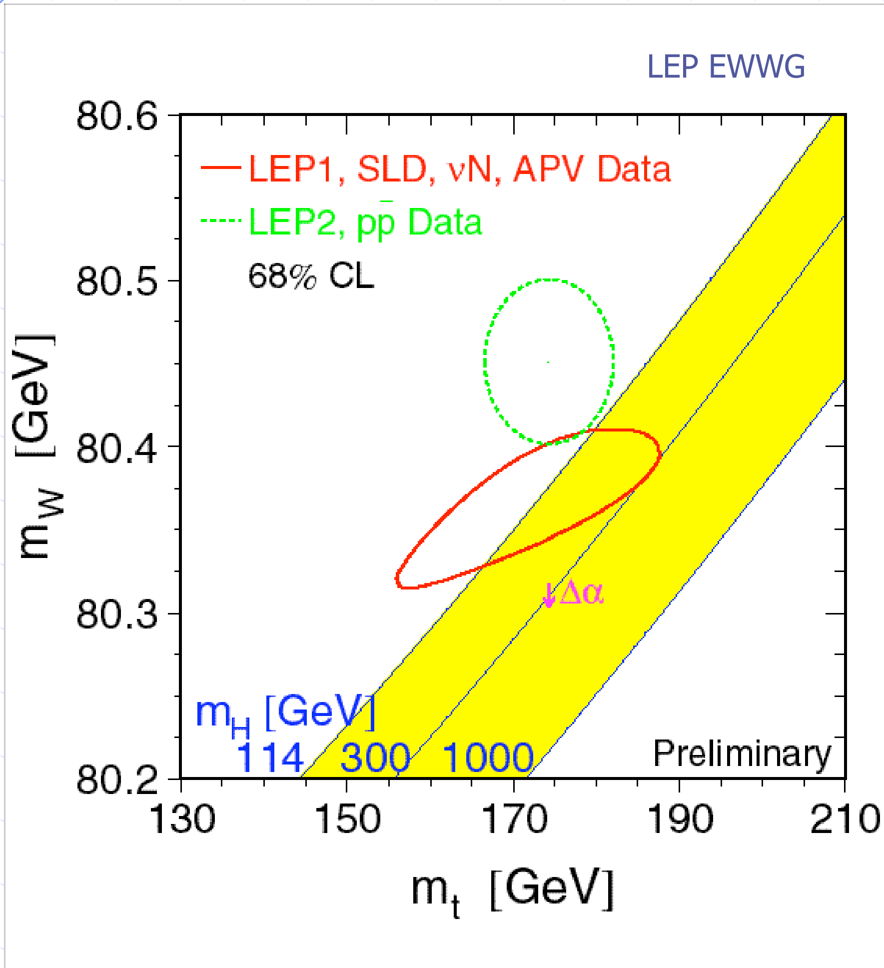
Search for the Higgs in Run 2

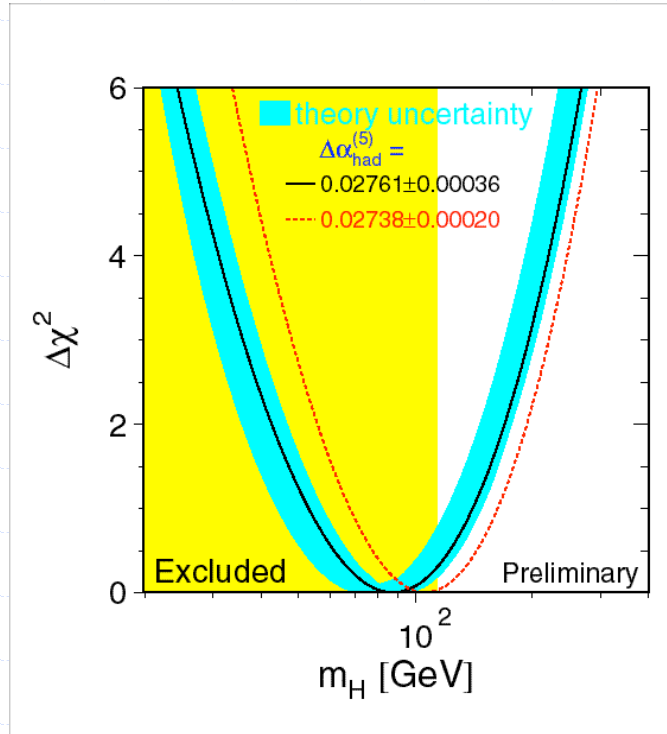
- Standard Model Higgs
  - search channels
  - improving the reach
- SUSY Higgs
  - interpretation of SM Higgs search
  - enhanced production modes

John Conway - Rutgers University

VIII Mexican Workshop on Particles and Fields - 19 Nov 2001

The Higgs is close!





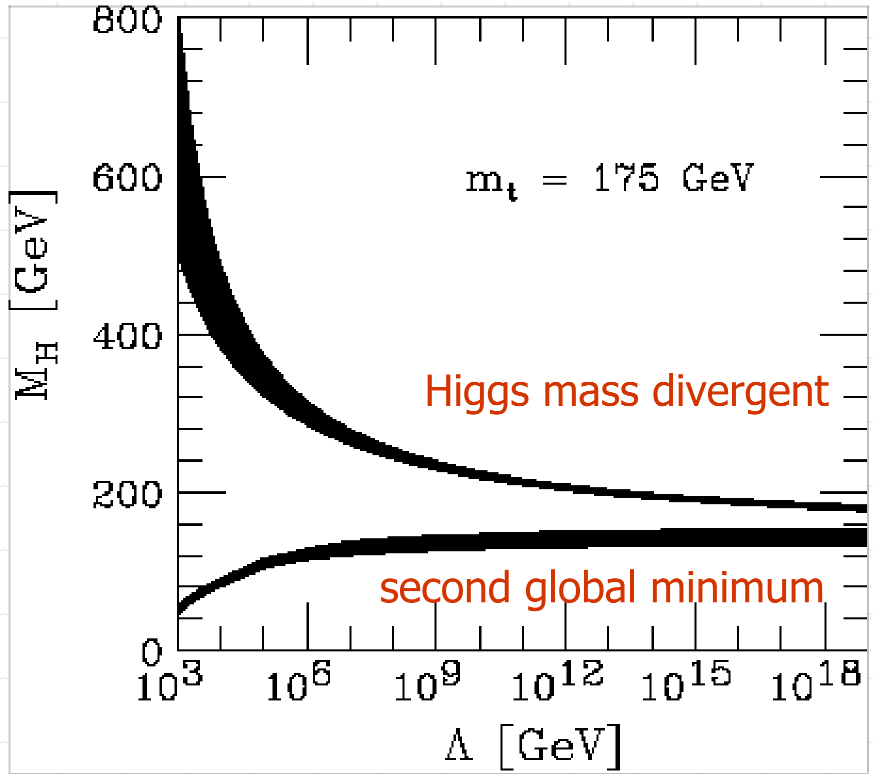
SM Higgs lies in mass range ~115-200 GeV

(Recent NuTeV results do not affect Higgs mass much.)

A Standard Model Higgs?

Standard Model posits two self-interacting scalar doublets

SM is at best an effective low-energy theory; must eventually break down at high scale < 10^{19} GeV



Various possibilities: SUSY (possibly with SM-like light scalar)
New strong dynamics (technicolor)

The Tevatron in Run 2

- new Main Injector
- new Antiproton Recycler
- luminosity goals:

Run 2a: 2 x 10^{32}/cm^2/sec

Run 2b: 5 x 10^{32}/cm^2/sec

Expect to accumulate 3 fb^{-1} in Run 2a, and 15 fb^{-1} in Run 2b

SM Higgs production

Cross section for production at Tevatron:

- gg □ H rate is large but suffers too much dijet background

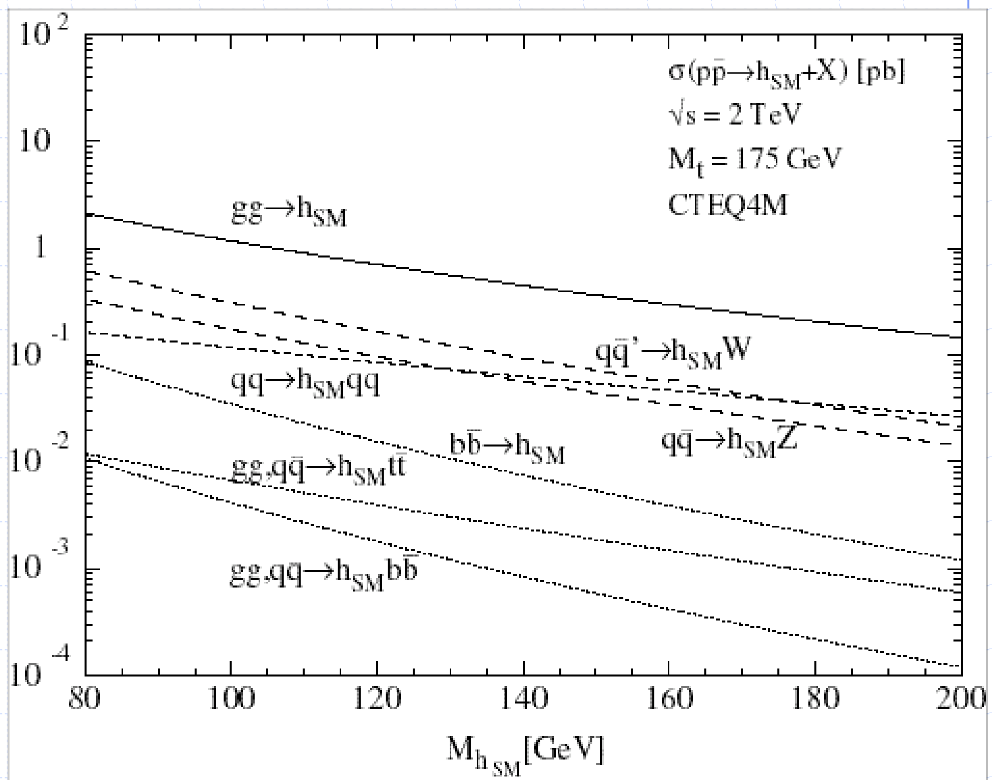
- main modes: WH, ZH

- best search channels:

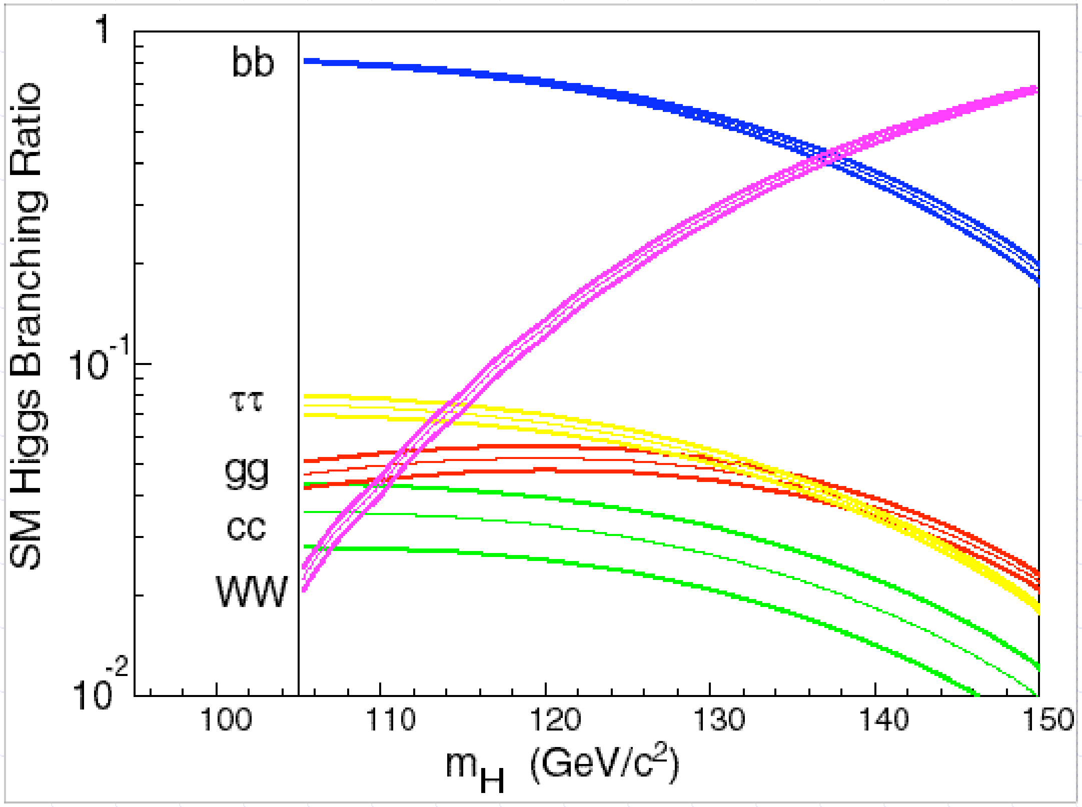
l□bb   ll□□

□□bb   lljj

llbb



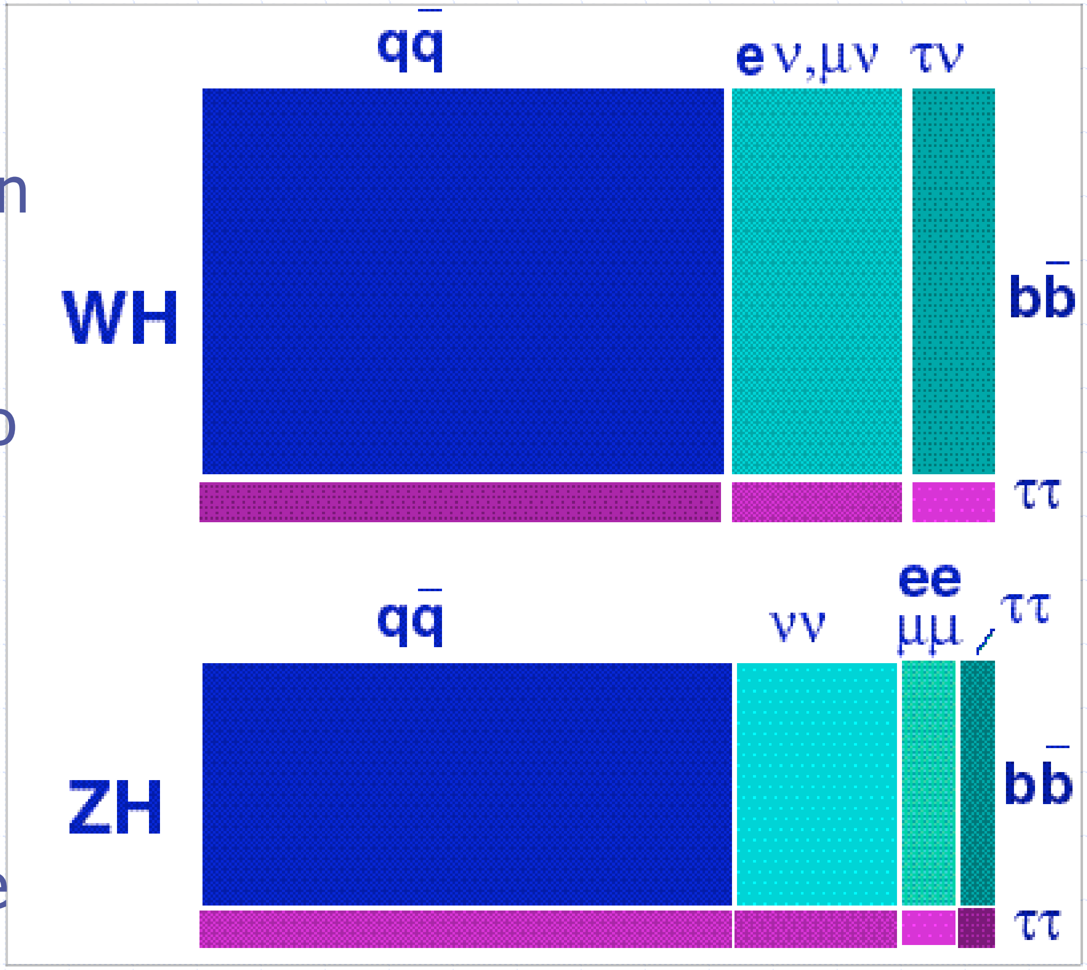
SM Higgs branching ratios



- bb mode is dominant < 138 GeV
- WW mode is dominant > 138 GeV
- □□ mode significant but the detectable rate is very tiny
- □□ mode too small

Low mass search channels

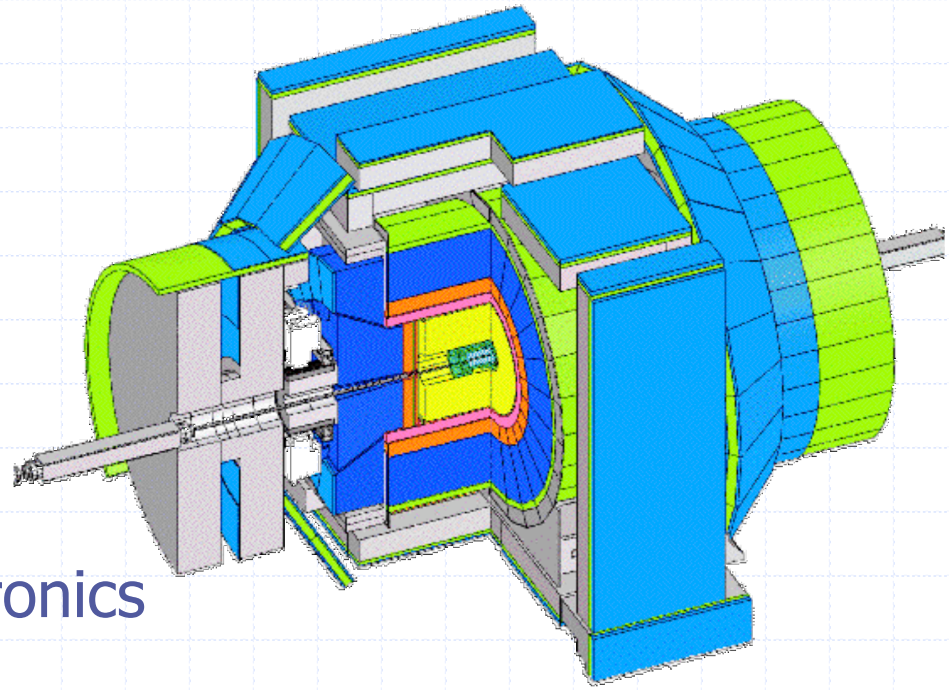
- channels depend on decay mode of W/Z
- lepton and neutrino channels allow good triggering and signal separation
- four-jet channel is biggest but has huge QCD background

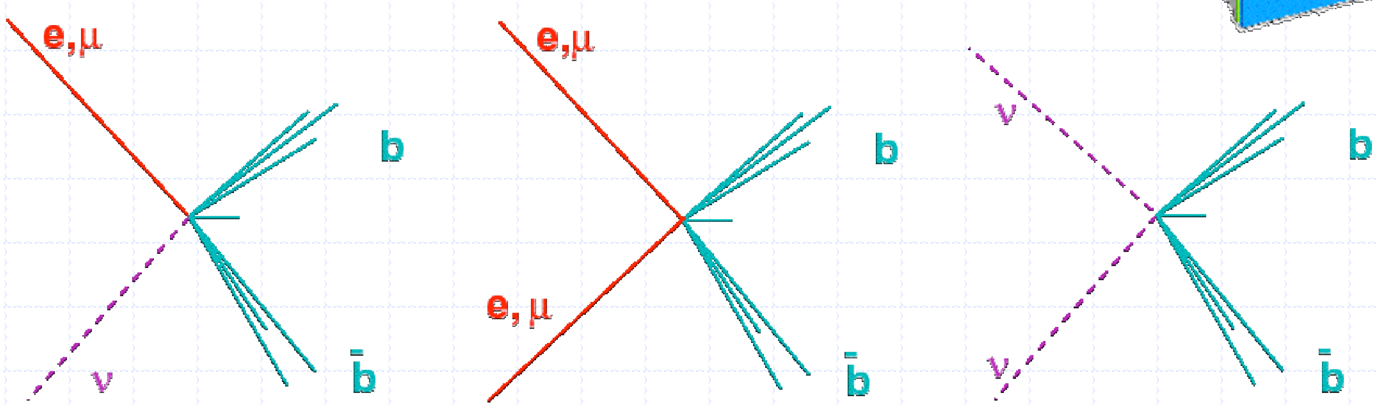


Leptons, missing E_T are key

CDF in Run 2
(see R. Erbacher's talk)

- all new tracking
- new DAQ system
- more muon coverage
- new calorimeter electronics





Main channels: cuts

l□bb

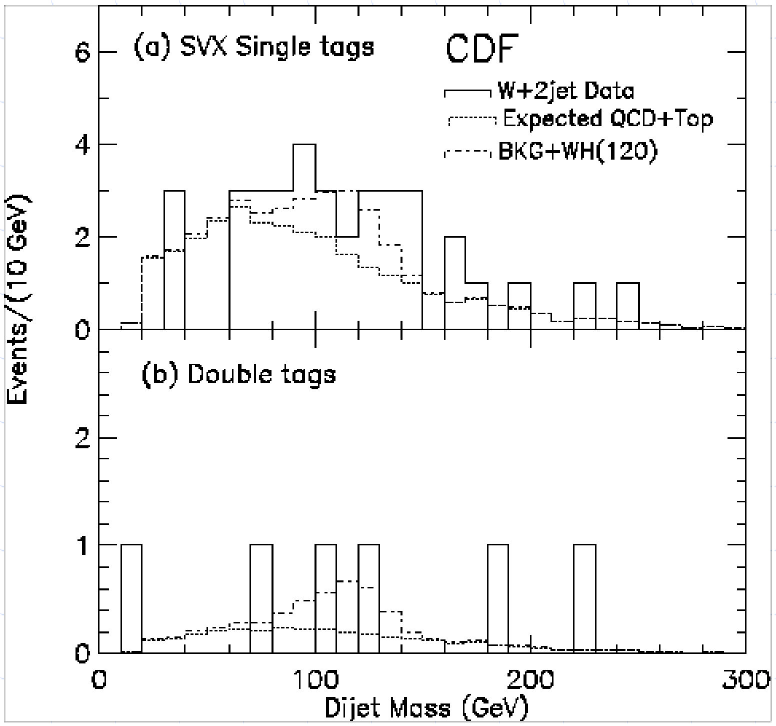
- lepton trigger (e,□)
- E_T(l) > 20 GeV
- missing E_T > 20 GeV
- 2 jets (E_T > 15, 10 GeV)
- b tag (tight/loose)
- cos□□ (jet-MET) …
- reconstruct bb mass

□□bb

- missing ET trigger
- 2 jets (ET > 20, 15 GeV)
- b tag (tight/loose)
- p_T(bb), …
- reconstruct bb mass

