Searches For Non-SM Higgs at the Tevatron

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On behalf of the CDF and D0 Collaborations
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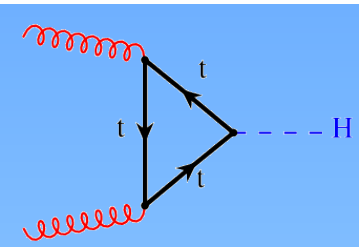
Outline

- Variation on SM search: Fourth Generation and Fermiophobic Higgs
- MSSM Neutral Higgs
- Hidden Valley

H→WW: 4th generation models



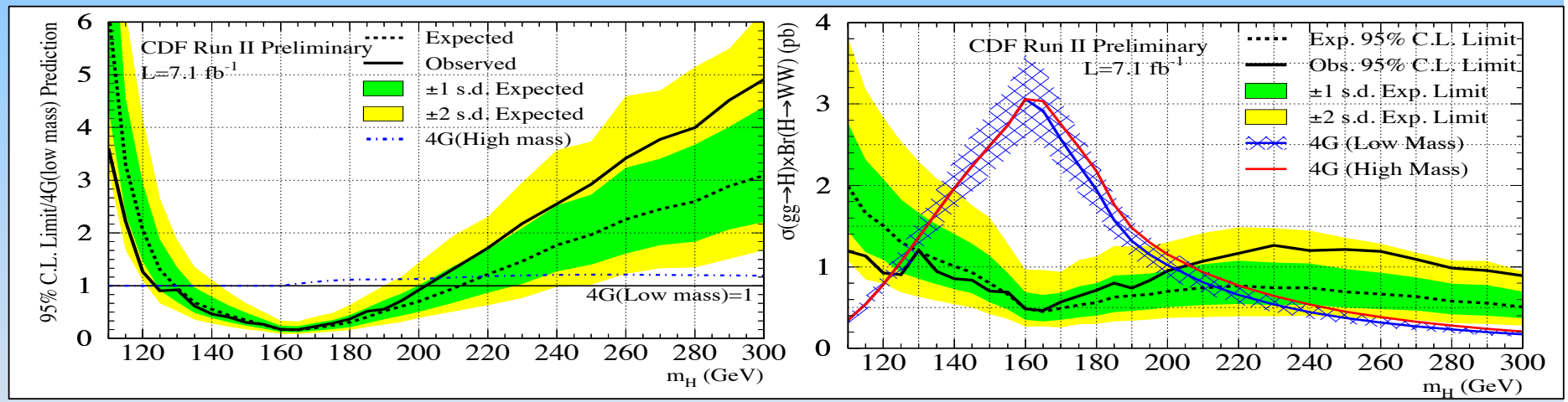
New

4th Generation of Fermions:

- Heavy t' and b' quarks
- Heavy neutrino
- May alter EWK constraints

Gluon Fusion:

- Higgs is production: quark loop
- In SM mostly top contributes
- If 4th Gen exists – enhanced by ~9
- Branching ratios change too



- Exclusion range 123-202 GeV/c^2
- Expected: 129-212 GeV/c^2
- CDF by itself comparable to Tev combination

- Previous results: (GeV/c^2)
  - Expected: 125-218 (CDF+D0), 150-190ish (CMS)
  - Observed: 131-204 (CDF+D0) , 144-207 (CMS)

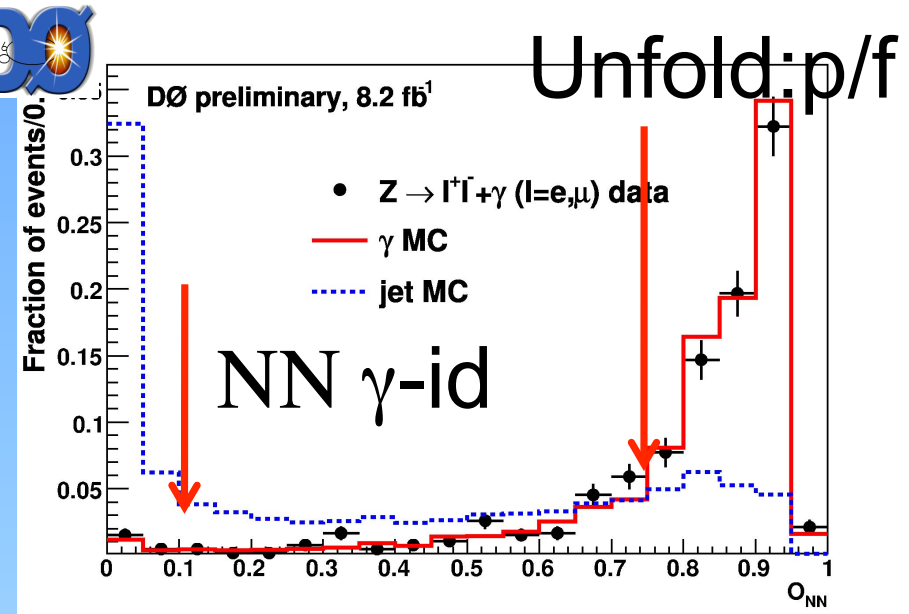
D0 h_f: Fermiophobic Higgs

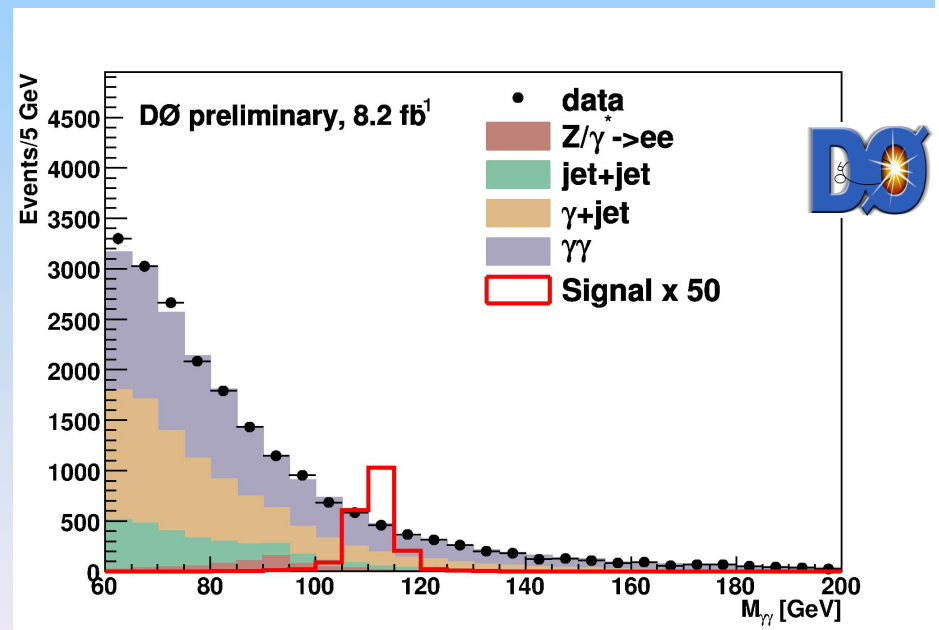
New

Unfold:p/f

- No fermion coupling: WH, ZH, VBF
- BR($h_f \rightarrow \gamma\gamma$)=6.2%, 33xSM, m_{Hf}=110 GeV/c^2
- 2γ E_T>25 GeV, $|\eta|$<1.1, NN-id
- Systematics: ε_γ,ε_j;Lumi, γ-ID, PDF, Track Veto, σ_Z, $\sigma_{\gamma\gamma}$
- BDT; Input: $M_{\gamma\gamma}$, E_{T1}^{γ} , E_{T2}^{γ} , $p_T^{\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$

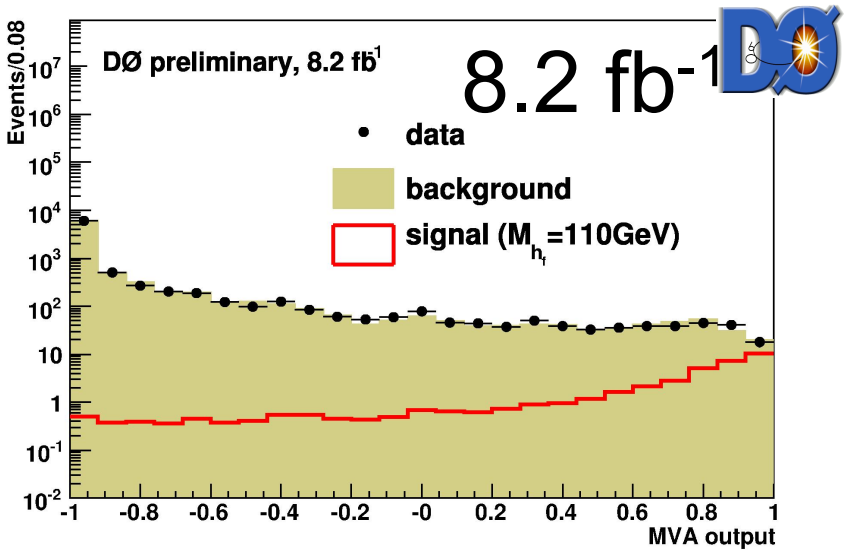
Background	%
$Z/\gamma \rightarrow l^+l^-$	3
$\gamma\gamma$	53
γ – jet	30
jet-jet	14

