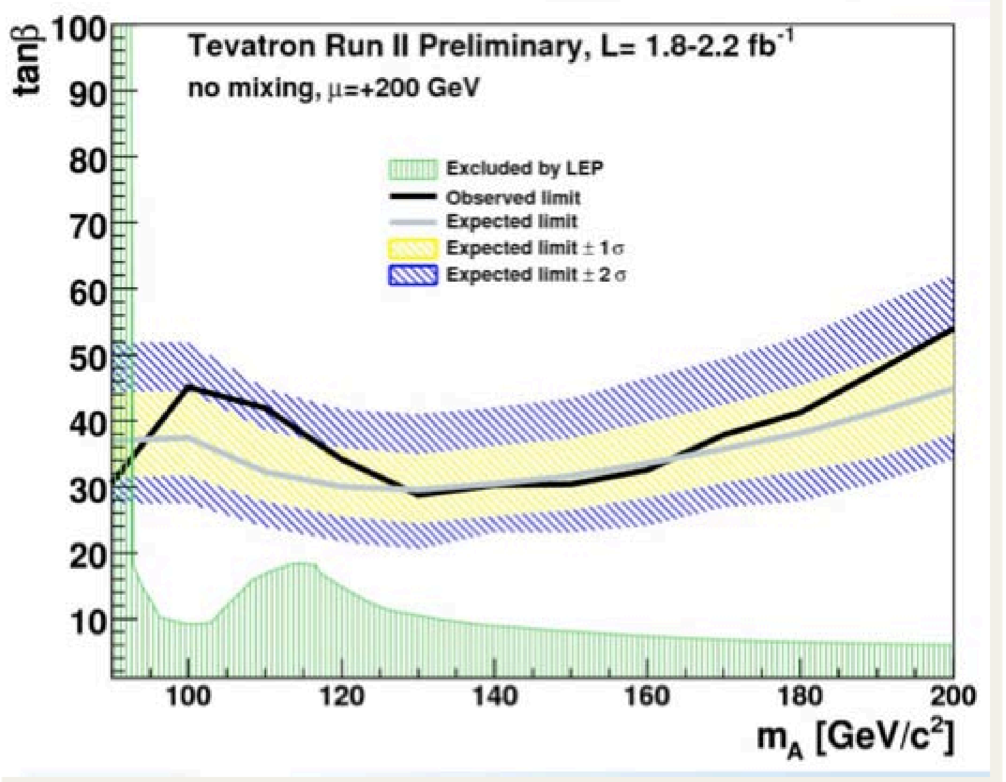
What Would a Signal Look Like ?



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

MSSM Higgs

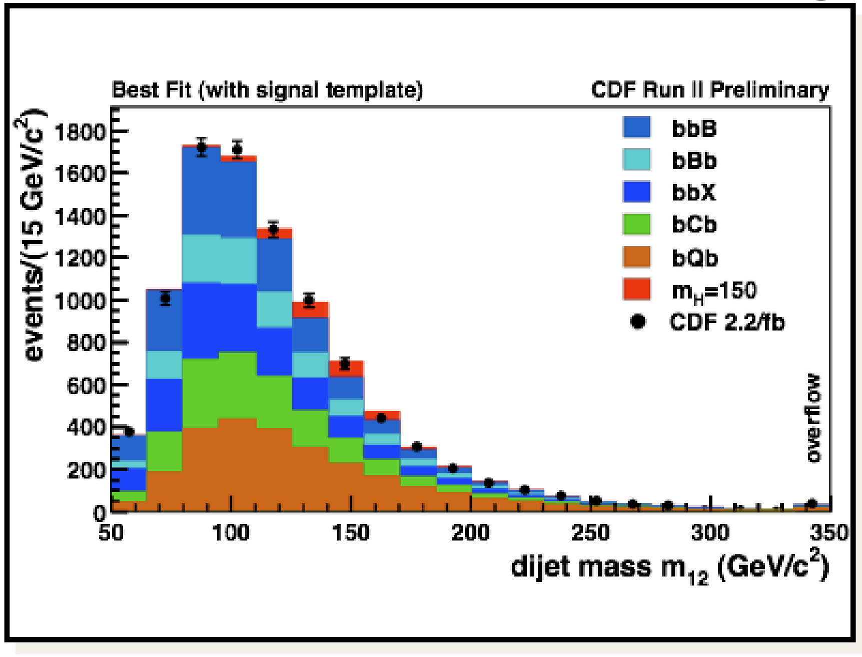
- Higgs coupling enhancement at large tanβ:
  - Large increase in cross-sections compared to SM
    - E.g. gg->h/A, gb->bA
  - Dominant gg->H->bb is still difficult, but new final states:
    - H->ττ, Hb->bbb, bττ, Hbb->bbbb, bbττ

