Searches for non-SM Higgs at the Tevatron

Greg Landsberg BROWN UNIVERSITY

For Andy Haas COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

and the CDF and DØ Collaborations

March 21, 2007

XLII[nd] Rencontres de Moriond
"QCD and High-Energy Hadronic Interactions"

Outline

- Will only cover new results since Moriond 2006
- Tevatron performance and detectors
  - See previous Tevatron talks
- Motivation
- Searches for exotic Higgses
  - Higgs in the 3γ + X final states (0.8 fb^{-1})
- Searches for MSSM-like Higgses
  - b and tau ID
  - 3b/4b final states (0.9 fb^{-1})
  - Di-tau final state (1 fb^{-1})
- Outlook
- Conclusions

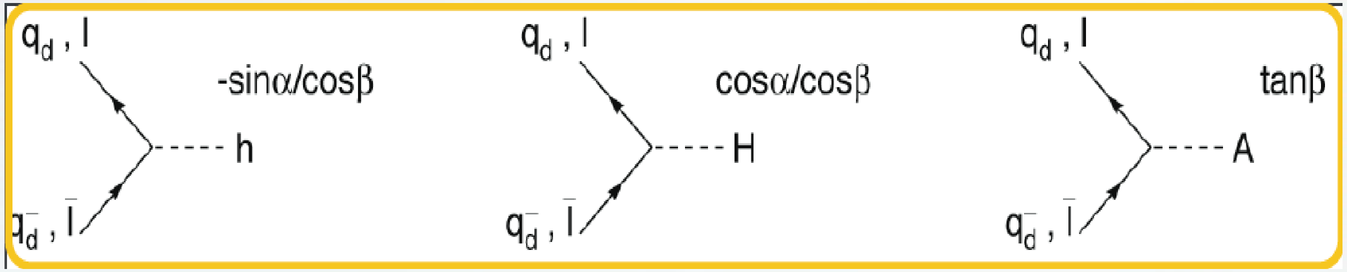
- I'd like to use this opportunity to thank the Moriond'07 organizers for their kind invitation and hospitality
- I'm indebted to the hundredths of my collaborators in CDF and DØ, who worked very hard to produce up-to-date results in several channels covered in this talk
- Special thanks to Gregorio Bernardi, John Conway, Andy Haas, Mark Owen, and Stefan Soldner-Rembold

Higgs Bosons Beyond the SM

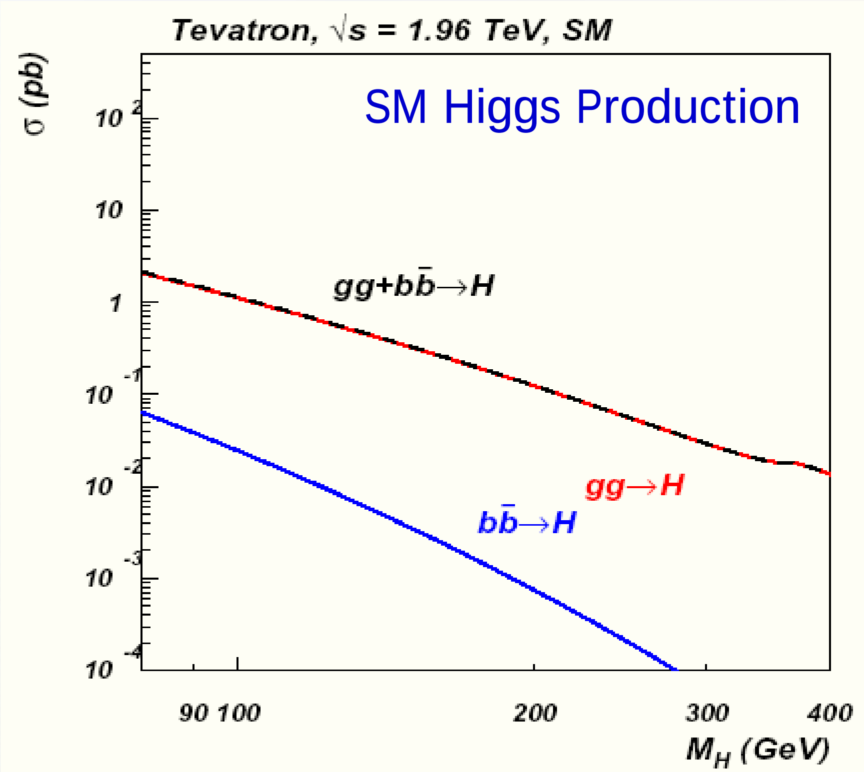
- Standard model is based on a single complex Higgs doublet
  - After EWSB, 4 degrees of freedom became longitudinal modes of W, Z, and a single massive scalar Higgs boson, h
- Nature doesn't have to be that simple; it is natural to expect that up- and down- type quarks receive masses via coupling to different Higgses
  - Generic 2HDM
    - H_u/H_d couple to up- and down-type quarks
    - $\tan\beta$ is the ratio of their vev's
    - After EWSB, four massive scalar (h, H, $H^{\pm}$) and one massive pseudoscalar (A) Higgs bosons
  - Most successful of them is SUSY
    - Explains EWSB, typically via radiative corrections
    - Requires light h: M_h < 135-140 GeV
  - The minimal description, MSSM, is described via a handful of additional parameters: $\tan\beta$, μ, A, and gaugino masses

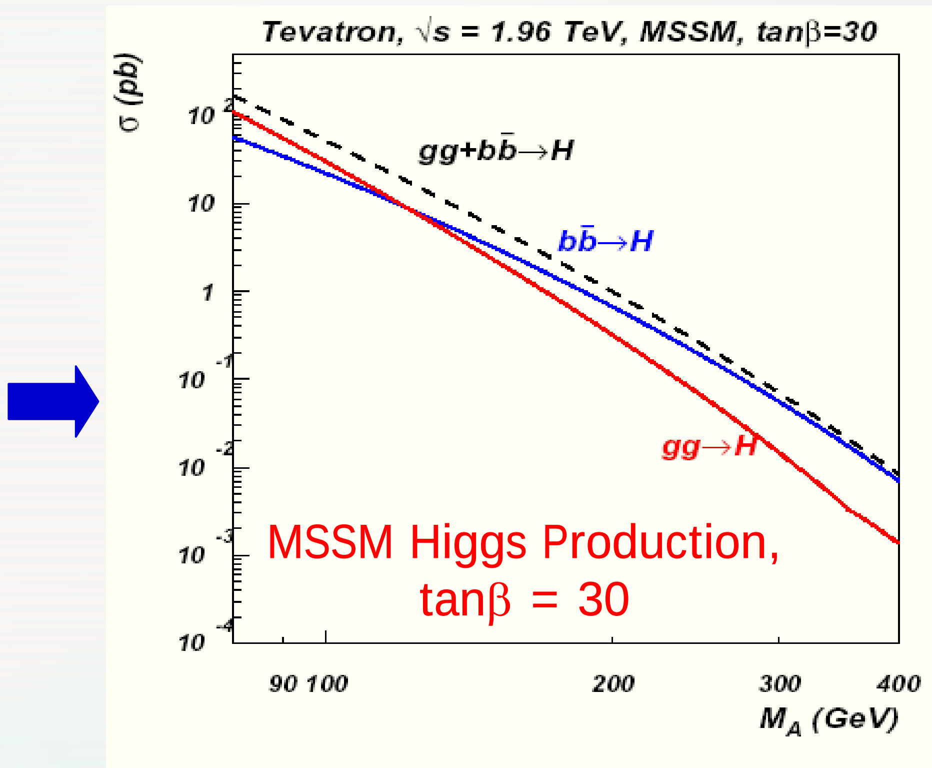
Higgs Bosons in the MSSM, cont'd

- Higgs coupling to the down-type quarks is enhanced as $\tan\beta$

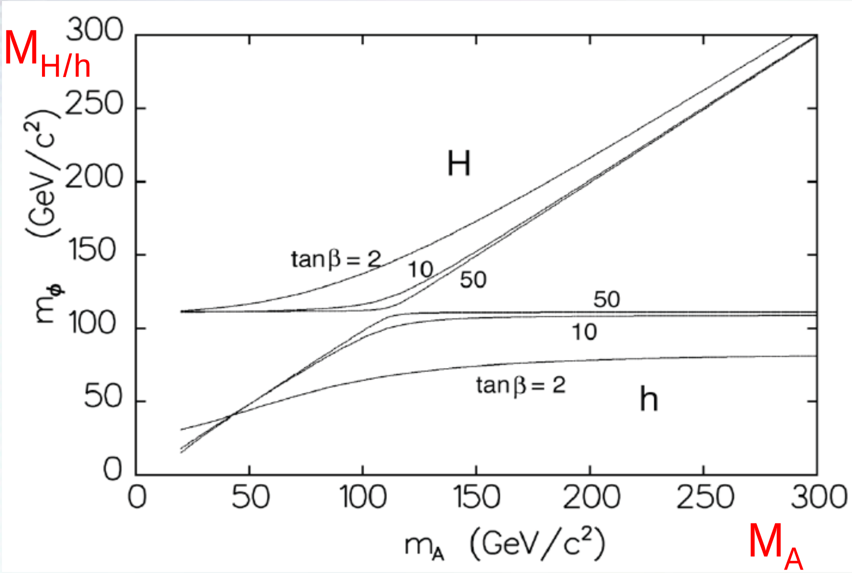


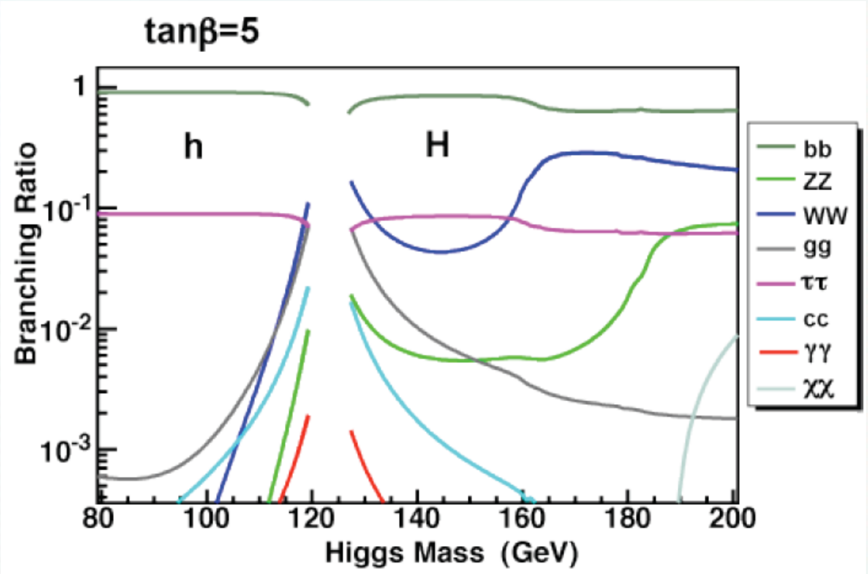
- Amplitude is ~$\tan\beta$, hence the cross section is enhanced as $\tan^2\beta$