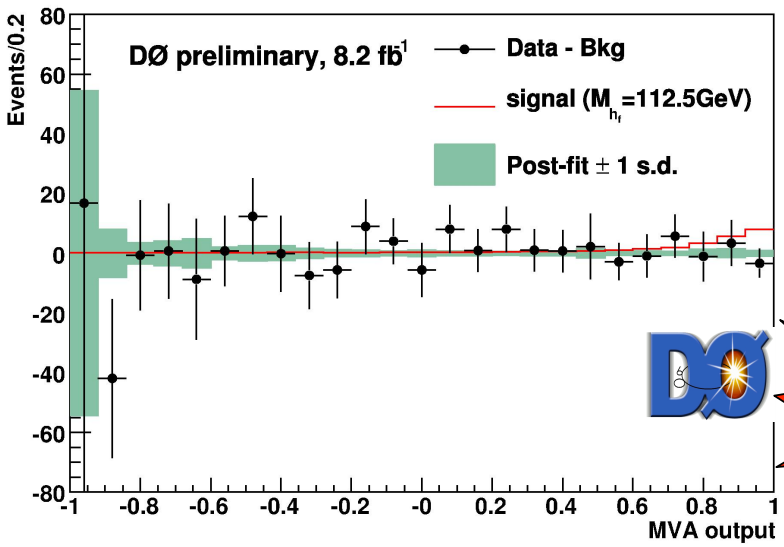




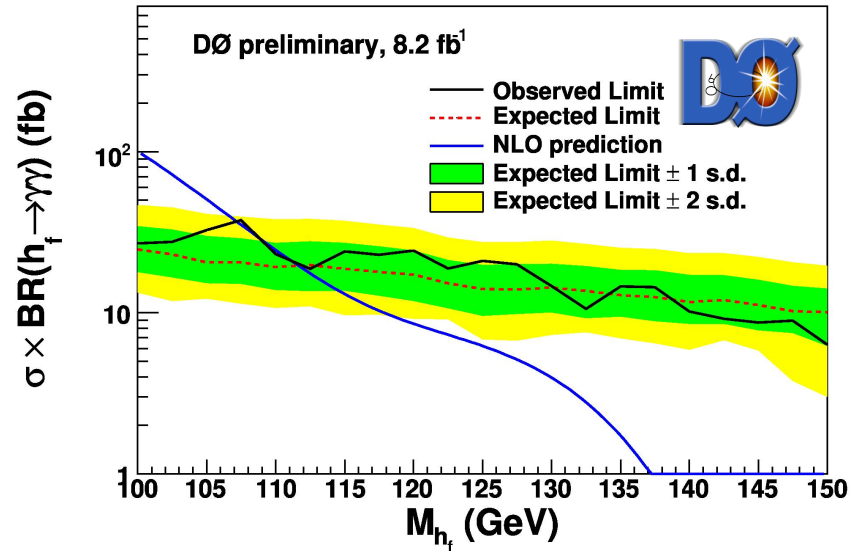
D0: Best h_f Limit, M_H<112 GeV/c^2

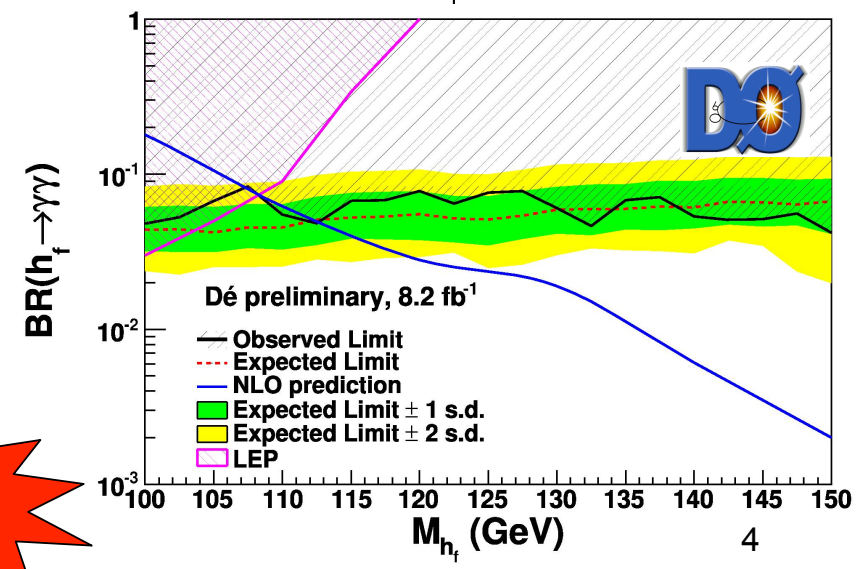
CDF:106 (2.7 fb^{-1}) , D0 102.5 (4.2 fb^{-1}), LEP: ~105/per exp, combined : 109.7 GeV/c^2





New





MSSM SUSY

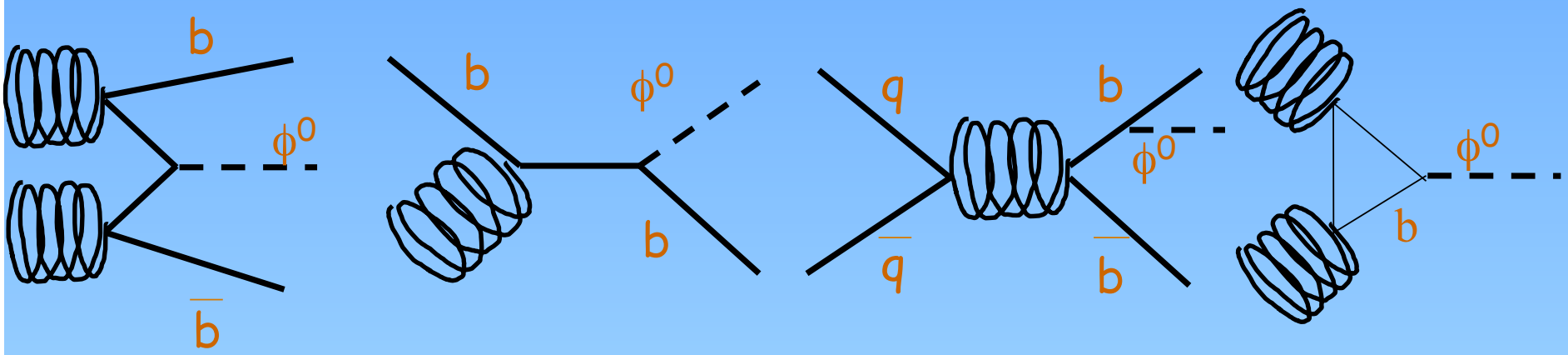
- Two Higgs doublet fields $H_{u,d}$ couple to u- and d-type fermions
- $\tan\beta = \langle H_d \rangle / \langle H_u \rangle$ enhanced
- 5 Higgs Bosons: H^0, h^0, A^0; $H^\pm$

Light	Heavier
SM-Like	Cross section $\tan^2\beta$ enhanced
h^0	"ϕ" $H^0\ A^0$
H^0	$h^0\ A^0$ Degenerate: x2

$M_h < 135\ \mathrm{GeV}/c^2$

$\tan^2\beta = 50^2$ x2=5000: fb → pb!

- Production:



- Decay: $\phi^0 \rightarrow \tau^+\tau^-$ (10%) ,$\phi^0 \rightarrow bb$ (90%)
- Detection:

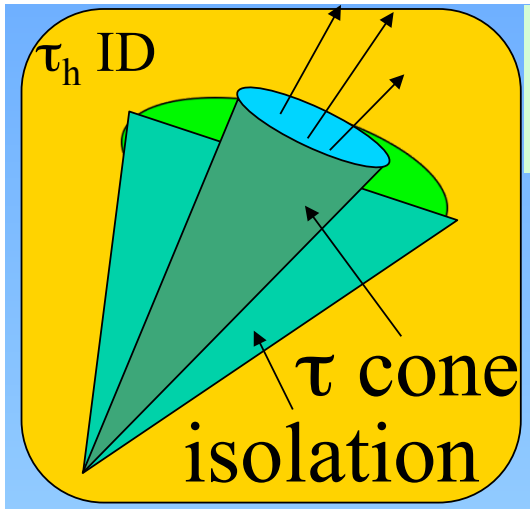
$b+\phi^0 \rightarrow b+bb$: Measure M_{bb} and separate flavor

ϕ^0 (b) $\rightarrow \tau^+\tau^-$(b)+ charge conjugate

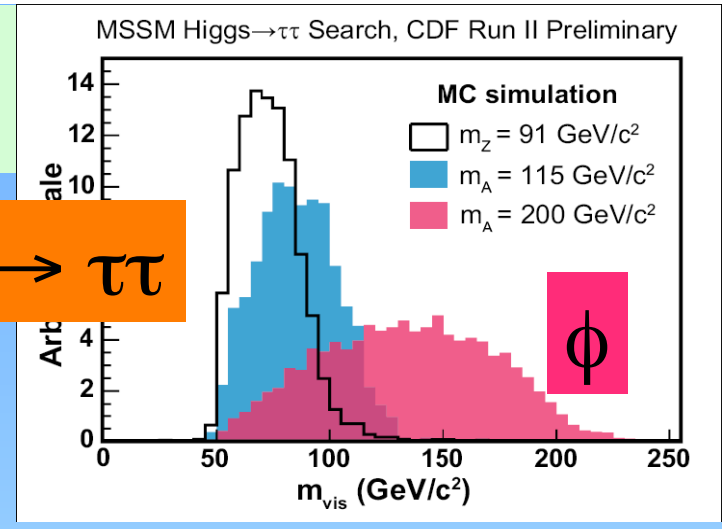
h = hadronic

$\mu^- \bar{\nu}_\mu \bar{\nu}_\tau$	$e^- \bar{\nu}_e \bar{\nu}_\tau$	$\mu^- \bar{\nu}_\mu \bar{\nu}_\tau$
$e^+ \nu_c \nu_\tau$	$h^+ \nu_\tau$	$h^+ \nu_\tau$