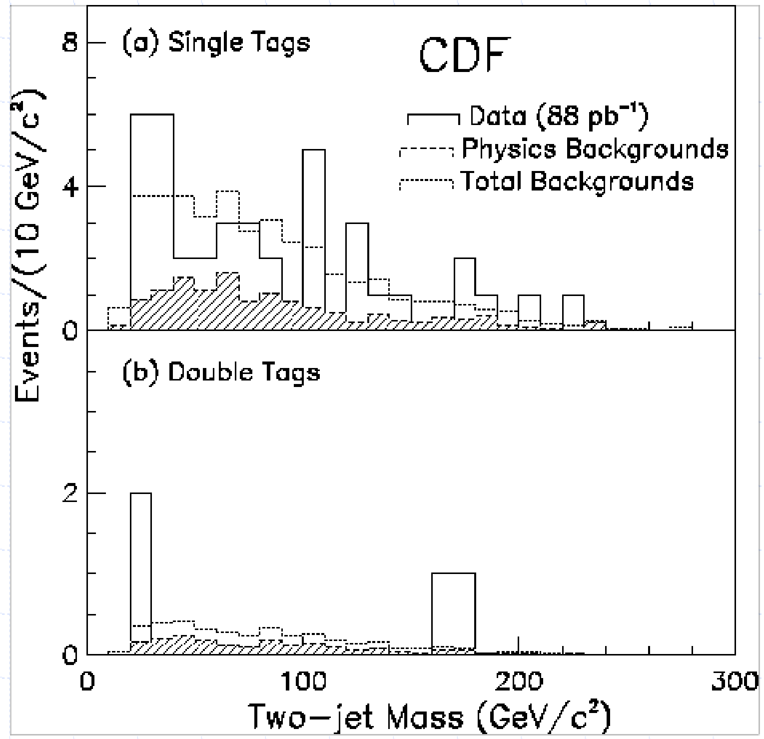
Mass distributions from Run 1

l□bb



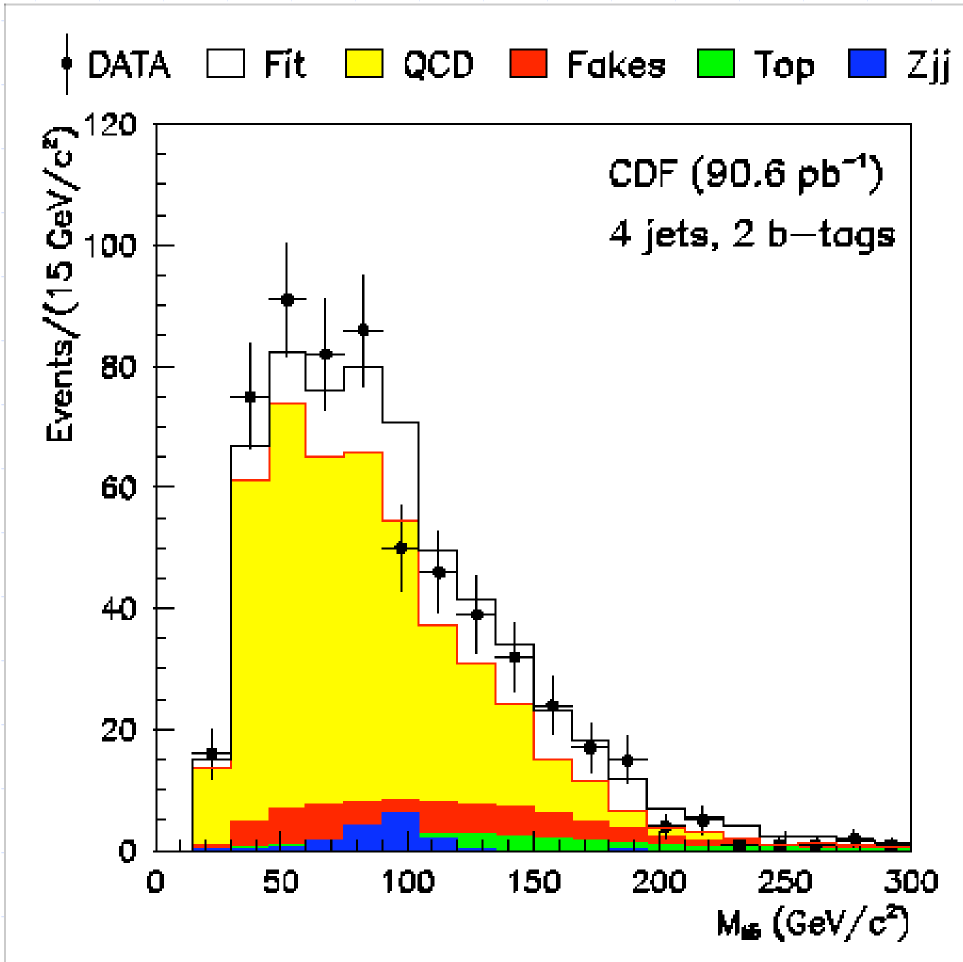
see 6; expect ~3

□□bb



see 4; expect ~4

Four-jet channel

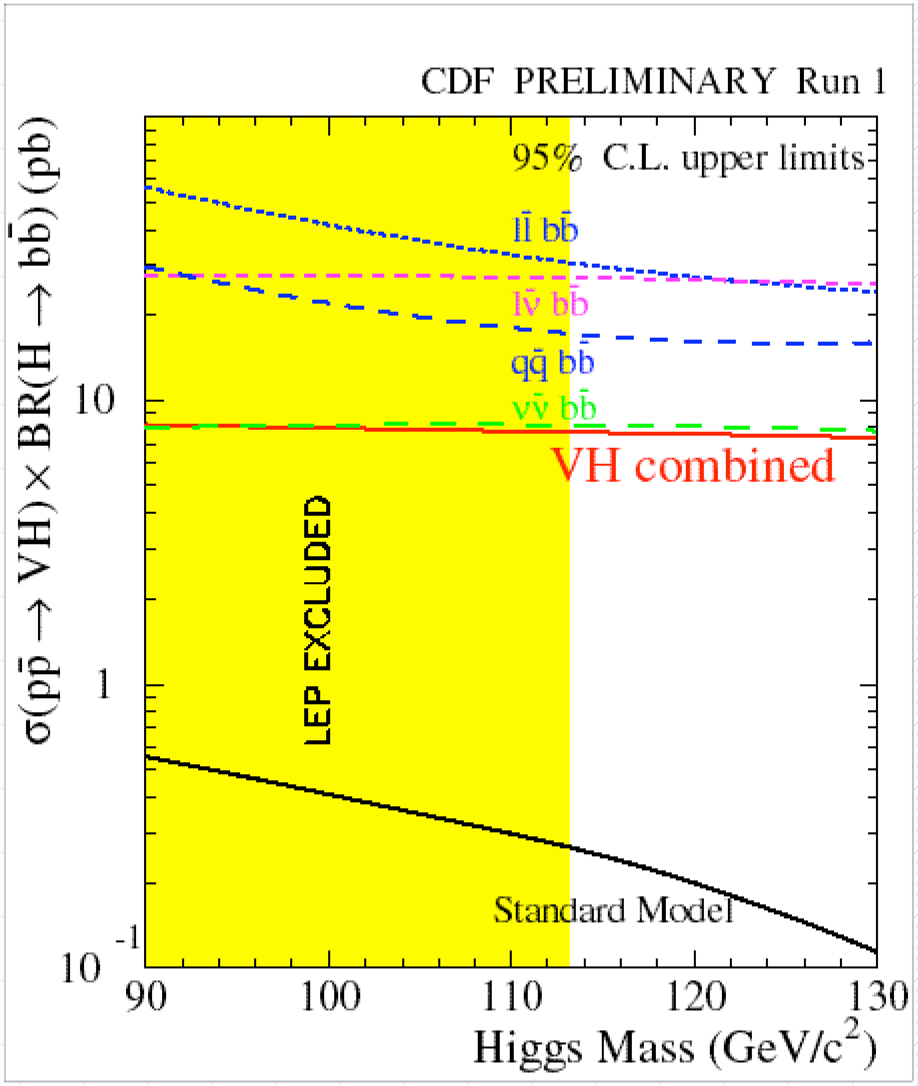


Surprisingly, we were able to use four-jet channel, using data to normalize large QCD multijet background.

(Downward fluctuation helped, too!)

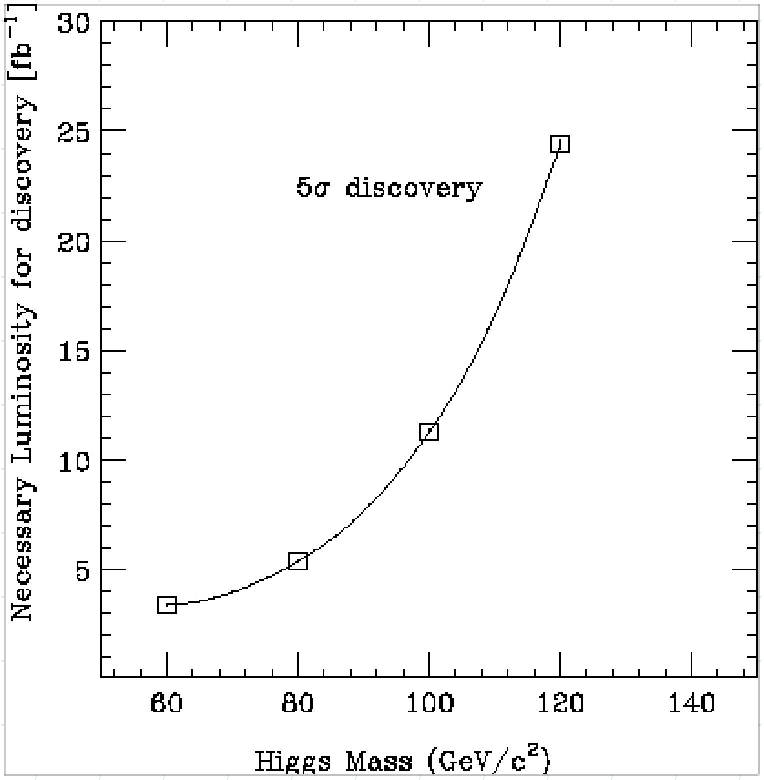
CDF result from Run 1

- Studied four channels including four jets
- Slight excess in l□bb channel degraded limit
- Final combined limit is more than x10 away from Standard Model
- Combination with likelihood method



Results of past studies

TeV 2000 report (1997) studied l□bb and □□bb channels: conclusion was that discovering the Higgs is not going to be easy!



Need to combine all channels and both experiments data!

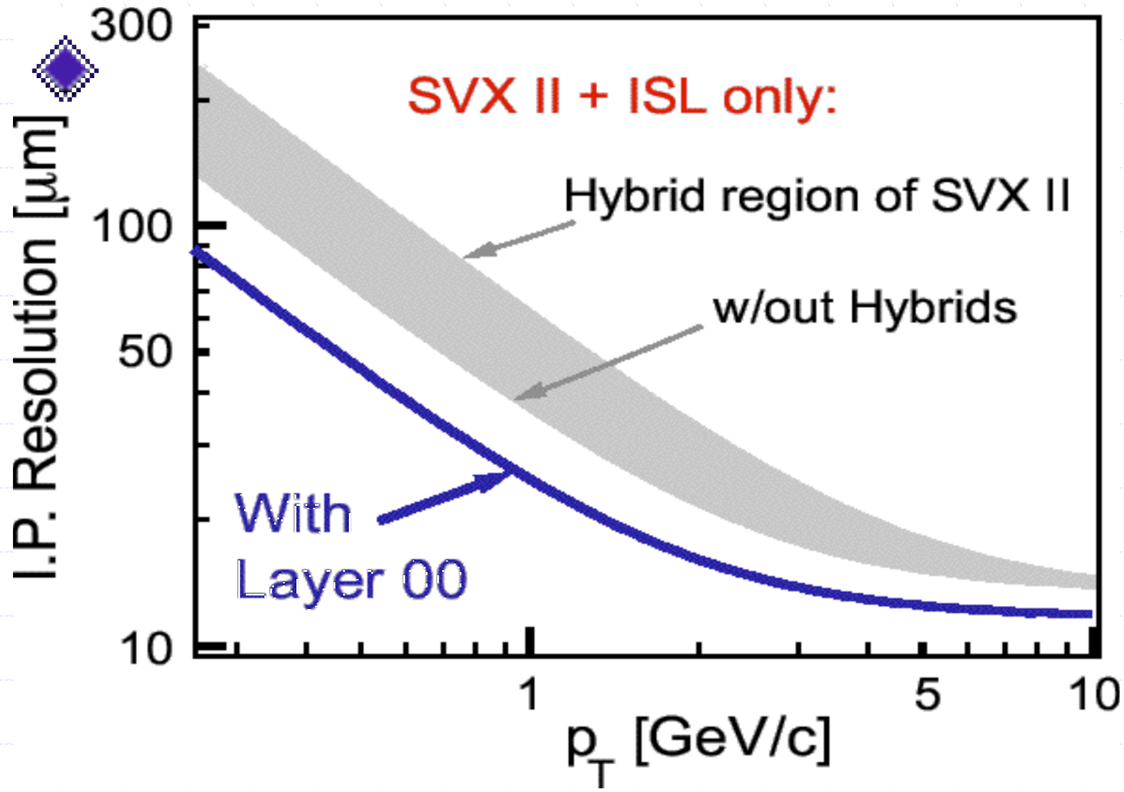
How will we improve?