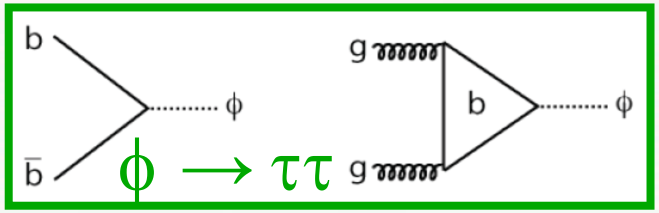


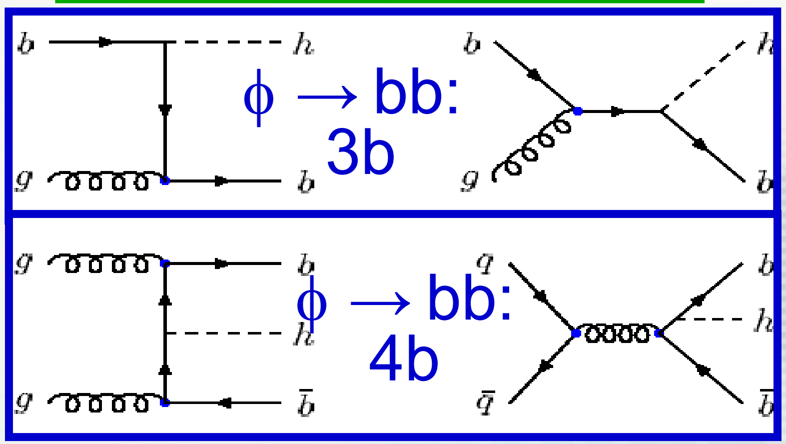
Higgs Bosons in the MSSM, cont'd





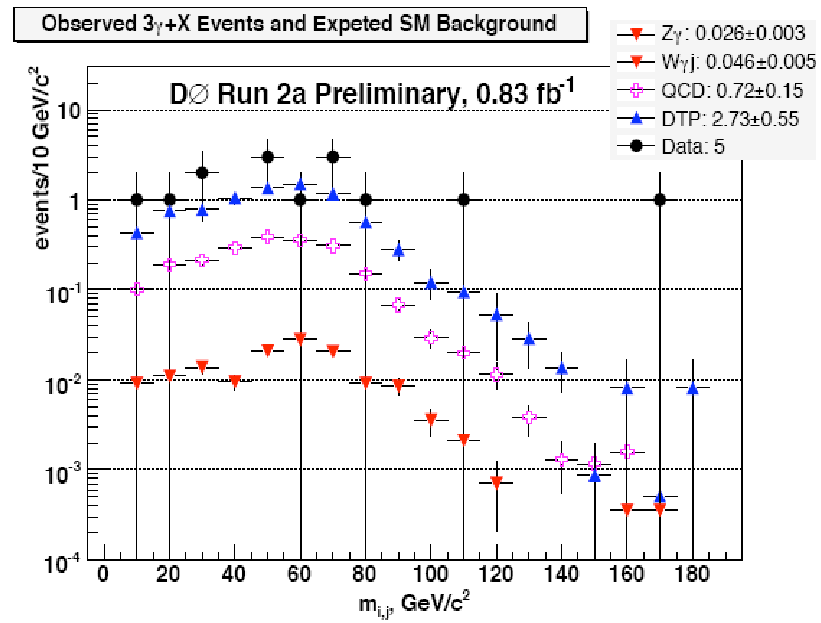
- For large $\tan\beta$, H/h and A (commonly called ϕ) are nearly degenerate in mass
  - Further increase in cross section
- For light and intermediate masses, Br($\phi \to bb$) ~ 90%, Br($\phi \to \tau\tau$) ~ 10%
  - Comparable sensitivities in these two channels as bb requires associated production to cope with backgrounds, leading to 3b and 4b final states





Fermiophobic Higgs in 3γ + X

- In certain 2HDM, couplings of light Higgs to fermions is suppressed
  - Sufficiently light h will decay to $\gamma\gamma$ with ~100% probability
- Explore $hW^{\pm}H^{\pm}$ coupling and look for associated $hH^{\pm}$ production
  - For $\tan\beta > 1$, $M_{H^{\pm}} < 200$ GeV, $M_h < 90$ GeV, $B(h \to \gamma\gamma) \approx 1$ and $B(H^{\pm} \to hW^{\pm}) \approx 1$
  - $p\bar{p} \to h_f H^{\pm} \to h_f h_f W^{\pm} \to \gamma\gamma(\gamma) + X$
- Experimentally look for 3γ + X to increase the acceptance
  - Require $\geq 3\gamma$, $E_T > 30, 20, 15$ GeV
  - Main background: direct triple photon production
  - Estimate from MC, corrected for the ratio of direct diphotons in the data vs. MC: 2.73 ± 0.55 events
  - Misidentified jets: 0.72± 0.15 events
  - Total bck: 3.5 ± 0.6 events
  - 5 events seen in data

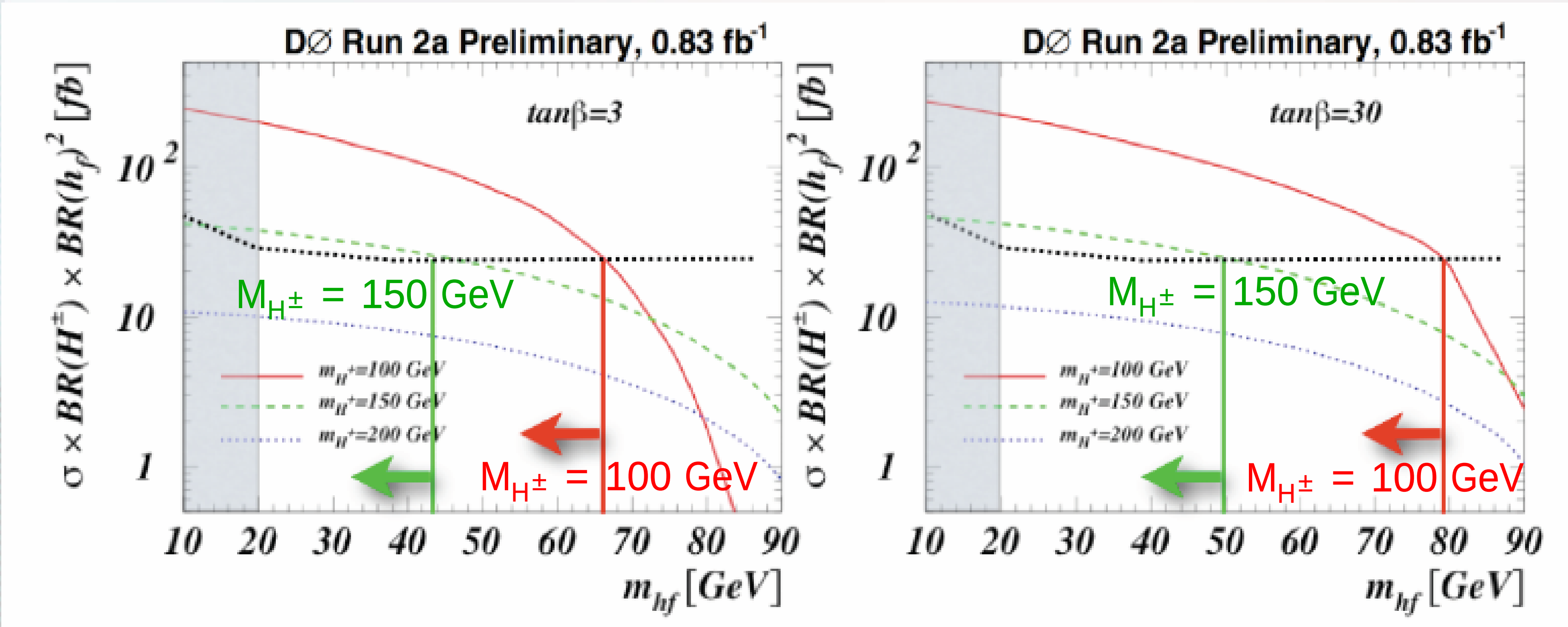


$M(\gamma_i\gamma_j)$ pair masses: 3 entries/event

- No obvious structure in the diphoton mass spectrum
- Further optimize against the QCD background by requiring $p_T(3\gamma) > 25$ GeV
- Observe 0 events with 1.1 ± 0.2 background events expected
- Corresponds to $\sigma(hH^{\pm}) < 25.3$ fb (95% CL)