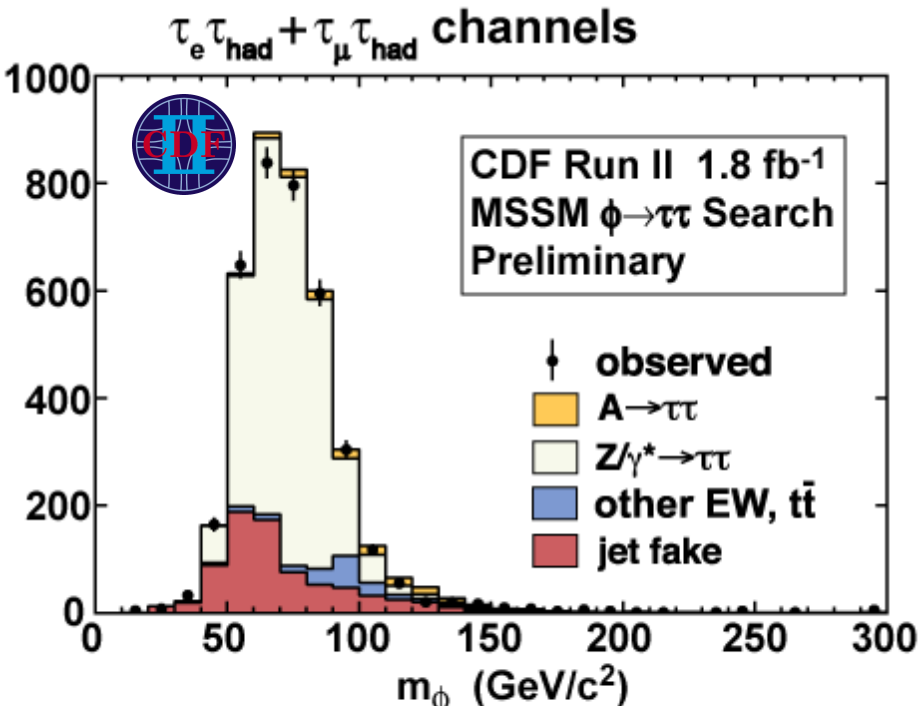
Measure Visible: $M_{e\mu}$ $M_{e\tau_h}$ $M_{\mu\tau_h}$

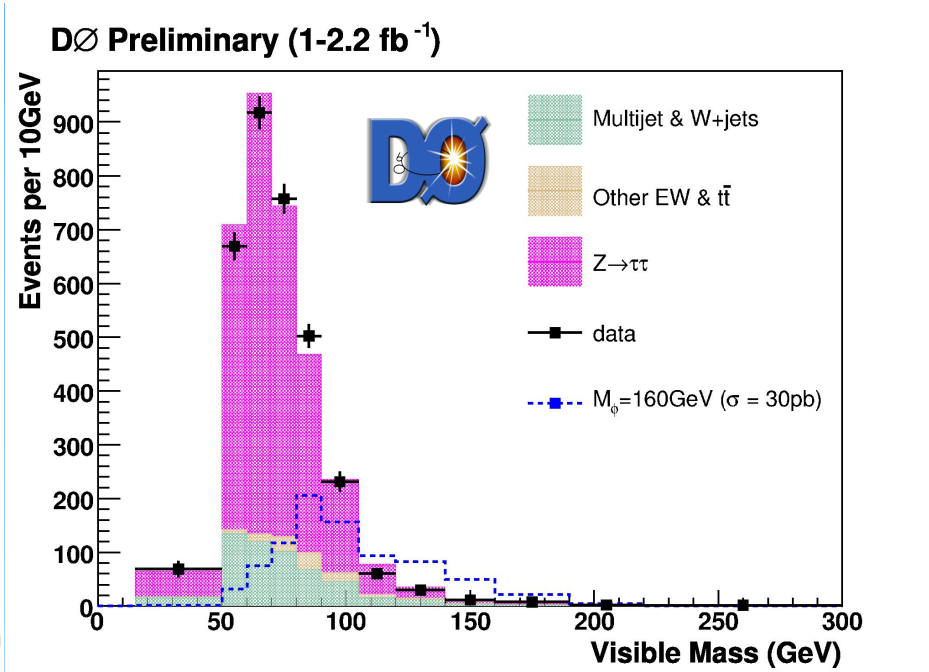


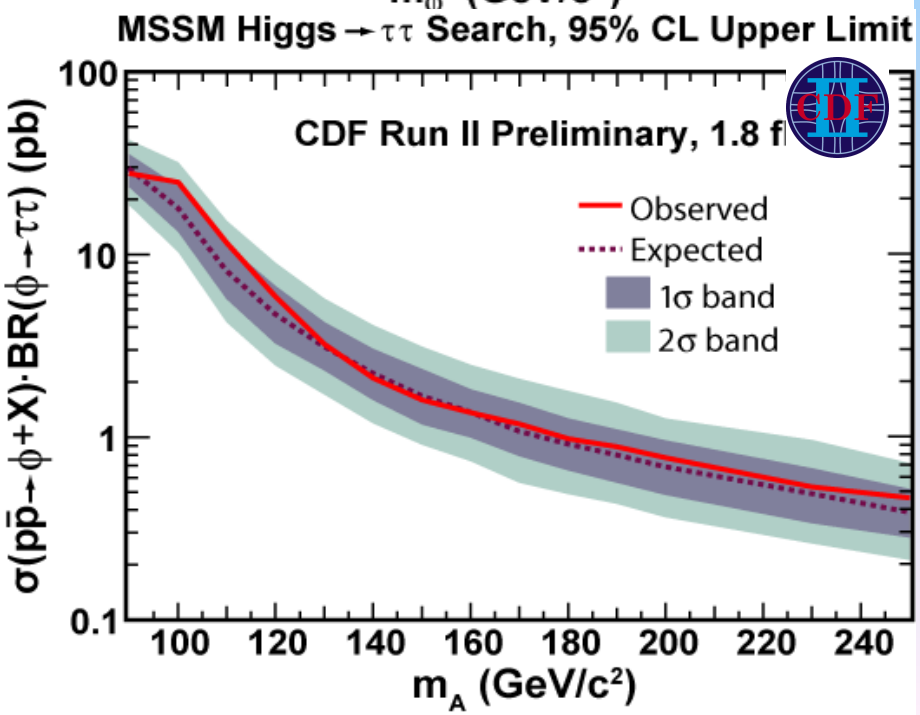
$(b)\phi \rightarrow (b)\tau\tau$

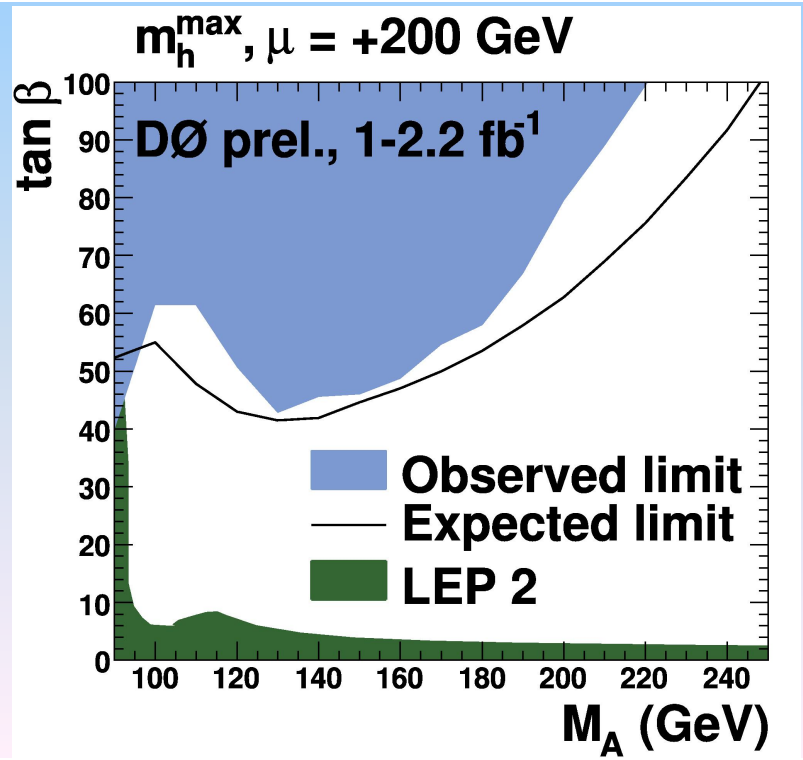


- Main backgrounds: $Z \rightarrow \tau\tau$, W+jets, dibosons
- One tau: semileptonic, p_T > 10, 20 GeV/c
- Other tau hadronic (CDF+D0) (and ν_τ): p_T > 10, 20 or semileptonic (CDF) p_T > 6,10 GeV/c
- Hadronic : Cone or NN Score (D0) with $\pi^\pm$, $\pi^\pm\pi^0$, 3-prong
- Reject non-$\tau\tau$ background
  - Lepton and missing energy inconsistent with W
  - H_T cut (CDF) or M_T (DØ)

