Standard Model and Supersymmetric Higgs at CDF

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on behalf of CDF collaboration

Outline:

Current Knowledge of Higgs

CDF searches :

- Direct Higgs (1 analysis)
- Associative Higgs (3)
- MSSM Higgs (2)

Tevatron Discovery potential

What we know about Higgs

- Higgs mechanism gives mass to Standard Model particles
- But required Higgs boson not yet discovered !
  - Therefore, some alternatives to experimentally check :

"Standard Model" (SM)

- Simplest Higgs mechanism possible
- Higgs is 1 particle
  - H
  - spin 0
  - electrically neutral
  - interacts with all SM particles
    - more strongly with higher mass particles

SM not wrong yet !

"Minimally Supersymmetric Model" (MSSM)

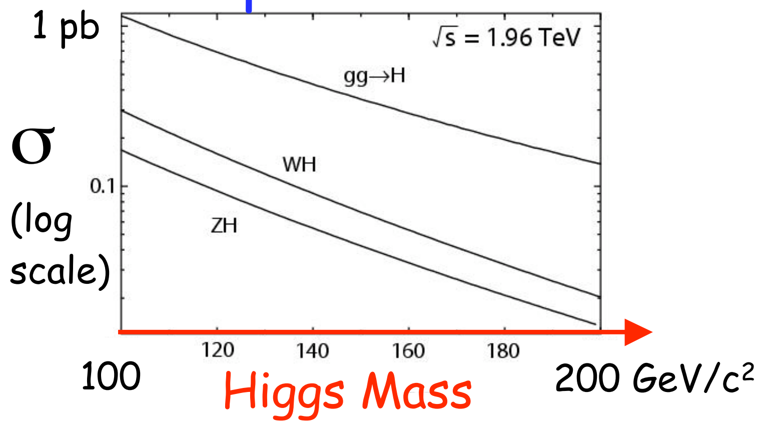
- Next most simplest Higgs mechanism possible
- Higgs are 5 particles
  - h, A, H, H+, H-
  - spin 0
  - electrically : -1,0, +1
  - interact with all SM particles
    - more strongly with higher mass particles
    - enhancement to down-type quarks from tan β parameter (relates to Vacuum Expec. Val.)

MSSM popular step toward unified theory

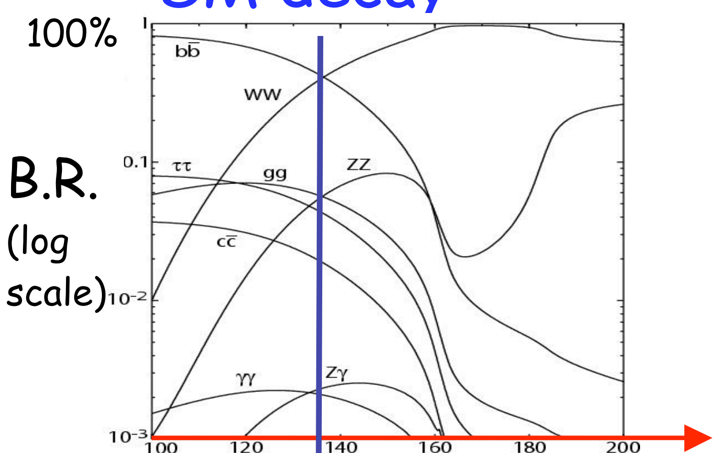
Higgs Production and Decay

($p\bar{p}$ collisions)

SM production



SM decay

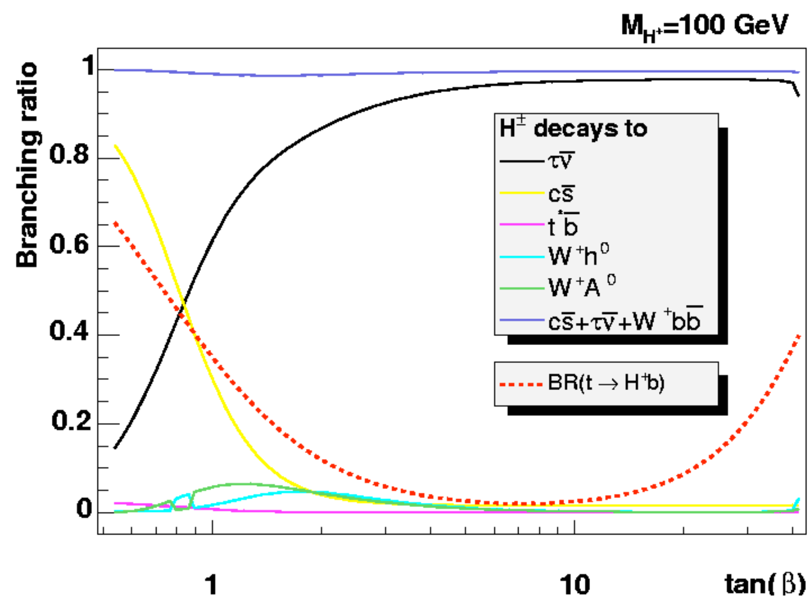


$H \to b\bar{b}$ at low M_H
$H \to \tau^+ \tau^-$ smaller

$H \to W^+ W^-$ dominates $M_H > 135$ GeV

MSSM production and decay

- 105 unknown parameters make this tough
  - tan β parameter most important at Tevatron
  - Charged Higgs, H^+
    - high tan β means Higgs couples to τ
  - Neutral Higgs, A
    - 90% decay to bb, 10% to ττ



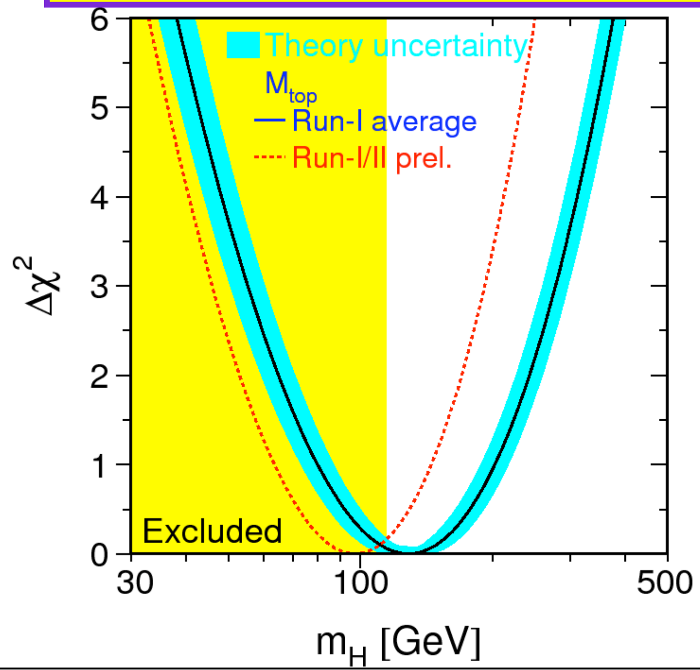
H^+ branching ratios for $m_H < m_t$

Expected Higgs mass (& type=SM or MSSM)