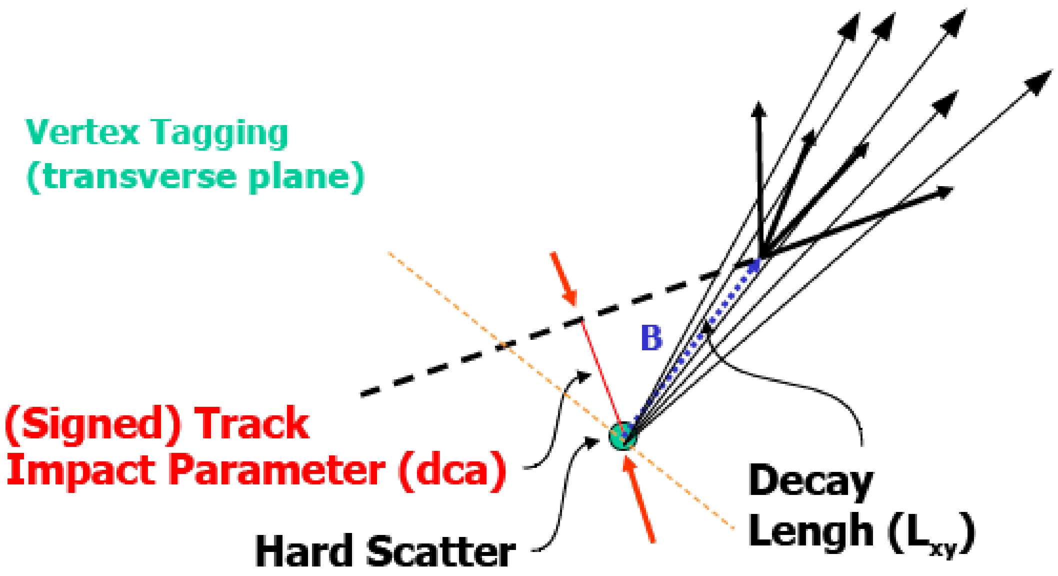
Fermiophobic Higgs Limits

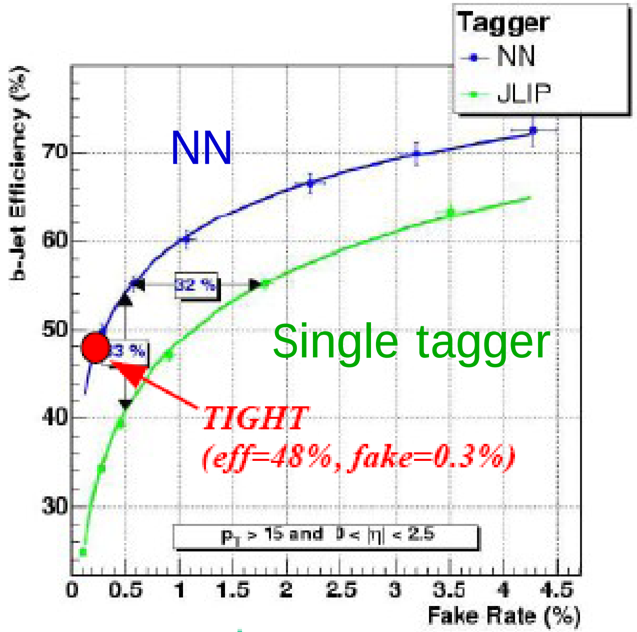
- Limits presented as exclusion in the fermiophobic Higgs mass m_h for several charged Higgs masses ($M_{H^\pm}$) and values of $\tan\beta$
- Sensitivity depends strongly on $M_{H^\pm}$ and rather weakly on $\tan\beta$
- Fermiophobic Higgs masses as large as 80 GeV are excluded for $M_{H^\pm}$ = 100 GeV and large $\tan\beta$



DØ b-tagging Performance

b-Jet Tagging





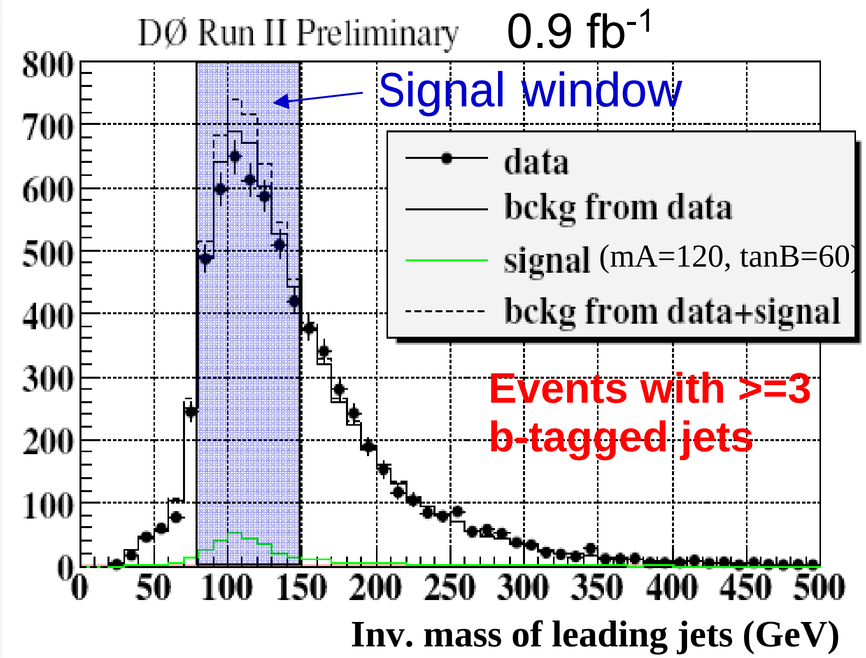
Combine in Neural Network:
- vertex mass
- vertex number of tracks
- vertex decay length significance
- chi2/DOF of vertex
- number of vertices
- two methods of combined track impact parameter significances

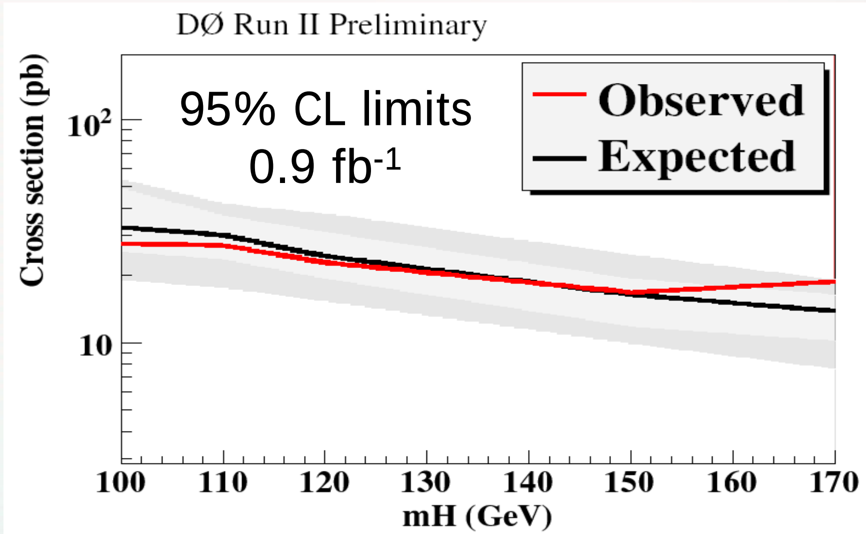
Several mature algorithms used:

3 main categories:
- Soft-lepton tagging
- Impact Parameter based
- Secondary Vertex reconstruction

H/A(→bb)+b[b]→bbb[b] Search

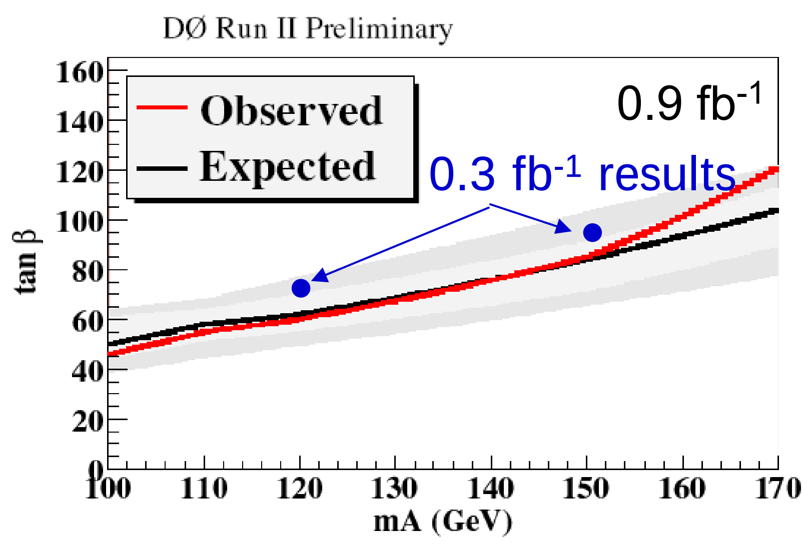
- Br(H/A → bb) ≈ 90% at high tanβ
- H/A → bb swamped by QCD bckg
- Look for associated b and H/A → bb
- ≥3 b-tagged jets with p_T > 40, 25, 15 GeV
- Signal: invariant mass of two leading jets peaks at M_A
- Backgrounds (from data):
  - Shape is from the double-b-tagged data sample (taking into account kinematic bias from the 3rd b-tag)
  - Size is normalized outside the “signal region” (for each point in M_A and tanβ plane)
- Good agreement between predicted background and the data: proceed w/ cross section limits (via CL_s method)

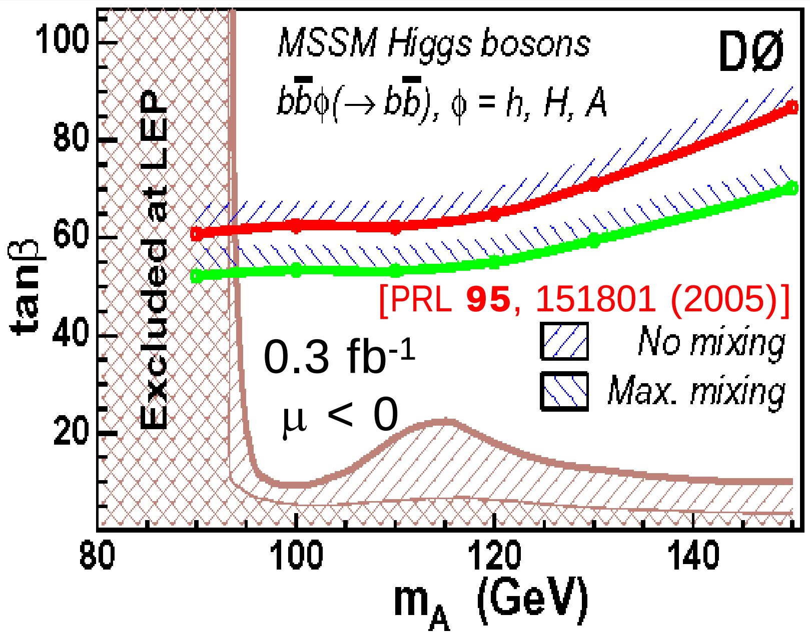




H/A(→bb) Limits

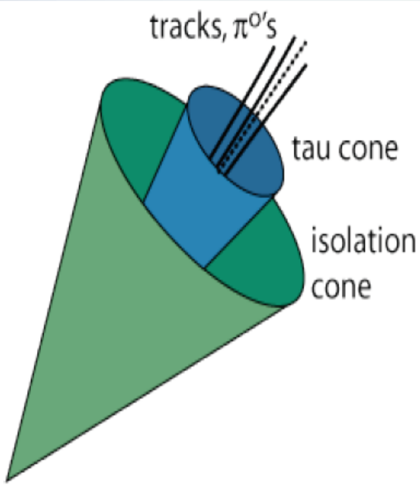
- Interpret these limits as upper tanβ limits for various Higgs masses
  - These limits are obtained using tree-level cross sections, w/o NLO and stop mixing effects – not directly comparable with published 0.3 fb^{-1} result
  - Cuts used for this preliminary result are not as well optimized as the ones for the published one
  - Moderate (~15%) improvement over the published limit is observed
- Already reaching sensitivity down to the "golden" value of $\tan\beta = M_t/M_b(M_Z) \sim 45$
- Maximum sensitivity expected for negative μ and maximum mixing in the stop sector ($X_t = \sqrt{6}M_{SUSY}$) [rather than in the no-mixing, $X_t = 0$] scenario