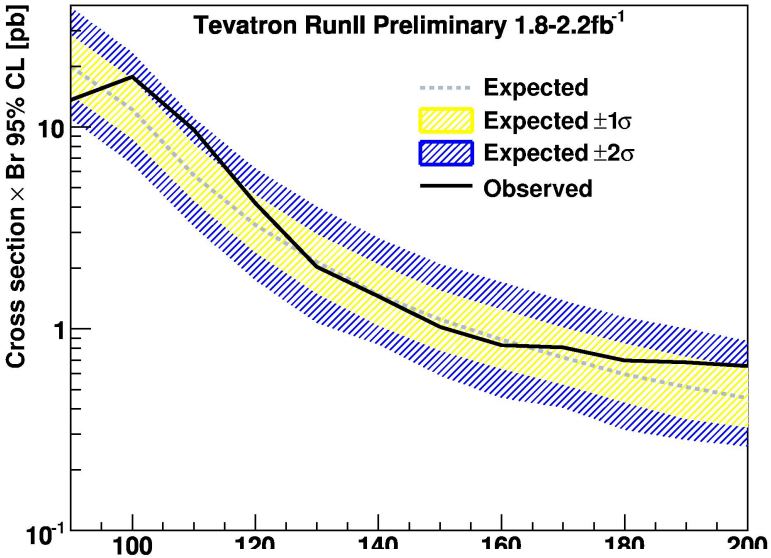

$\tau_e\tau_{had} + \tau_\mu\tau_{had}$ channels
CDF Run II 1.8 fb^{-1}
MSSM $\phi\to\tau\tau$ Search
Preliminary
observed
$A\to\tau\tau$
$Z/\gamma^*\to\tau\tau$
other EW, $t\bar{t}$
jet fake
m_ϕ (GeV/c^2)

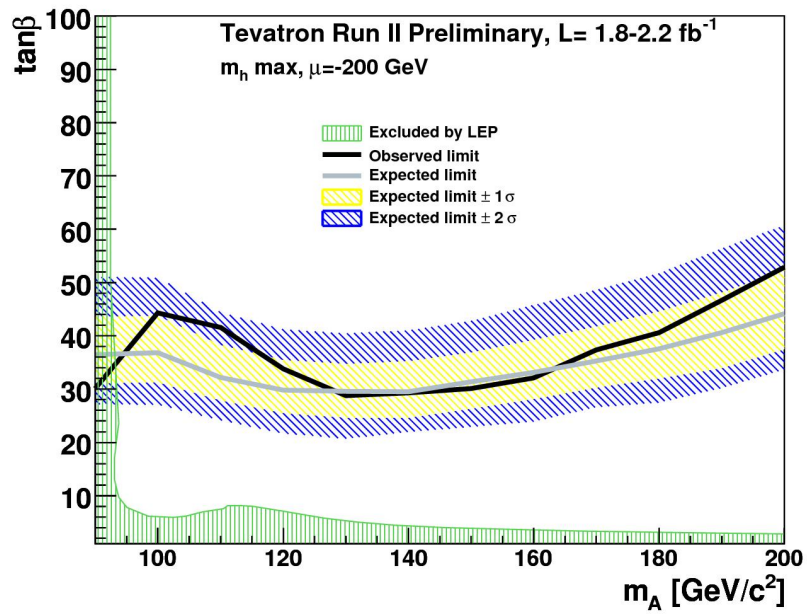

DØ Preliminary (1-2.2 fb^{-1})
Events per 10GeV
Multijet & W+jets
Other EW & $t\bar{t}$
$Z\to\tau\tau$
data
M_ϕ=160GeV (σ = 30pb)
Visible Mass (GeV)

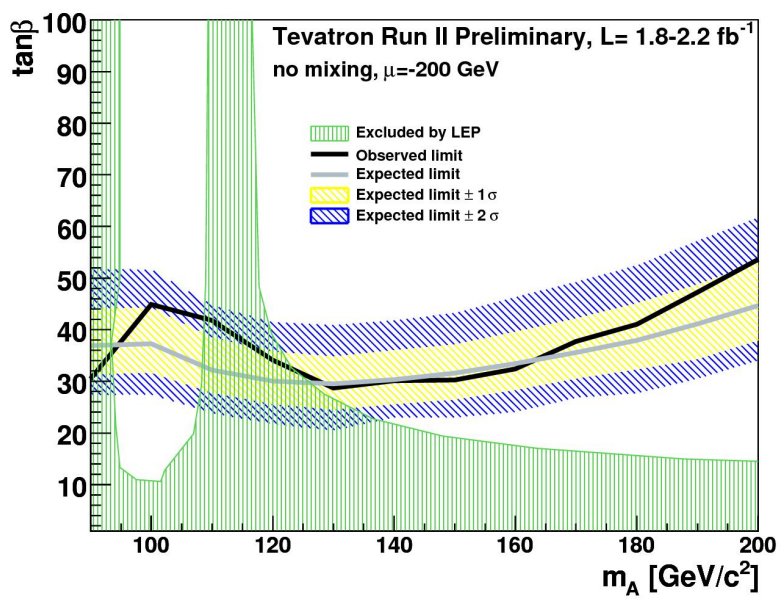

MSSM Higgs $\to\tau\tau$ Search, 95% CL Upper Limit
CDF Run II Preliminary, 1.8 fb
Observed
Expected
1σ band
2σ band
$\sigma(p\bar{p}\to\phi+X)\cdot BR(\phi\to\tau\tau)$ (pb)
m_A (GeV/c^2)


m_h^{max}, μ = +200 GeV
DØ prel., 1-2.2 fb^{-1}
Observed limit
Expected limit
LEP 2
tan β
M_A (GeV)

Combined CDF and D0 Results

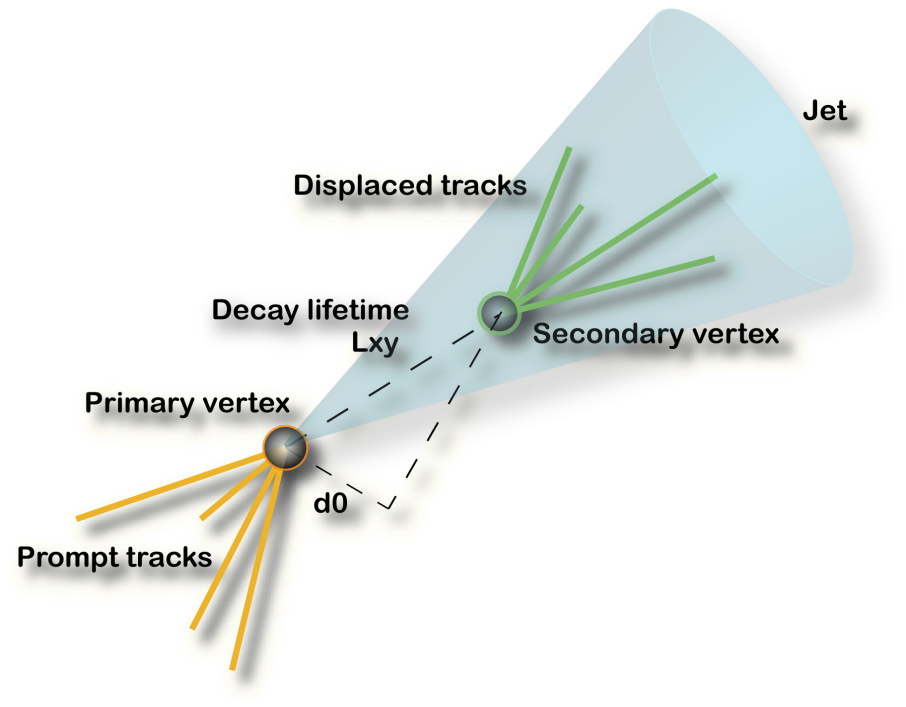


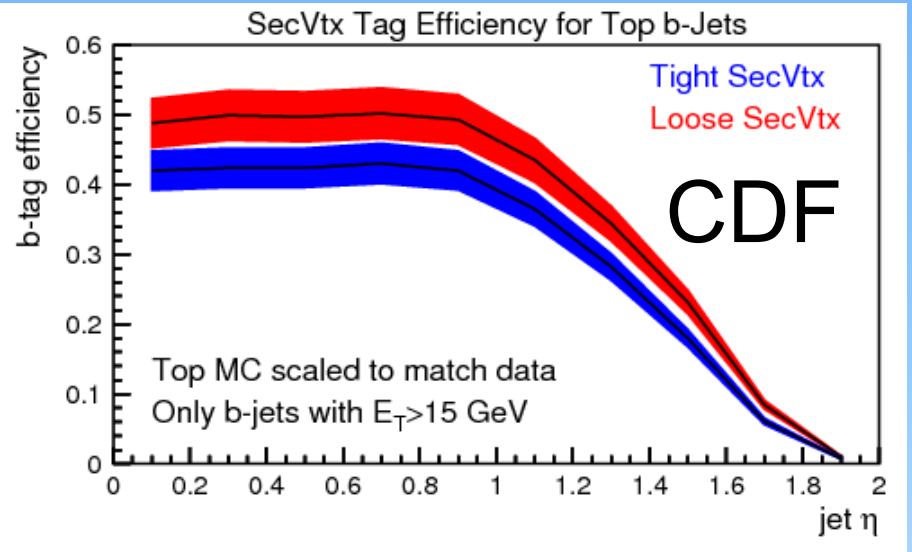


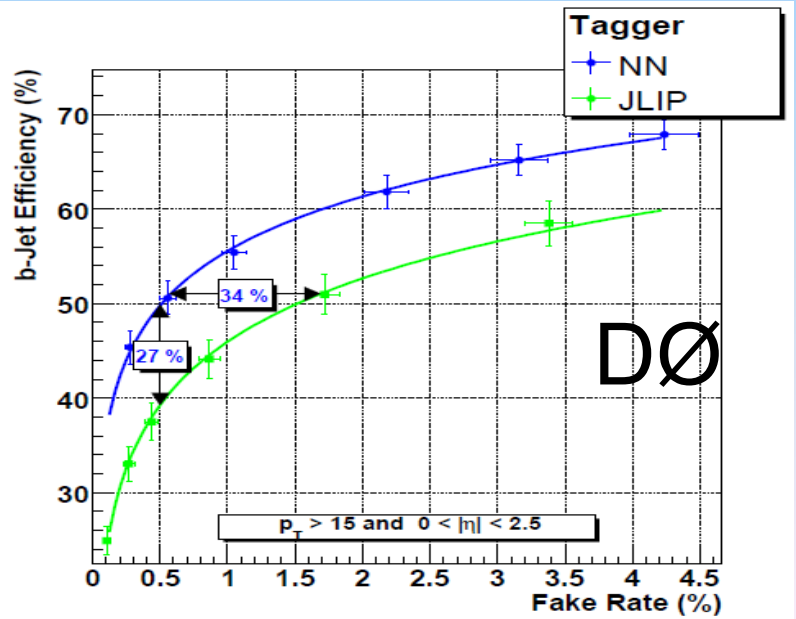


- Sensitivity and exclusion for tanβ of order 30.