SM: From electroweak fits with new CDF/D0 Run I/II top mass 172.7 + 2.9 GeV/c^2

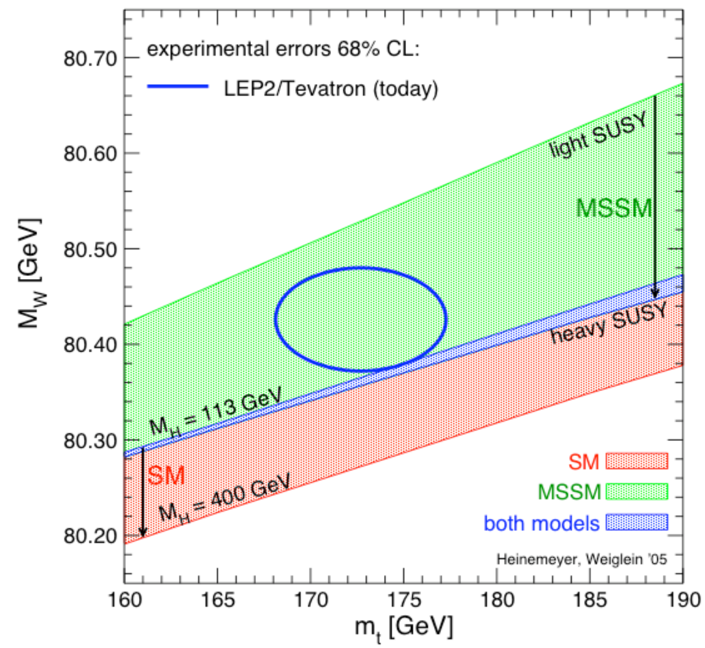
$$M_H = 91^{+45}_{-32}\,\mathrm{GeV/c^2}$$

$$M_H < 186\ \mathrm{GeV/c^2}\ @95\%\ \mathrm{C.L.}$$



Direct LEP M_H > 114.4 GeV @ 95% CL

MSSM: top mass, W mass makes MSSM favorable



SM Higgs Channels :

$p\bar{p} \rightarrow W^* \rightarrow WH \rightarrow l\nu b\bar{b}$

$p\bar{p} \rightarrow Z^* \rightarrow ZH \rightarrow l^+l^-b\bar{b}$

$p\bar{p} \rightarrow Z^* \rightarrow ZH \rightarrow \nu\nu b\bar{b}$

$p\bar{p} \rightarrow H \rightarrow W^+W^- \rightarrow l^+l^-\nu\bar{\nu}$

Search for SM $p\bar{p} \rightarrow W^* \rightarrow WH \rightarrow l\nu bb$

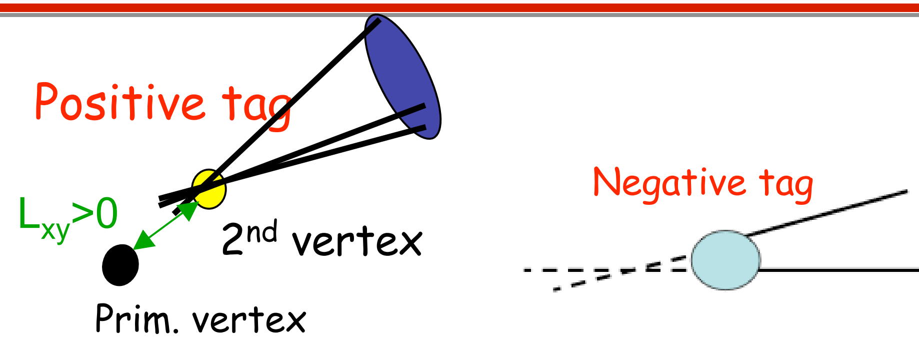
- Strategy :

high P_T lepton + missing energy + 2 jets

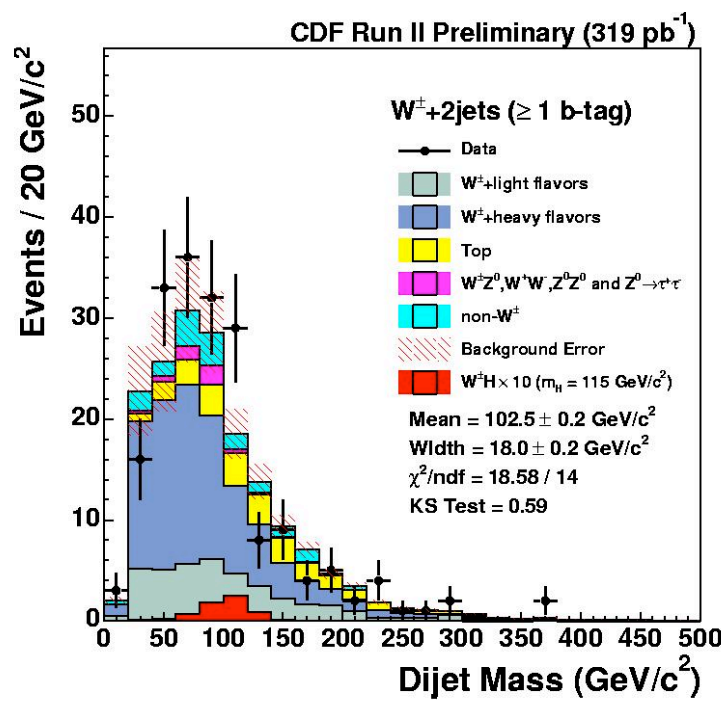
➢ Separate signal from W+heavy flavor and W+light flavor backgrounds

➢ Use b-tagging algorithm

➢ Requires MC estimations and excellent knowledge of "mistag" rate of light flavor jets



W+light flavor estimated from number of tags with negative lifetime



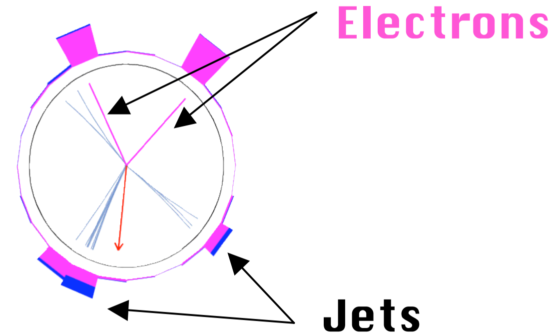
Results :