• higher energy (1.8 → 2.0 TeV)	1.3
• better lepton coverage	1.1
• improved b tagging	2.0
• better mass resolution	1.3
• good control of background	1.1
• better separation (NN, SVM…)	1.3
• more data!	12

ultimate improvement factor: >50

b tagging in Run 2

- L00 mounted on beampipe
- 5-layer SVX-II
- ISL (we hope!)
- SVT - silicon vertex trigger

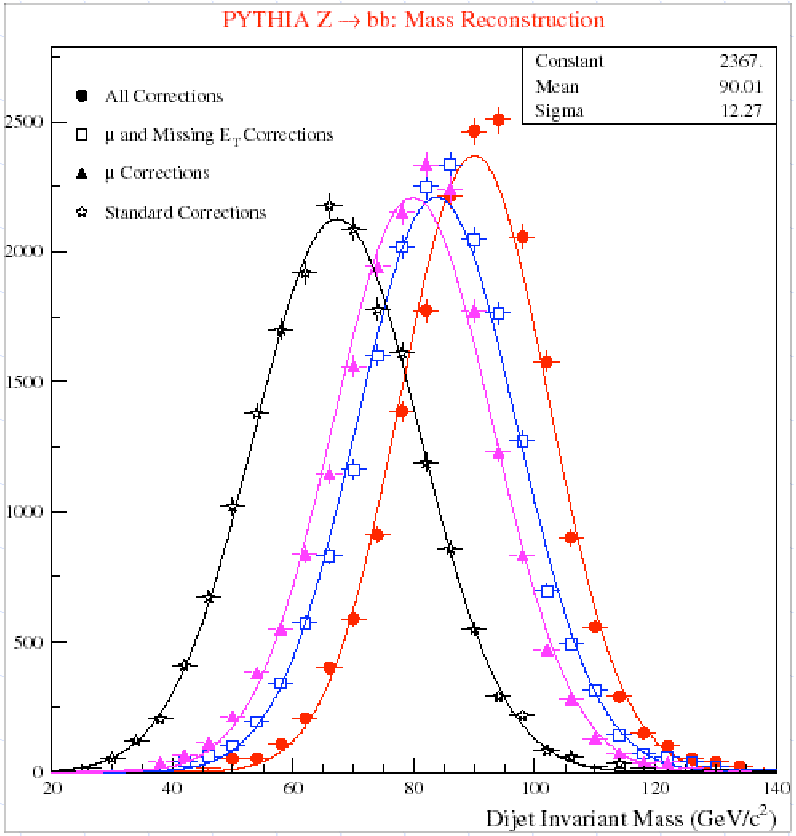


In Run 2 we have 3-D vertexing, improved resolution - hope to obtain ~60% efficiency for taggable b jets

Improving bb mass resolution

- need to optimize jet four-vector resolution
- need to optimize kinematic corrections

Test case: Z □ bb

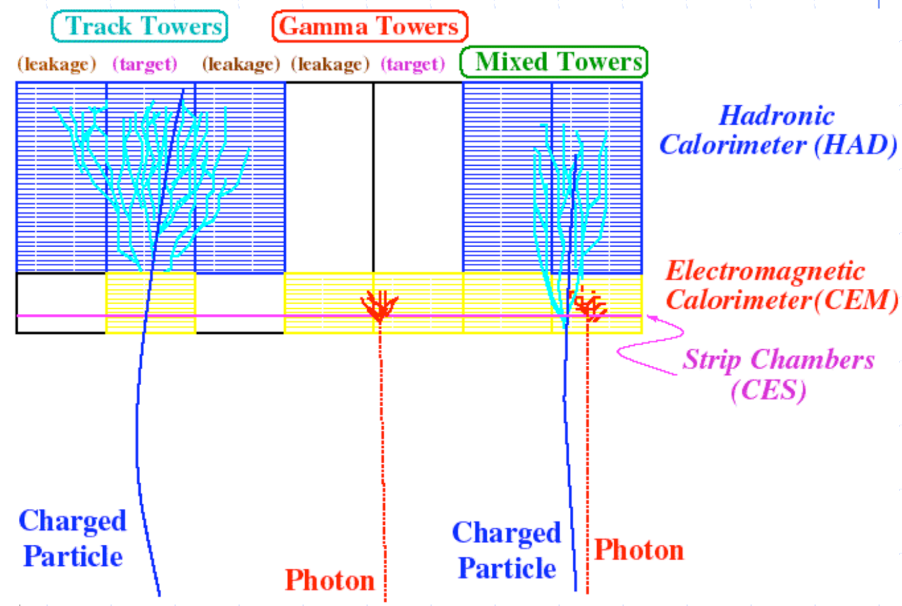


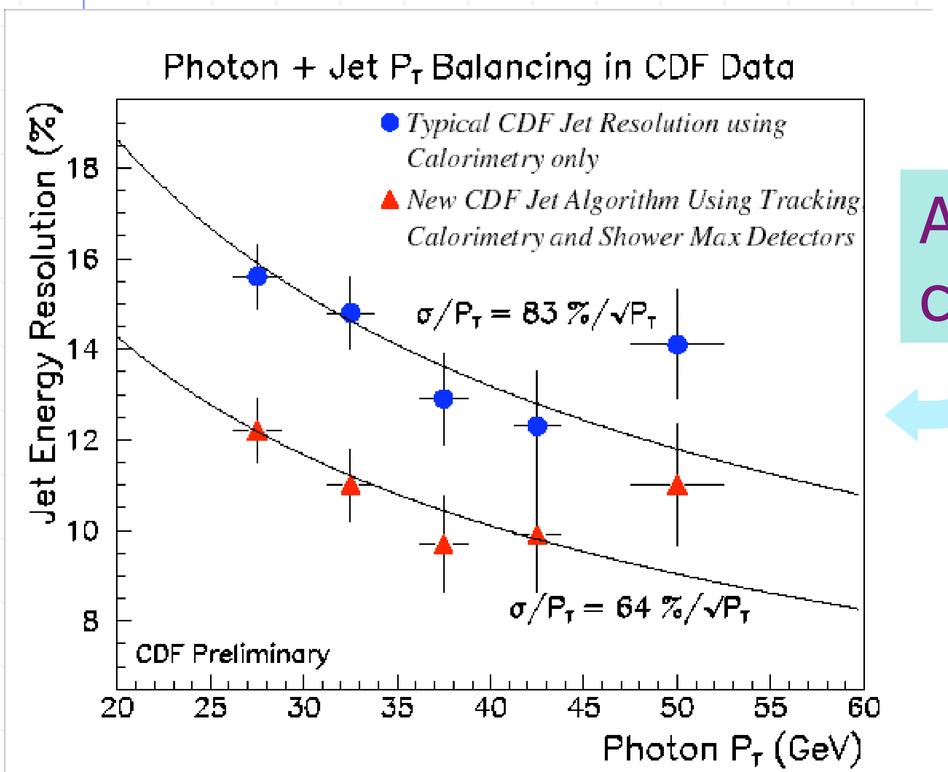
Here we use “standard” CDF Run 1 jet energy corrections, then apply corrections for missing E_T and presence of muons

result: 13.5% for Z

Run 2: use all available jet energy information

Start by classifying towers by pattern of energy deposition shown here:





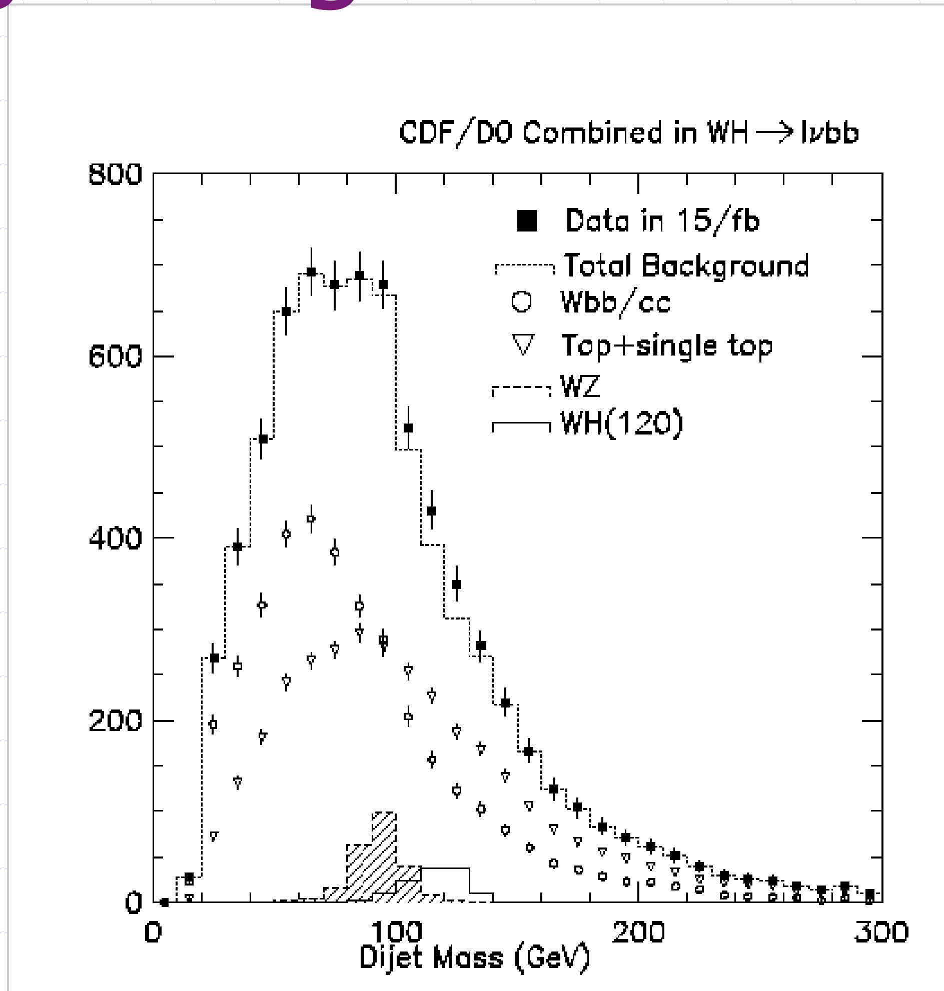
Attain ~30% improvement compared with calorimeter only.

Bottom line: hope to attain 10-12% resolution for SM Higgs in bb channels.