B-Jet Identification







CDF : displaced vertices with L_{xy}/σ cut

Vertex mass separation

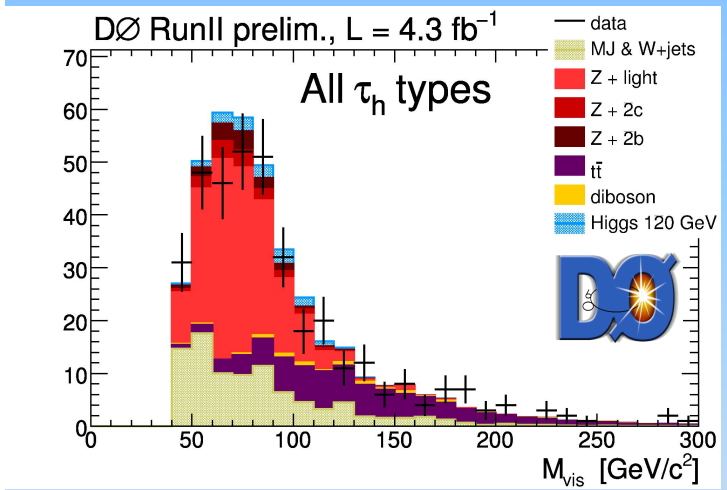
DØ : combine vertex properties and displaced track info with NN

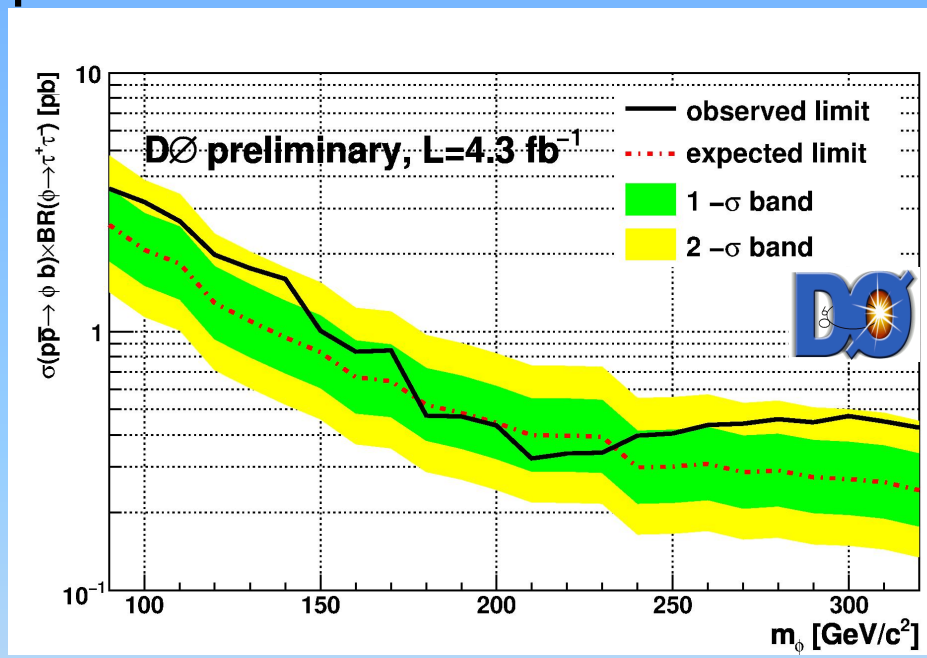
Tag to η beyond 2

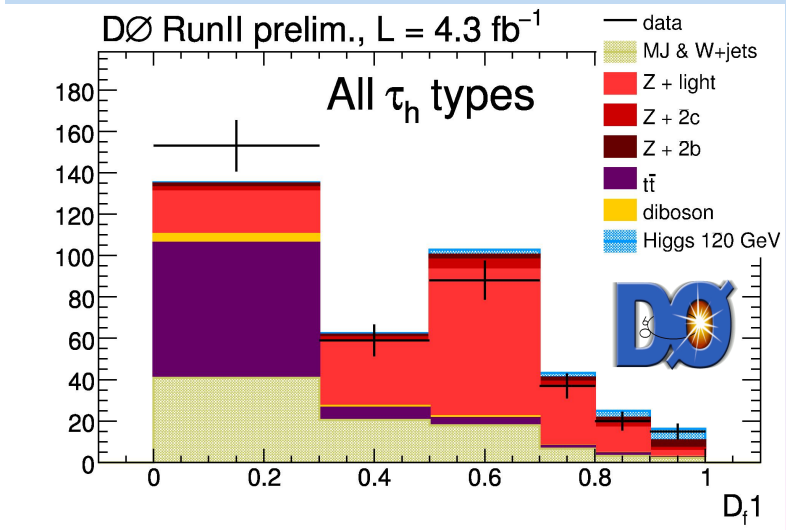
DØ $\tau_\mu \tau_h b$ Results

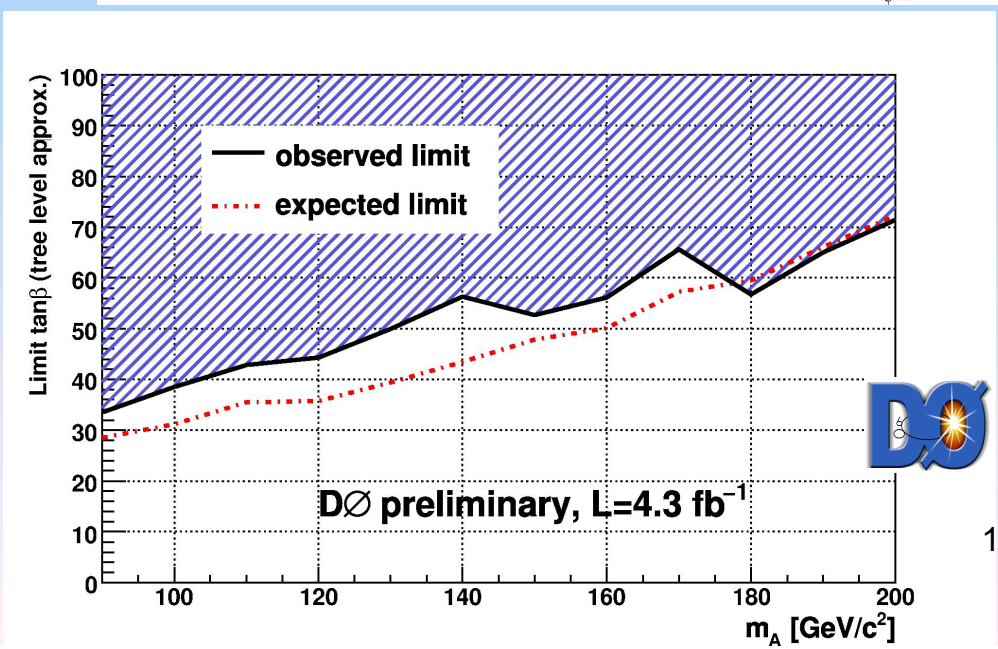
Multivariate discriminate against multijet,top. One input shown, M_{vis}

No Signal: Limit on cross section and in $\tan\beta$ – m_A plane: Sensitivity ~40