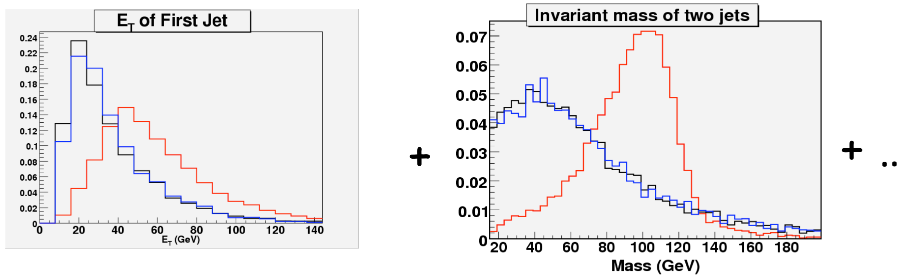
- Examine dijet mass for resonance
- Consistent with SM
- Set a limit on Higgs production :

$\sigma(M_H = 115 \text{ GeV}) < 8.6$ pb

Search for SM pp → Z* → ZH→l^+l^-bb

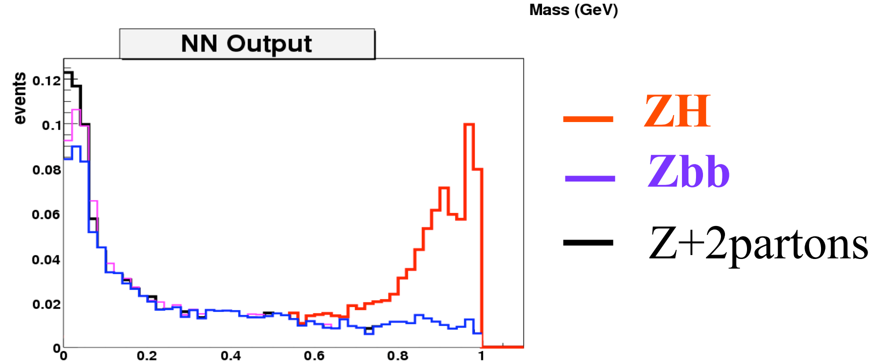
- Strategy :
  - Identify Z boson decaying to two high Pt leptons + 2 or 3 jets (w/ b-tag)
  - Lepton ID cuts into acceptance
  - Use Artificial Neural Net (NN) to separate signal with main bkg of Z+jets





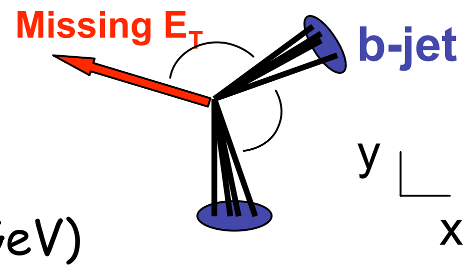
Results :

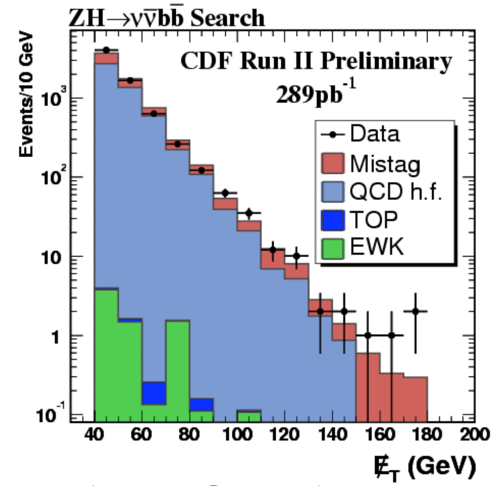
- NN improves S/B resulting in effective 1.6 increase in luminosity
- Expect result with 1 fb^{-1} data



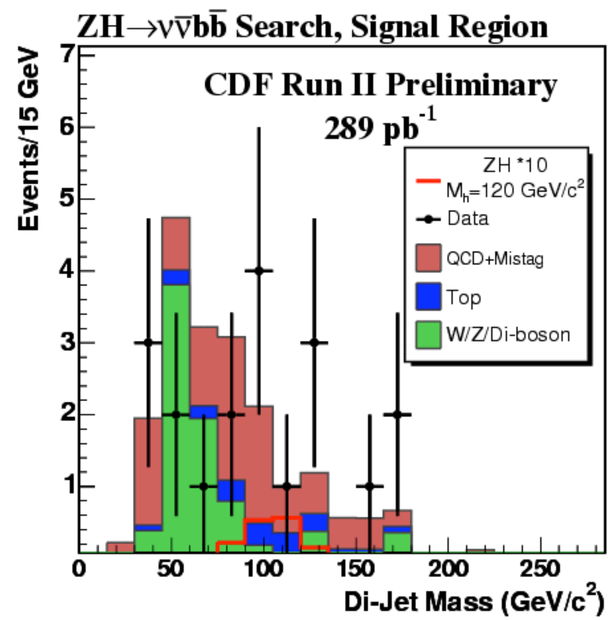
Search for SM pp → Z* → ZH→ννbb

- Strategy :
  - Z decays to neutrinos
  - Search for large missing transverse energy (MET > 70 GeV) with 2 jets, 1 b-tag
  - Need to model MET well
  - Remove events where MET aligns with jet (mismeasured QCD dijet)





Scale MC to reproduce MET in data

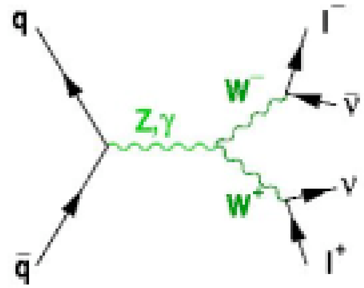


Results :

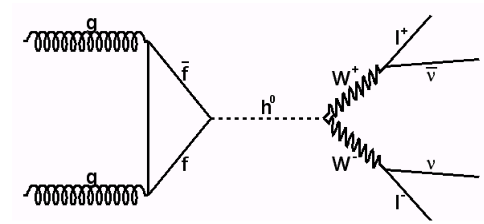
- Consistent with SM
  - Set a limit on Higgs production
  - σ (M_H=115 GeV) < 5 pb

