Higgs Prospects at the Tevatron: An Overview

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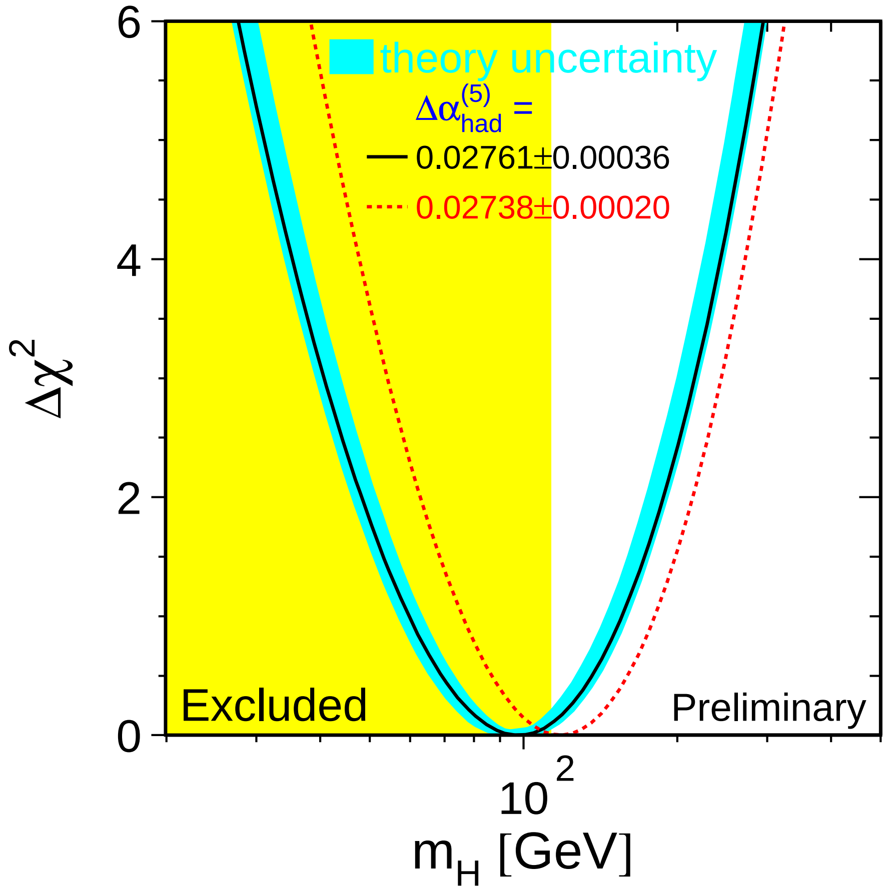
Workshop on the Future of Higgs Physics
FNAL May 3-5, 2001

- Higgsology:
  The Basics
- Standard Model Prospects for Run II
  Low Mass Region
  High Mass Region
- SUSY Higgs's: Experimental Aspects
  Searches for large $\tan\beta$
  Charged Higgs Bosons
- A New Channel: $t\bar{t}\,\mathrm{H}^0$
- Diffractive Production
- Conclusions

- Direct Searches: LEPC combination (Nov 2000)

$$M_H > 113.5 \text{ GeV OR } M_H \approx 115 \text{ GeV}$$

- Fits to Precision Electro-Weak Data



LEP EW Working Group

- Fit for the Higgs Mass (LEP EWWG 2001):

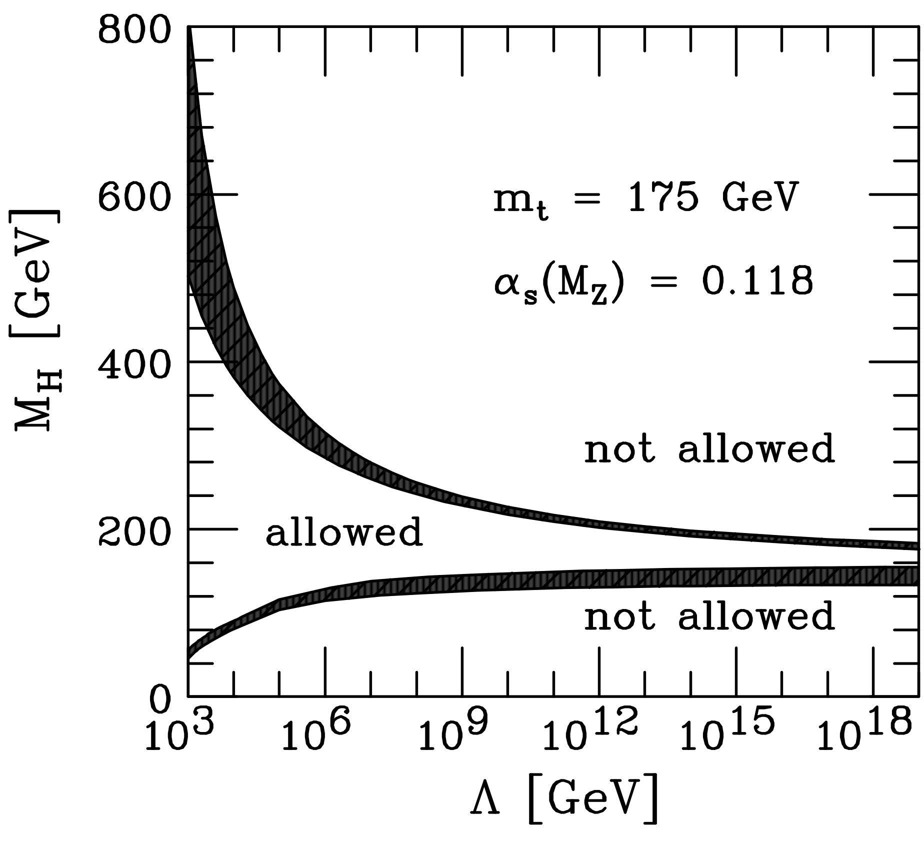
$$M_H = 98^{+58}_{-38} \text{ GeV}$$

$$M_H \lesssim 212 \text{ GeV at } 95\% \text{ CL}$$

- The phenomonologically interesting mass regions:
  1. The MSSM requires $M_h \lesssim 125 - 130$ GeV
  2. Any weakly coupled SUSY theory requires $M_h \lesssim 200$ GeV
  3. The Standard Model requires $130 \lesssim M_{\mathrm{H}} \lesssim 180$ GeV

     Vacuum Stability $\Longrightarrow$ Lower bound

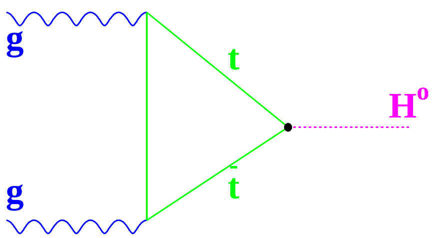
     Landau Pole $\Longrightarrow$ Upper bound