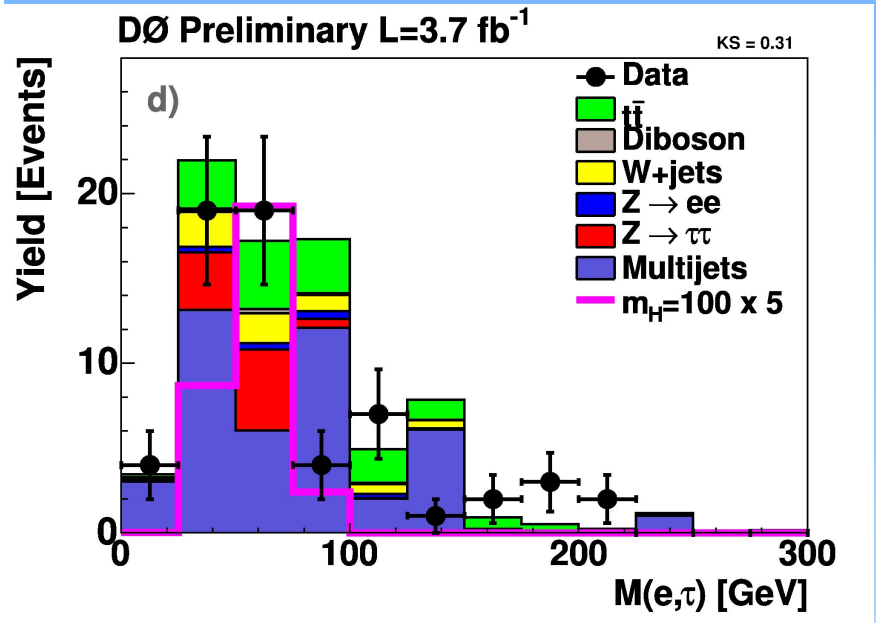


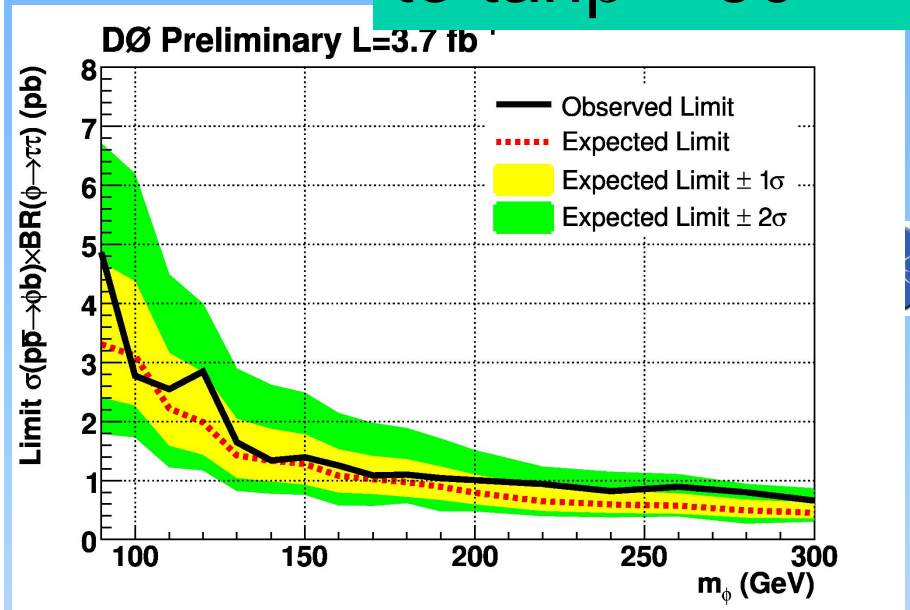


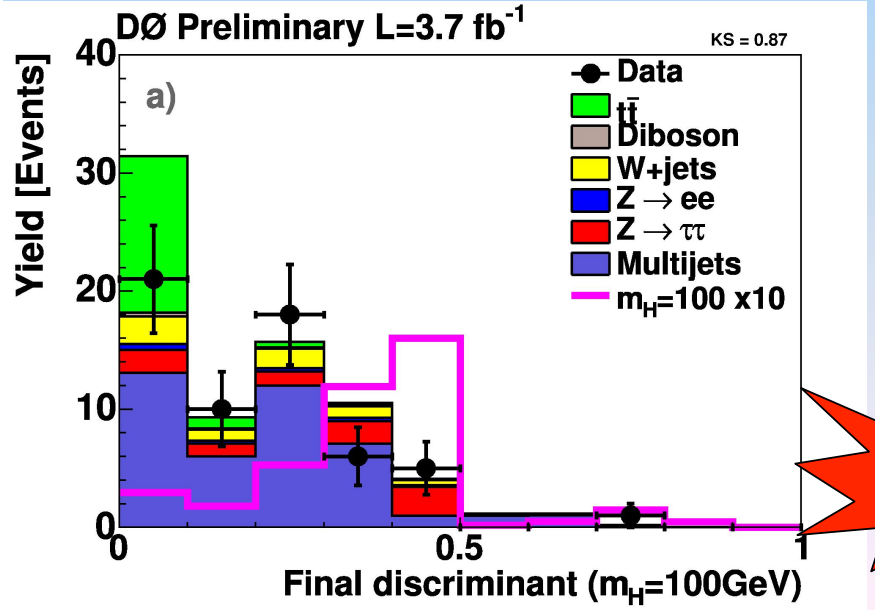


DØ $\tau_e\tau_h b$ Results

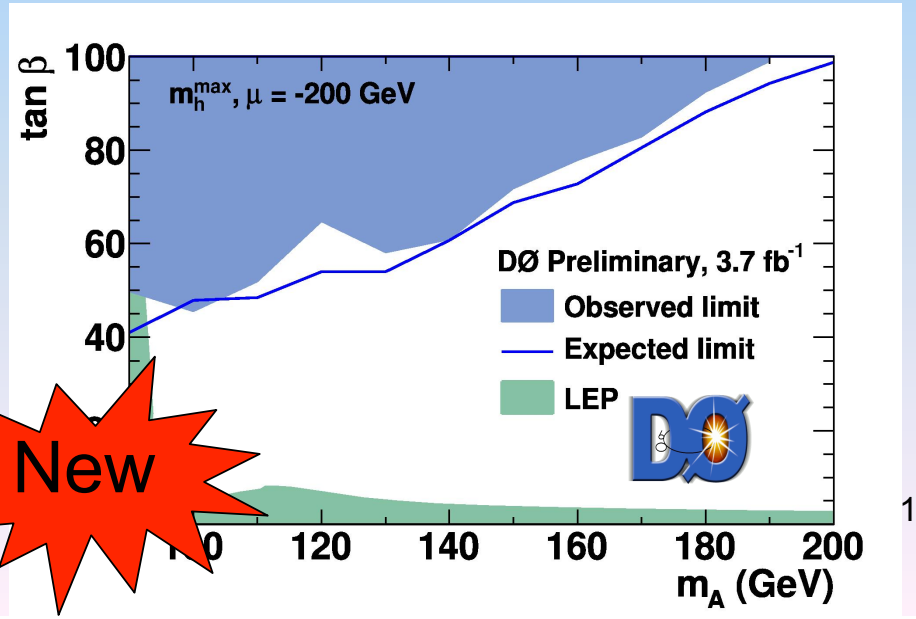
Exclude, sensitive to $\tan\beta \sim 50$