Search for SM $p\bar{p} \to H \to W^+W^- \to l^+l^-\nu\nu$

- Strategy :
  - Most sensitive channel to high mass Higgs
  - Search for 2 high P_T leptons and MET
  - Angular correlations between leptons different than WW BKG since H is scalar



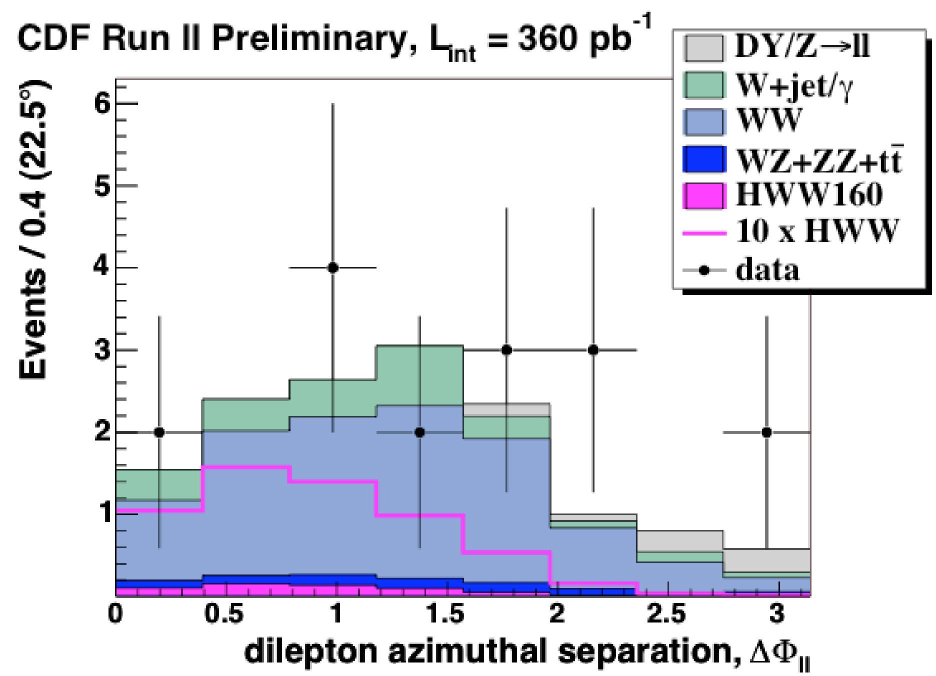
Background



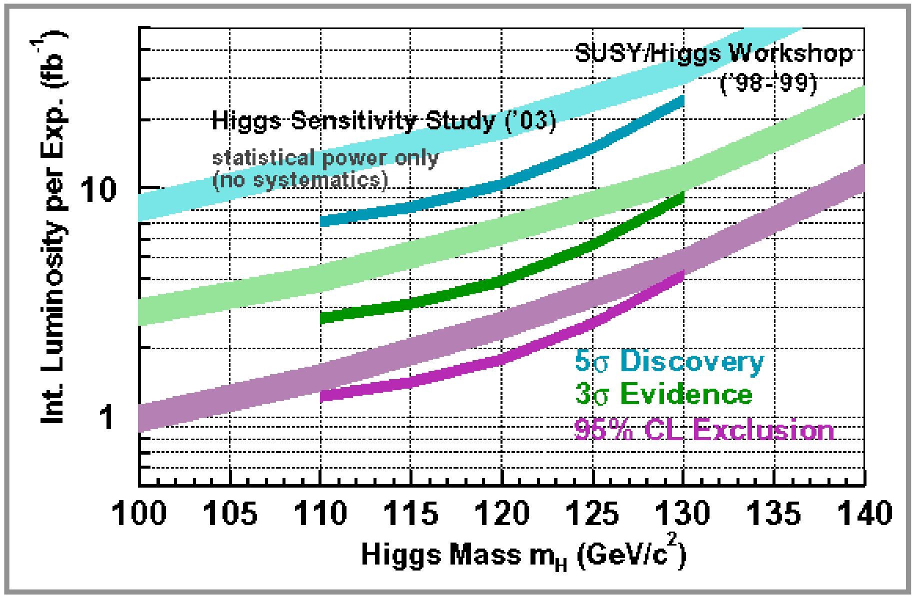
Signal

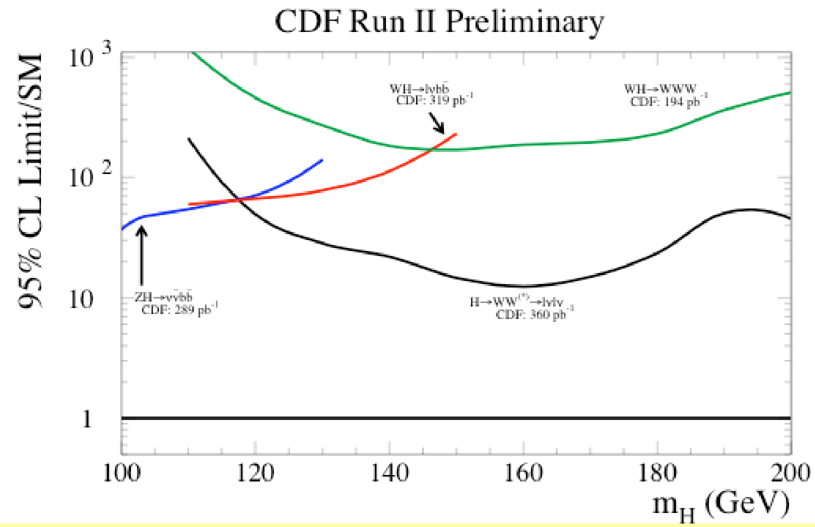
Results :

- Consistent with SM
  - 13.8 + 1.2 pred. bkg
  - 0.58 +- 0.04 pred. sig
  - 16 in data
  - σ (M_H=160 GeV) < 3.2 pb