Understanding backgrounds

This plot illustrates the bb mass spectrum for the l□bb channel…

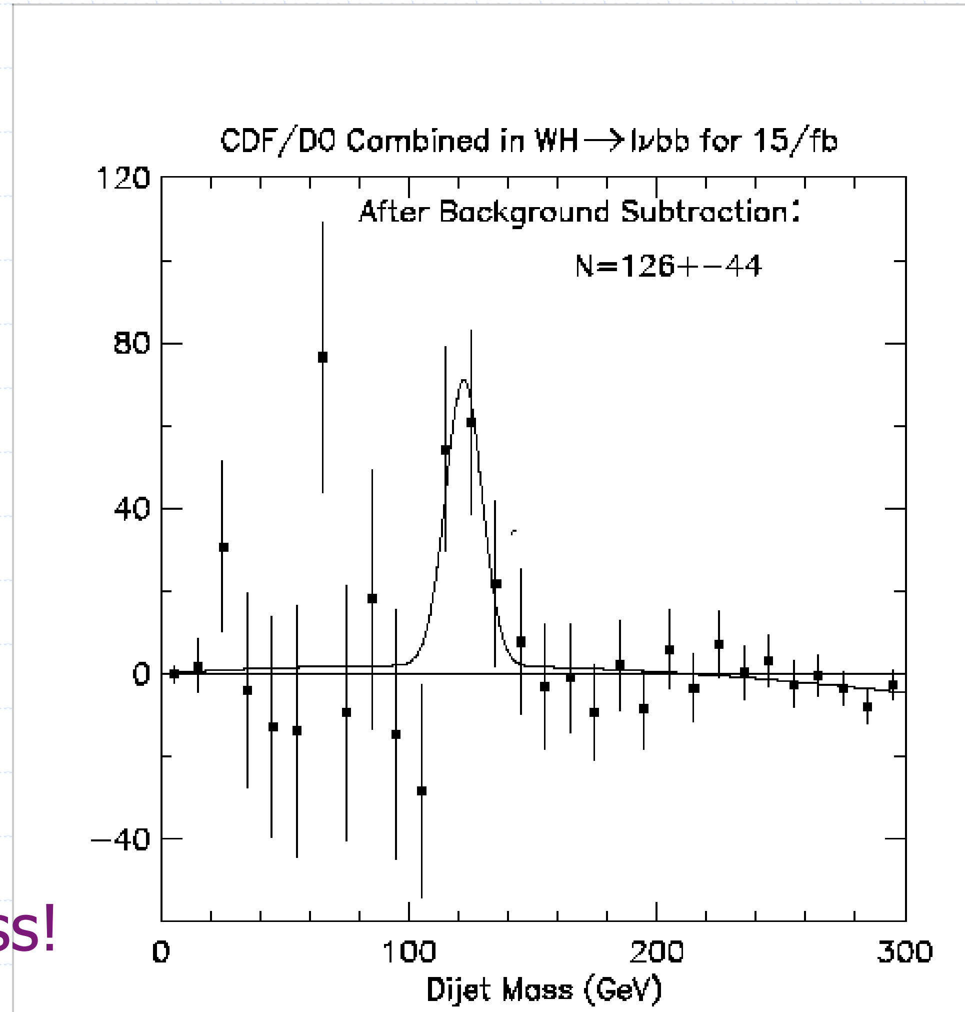
Can you see the Higgs signal after 15 fb^{-1}?



See the plot with background subtracted, next slide □

Distribution of bb mass in lνbb channel after taking observed bb mass distribution after 15 pb^{-1} and subtracting expected background processes.

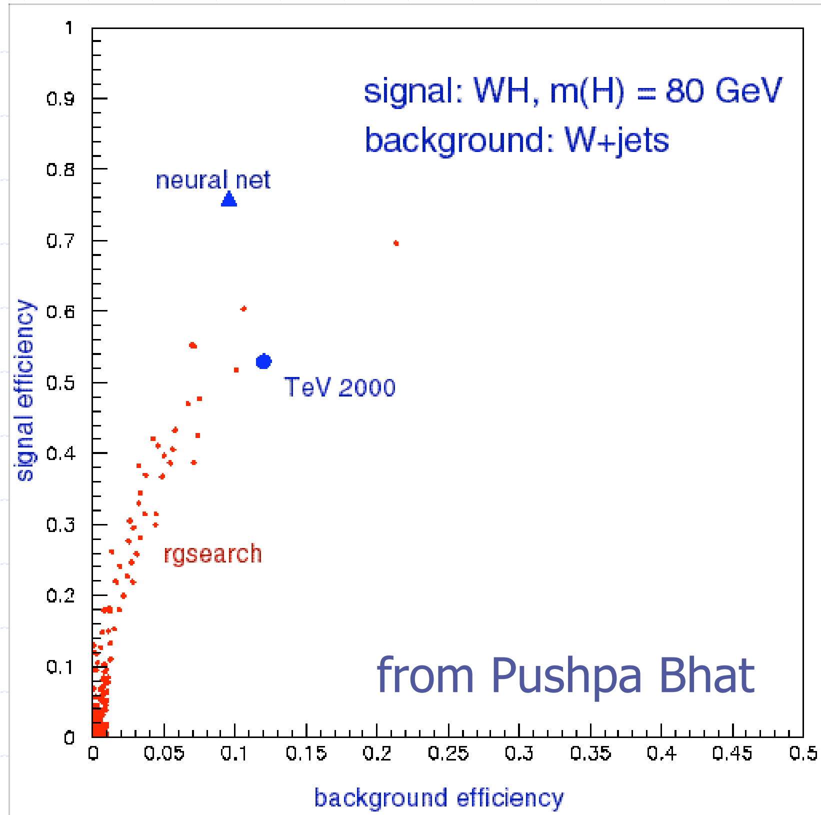
- This is a tough business!



We need exquisite control of backgrounds, especially the irreducible Wbb, Wcc, Zbb, Zcc ones. Must use data and latest Monte Carlo simulations of kinematics.

Improving separation

Run 2 workshop showed that bringing neural network signal/background separation can improve sensitivity by ~30%.



We are studying optimal way to incorporate multivariate techniques (NN, SVM, PDE, …) to attain optimal sensitivity

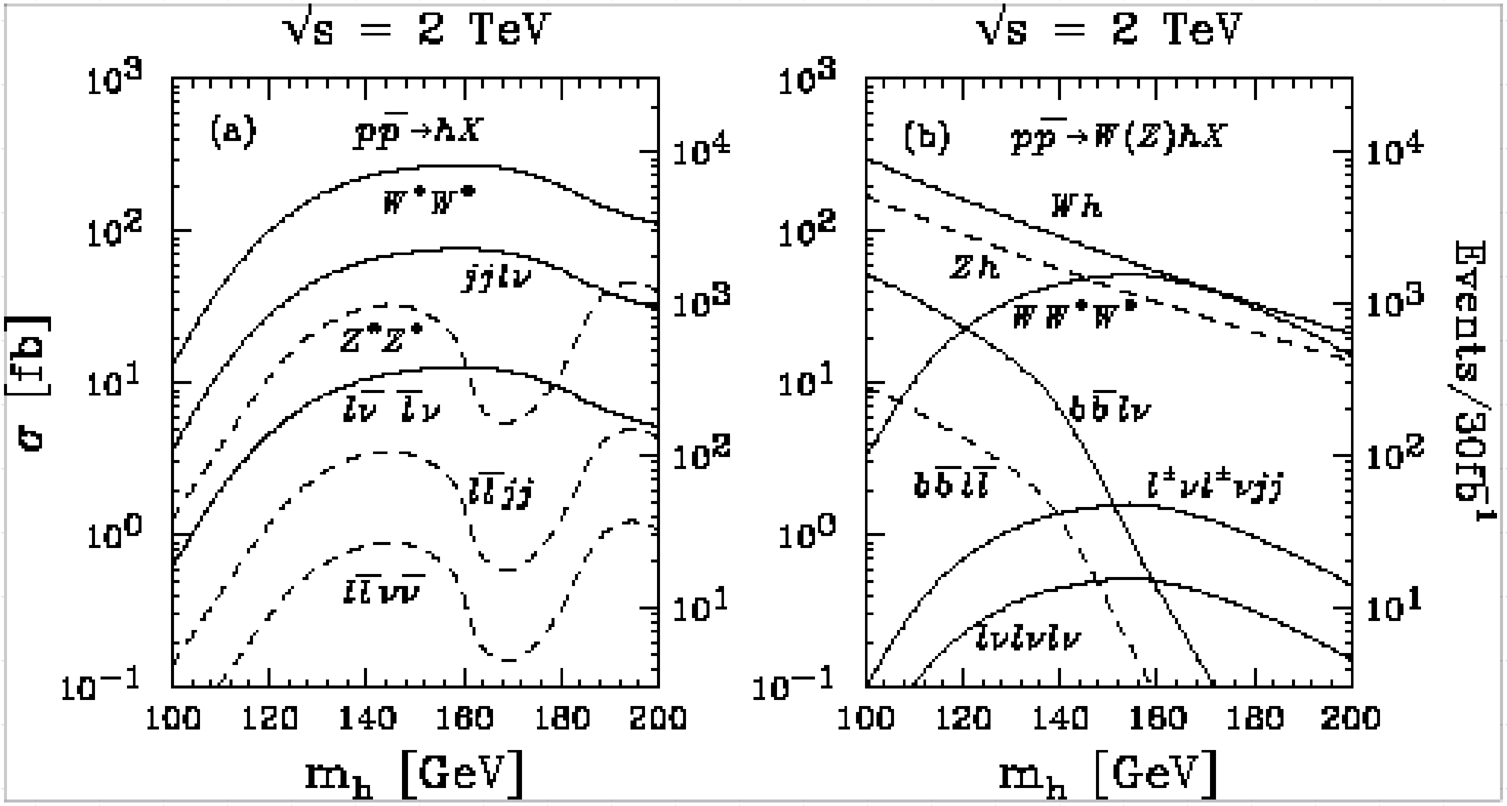
Low mass SM Higgs sensitivities

S/ B at 1 fb^{-1} for single-bin counting experiment

channel	110 GeV	120 GeV	130 GeV
l□bb	4.8	4.4	3.7
□□bb	6.3	4.7	3.9
llbb	0.8	0.8	0.6
qqbb	0.07	0.05	0.03

□□bb is the most sensitive mode!

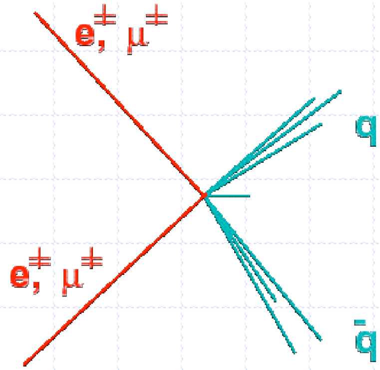
High-mass search channels



For Higgs mass > 140 GeV, WW decays dominate - can consider various WW, WWW, WWZ search channels

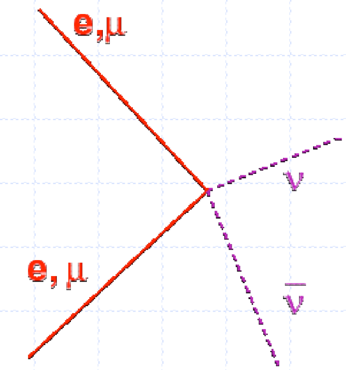
Most promising channels for high mass Higgs:

$l^{\pm}l^{\pm}jj$



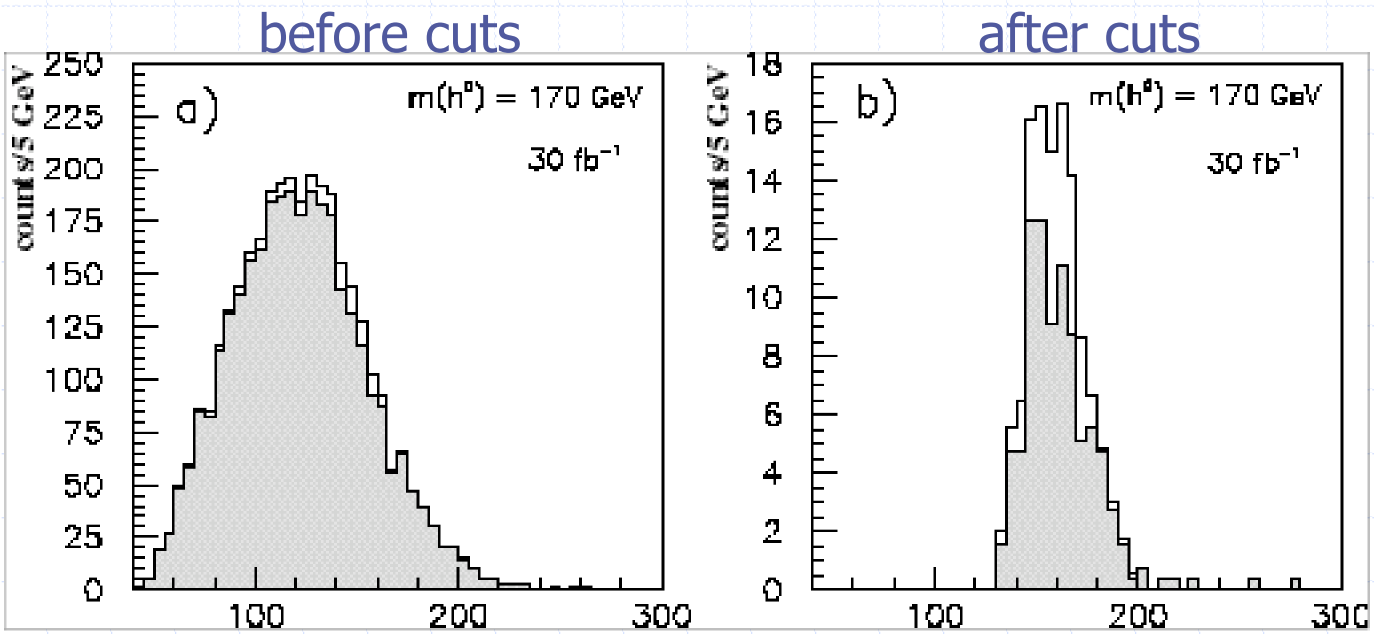
- used extensively in Run 1 SUSY searches
- fairly high rate via WWW/ZWW decays
- built in control from opposite-sign channel