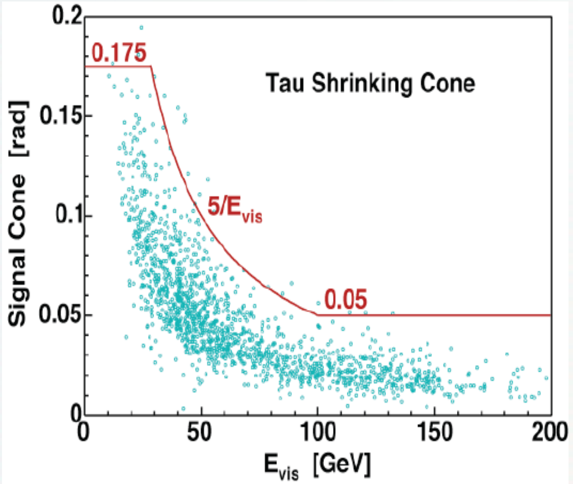




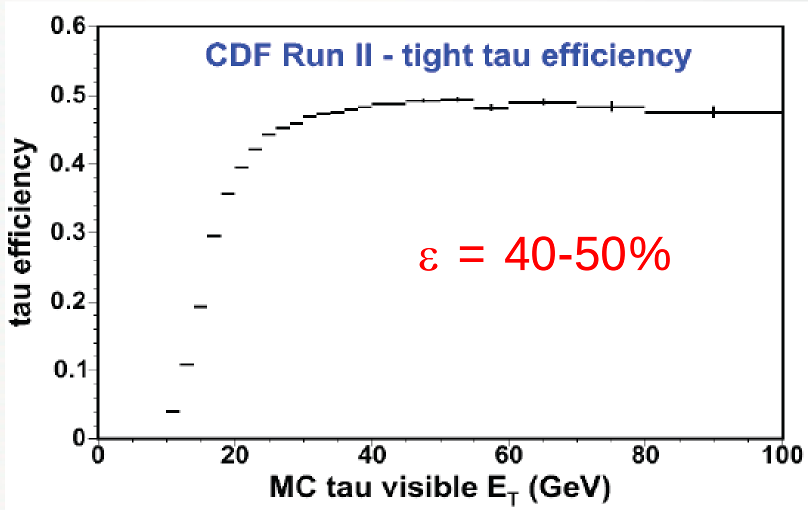
Tau ID at the Tevatron

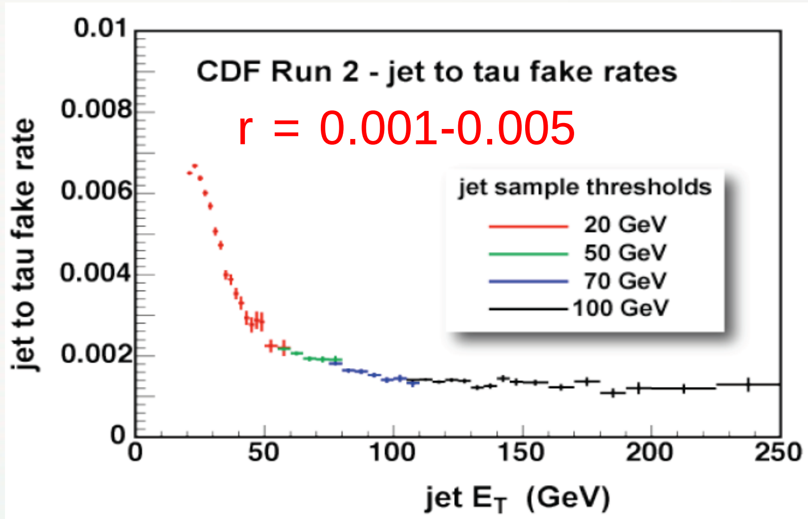
- Variable-size isolation cone:





- Performance:

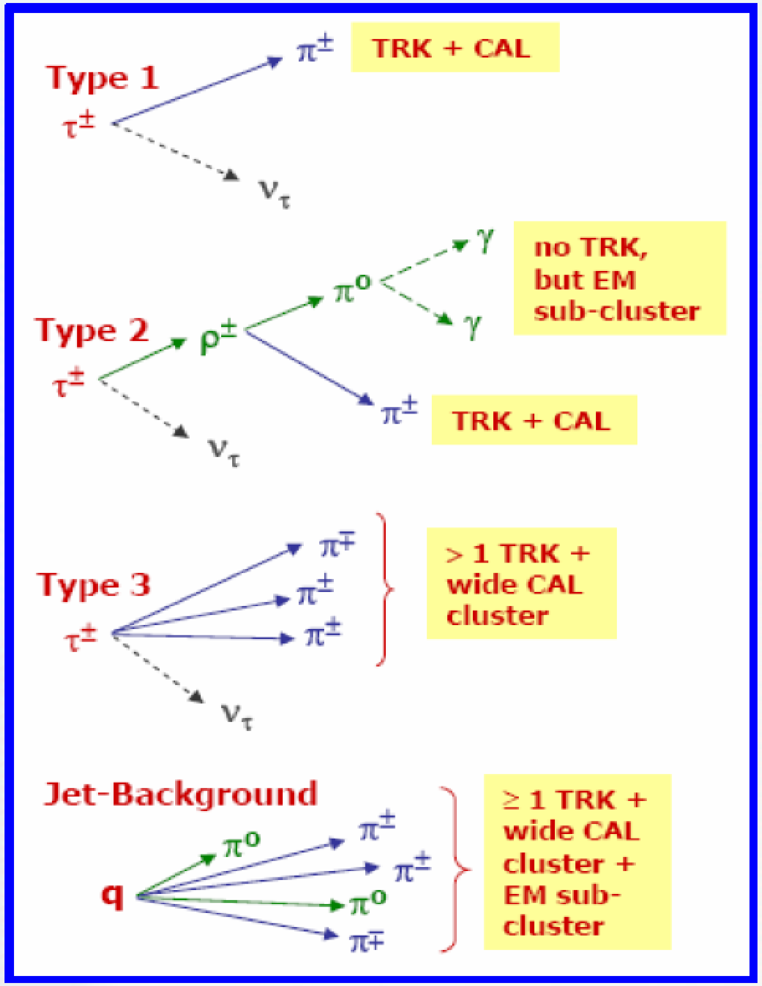




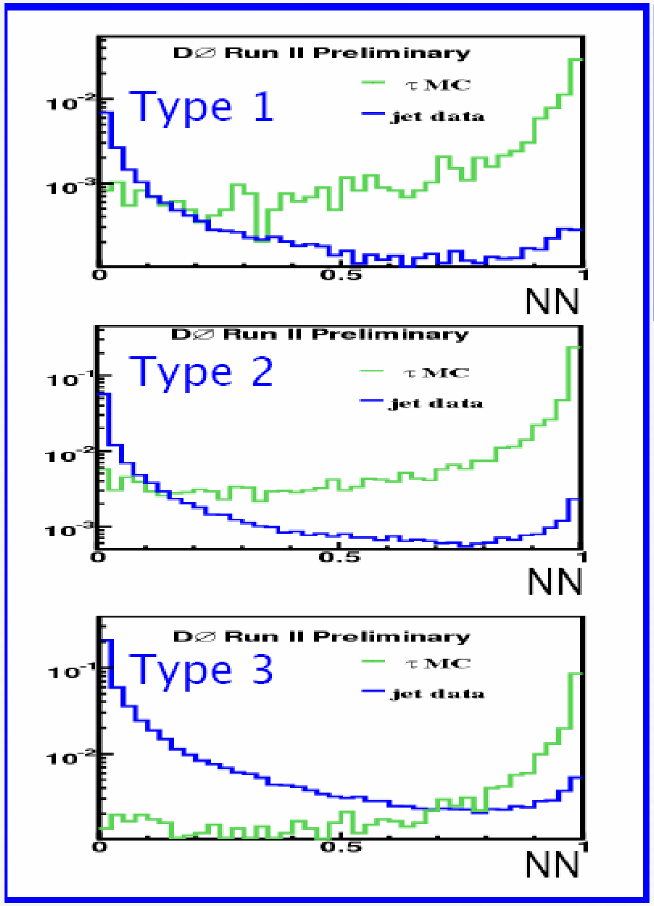
- Require one or three tracks with p_T > 1 GeV in the isolation cone
  - For three tracks the total charge must be ±1
  - p_T^{had} > 15 (20) GeV for 1 (3) prongs
  - M^{had} < 1.8 (2.2) GeV
- Reject electrons via E/p cut
- Validated via W/Z measurements

Tau ID at the Tevatron, cont'd

- Neural-net based ID
- 3 NN's for three distinct τ types:



- Performance (for p_T > 15 GeV):



Tau Type	1	2	3
Reconstruction			
Jets	1.5	10	38
Taus	9.1	50	20
NN > 0.9			
Jets	0.04	0.2	0.8
Taus	5.8	37	13