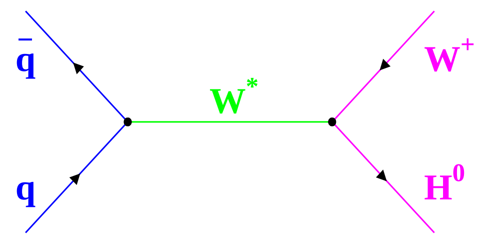


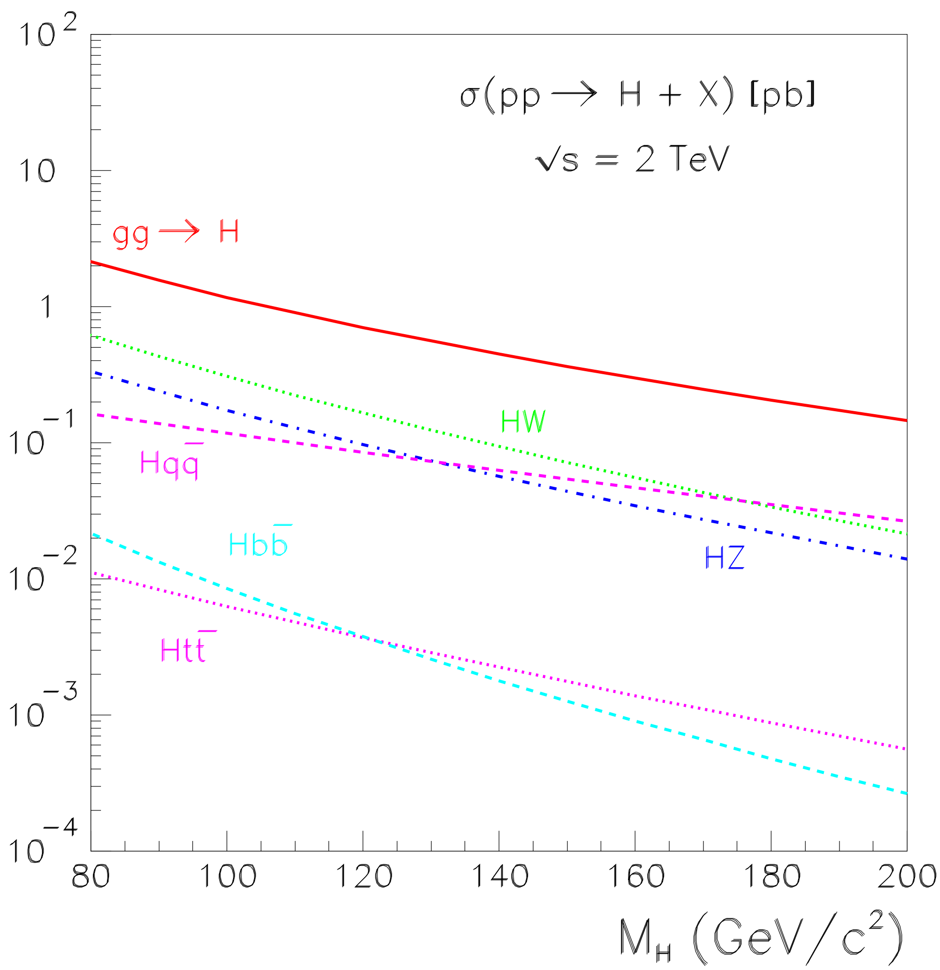
Risselmann, hep-ph/9711456

- If one could probe the SM Higgs up to ∼ 180 GeV…

  $\Longrightarrow$ Profound implications for $\Lambda_{\text{New Physics}}$



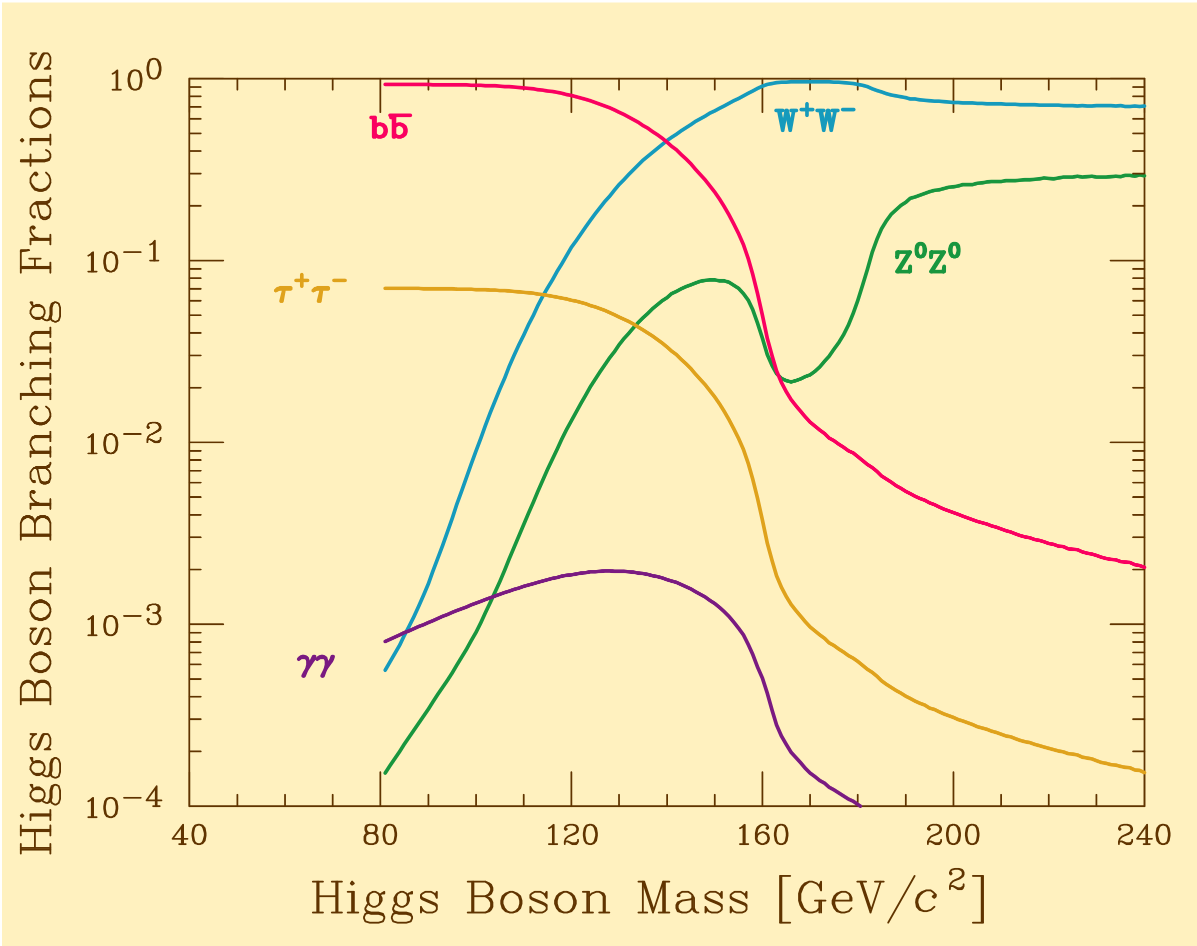




- Gluon fusion has the largest cross-section, but …

  … WH/ZH production is most accessible

- Certain cross sections can be enhanced by *New Physics*



- For $M_{\rm H} \lesssim 135$ GeV:

  $\rm H^0 \to b\bar{b}$ dominates . . . but rate is falling rapidly

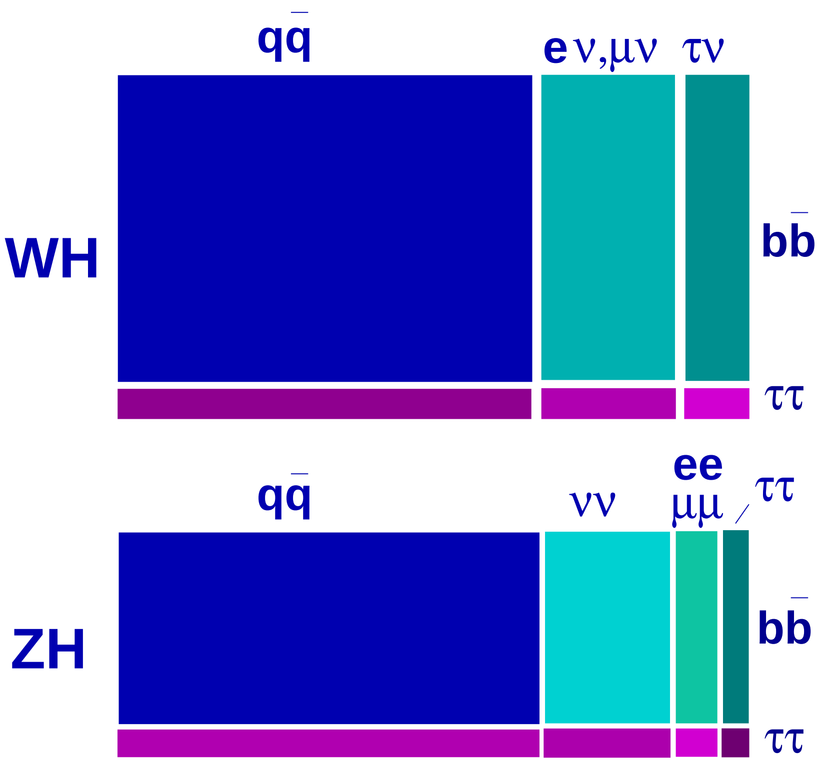
  QCD background precludes using $gg \to \rm H^0 \to b\bar{b}$

- For $M_{\rm H} \gtrsim 135$ GeV:

  Gauge boson decays take over

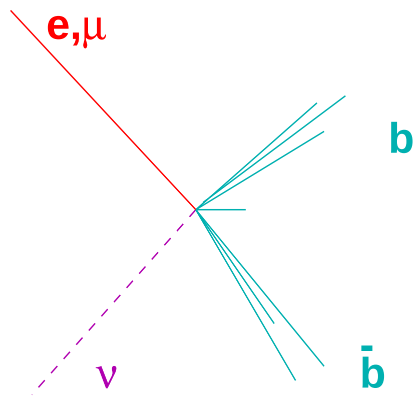
  In particular: $\rm H^0 \to WW^{(*)}$

- For $M_{\rm H} \lesssim 130$ GeV, BR($\rm H^0 \to b\bar{b}$) $\gtrsim 60\%$
  $\Longrightarrow$ focus on associated production (WH/ZH)



- Best prospects for final states with leptonic W/Z decays
  as QCD backgrounds prohibative for $q\bar{q}b\bar{b}$ channel
- SM background processes include:
  $Wb\bar{b}$, $Zb\bar{b}$ $t\bar{t}$, ZZ, WZ, $W^* \to t\bar{b}$
- Ultimately the sensitivity will depend on
  Performance of b-tagging algorithms
  Jet-jet mass resolution:

Barberis, Yao, Bhat, Prosper, Bokhari, Gilmartin



- Inclusive high-p_t lepton trigger OR Jets + $\not\!\!E_t$
- Central e or μ with $p_t > 20$ GeV and $\not\!\!E_t > 20$ GeV
- Two b-tagged jets: tight SVX with loose SVX or SLT
- Multivariate Analysis $\Longrightarrow$ Increased sensitivity