$l^{+}l^{-}$□□



- copious production via gluon fusion
- enormous (~10 pb) background from WW
- many finely tuned cuts to separate signal

Using "transverse cluster mass" to distinguish signal and background in ll□□ channel



definition of transverse cluster mass:

$$M_C \equiv \sqrt{p_T^2(\ell\ell) + m_T^2(\ell\ell)} + \not{E}_T$$

High mass SM Higgs sensitivities

S/ B at 1 fb^{-1}

channel	160 GeV	170 GeV	180 GeV
ll□□	0.7	0.7	0.5
l lqq	0.54	0.50	0.34

- trilepton channel studied extensively: rate simply too small to obtain limit
- controlling the backgrounds is a major challenge: must rely on real data, extrapolate into signal region

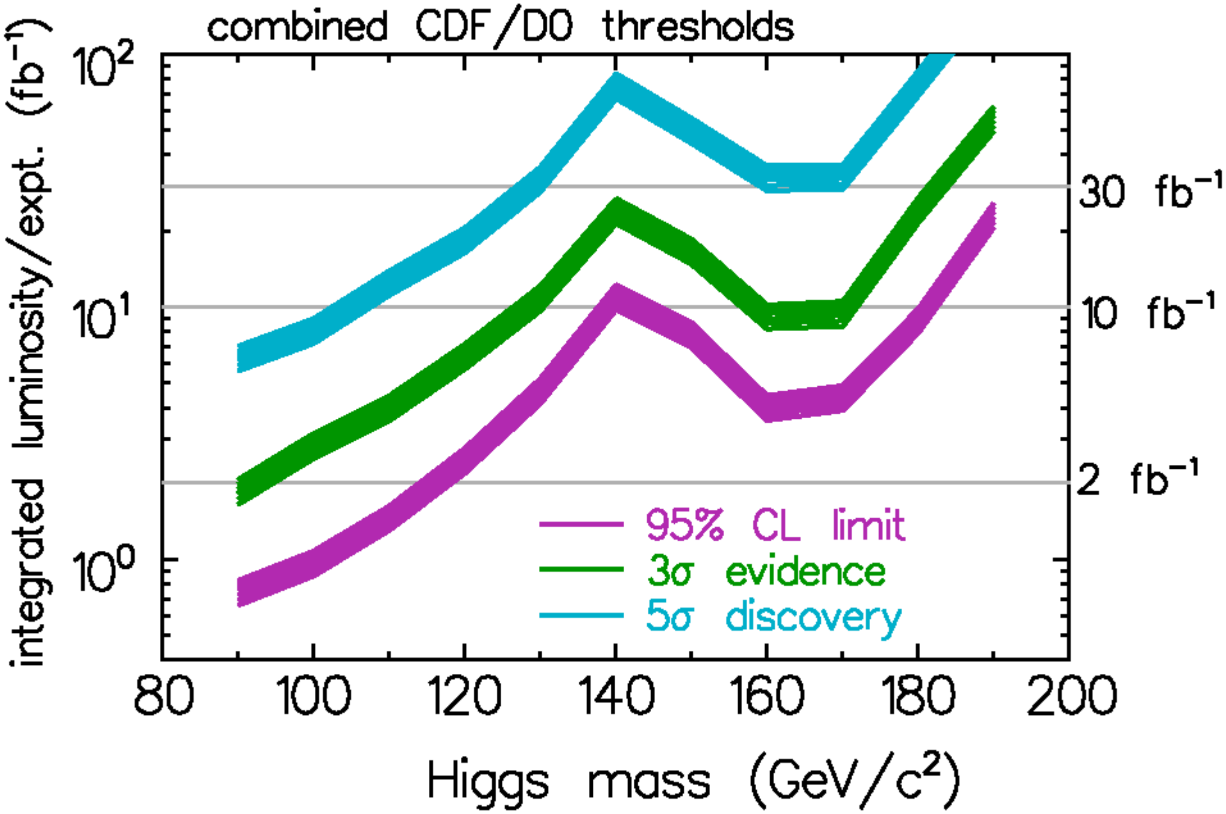
Statistical method to combine channels

- Form joint likelihood from product of Poisson probability of each outcome in each channel in each experiment (CDF an D0). (Single bin!)

- Convolute systematic errors by integration over gaussian prior.

- Find integrated luminosity for which 50% of the cases result in desired statistical confidence: 95% CL, 3σ, 5σ

SM Higgs reach in Run 2



CDF+D0 combined integrated luminosity thresholds assuming 10% mass resolution, NN selection, nominal systematics

Caveats

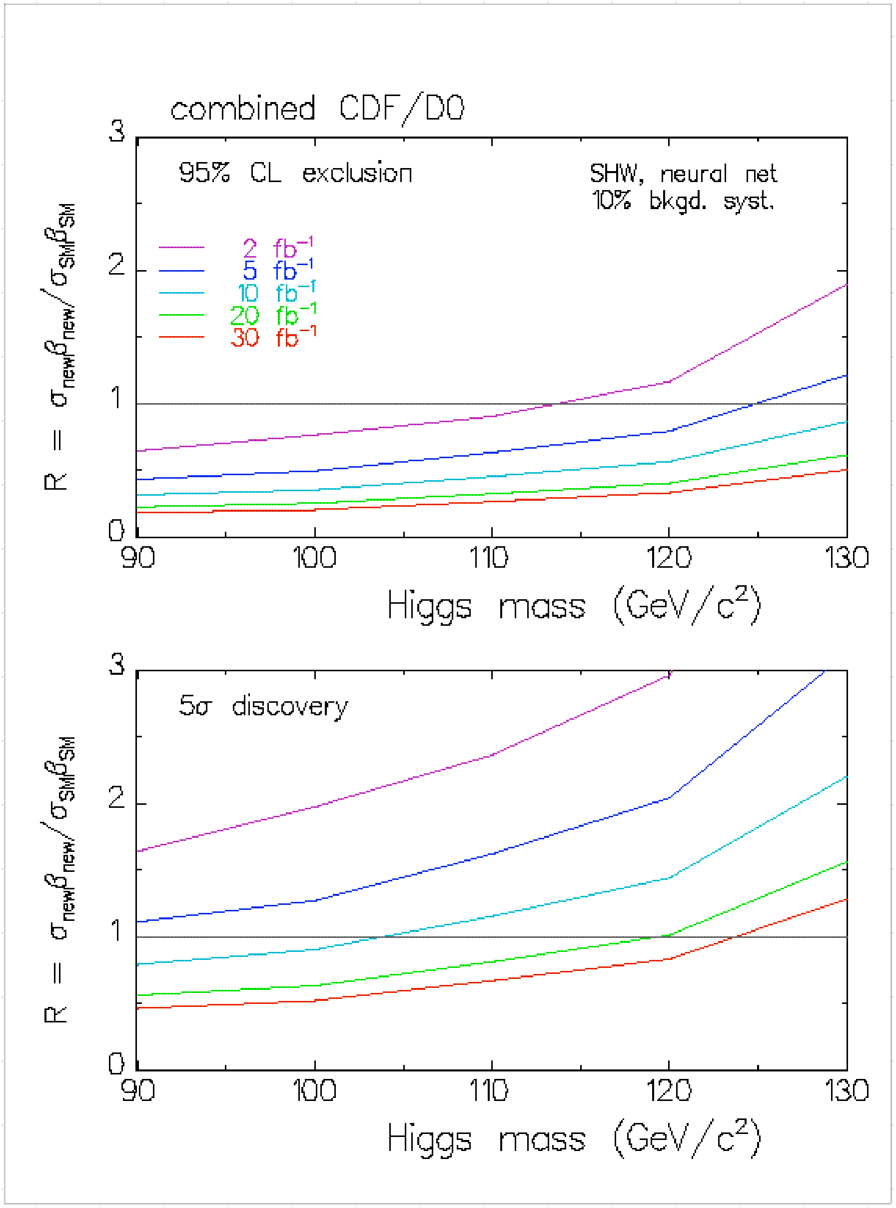
- bands on plot on previous page indicate estimate of uncertainty in reach
- assumed 10% mass resolution is probably aggressive
- may do better in b tagging than assumed
- may do worse in controlling background shape
- fitting spectrum (rather than single mass bin) may help
- need full simulation and real data!

"R" plots

Study Higgs sensitivity in terms of ratio of cross section for some non-SM Higgs to SM

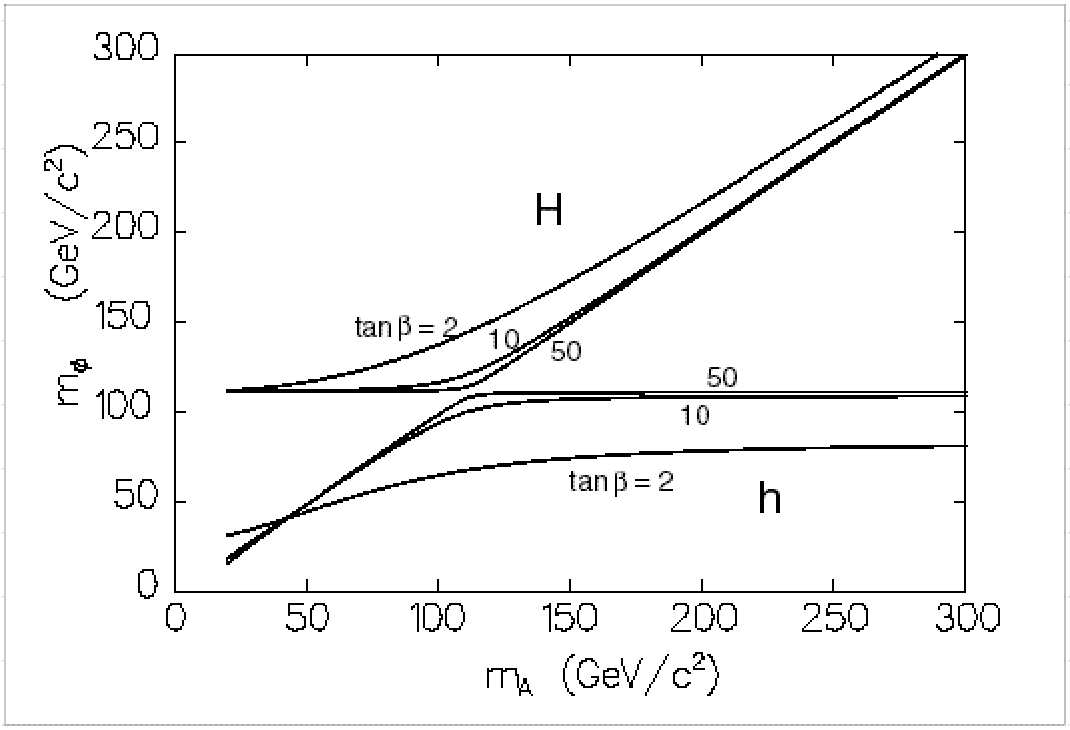
(Here use low-mass bb channels only)

Can be used to estimate reach in arbitrary model.