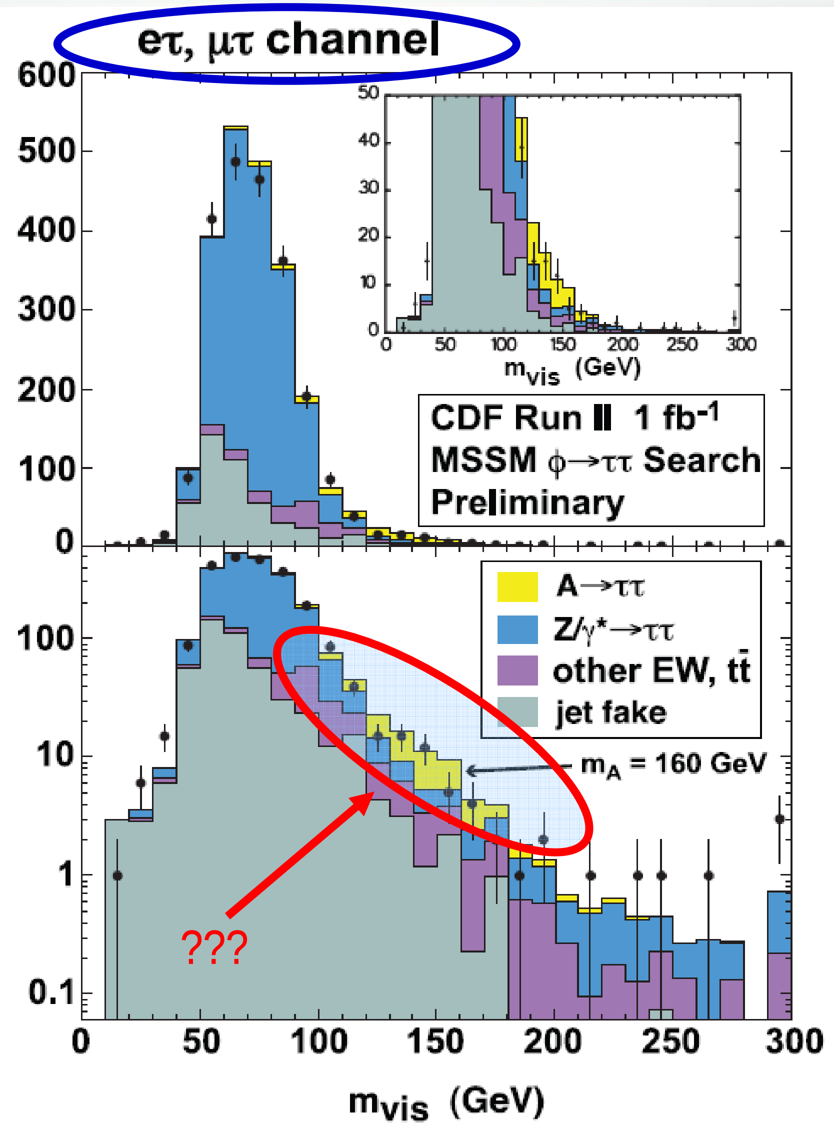
- Validated with the Z's (the first Tevatron Run II Z cross section measurement)

MSSM Higgs in the ττ channel

- Complementary to the $\phi(\rightarrow bb)$ searches: higher sensitivity for $\mu > 0$
- Lower branching fraction but lower backgrounds
- The only channel that allows for the Higgs spin determination
- New CDF analysis with 1 fb^{-1}
  - –e+h, μ+h, e+μ channels
  - –Jet background is suppressed by requiring H_T > 55 GeV
  - –W-background is removed by cutting on the MET projection on the bisector of the two taus

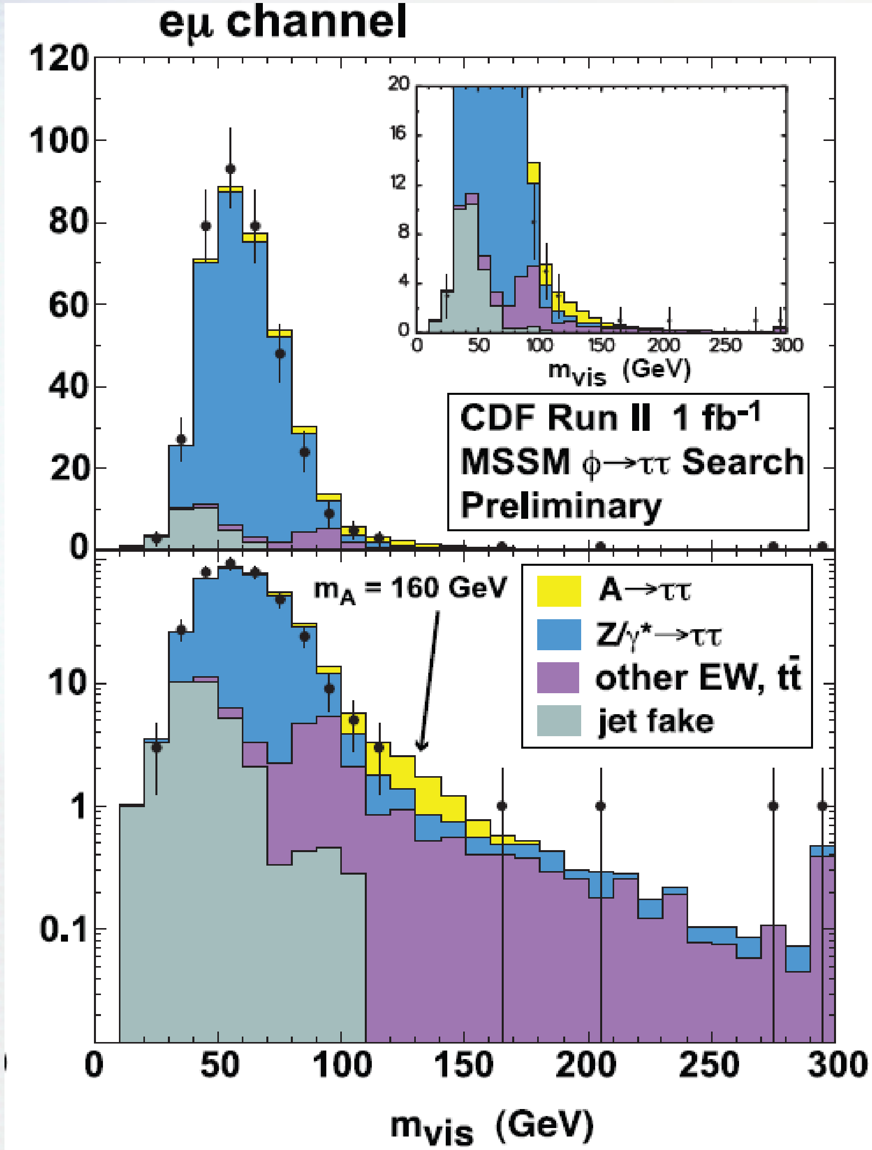
source	$\tau_e\tau_{had}$	$\tau_\mu\tau_{had}$	$\tau_e\tau_\mu$
$Z \to \tau\tau$	793.0 ± 4.7	796.6 ± 4.6	312.4 ± 2.9
$Z \to ee, \mu\mu$	68.3 ± 1.9	63.2 ± 1.8	11.9 ± 0.8
di-boson events	1.5 ± 0.02	1.2 ± 0.02	6.1 ± 0.1
$t\bar{t}$	1.3 ± 0.03	1.1 ± 0.03	4.7 ± 0.07
jet fakes	331.7 ± 18.2	139.4 ± 11.4	33.5 ± 3.2
Sum BG	1195.9 ± 18.9	1001.5 ± 12.5	368.6 ± 4.4
DATA	1215	1000	374

- Combined efficiency: 1 – 3%

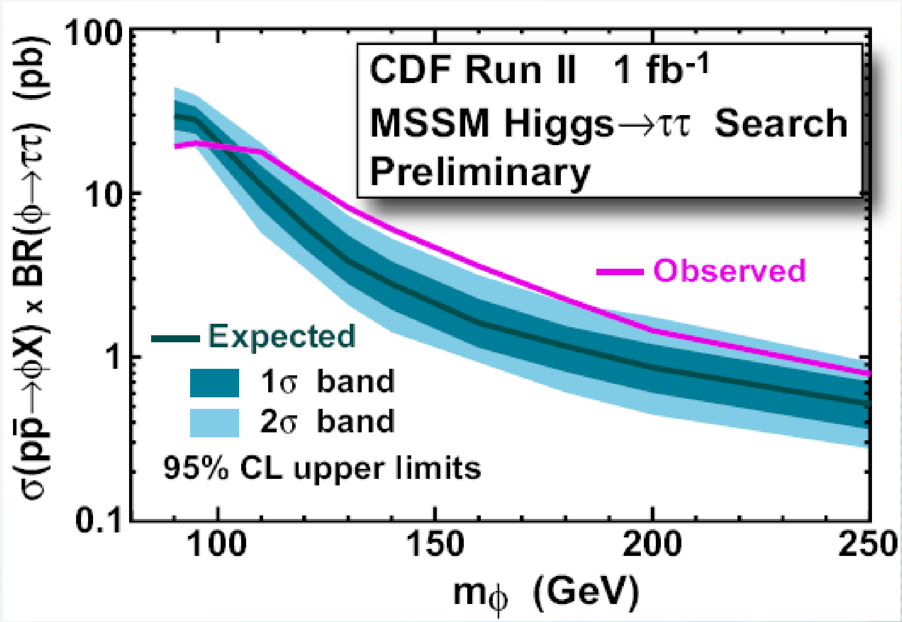


CDF $\phi(\rightarrow\tau\tau)$, cont'd

- Inconclusive plot in the eμ channel:

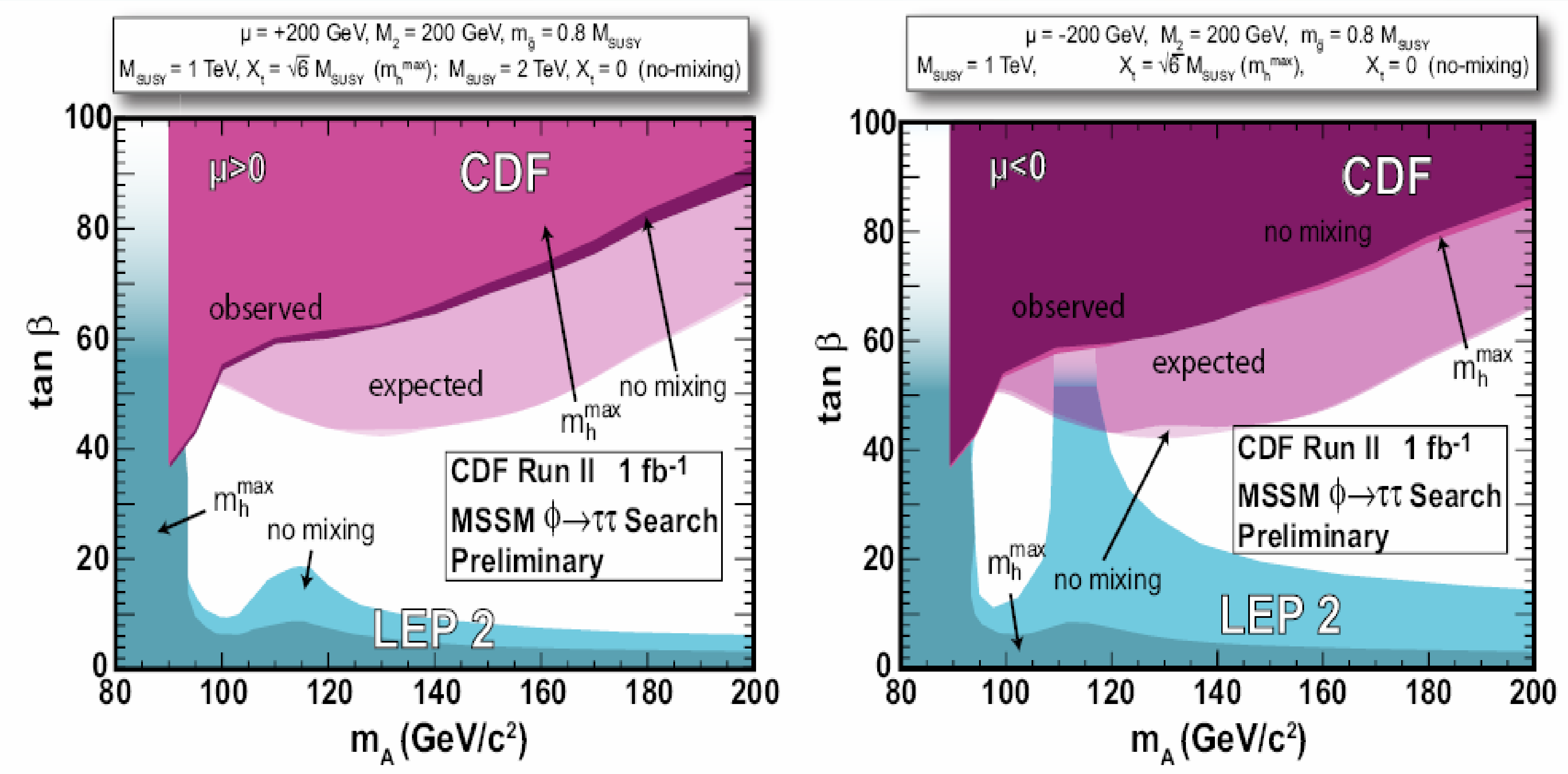


- Best fit corresponds to M_ϕ ~ 160 GeV and σ x Br($\phi \rightarrow \tau\tau$) ~2 pb, i.e. tanβ ~ 50
- While the significance at the best-fit mass exceeds 2σ, careful analysis of all channels and all search windows shows that the overall significance of the excess is less than 2σ
- Proceed with setting limits:



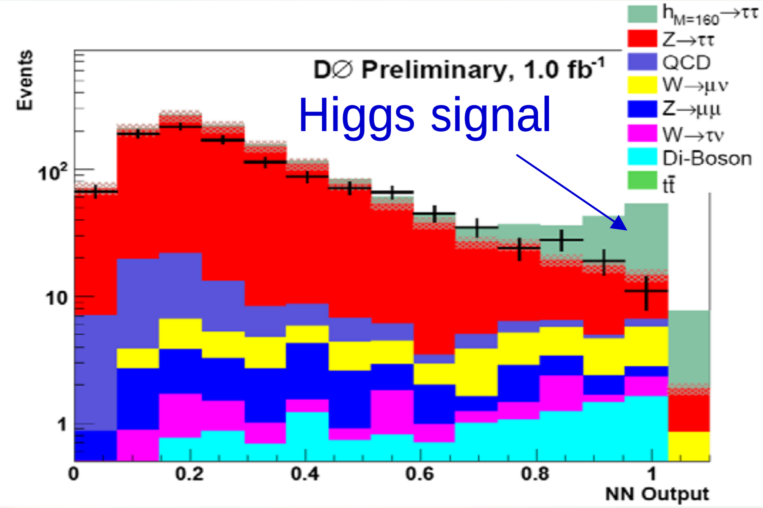
CDF $\phi[\rightarrow\tau\tau]$, cont'd

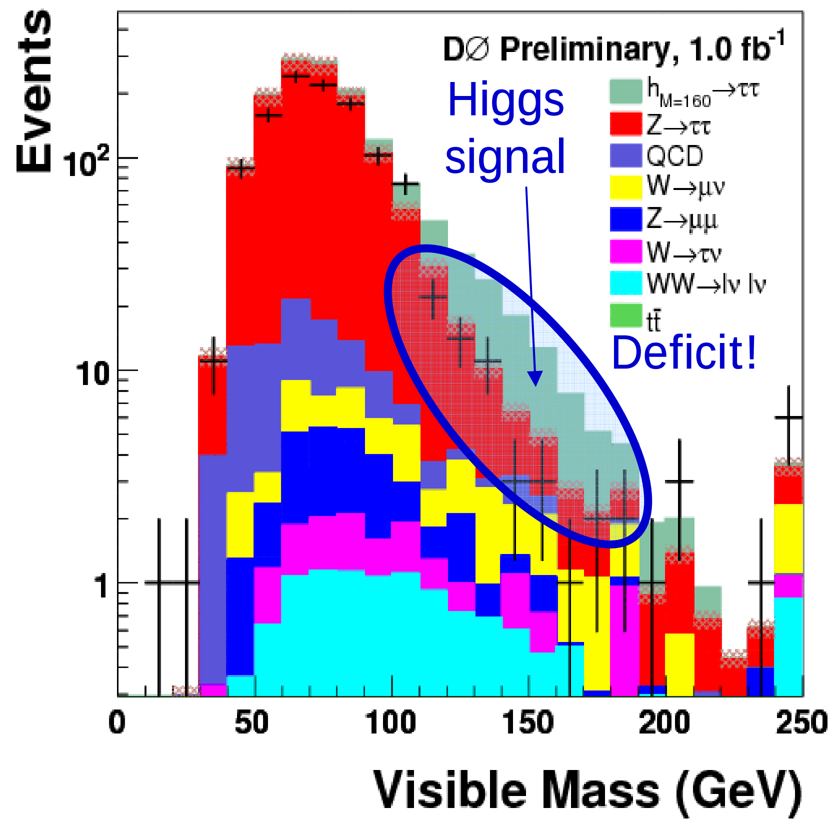
- Further interpret these cross section limits in the MSSM framework:



DØ $\phi[\rightarrow\tau\tau]$

- Given the CDF hint, it is interesting to see what the other Tevatron experiment has to say in this channel
- The analogous DØ analysis in the μ+h channel just became available!
- Also based on 1 fb^{-1} of data
  - Cut on M_W^{vis} < 20 GeV to remove W background $\left[M_W^{vis} = \sqrt{2E_\mu \not{E}_T \frac{p^\mu}{p_T^\mu}(1-\cos\Delta\varphi)} \right]$
  - Mass-dependent NN optimization for signal/ background separation (M^{vis}, μ and τ kinematic parameters)