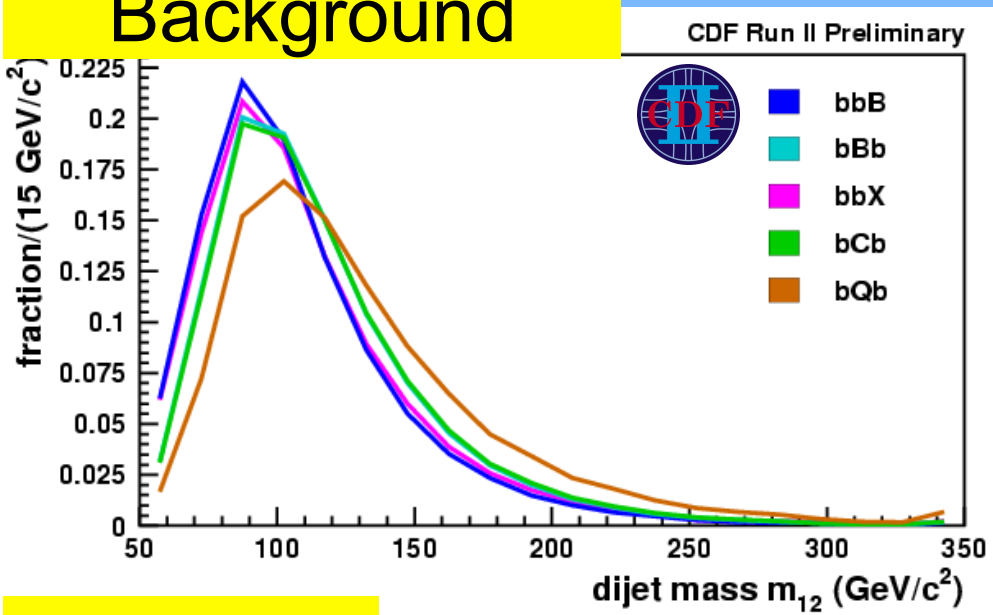


New

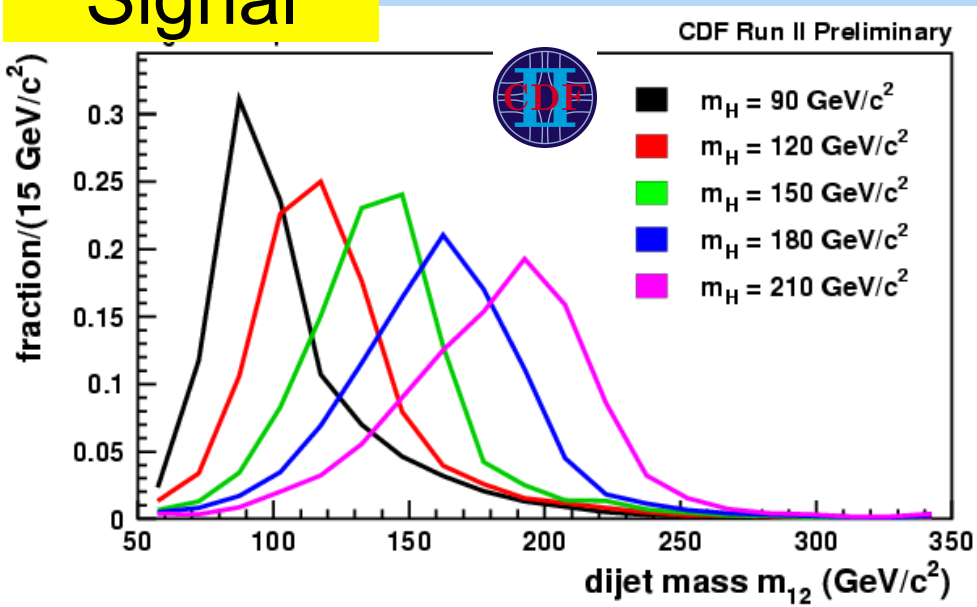


CDF 3b Channel

Background

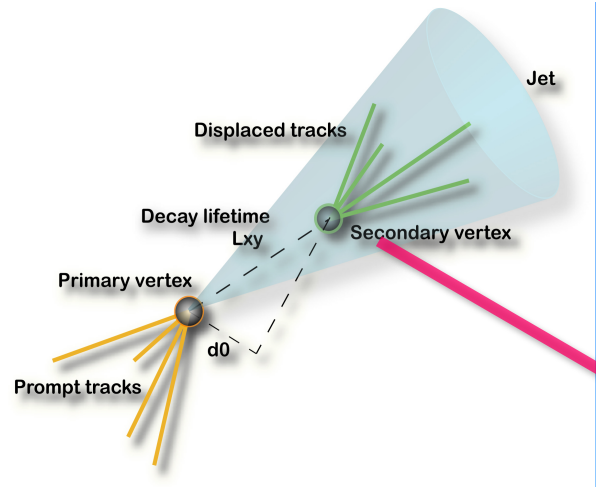


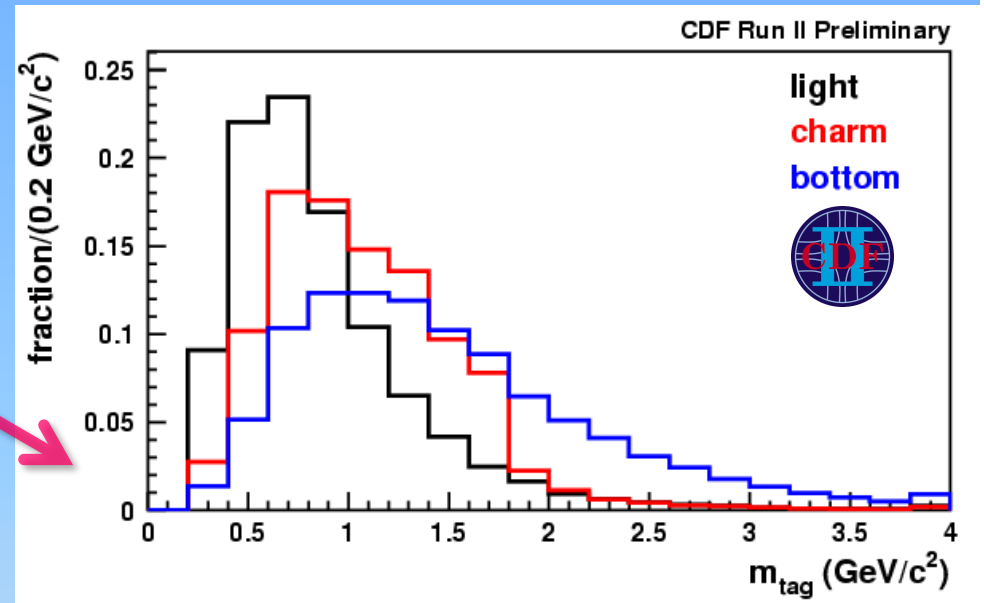
Signal



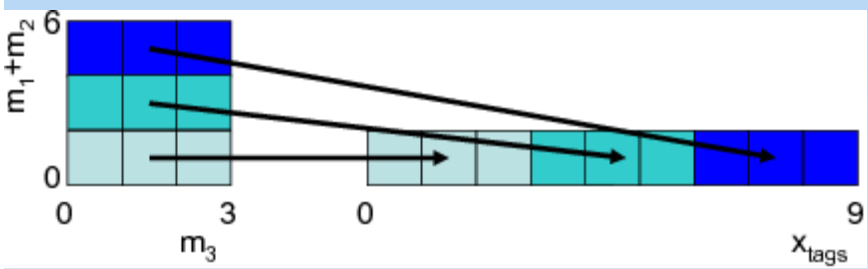
- Event Selection: 3 b-tagged jets, E_t >20 GeV. Trigger tracks: d_0 > 100 μm
- Search in mass of two lead jets m_{12}
- Backgrounds are QCD events with two true b-tags, and a b/c/fake tag
- Characteristic m_{12} spectra
- Start from $b\bar{b}$+jet data sample (corrected double-tags), weight events by flavor hypothesis
- Fit the observed m_{12} spectrum with the backgrounds and a Higgs shape

CDF 3b: Extra Discriminant





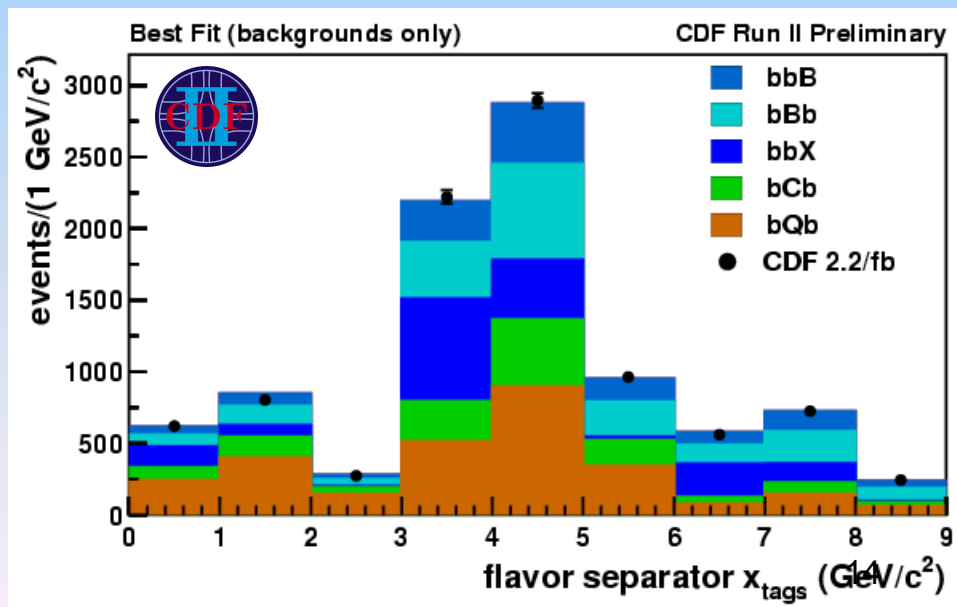
Improve prediction of total background m_{12} using invariant mass, m_j, of tracks in each vertex