Summary of SM Higgs searches





2003 Sensitivity Projections

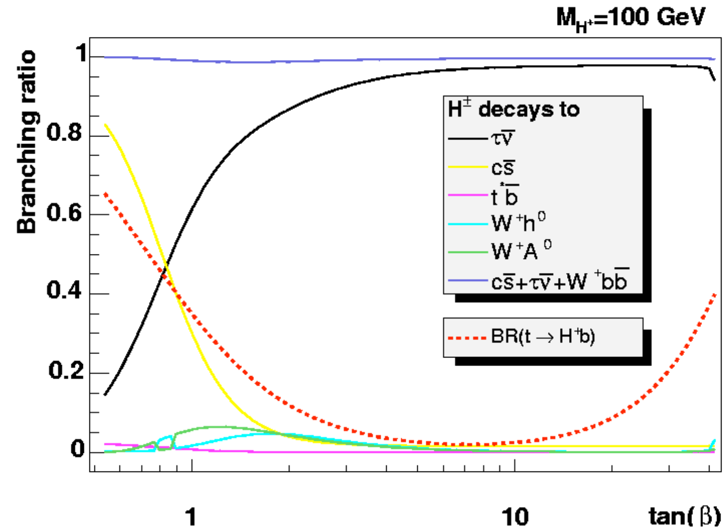
- m_H = 115 GeV
  - ~ 2 fb^{-1} for exclusion (if not there)
  - ~ **4 fb^{-1}** for m_H = 115 3σ evidence
- Assumes :
  - all Higgs channels combined at both CDF and D0
  - realistic data, no systematics
- 8 fb^{-1} by 2009 is design

2005 Status

- CDF preliminary results with 200 - 400 pb^{-1} data
  - channels not combined, some missing
  - need factor of 30-40
    - factor of ~20 from data up to 2009
    - factor of 2 from CDF/D0 combination
- Working on ways to improve sensitivity
  - Neural Nets for everyone ! (factor of ~1.7)
  - Improved jet resolution (1.1 for each 1%)
  - Improved lepton acceptance (> 1.5)

Search for MSSM $t \rightarrow H^{+}b$

- Strategy :
  - In SM
    - $t \rightarrow W^{+}b$
    - $W^{+} \rightarrow l^{+}\nu$ (1/3), $W^{+} \rightarrow qq$ (2/3)
  - In MSSM (for $M_H < M_t$)
    - $t \rightarrow H^{+}b$, $t \rightarrow W^{+}b$
    - At high tan β, $H^{+} \rightarrow \tau\nu$
    - At low tan β $H^{+} \rightarrow c\bar{s}$
  - Find excesses and deficits w.r.t. SM top !

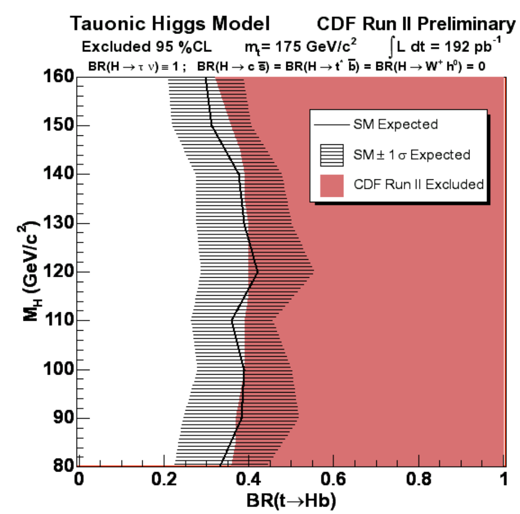


Results :

- No significant excesses or deficits found
- We can exclude regions of the M_{H+} vs tan β plane for various MSSM scenarios
- Branching ratio limit independent of MSSM scenarios

BR($t \rightarrow H^{+}b$)<0.4 @95%CL for **80 GeV<$mH^{\pm}$<160 GeV**

M_{H+}



BR($t \rightarrow H^{+}b$)

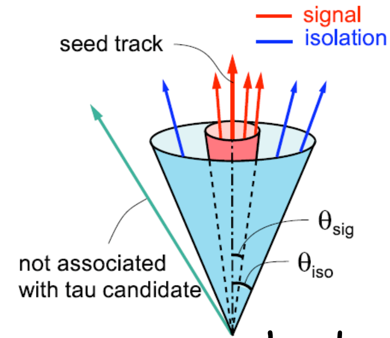
Search for MSSM $A/h \rightarrow \tau^+\tau^-$

- Strategy:
  - high tan β enhances production of A
  - more stable to radiative corrections than $A \rightarrow bb$
  - identify events with two taus

    one leptonic: $\tau \rightarrow \nu + e\nu\ /\ \mu\nu$

    one hadronic: "narrow" jet

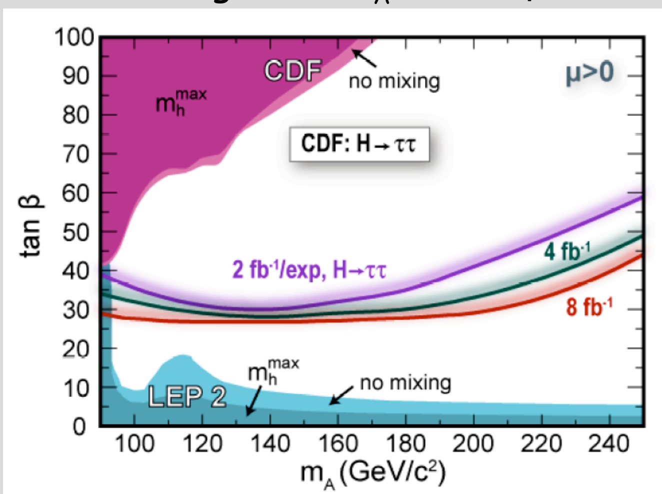
  - Cut on sum of transverse (from $e/\mu + \tau_h$) and missing (ν) energy

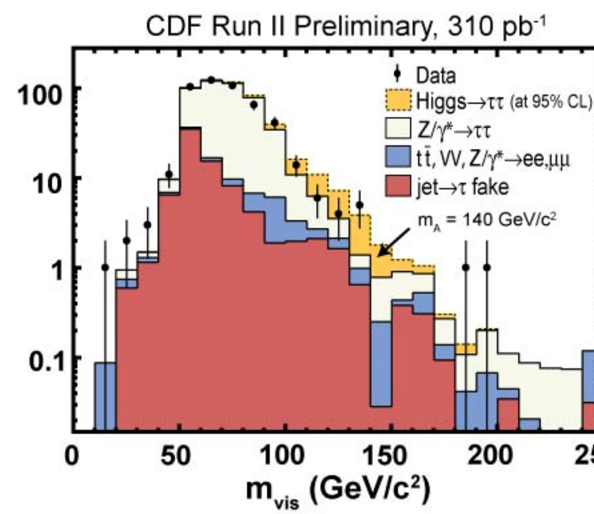


hadronic tau

Results:

- consistent with SM
- exclusion in region of m_A vs. tan β





Visible + missing transverse mass

Conclusions

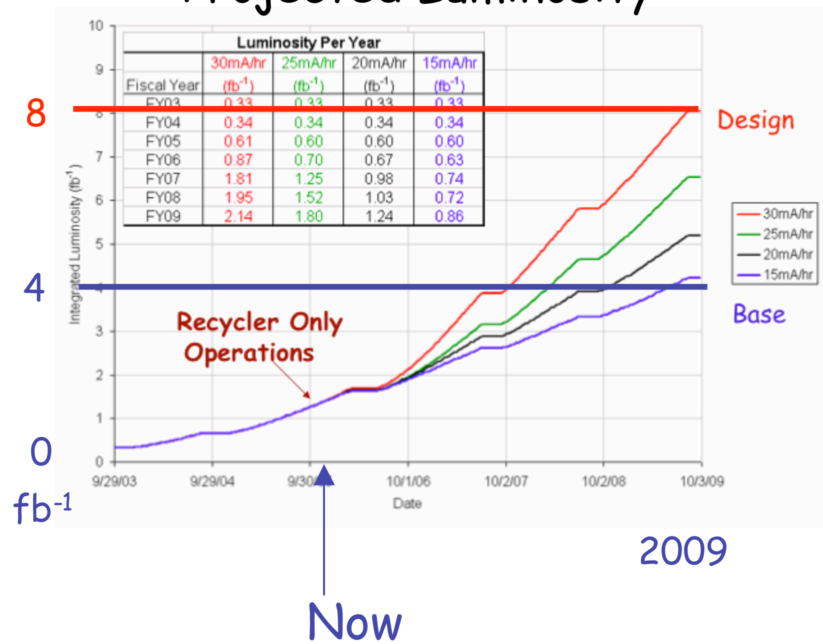
- CDF exploring all SM and MSSM Higgs possibilities
- SM
  - Direct Higgs production
    - high production cross-section
    - $H \rightarrow WW$
  - Associative higgs production
    - leptons + b jets (+ miss. E.) distinct signature
    - $WH \rightarrow l\nu$, $ZH \rightarrow \nu\nu bb$, $ZH \rightarrow l^+l^- bb$

  Limits will improve with luminosity and smarts !

  4 - 8 fb^{-1} can find us a light Higgs
- MSSM
  - Neutral Higgs
    - production cross section enhanced $(\tan\beta)^2$
    - $A \rightarrow \tau^+ \tau^-$
  - Charged Higgs
    - capitalize on knowledge of top
    - $t \rightarrow H^+ b$

  Cutting into allowed MSSM parameter space !

Projected Luminosity

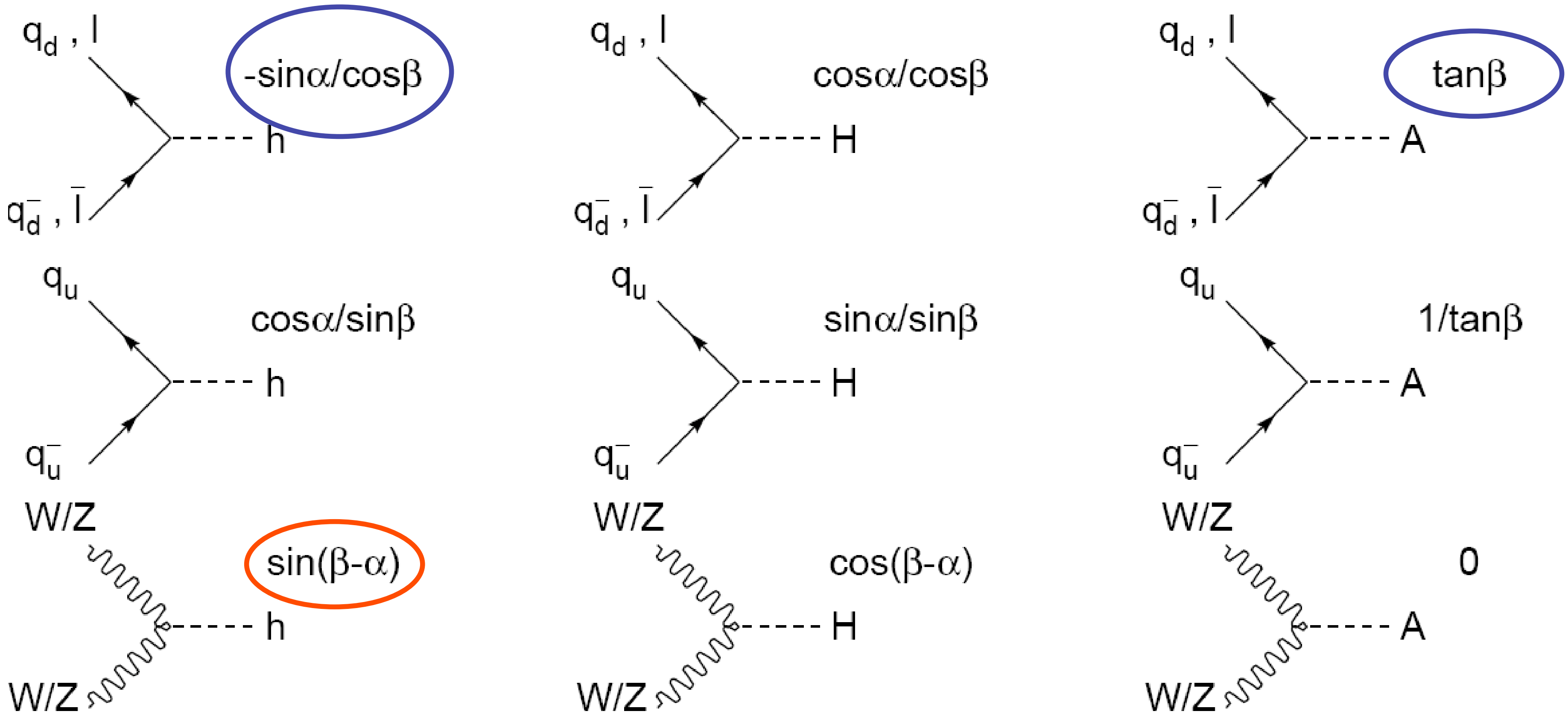


Fiscal Year	30mA/hr (fb^{-1})	25mA/hr (fb^{-1})	20mA/hr (fb^{-1})	15mA/hr (fb^{-1})
FY03	0.33	0.33	0.33	0.33
FY04	0.34	0.34	0.34	0.34
FY05	0.61	0.60	0.60	0.60
FY06	0.87	0.70	0.67	0.63
FY07	1.81	1.25	0.98	0.74
FY08	1.95	1.52	1.03	0.72
FY09	2.14	1.80	1.24	0.86

Accelerator Division, CDF, and D0 working together against the clock

BACKUPS

Couplings of MSSM Higgs Bosons Relative to SM



W and Z couplings to H, h are **suppressed** relative to SM (but the sum of squares of h^0, H^0 couplings are the SM coupling). Yukawa couplings (scalar-fermion) **can be enhanced**

So How Do We Get There??