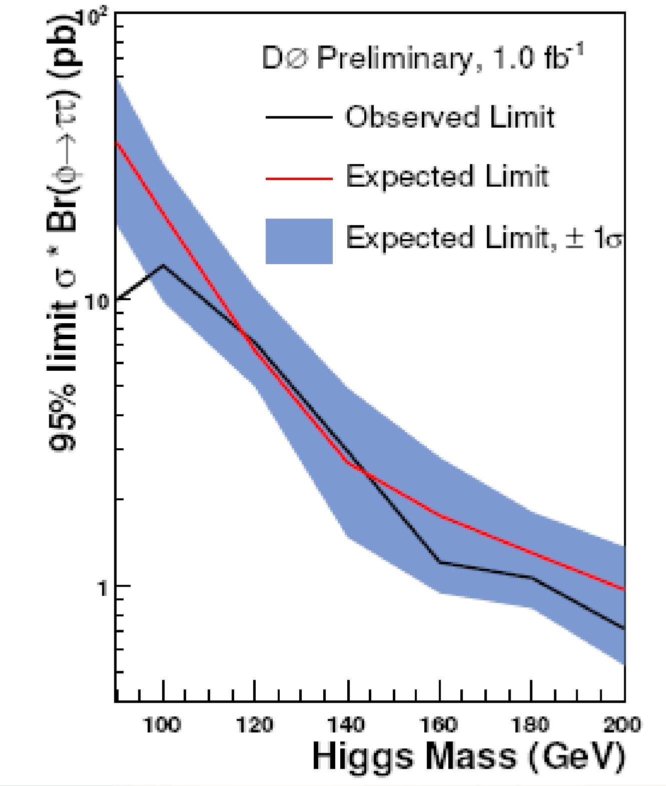


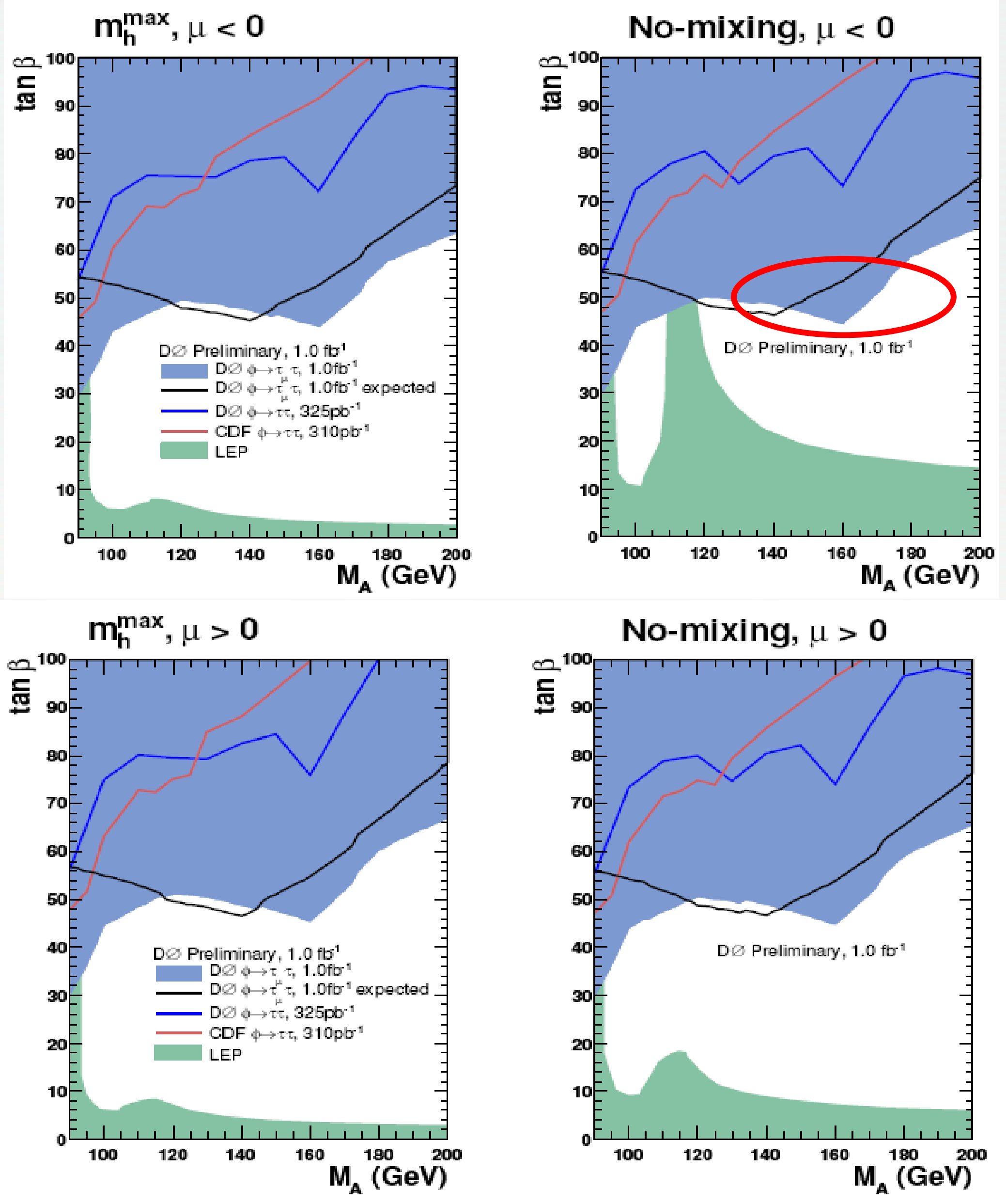


- In the absence of signal evidence, proceed with setting cross section limits on ϕ production (CL_s method) and their MSSM interpretation

DØ φ[→ττ], cont'd

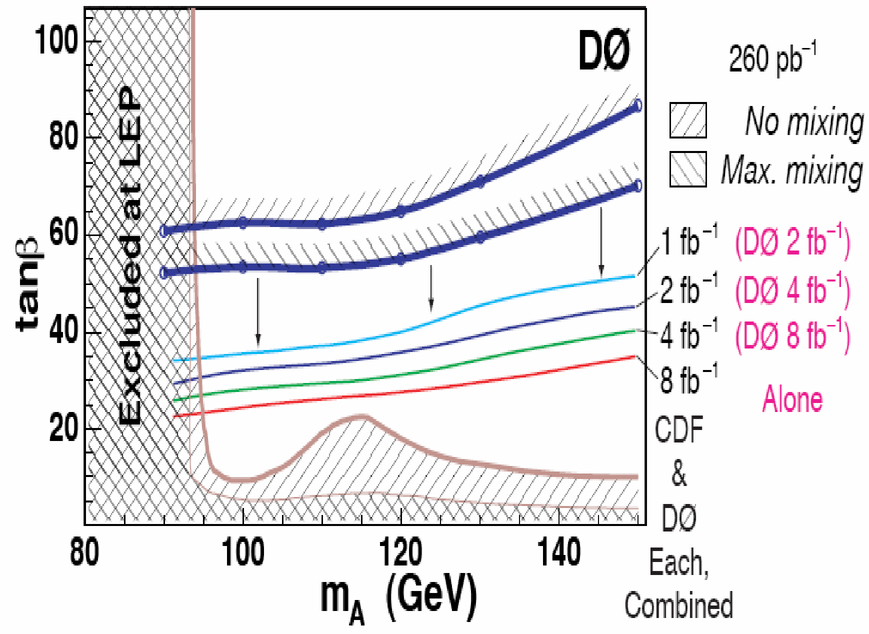
DØ Preliminary, 1 fb^{-1}
95% CL exclusions

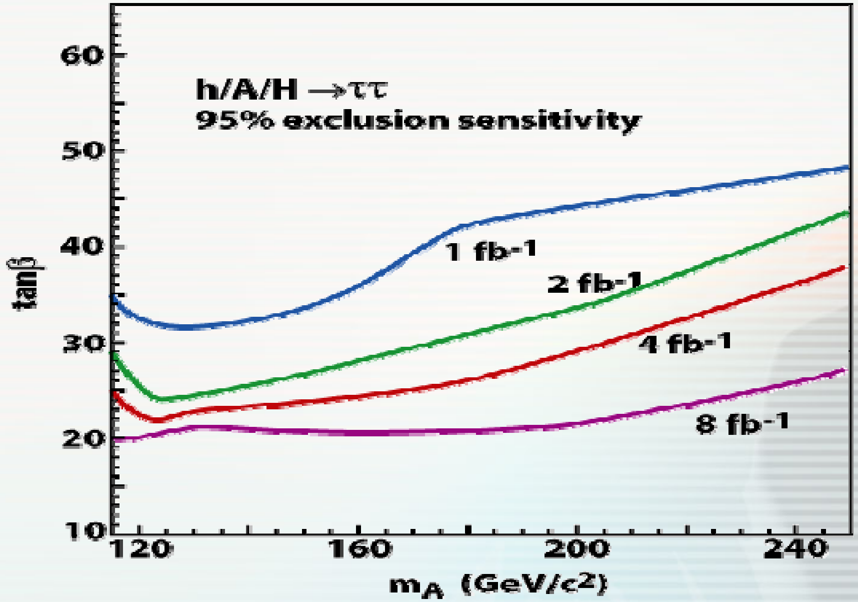




Conclusions and Outlook

- Results from the first ~1 fb^{-1} of Run II data show very promising sensitivity, but no evidence for beyond the SM Higgs
- Expect up to 8 fb^{-1}/exp in Run II
- CDF and DØ will combine $H/A \to \tau\tau$, $b(H/A) \to bbb$, and $b(H/A) \to b\tau\tau$ (not discussed), channels (this summer?)
  - Working group is in place for the combination of DØ and CDF
- By the end of Run II, make a discovery or …
- … exclude:
  - up to m_A ~ 250 GeV for large $\tan\beta$
  - down to $\tan\beta$ ~ 20 for low m_A



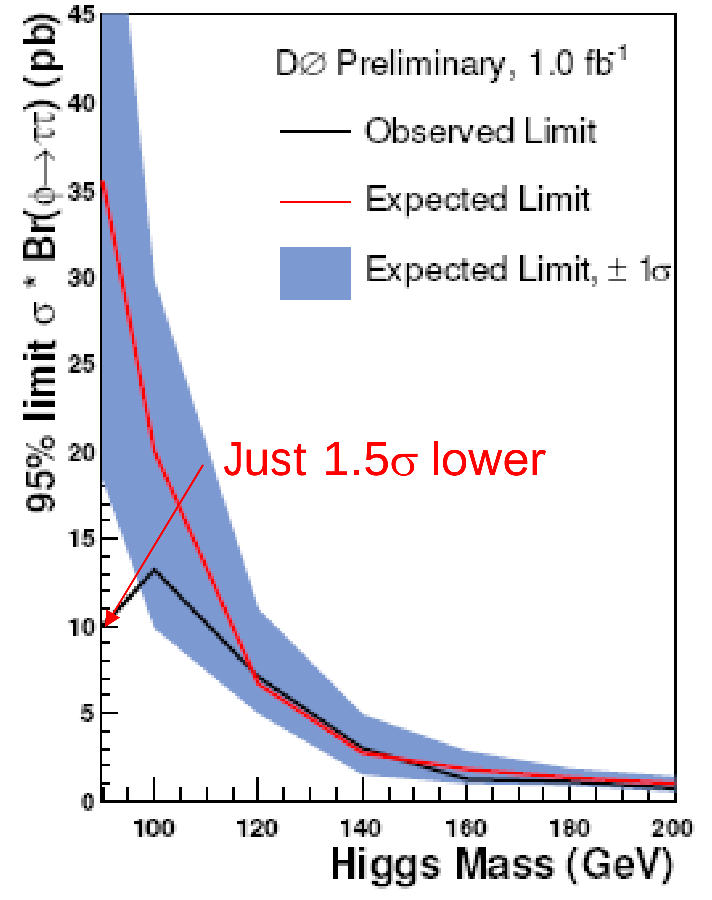


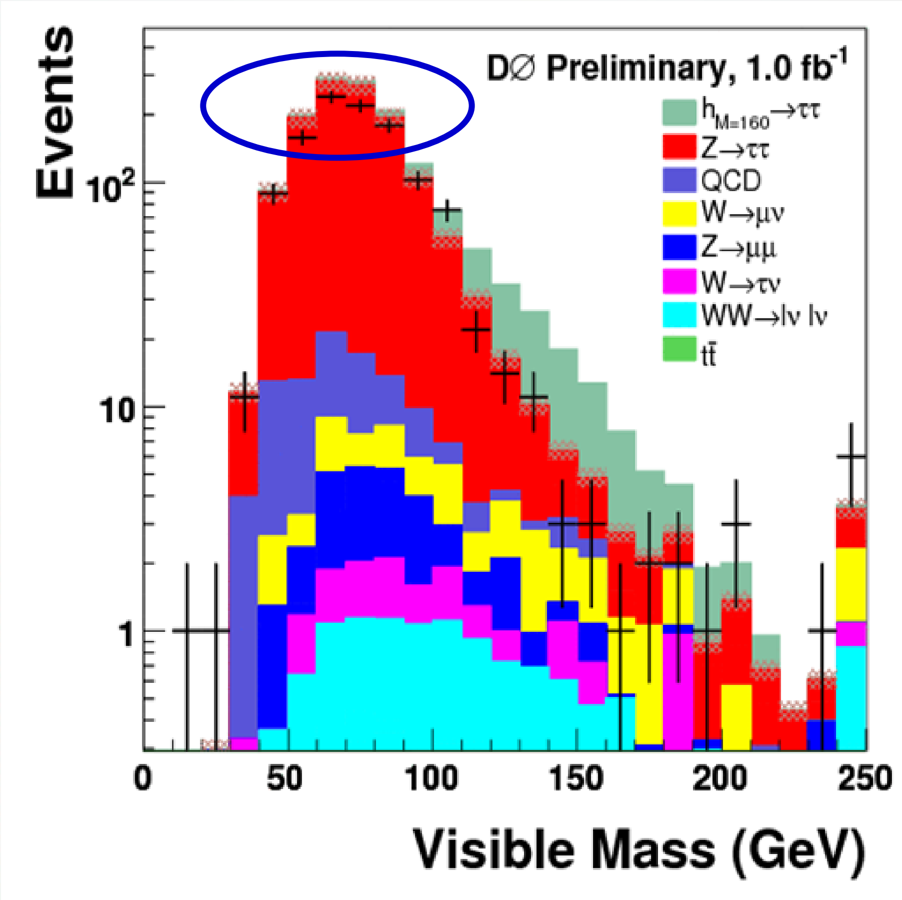
Backup Slides

FAQ #1: Why DØ $\phi(\rightarrow\tau\tau)$ Limit is so good at low masses?