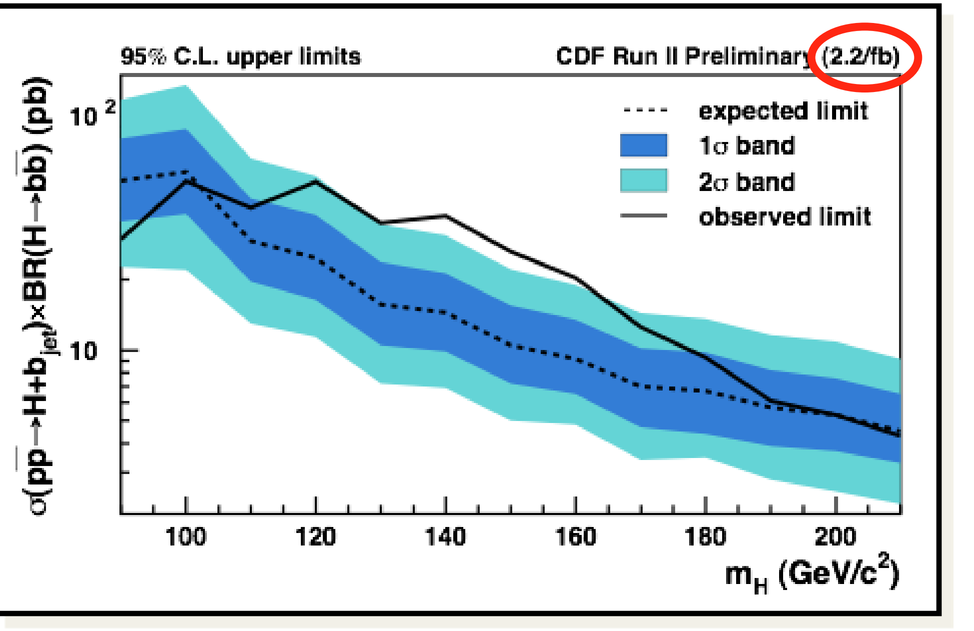


- Combined 2 ifb result for h->ττ

MSSM Higgs

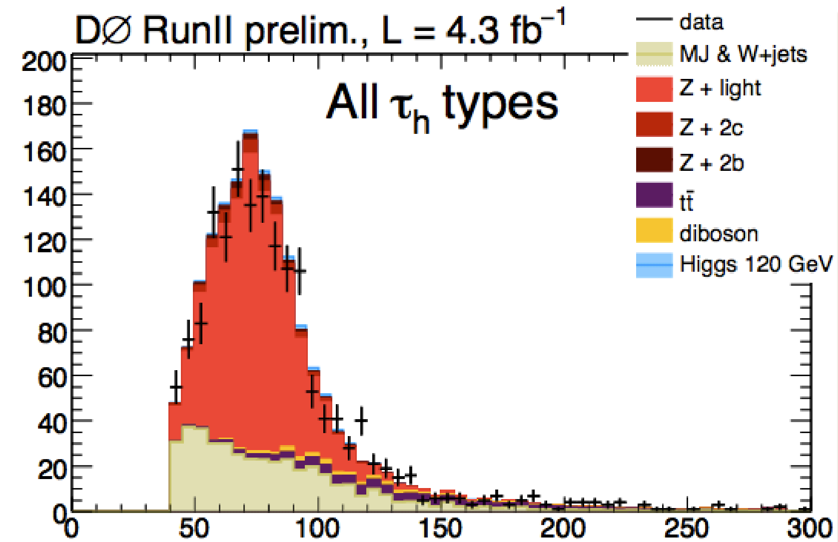
- MSSM Higgs 3b search (Φ+b → bb+b)
  - Complements MSSM H → ττ search
  - Relies on CDF's trigger-level b-tagging used in b physics
  - New version of analysis 2x more acceptance
    - m_H = 140 GeV most significant excess