MSSM Higgs

five Higgses: h, H, A, $H^{\pm}$ two parameters: $\tan\beta$, m_A



- SM-like light scalar h in "decoupling limit" (large m_A)
- possibly more than one Higgs in mass window

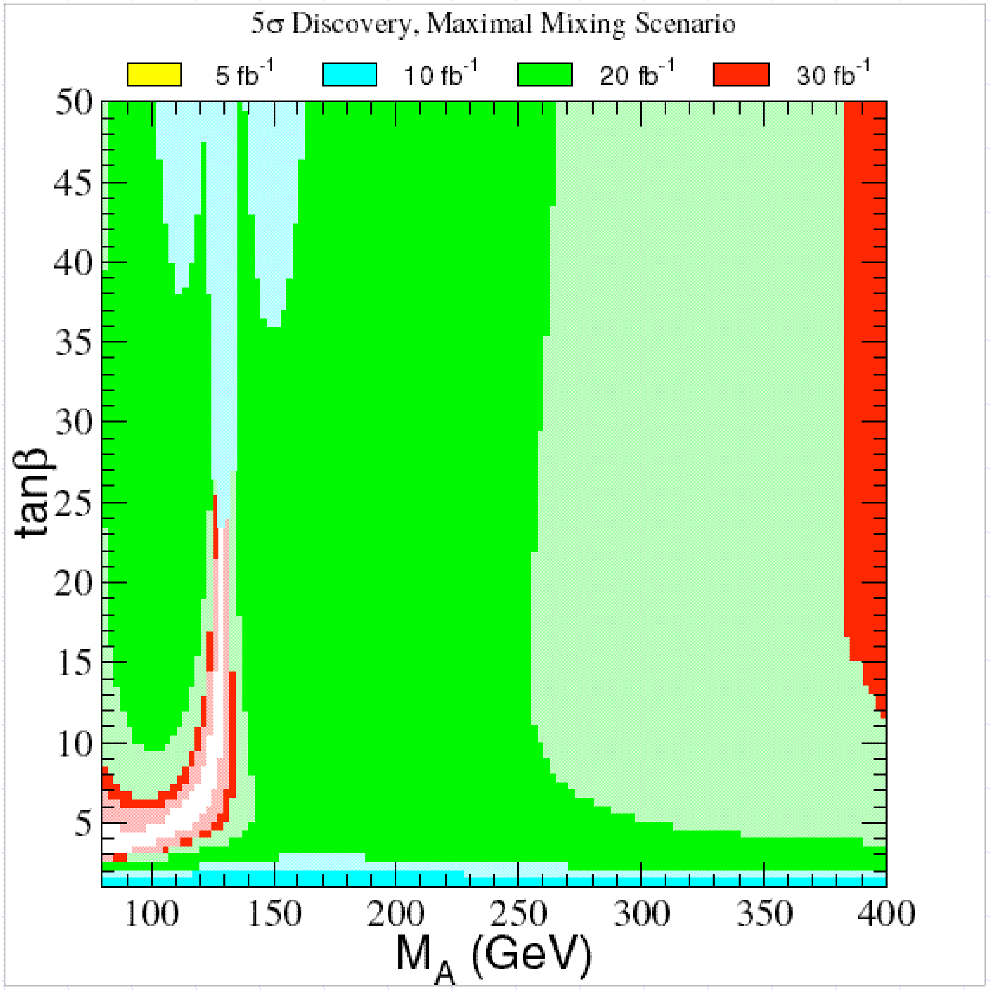
MSSM Higgs from SM search

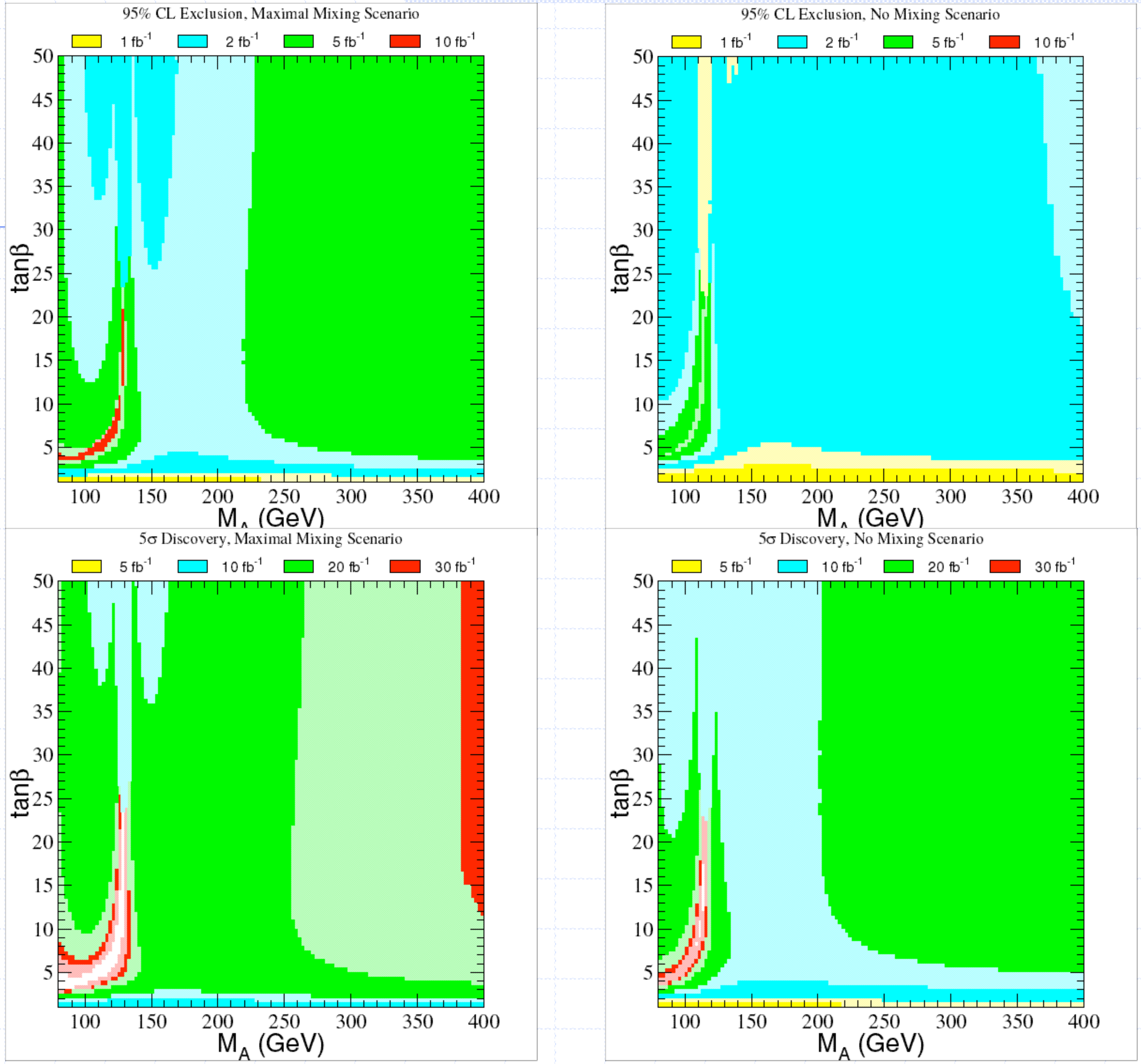
Pretty colors…what does it mean??

 interpret SM Higgs search in MSSM plane

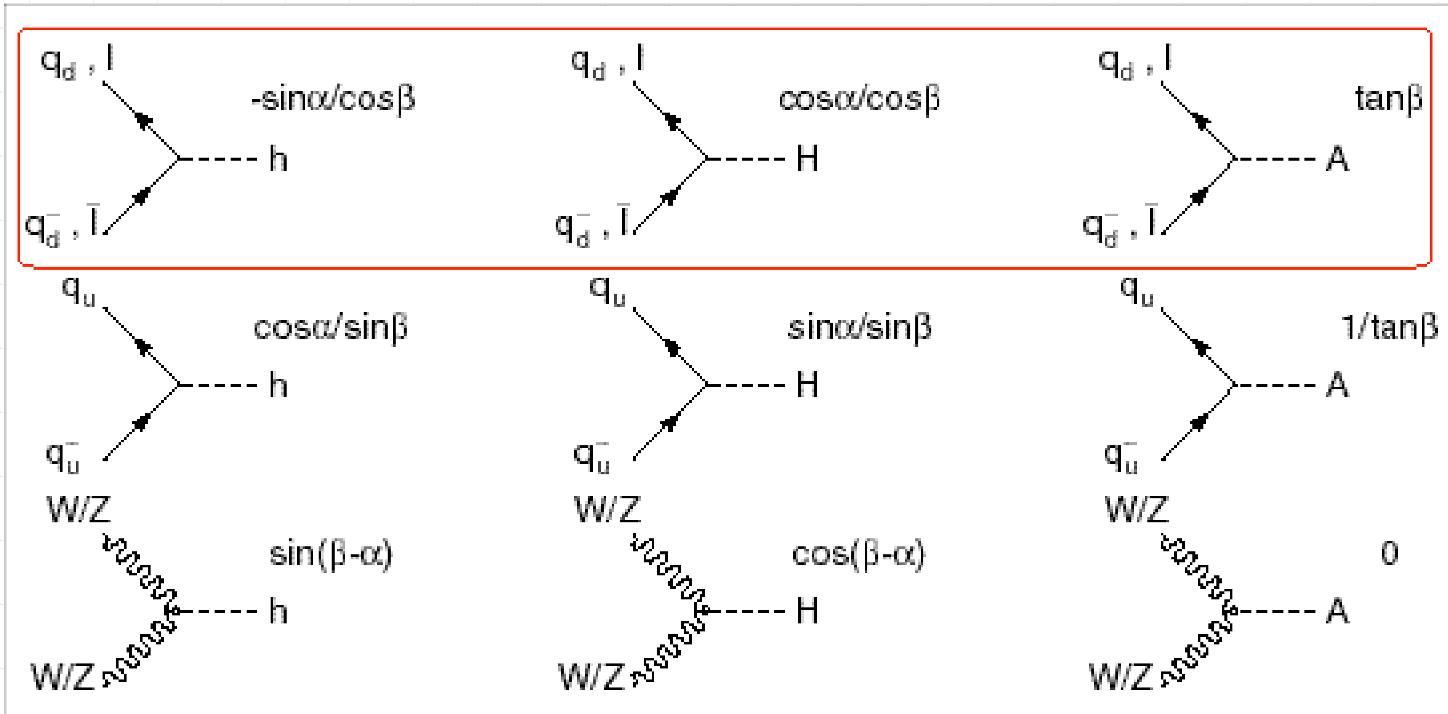
 can discover SUSY Higgs over wide range with 20 fb^{-1}

(easier in minimal mixing case)