Expected Events and Sensitivity per fb^{-1}					
Mass (GeV)	90	100	110	120	130
S	8.7	9.0	4.8	4.4	3.7
B	28	39	19	26	46
$S/\sqrt{B}$	1.6	1.2	1.1	0.9	0.5

- Possible improvements:

  Use of $W \to \tau$ hadronic 1-prong decays

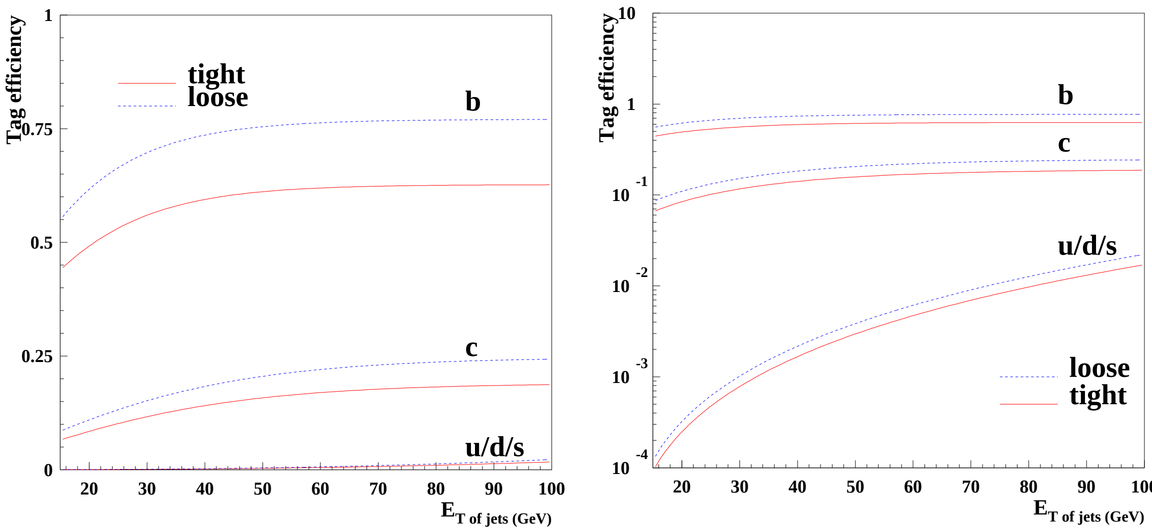
  Further refinements of multivariate selection
- Benchmark process: WZ with $Z \to b\bar{b}$

- b-jet tagging: Will it be good enough?

  Extrapolation from CDF Run I efficiciency

  Use MC for Run II acceptance

  Includes $b \to \mu$ soft lepton tag



- Arguably a "conservative" extrapolation

  Both CDF and DØ Si detectors are superior

  Improved impact parameter resolution

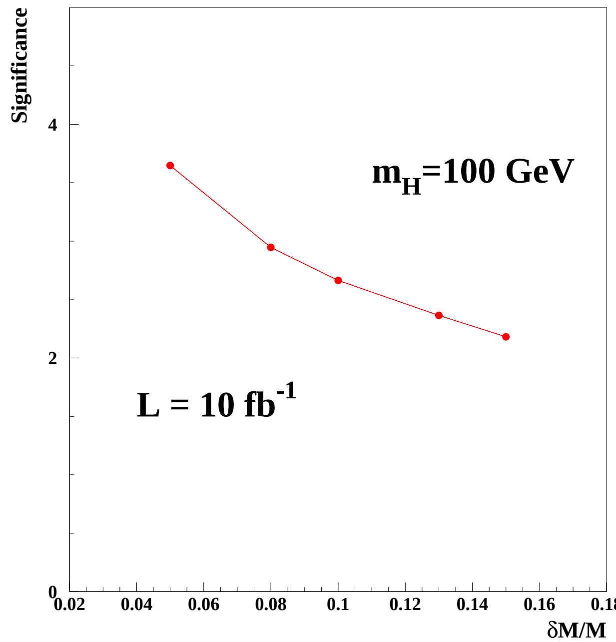
  3-D vs 2-D vertexing possible

- For $b\bar{b}$ bkgds: relative $\mathcal{L}$ roughly goes as $(1/\epsilon_b^{rel})^2$

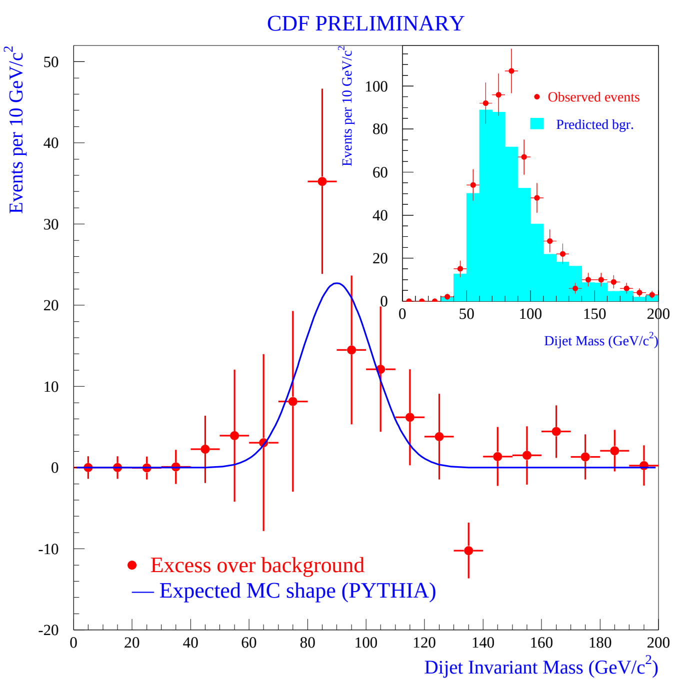
  e.g. 60% $\to$ 65% would result in same signal significance for $\sim$ 20% less $\int \mathcal{L}dt$

- Dependence of signal significance on $b\bar{b}$ mass resolution

For Run II
Aim for $\sigma(M_{b\bar{b}}) \sim 10\%$
30% better than Run I

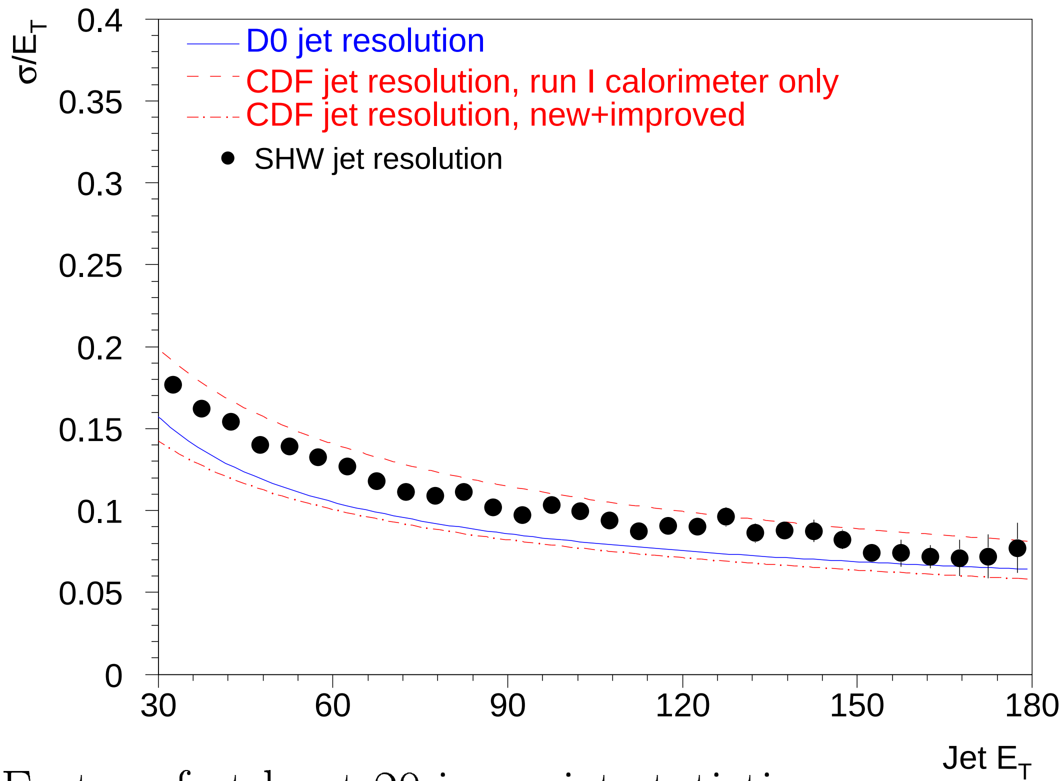


Barberis



CDF Run I: $Z^0 \to b\bar{b}$
"Calibration" for
Run II Higgs

- Run I Jet E_T resolution vs. Fast MC



Hobbs

- Factor of at least 20 in $\gamma-$jet statistics

  $\Longrightarrow$ *improved jet energy scale*

- Significant sample of $Z^0 \rightarrow b\bar{b}$ events for calibration

  Both Lepton and Sec. Vtx. based triggers

- Corrections for $b \rightarrow \ell$ effects have been studied

  Can get 12% at $M = 120\ GeV$

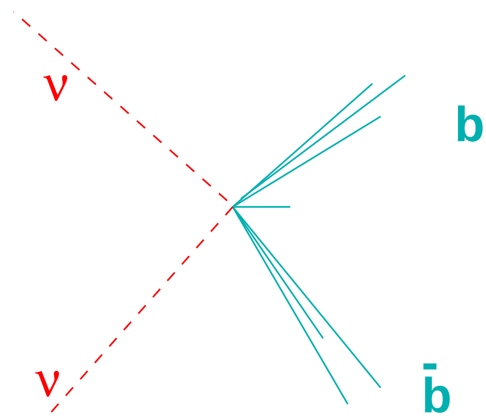
  Effect verified in Run I for $Z^0 \rightarrow b\bar{b}$