Luminosity Equivalent $(s/\sqrt{b})^2$

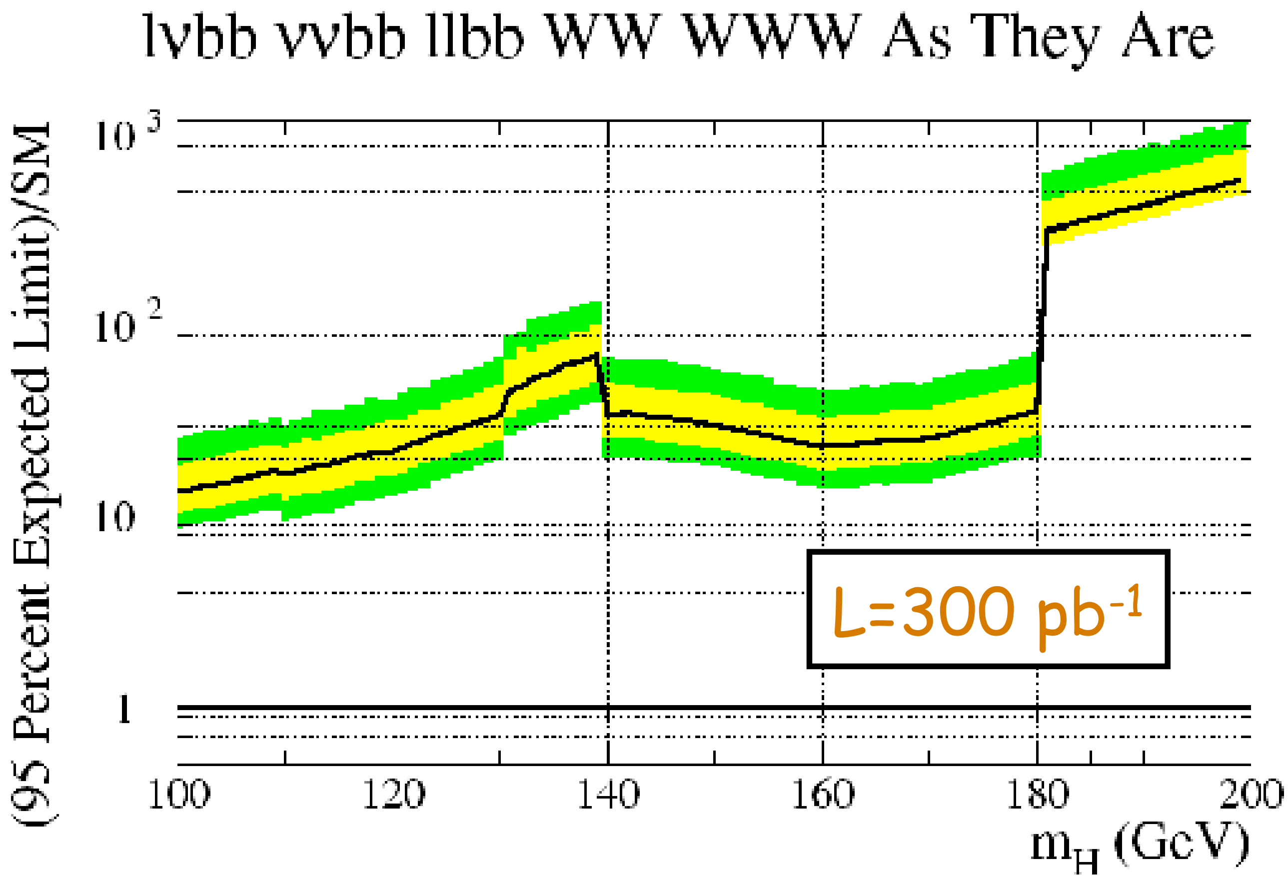
Start with existing channels, add in ideas with latest knowledge of how well they work.

Improvement	WH→lνbb	ZH→ννbb	ZH→llbb
Mass resolution	1.7	1.7	1.7
Continuous b-tag (NN)	1.5	1.5	1.5
Forward b-tag	1.1	1.1	1.1
Forward leptons	1.3	1.0	1.6
Track-only leptons	1.4	1.0	1.6
NN Selection	1.75	1.75	1.0
WH signal in ZH	1.0	2.7	1.0
Product of above	8.9	13.3	7.2
CDF+DØ combination	2.0	2.0	2.0
All combined	17.8	26.6	14.4

Expect a factor of ~10 luminosity improvement per channel, and a factor of 2 from CDF+DØ Combination