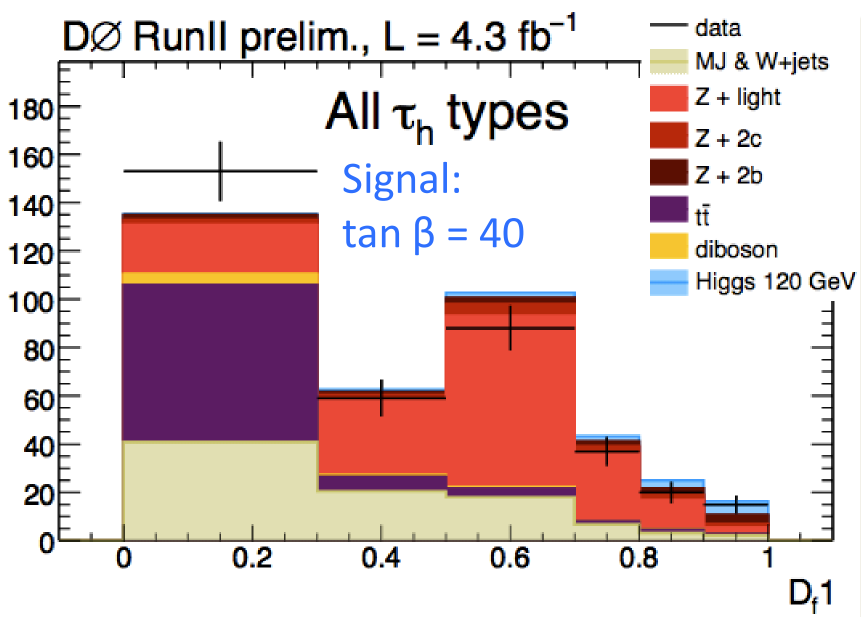


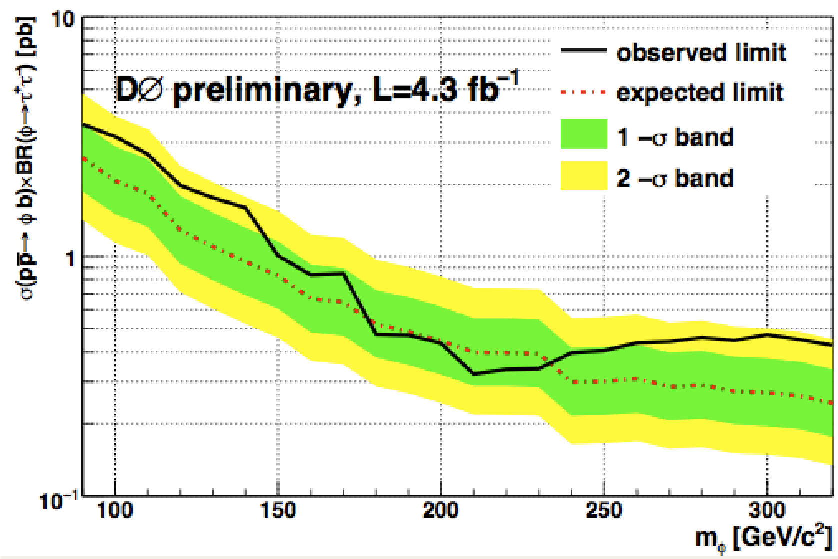


New MSSM Higgs search

- 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







Luminosity Projections

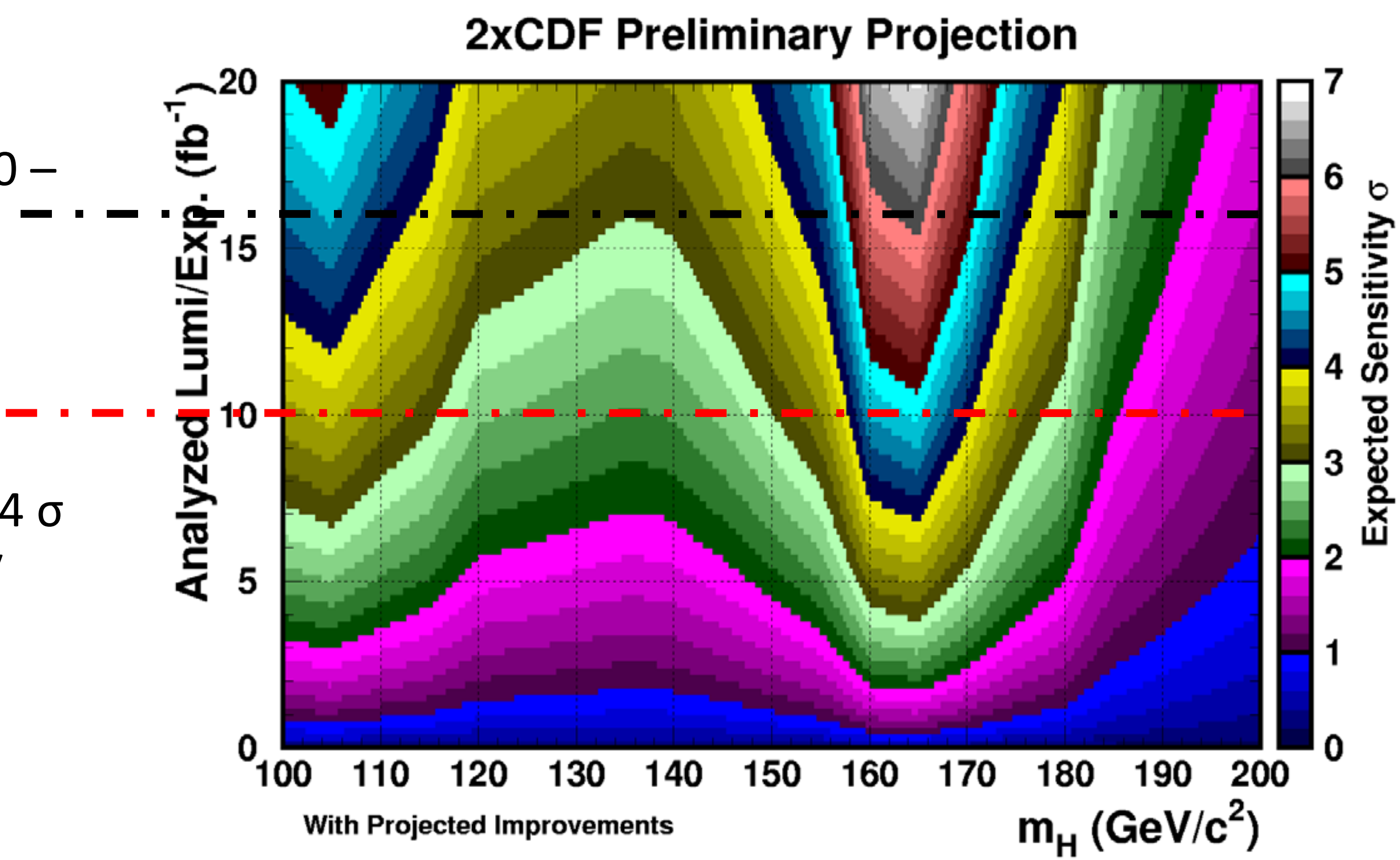
~16 fb^{-1} :*

> 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

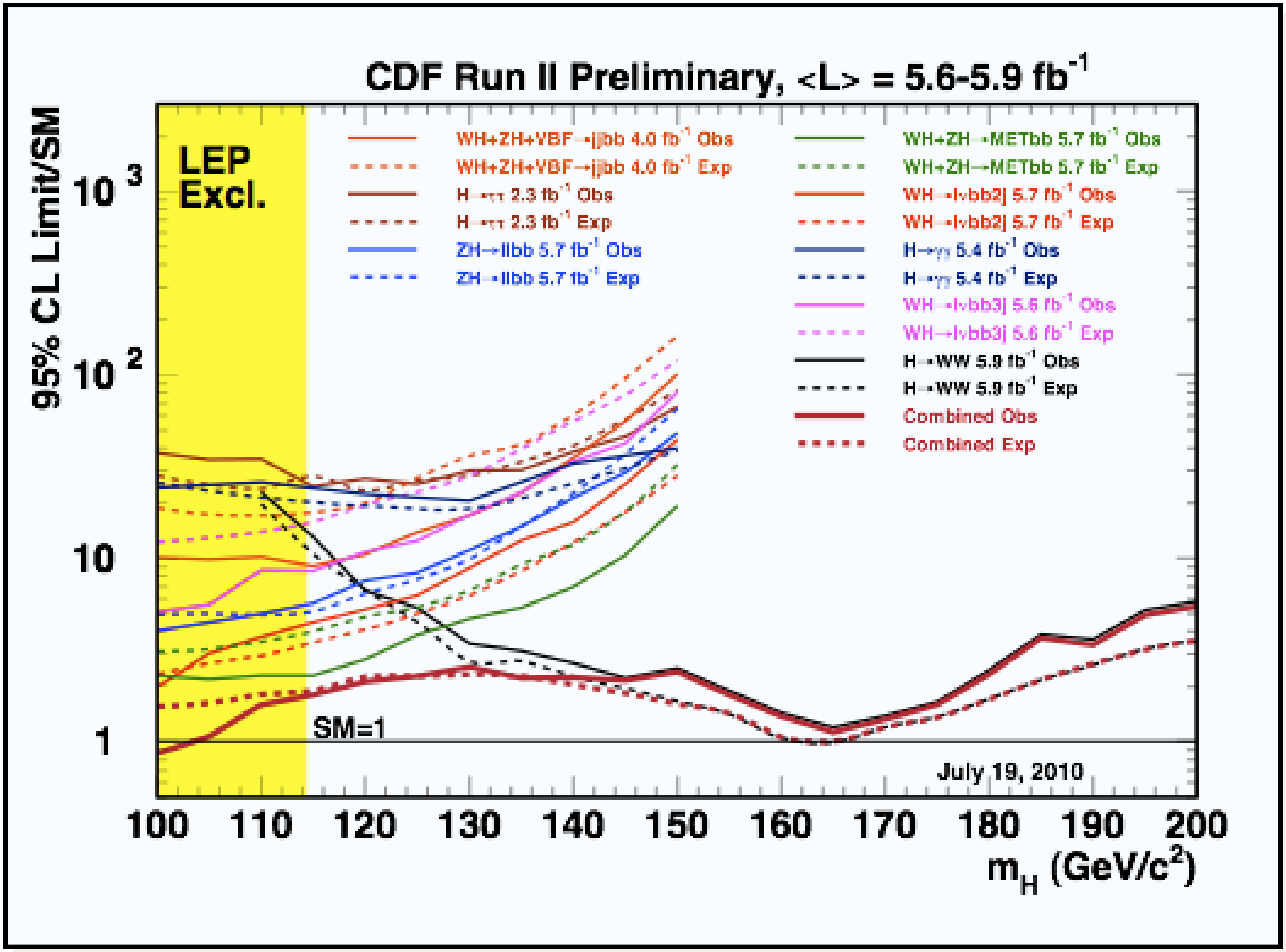


* 16 fb^{-1} : based on "Run III" proposal to run 3 more years

Summary

- Both CDF and D0 have an extensive program of searches for Higgs
  - Significant improvement in terms of better use of the data:
    - More complex techniques possible given excellent understanding of the detectors and extensive experience
    - Improved acceptances and categorization lead to better sensitivities
  - Tevatron SM Higgs sensitivity approaches exclusion of the entire range m<180 at 95% CL
- Evidence for Higgs may be not too far away

What goes into the combination?



Improvements for 115 GeV Higgs for CDF

Type	Projected improvements	WHlvbb, %	ZHllbb, %	VHMETbb, %
TRIGGERS	Single stub muons	5	3	NO
	Complete OR	5	3	8
	Multivariate turn-on curves	5	DONE	5
LEPTON ID	Multivariate elec ID	10	10	NO
	Multivariate muon ID	5	DONE	NO
OTHER	Relaxed cuts	2	DONE	2
	Track-based variables	5	2	DONE
	Color flow	3	3	3
B-TAGGING	NN B-tags	DONE	6	6
	NN flavor separator	DONE	DONE	5
	Soft-electron b-tag	5	5	5
	Silicon clustering algorithm	15	15	15
JET EN RESOL.	Track + CAL	3	1	DONE
	B-specific NN	DONE	1	3
	PI-0 corrections	5	1	5
TOTAL	All improvements	90%	60%	70%

(Multiplicative total: 1.05*1.05*1.15...)

- **115 GeV Higgs searches dominated by WH→lvbb, ZH→llbb, VH→METbb**
- **~ 50% gain required in each channel to reach projected sensitivity**

Fermilab PAC, August 2010 14