- If only 12% mass resolution is obtainable

  Increases required $\int \mathcal{L}dt$ by 20%

SM Higgs Search: $H^0Z^0 \to \nu\bar{\nu}b\bar{b}$ Channel

Yao, Jesik, Demina, Bokhari, Kilminster, Hedin



- $\not{E}_t$ + jets trigger ($\not{E}_t > 35$ GeV)
- Two b-tagged jets: $p_t^1 > 20$ GeV, $p_t^2 > 15$ GeV, $|\eta| < 2$
- Veto isolated "leptons"
- Jet-$\not{E}_t$ cut: $\Delta\phi_{b-\not{E}_t} > 0.5$
- $t\bar{t}$ veto: $H_T < 175$ GeV
- From the Neural network based selection:

Expected Events and Sensitivity per fb^{-1}					
Mass (GeV)	90	100	110	120	130
S	12.	8.	6.3	4.7	3.9
B	123	70	55.	45	47
$S/\sqrt{B}$	1.1	1.0	0.8	0.7	0.6

- QCD di-jet background:

  Difficult to measure:

  Large cross-section and low efficiency

- From Run I CDF $H^0Z^0 \rightarrow \nu\bar{\nu}b\bar{b}$ analysis

  QCD background 50% of total

  1.9 ± 0.4 *events of* 3.9 ± 0.6 *total*

- DØ Run I Jets + $\not{E}_t$ analyses

  Stop search: SM background 16.7 ± 1.7 *events*

  QCD contribution 0.4 ± 0.4

  Caveat: Lower luminosity (Run IA)

  Aside: $\sigma(\not{E}_t) = 1.08 + 0.019 \times (\sum E_T)$

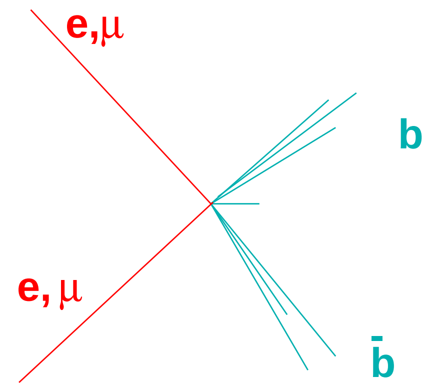
- Current studies disagree at the 20-30% level

  Conservatively have taken most pessimistic result

  QCD background as 50% of total

  i.e. *equal to the SM contribution*

Yao, Jesik, Kruse, Kilminster



- Inclusive high p_t lepton trigger
- Two like-type leptons: $p_t^1 > 20$ GeV, $p_t^2 > 10$ GeV, $|\eta| < 2$
- Consistency with a Z^0 hypothesis: $|M_{\ell\ell} - M_Z| < 15$ GeV
- Two b-tagged jets: $p_t^1 > 20$ GeV, $p_t^2 > 15$ GeV, $|\eta| < 2$
- Small rate but good S/B
- Kinematic fit may further enhance sensitivity

  Can taus help?

Expected Events and Sensitivity per fb^{-1}					
Mass (GeV)	90	100	110	120	130
S	1.2	0.9	0.8	0.8	0.6
B	2.9	1.9	2.3	2.8	1.9
$S/\sqrt{B}$	0.7	0.7	0.5	0.5	0.4

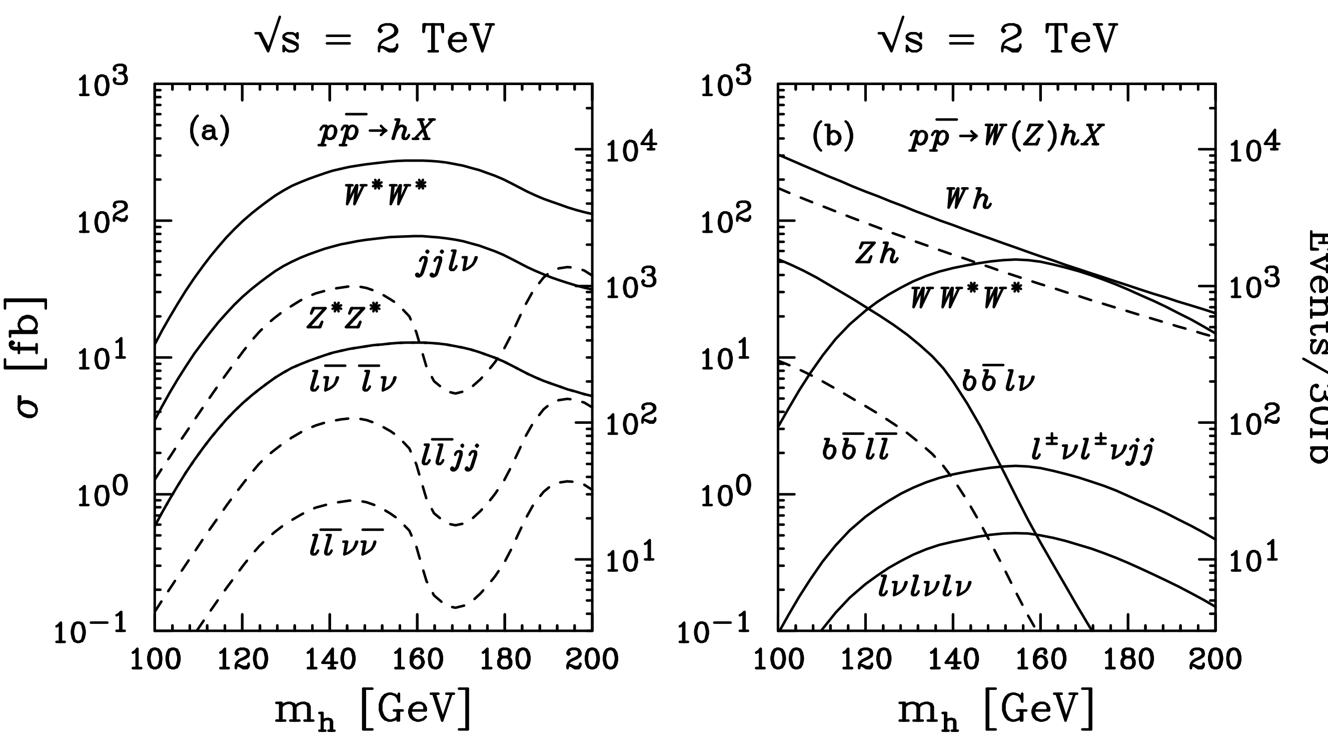
- Associated production with $H^0 \to b\bar{b}$ peters out at 130 GeV

  How to extend the reach of the Tevatron?

- Make use of the rising $H^0 \to WW^{(*)}$ branching ratio

  Exploit the large $gg \to H^0$ cross section

  Identify final state topologies with small SM contribution



Han, Turcot and Zhang

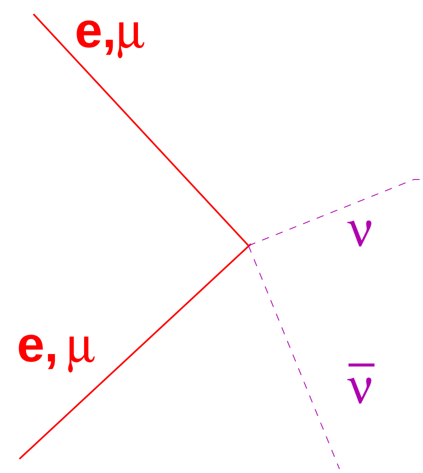
- Focus on leptonic Gauge Boson Decays:

  Excellent trigger topologies

  QCD-related backgrounds less of a problem

- Consider inclusive production:

$$p\bar{p} \to HX \to WW^{(*)}X \to \ell\nu\ell'\bar{\nu}'$$



Han, Turcot and Zhang

- Leading contribution from gluon fusion channel

$\sigma(gg \to \mathrm{H}^0) \times \mathrm{B}(\mathrm{H}^0 \to \mathrm{WW}^{(*)}) \times \mathrm{B}(\mathrm{W} \to \mathrm{e}, \mu)^2$

Mass (GeV)	140	150	160	170	180	190
$\sigma \times B$ (fb)	11.2	12.8	13.9	12.2	9.8	6.9

- Standard Model backgrounds:

  WW$\to \ell\nu$ $\ell'\bar{\nu}'$: 1090 fb $\tau^+\tau^- \to \ell\nu\nu$ $\ell'\nu\nu$: 23 pb