Sensitivity with Existing CDF Analyses

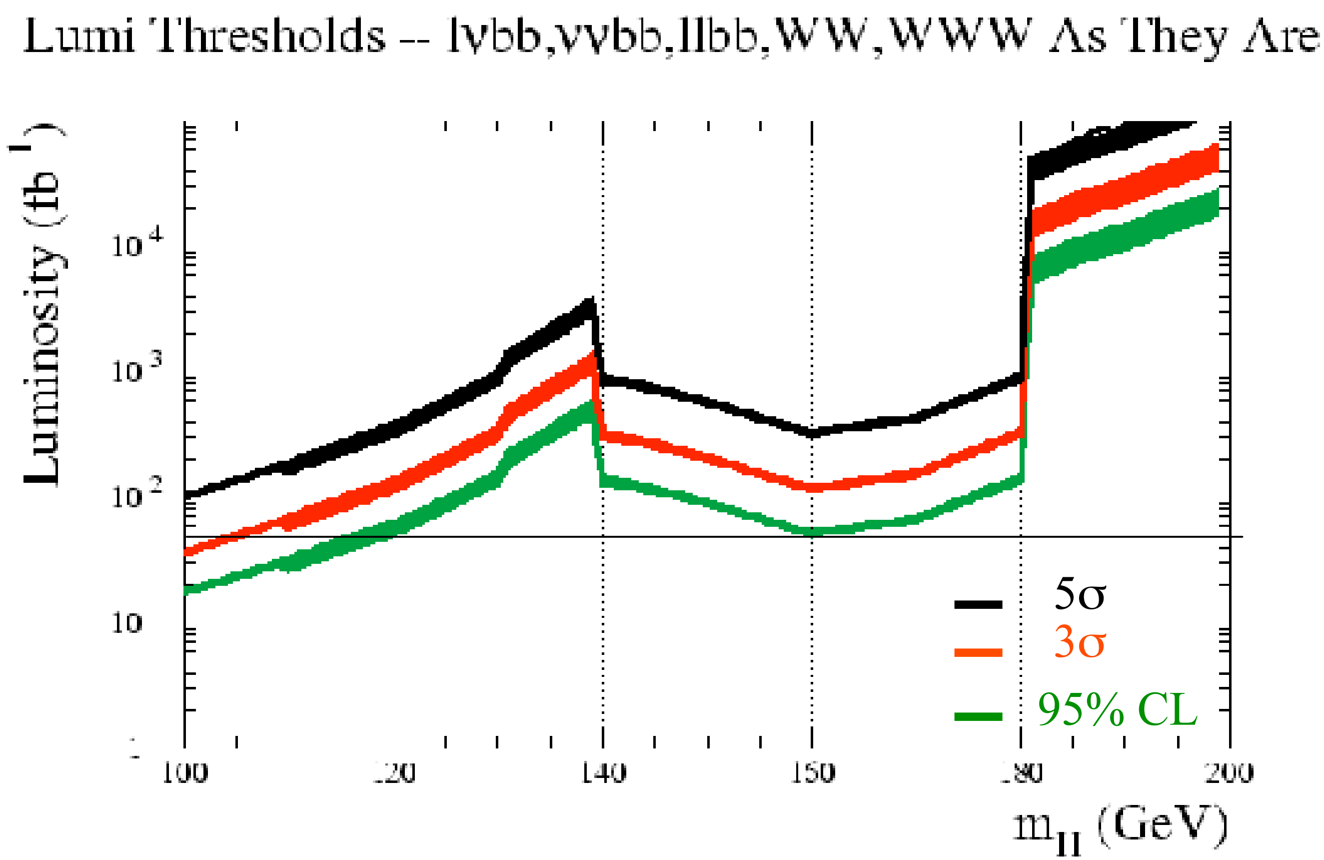
Cross-Section times branching fraction limit as a multple of the SM rate



Luminosity Thresholds for CDF's Channels Combined

Assumption: Systematic errors scale with $1/\sqrt{\int \mathcal{L}dt}$

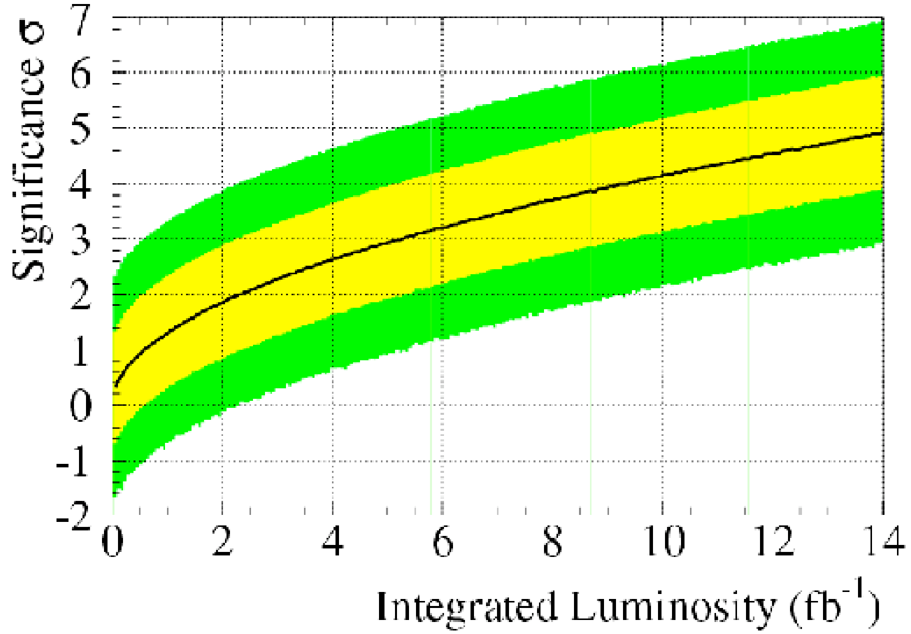
All channel's luminosities scaled to 300 pb^{-1} and then scaled together



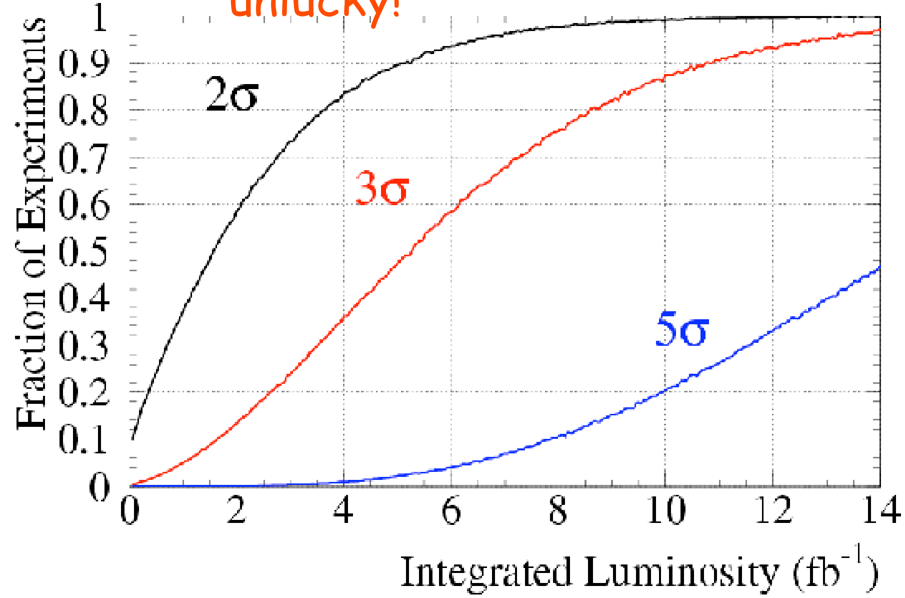
Width of bands given by systematic errors on/off

Expected Signal Significance CDF+DØ vs Luminosity

It's possible to be lucky or unlucky!



per experiment



per experiment

m_H=115 GeV assumed

CDF sees Z→bb decays in Run 2

Double b-tagged events with no extra jets and a back-to-back topology are the signal-enriched sample: E_t^3<10 GeV, $\Delta\Phi_{12}$>3

Among 85,784 selected events CDF finds 3400±500 Z→bb decays
- signal size ok
- resolution as expected
- jet energy scale ok!

This is a proof that we are in business with small S/N jet resonances!

CDF expects to stringently constrain the b-jet energy scale with this dataset