•… theorists often ask us this question…

•The reason is 1.5σ-high predicted $Z(\rightarrow\tau\tau)$ background

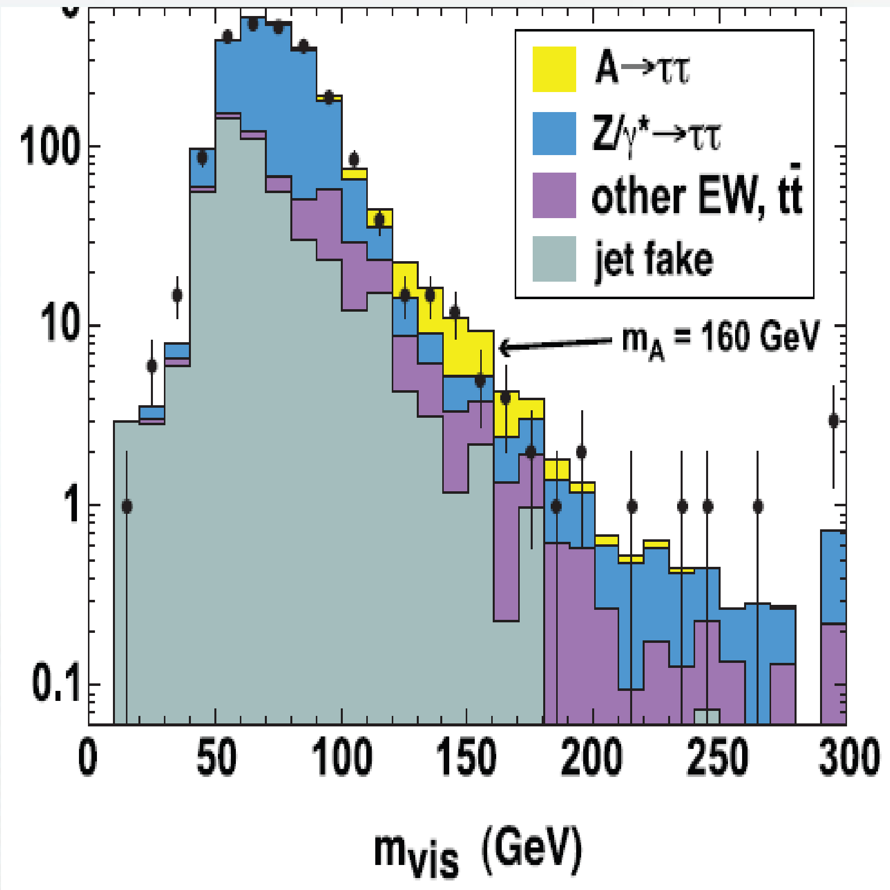


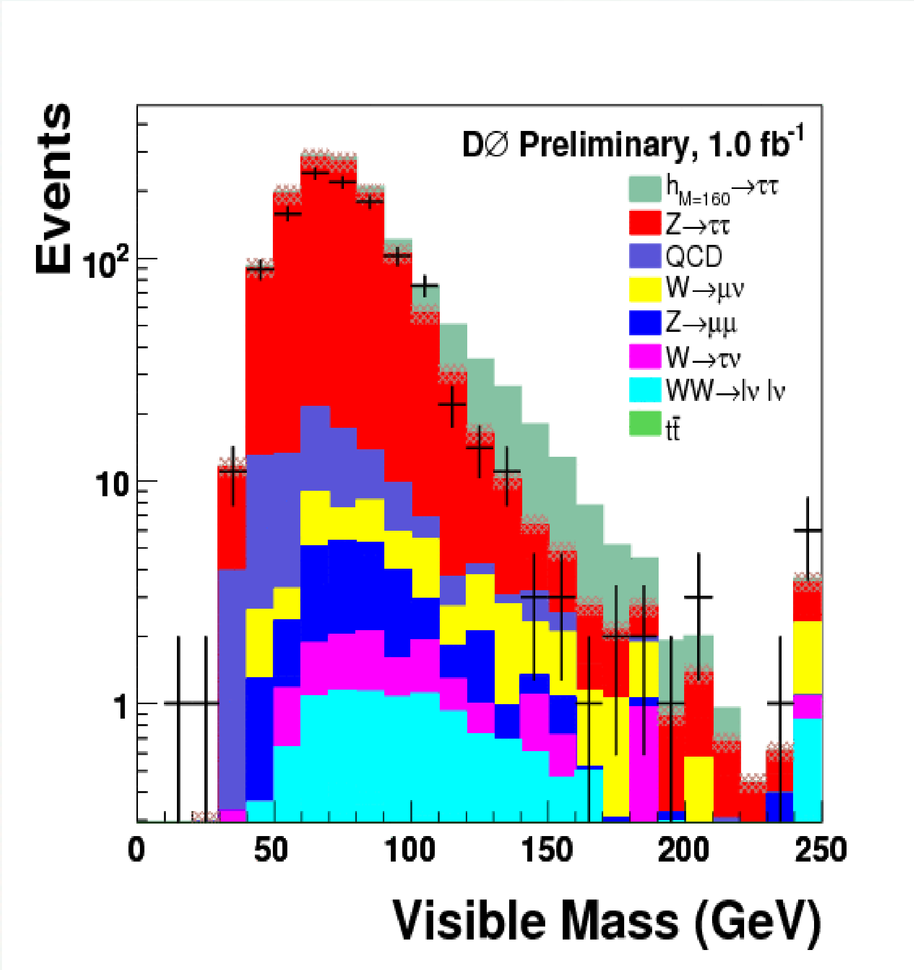


Assume lumi is off by 1σ; limits: 1.2pb → 2.6pb observed, $1.8^{-0.8}_{+1.0}$ pb expected

FAQ #2: Comparison with CDF

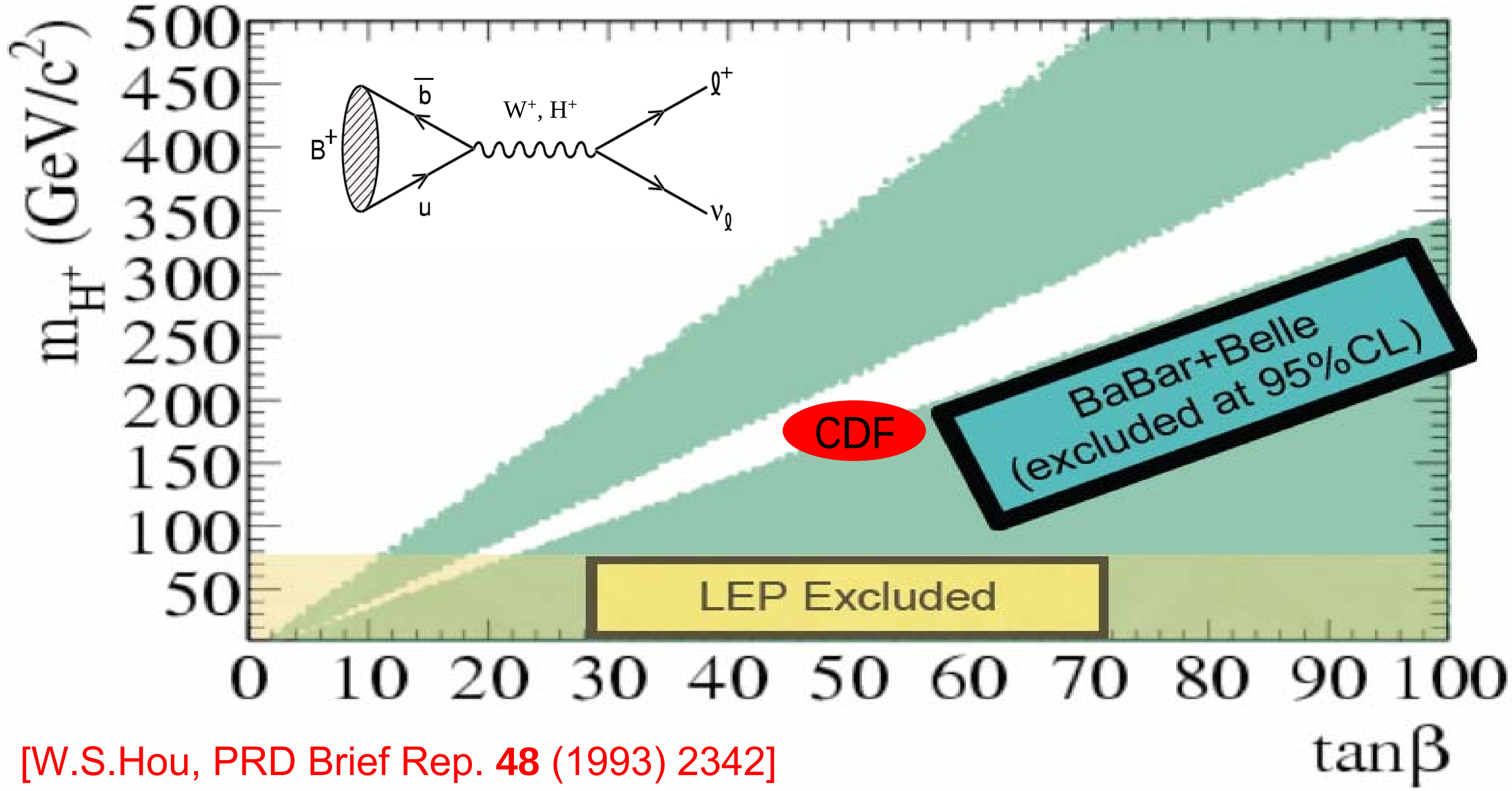
- Clear deficit where CDF sees an excess
- Adding the two experiments together gives perfect agreement





FAQ #3: Is 160 GeV A/H Reasonable?

- Very much so!
- In fact it's a perfect mass from the point of view of theory
  - Almost too good to be true!
  - Was it Jack Gunion who messed with John Conway's root file?
- Also allowed by the BaBar/Belle B $\rightarrow \tau\nu$ analysis:



[W.S.Hou, PRD Brief Rep. **48** (1993) 2342]

FAQ #4: Detector Upgrades

- Limited detector upgrades will help:
  - Trigger (CDF, DØ)
  - Inner silicon replacement (DØ)