  $t\bar{t} \to b\ell\nu$ $\bar{b}\ell'\nu$: 722 fb WZ, ZZ, and tW: $\sim$ 220 fb

- $\sum$ Background. $\approx$ 25 pb $\Longrightarrow S/B \sim 4 \times 10^{-4}$

- Step 1: Basic Cuts:

  Maintain high efficiency while reducing $\tau\tau$ and $t\bar{t}$

Backgrounds (fb)

$\sum$ Bgd.	WW	$t\bar{t}$	$\tau\tau$	WZ	ZZ	tW	W+fake
165	127	12.7	< 0.1	4.44	2.36	0.6	17.8

  W+fake evaluated assuming $P(j \to e) = 10^{-4}$

- Step 2: Apply 6-variable $\mathcal{L}$ikelihood discriminant
- Step 3: Background Normalization

  Dominated by WW and W plus fake ($j \to e$)

Post-$\mathcal{L}$ Backgrounds (fb)

$\sum$ Bgd.	WW	$t\bar{t}$	$\tau\tau$	WZ	ZZ	tW	W+fake
106	83	4.5	~ 0	3.1	1.8	0.6	13

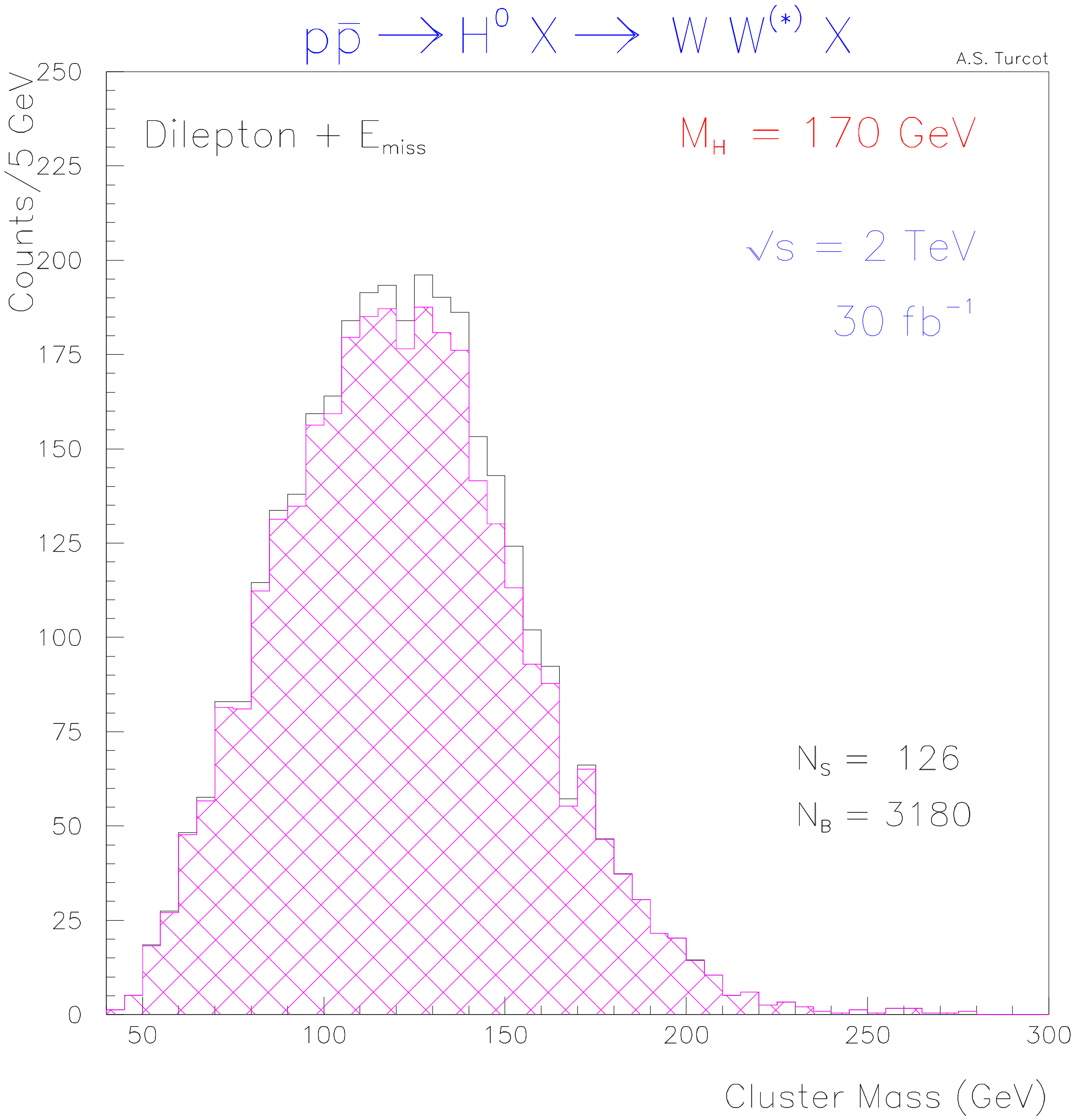
- Step 4: Final Selection:

  Exploit different kinematics of WW *production*

  Continuum vs. *at threshold via a spin 0 resonance*

  Utilize angular correlations between the leptons and $\not{E}_t$

- Before "Turning the Screw"

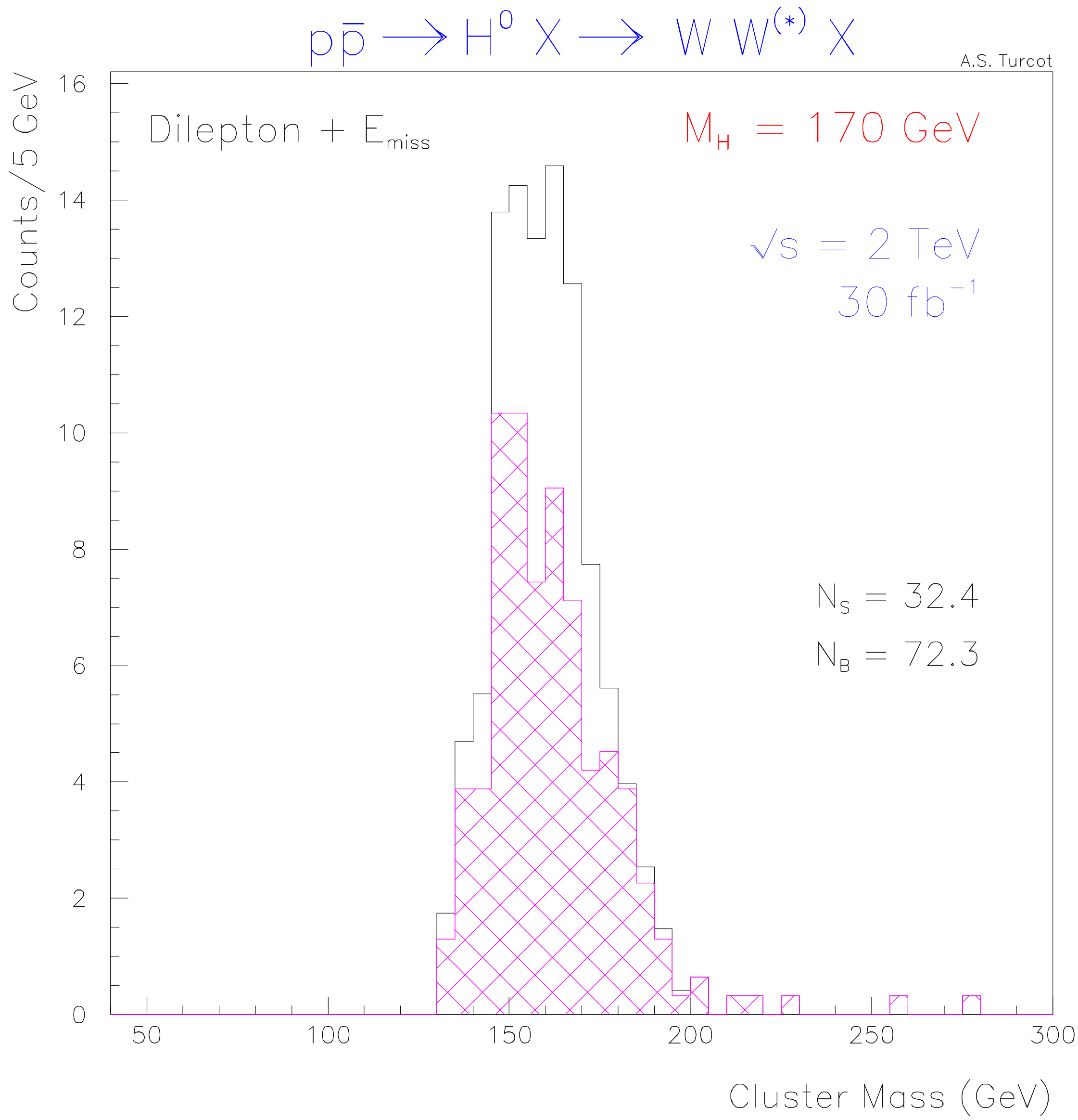


- Normalization of the Background

  $10\ fb^{-1} \Rightarrow 3.1\%$ statistical error

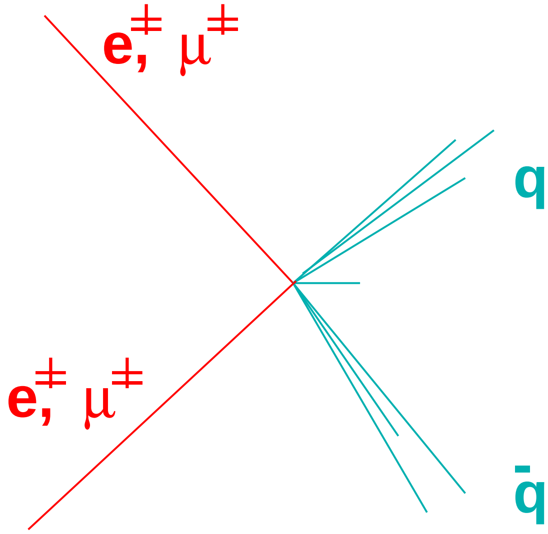
  Higgs "contamination": $S/B \sim 3-5\%$