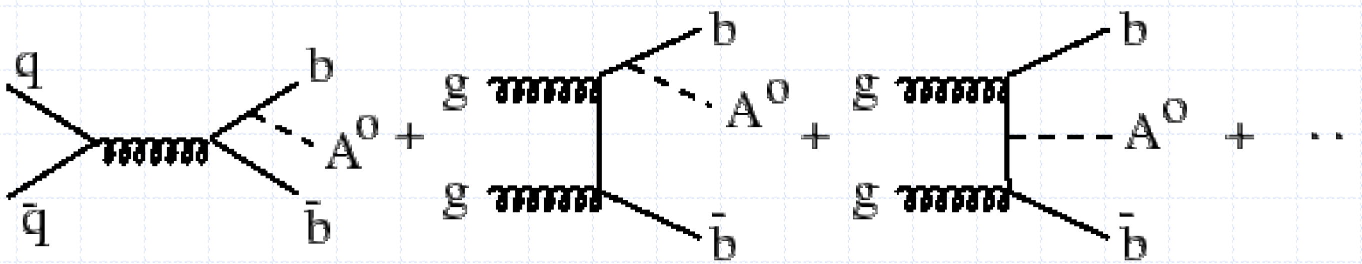

95% CL Exclusion, Maximal Mixing Scenario
1 fb^{-1} 2 fb^{-1} 5 fb^{-1} 10 fb^{-1}
95% CL Exclusion, No Mixing Scenario
1 fb^{-1} 2 fb^{-1} 5 fb^{-1} 10 fb^{-1}
5σ Discovery, Maximal Mixing Scenario
5 fb^{-1} 10 fb^{-1} 20 fb^{-1} 30 fb^{-1}
5σ Discovery, No Mixing Scenario
5 fb^{-1} 10 fb^{-1} 20 fb^{-1} 30 fb^{-1}
tanβ
5 10 15 20 25 30 35 40 45 50
100 150 200 250 300 350 400
M_A (GeV)

High tan□: enhanced production



Couplings to down-type quarks and leptons greatly enhanced if tan□ is large (e.g. tan□ □ m_t/m_b)

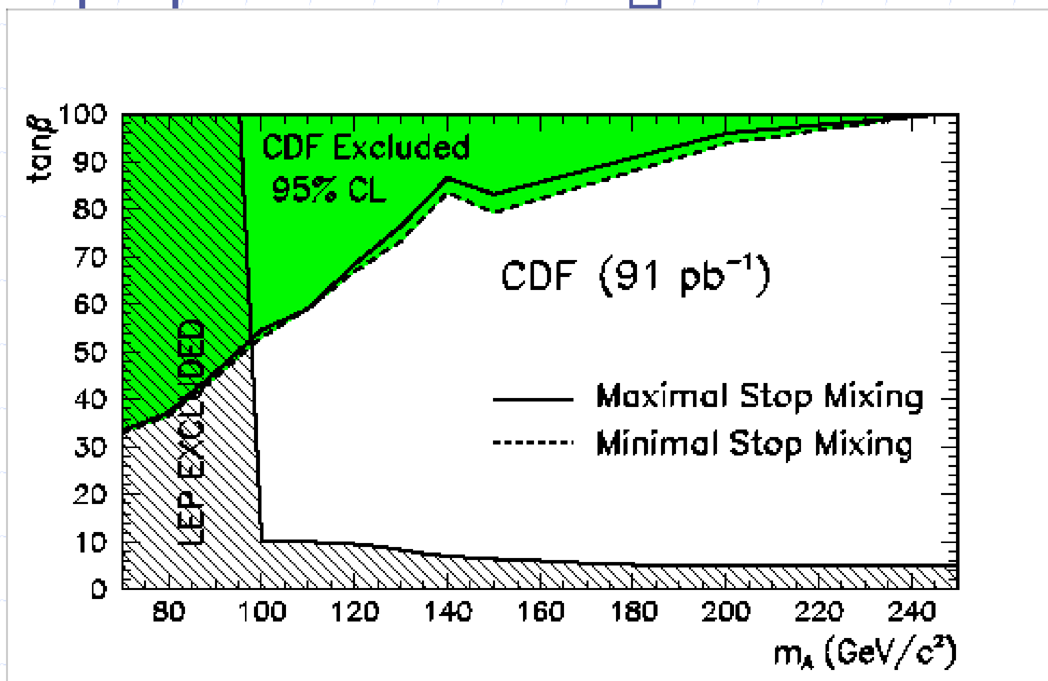
Four-b-jet final state: bbh/bbA/bbH



- cross section proportional to $\tan^2$

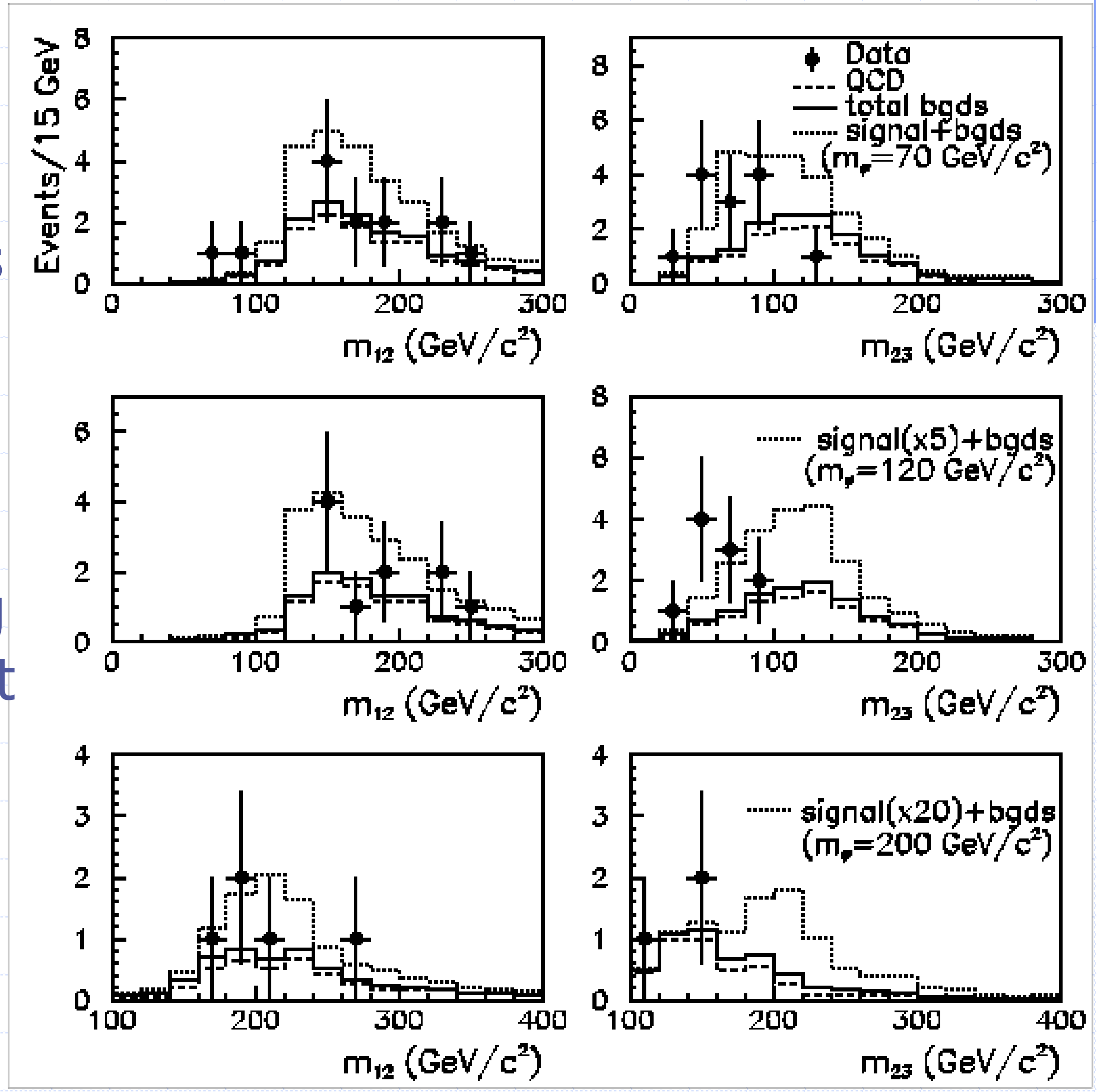
Get distinct events with four b jets!

Run 1 result: large area of MSSM plane excluded

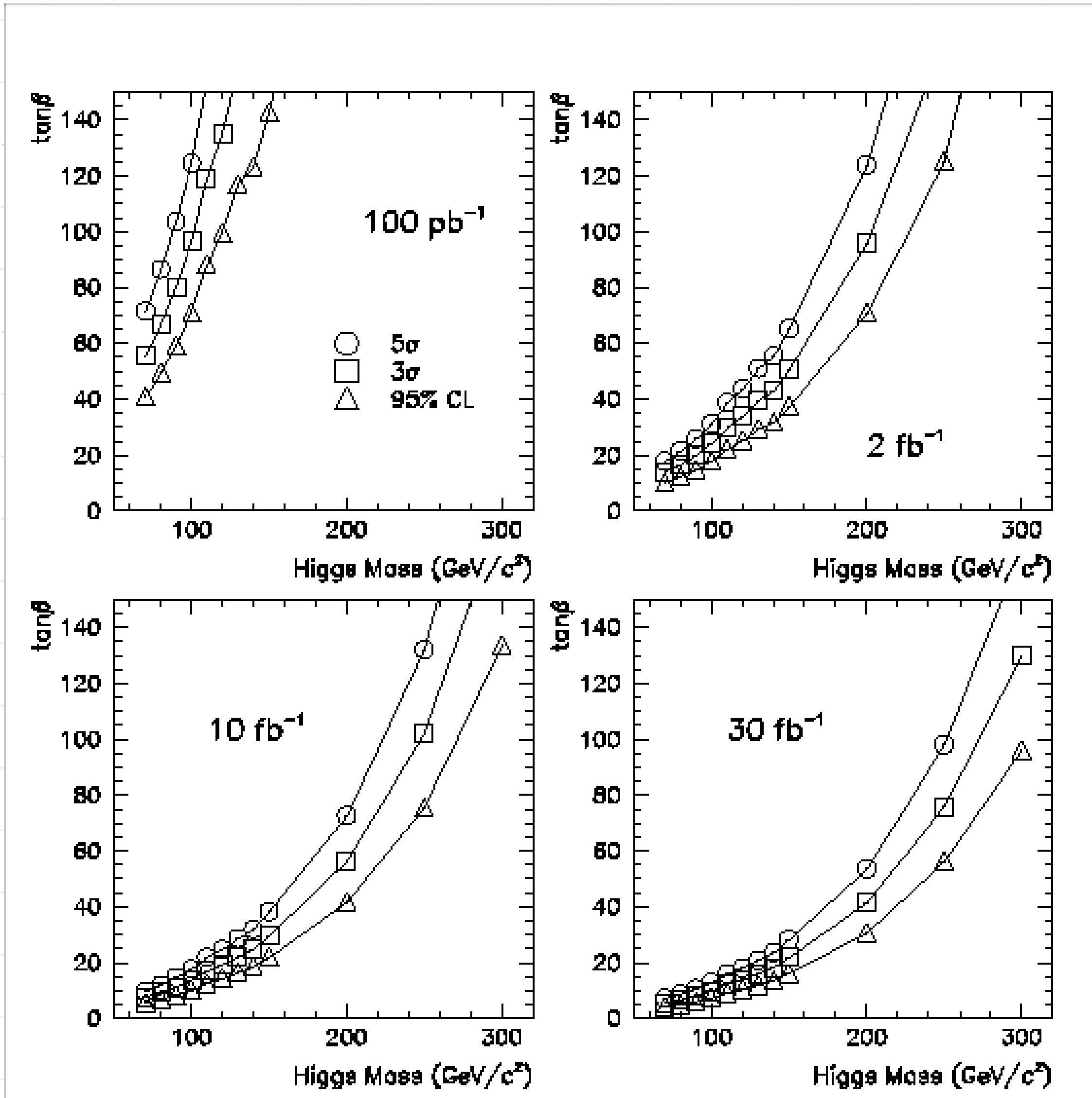


Mass distributions from which limits in four-b channel were derived:

Switch from using m(23) to m(12) at about 120 GeV



With lots of data we can hope to extend rather low into the MSSM plane - this search is limited only by statistics, and depends on the cube of the b tag efficiency!!



better than either charged Higgs or gg H   analyses

Summary

- The Higgs is tantalizingly close!

- Tevatron and experiments enjoy major upgrades giving greatly increased sensitivity

- SM Higgs is difficult: 95% CL possible up to 190 GeV, but 5□ only to about 120 GeV mass

- MSSM Higgs production enhanced; high tan beta accessible to search