- After "Turning the Screw"



- WW background reduced by a factor of 40! ($M_{\rm H} = 170$)
- Clear excess from Higgs production

Han, Schmitt, Turcot, Zhang



- Distinct Signature: $\ell^{\pm}\ell^{\pm}$ *jet jet* X

  Standard *New Physics* search topology

- First proposed for H^0 search by Marciano, Stange and Willenbrock (Phys. Rev. **D49**, 1354 (1994))

- Four contributions to consider

  W H → W W W → $\ell^{\pm}\nu$ $\ell^{\pm}\nu$ jj

  Z H → Z W W → $\ell'\ell'$ $\ell^{\pm}\nu$ jj

  W H → W Z Z → $\ell^{\pm}\nu$ $\ell'\ell'$ jj

  Z H → Z Z Z → $\ell\ell$ $\ell'\ell'$ jj

- Veritable minefield of SM backgrounds to consider:

  Di-boson, $t\bar{t}$, Tri-boson, $t\bar{t}V$, fakes …

- Event selection is independent of Higgs mass

  Straight counting experiment

Expected Signal Events per fb^{-1}									
M_{H} (GeV)	120	130	140	150	160	170	180	190	200
σ (fb)	0.08	0.15	0.29	0.36	0.41	0.38	0.26	0.20	0.16

- Mass Independent background cross section: 0.48 fb

  Dominant contributions are:

  $\sigma(\mathrm{WZ}) = 0.15$ *fb*

  W/Zjjj = 0.15 fb (requires $j \to e$)

  (determined from D0 Run I W+3j rates)

  Sum of $t\,\bar{t}$, di/tri-boson, $t\bar{t}V$ = 0.18 fb

- Good S/B but low rate limits statistical significance
- $\mathrm{H}^0 \to ZZ$ becomes important at high mass
- Control of systematics will be challenging

- Bayesian combination: All channels and both experiments:

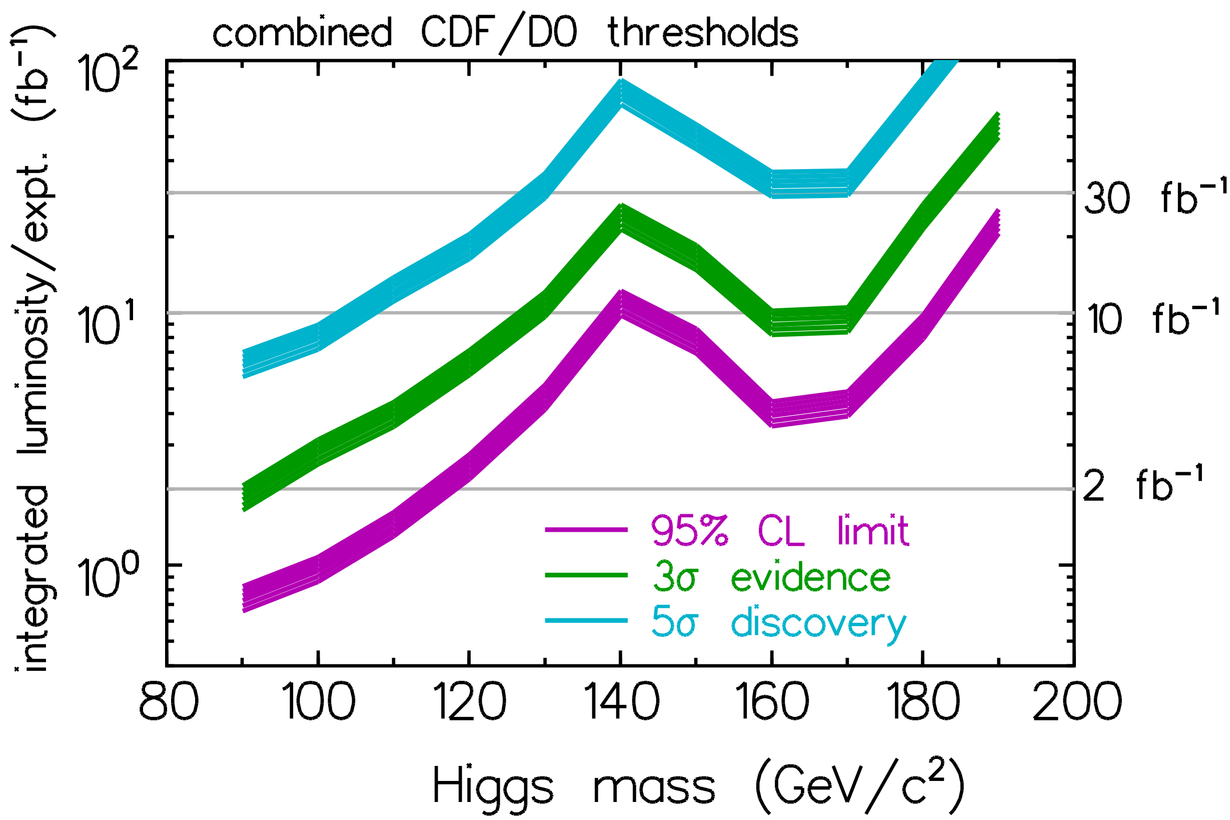
  Assume 10 % $m_{b\bar{b}}$ resolution

  Neural network analysis for $\mathrm{H}^0 \rightarrow b\bar{b}$ *channels*

  Conservative treatment of QCD bgd. for $\mathrm{H}^0\mathrm{Z}^0 \rightarrow b\bar{b}\nu\bar{\nu}$

  Systematic error: Min. of 10% or $1/\sqrt{\int \mathcal{L}dt \times B}$

  Bands represent 30% effect from in $m_{b\bar{b}}$, ϵ_b, bgds.



- 95% CL exclusion up to ~ 185 GeV for 10 fb^{-1}
- 3σ or better observation up ~ 185 GeV for ~ 20 fb^{-1}
- 5σ discovery up ~ 125 GeV for ~ 30 fb^{-1}

Model Independent Sensitivities

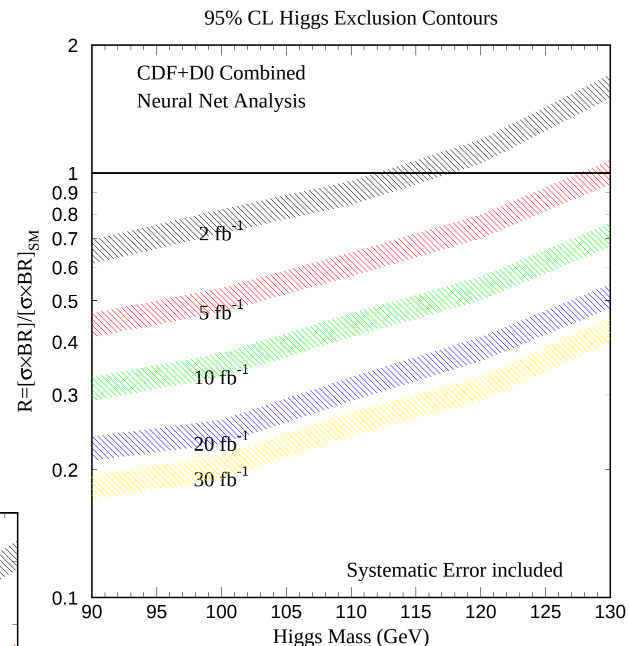
- Model Independent interpretation of $b\,\bar{b}$ channels

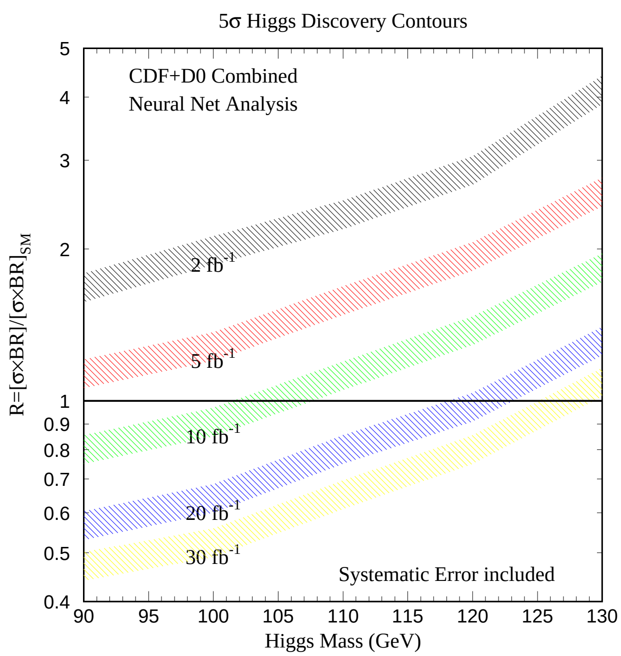
  Define

$$R = \frac{\sigma \times BR\ \ (New\ Physics)}{\sigma \times BR\ \ (Standard\ Model)}$$

Exclusion

$\Longrightarrow$





Discovery

$\Longleftarrow$

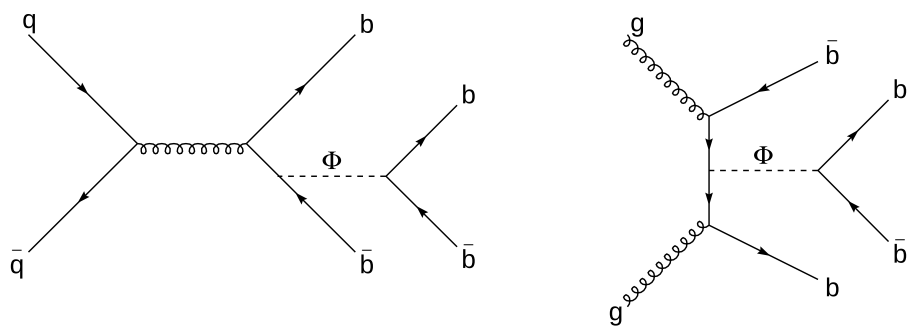
- Application to SUSY in next talk (Mrenna)

Roco, Belyaev, Valls

- Large $b\bar{b}$ cross section at the Tevatron can be used to exploit enhanced Yukawa couplings

  e.g. A$b\bar{b}$ coupling $\propto \tan\beta \Longrightarrow$ cross section goes as $\tan^2\beta$

  look for $b\bar{b}\phi$ production, $\phi \equiv$ h, H, A



- Two different event selections: Common features

  Trigger: 4 jets of $E_T > 15$ GeV

  3 of the 4 leading jets are b-tagged

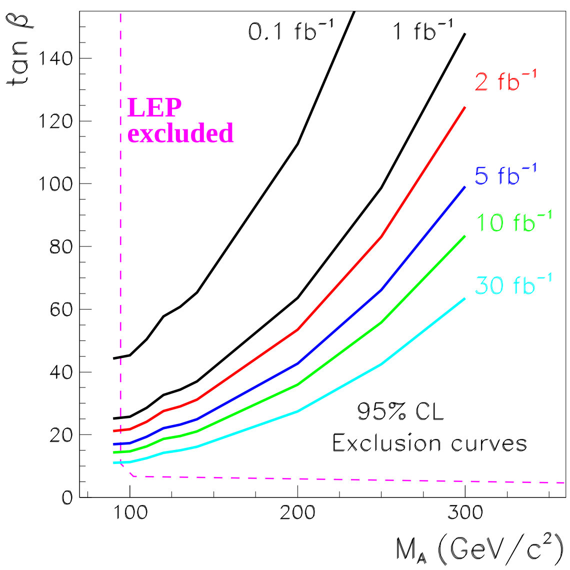
  Mass dependent jet E_T selection

  e.g. leading jet $p_T > M_\phi/2 - 5$ GeV

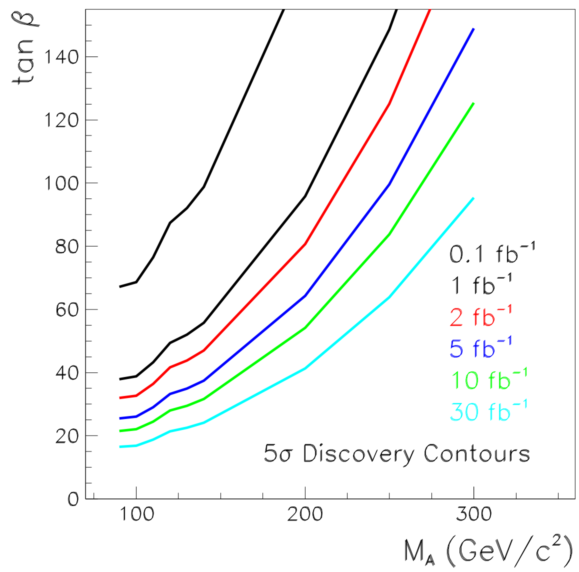
- CDF: Extrapolation of Run I analysis with Run II SVX
- DØ: More reliant on Monte Carlo
- Despite different starting assumptions and methods Results agree at the level of 15-20%

- Sensitivity in $\tan\beta$ *vs* M_A plane

Exclusion



Discovery



- Sensitivity for M_A up to 125 GeV with 2 fb^{-1} for "interesting" region $\tan\beta \sim m_t/m_b \sim 35$

  Relatively modest $\int \mathcal{L}dt$ *required*

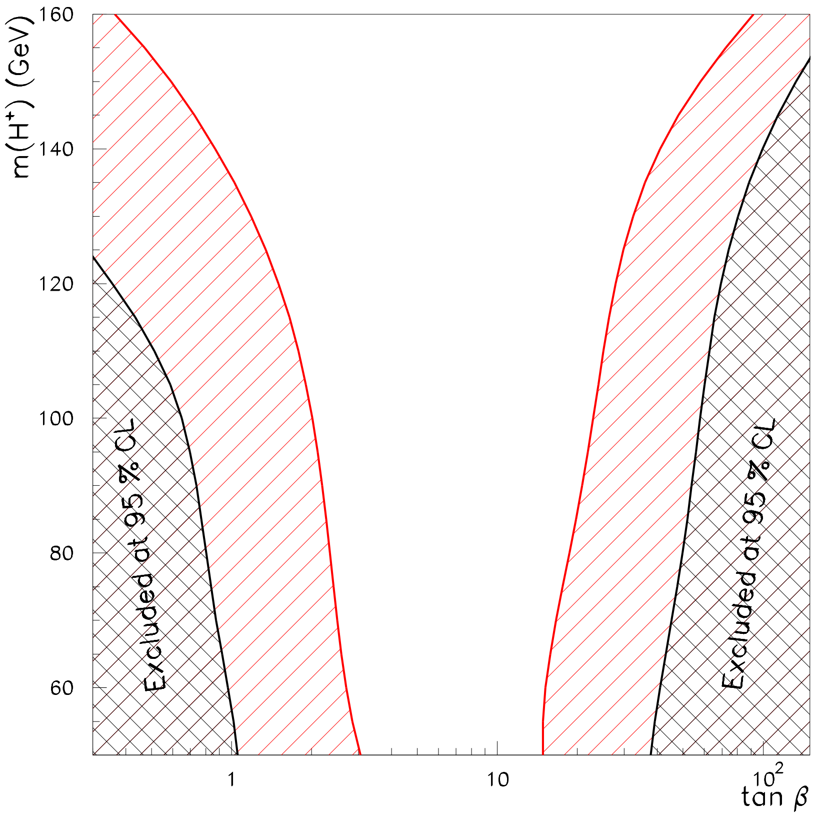
- Limited by trigger efficiency: Jets only at level 1

  Level 2 secondary vertex triggers will help

- Improvements from $\phi \to \tau\tau$ (see talk by Connolly)

Chakraborty

- The *Gold-Plated* signature for a non-minimal Higgs Sector



- Current limits based on decay mode $t \to \mathrm{H}^+\bar{b}$

  Compare expected $\sigma(t\bar{t})$ *with* $N(t\bar{t})$ *observed*

  Set limits on "disapperence" via $t \to \mathrm{H}^+\bar{b}$ *decay*

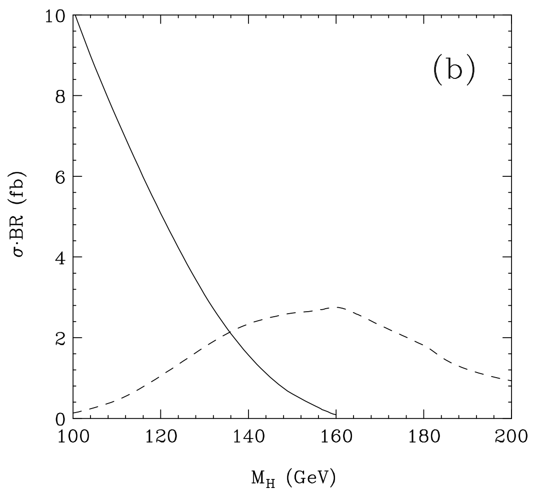
  Large $\tan\beta$*: can also look for excess of* $b\tau X$ *events*

- Closing the Chimney will be tough

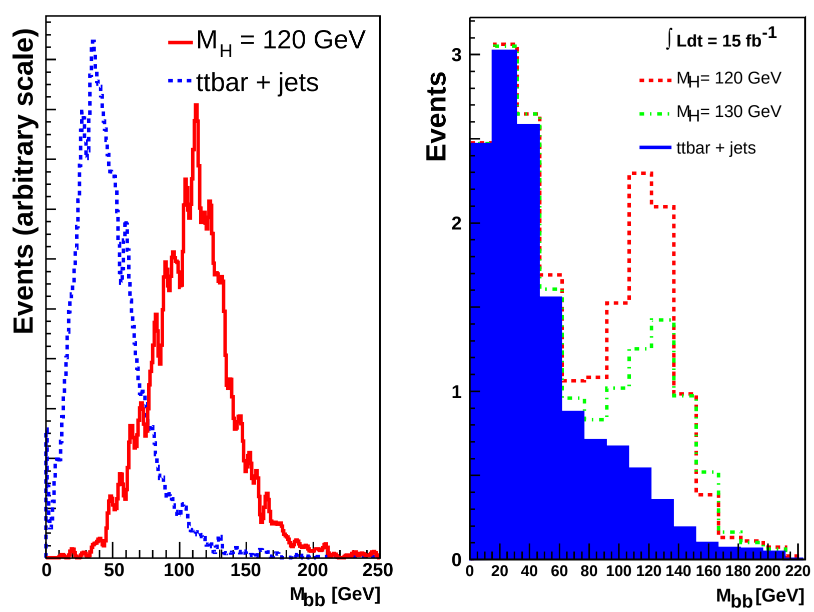
  Drell-Yan H^+H^- *production?*

- A recent development: Goldstein *et al* hep-ph/0006311
- Leads to spectacular topologies

$$t\bar{t}\,\mathrm{H}^0 \to b\bar{b}\;\; b\,W^+\,\bar{b}\,W^-\;(M_H \lesssim 135\text{ GeV})$$
$$t\bar{t}\,\mathrm{H}^0 \to W^{(*)}W\;\; b\,W^+\,\bar{b}\,W^-\;(M_H \gtrsim 135\text{ GeV})$$



Experimentally challenging
Small $\sigma \times BR$
Multi-jet reconstruction is key
b-jet tagging is critical
(see talk by Incandela)



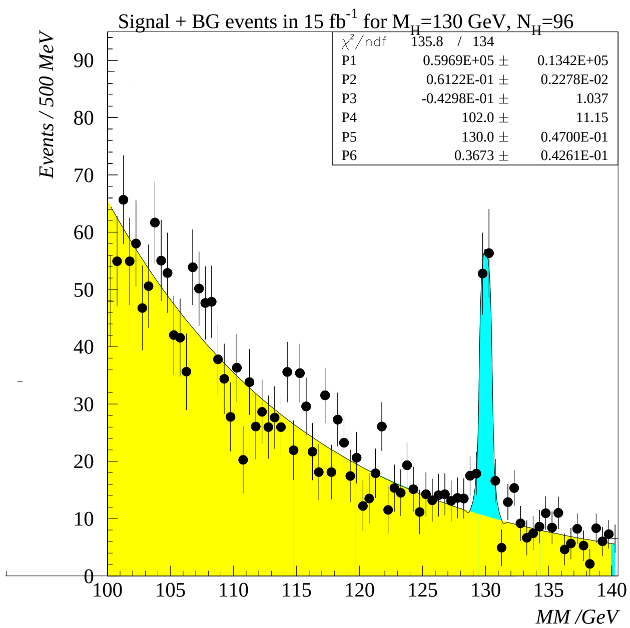
- Could provide a critical verification of a weak H^0 signal

Albrow et al

- Diffractive Higgs production $p\,\bar{p} \to p + \mathrm{H}^0 + \bar{p}$
- Basic Idea:

  Tag elastically scattered p and $\bar{p}$ and exploit

  excellent missing mass resolution: 250 MeV/event



- Difficult to evaluate the Higgs sensitivity

  Xsec uncertainty: factor of 100 (Non-Perturb.)

  Rapidity gap survival fraction?

  Radiative tails in missing mass distribution?

- Clearly merits further investigation:

  Key measurement to perform: $p\,\bar{p} \to p + \chi_b(0^{++}) + \bar{p}$

- Strong experimental and theoretical motivation that the Higgs is close at hand

  How close is the question...

- Run II Prospects: Standard Model

  The Tevatron has the potential to cover most of the mass range preferred by the ElectroWeak fits

  Key luminosity will be 10 fb^{-1} per detector

  Exclude SM Higgs up to ~ 185 GeV or better yet, clear evidence of a signal will be emerging

- What about the 115 GeV Higgs from LEP?

  If it is not there, 2 fb^{-1} per experiment will rule it out

  Verification at the 3σ level will require 5-6 fb^{-1}

- Supersymetric Higgs Bosons:

  Experimentally exciting possibilities in $b\bar{b}\,\phi$ and Charged Higgs production

- A new channel $t\bar{t}\,\mathrm{H}^0$ looks promising

  Will it be the "little bit extra"? $3 \rightarrow 5\sigma$

- Diffractive production:

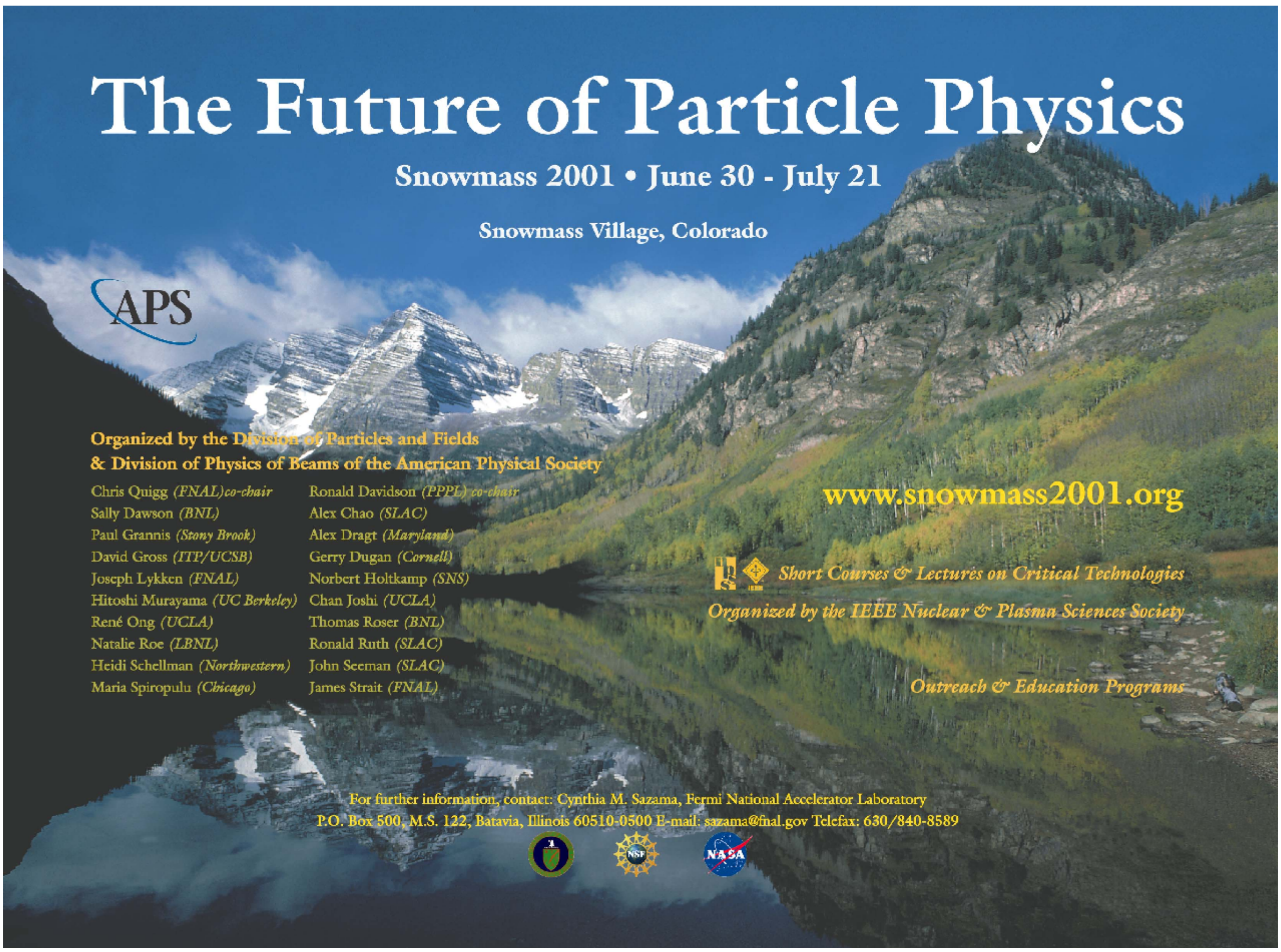
  Despite uncertainties, it could yield a big surprise

The End?

- For Higgs Physics …

…the Future is Now

See You at Snowmass!



The End