Unstack into 1D variable "x_{tags}" for plotting/fitting

m_1+m_2 : bbb+bbx / bcb+bqb

m_3 : bbx / bbb+bcb+bqb

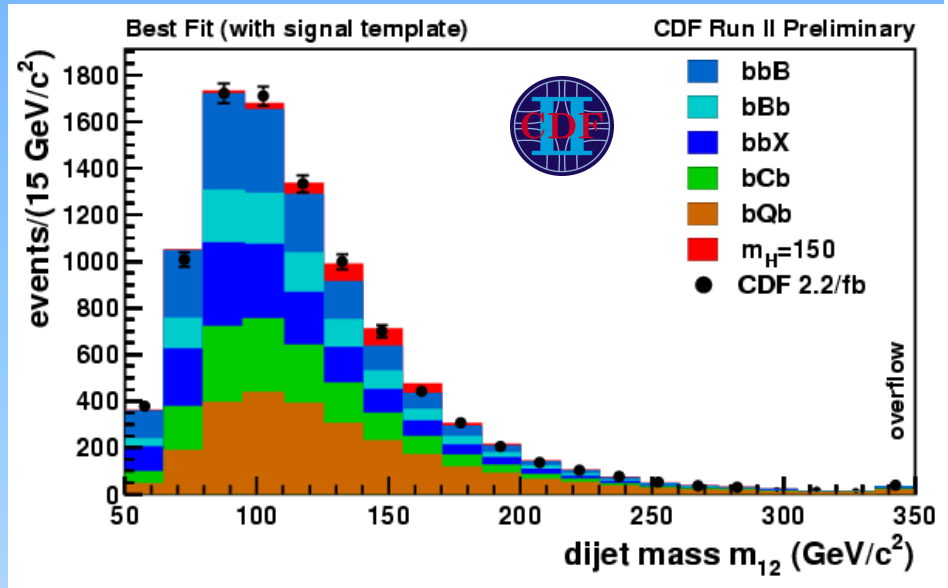


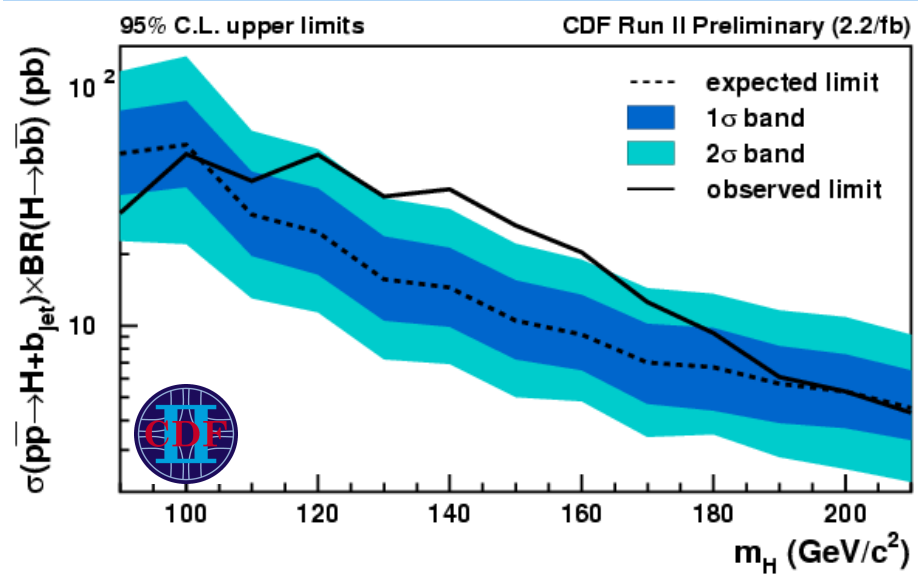
Fits are 2D – m_{12} vs x_{tags}

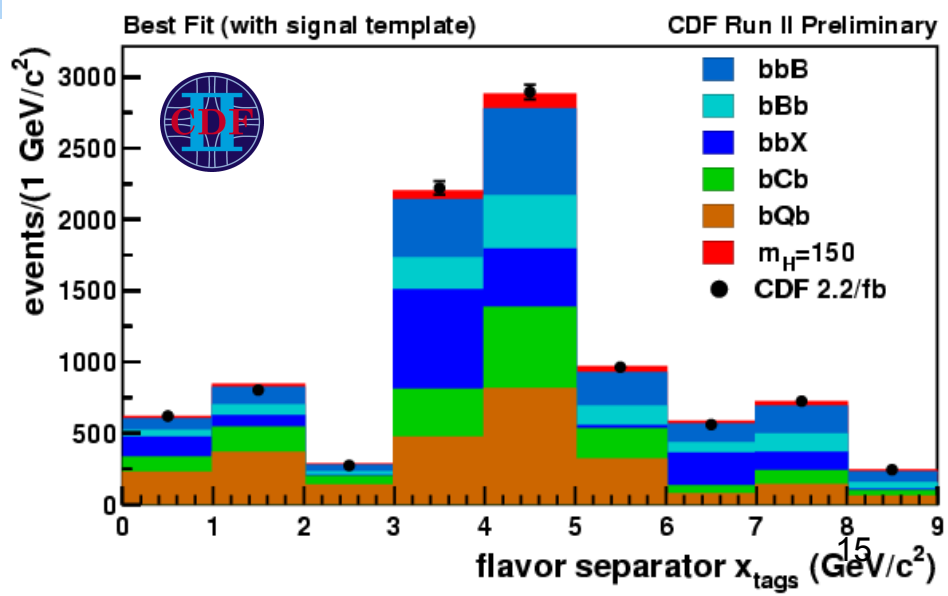
CDF 3b Results

Most significant excess @ 140 GeV/c^2

No significant excess observed
Set limits on σ x BR

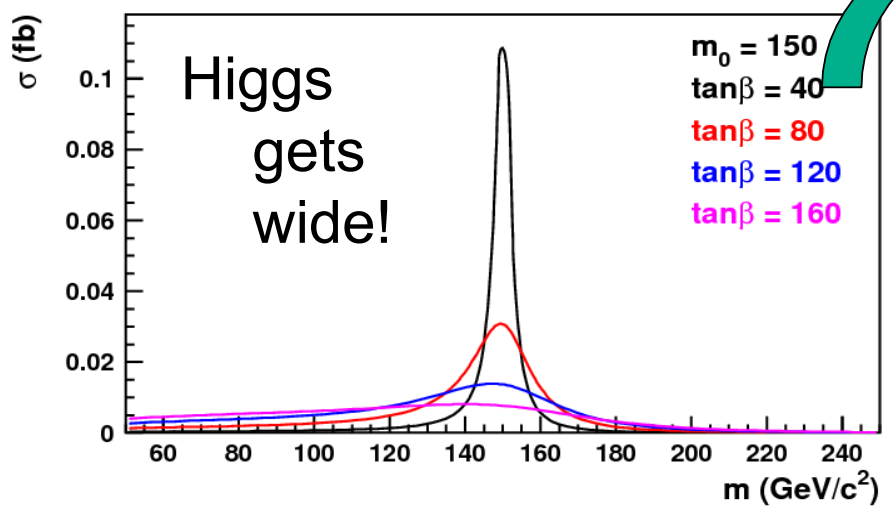


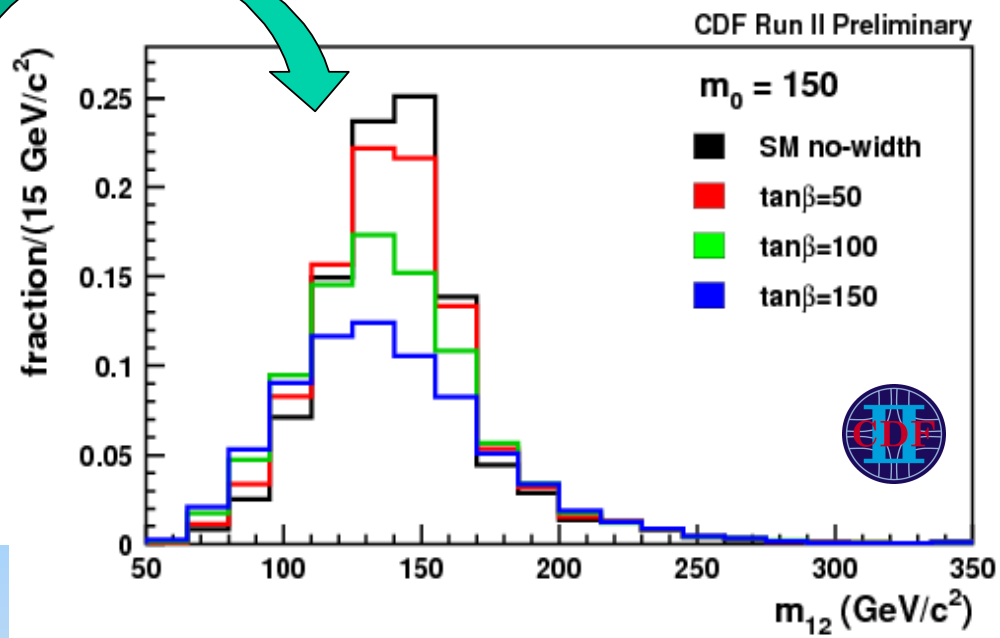




MSSM Interpretation

Fold in Detector

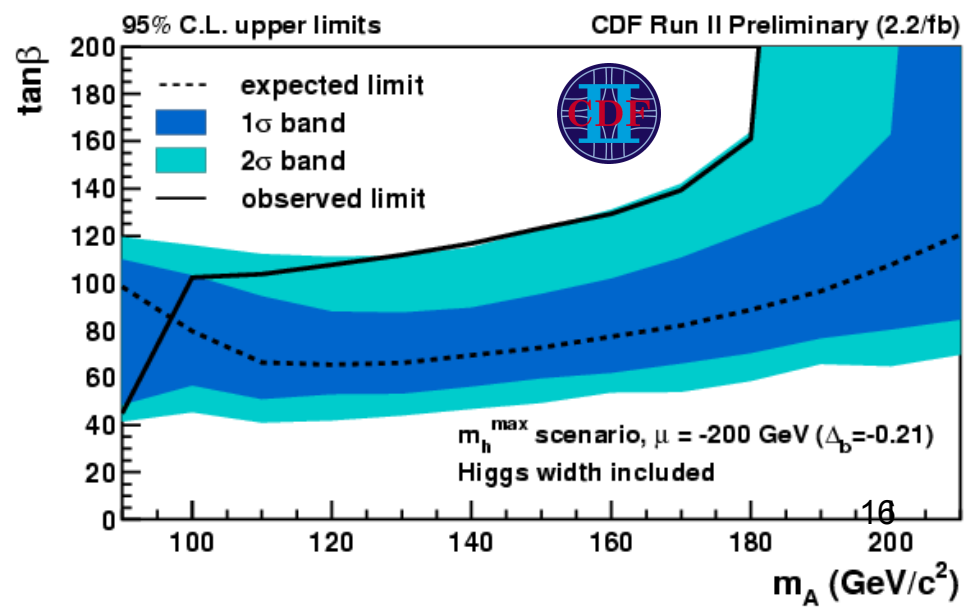




Include effect of Higgs width (~20% for tanβ = 100)

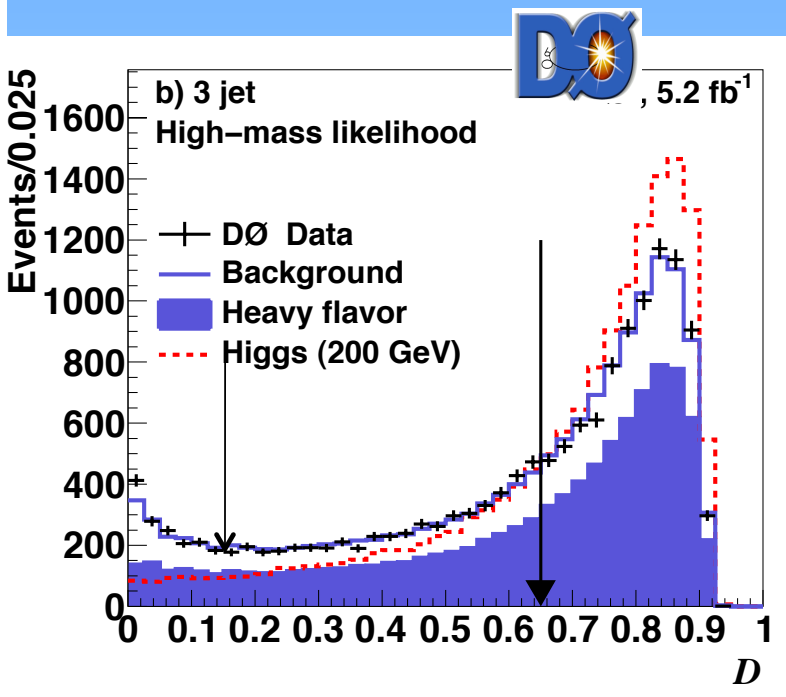
Lose sensitivity (lower S/B) Lowers event yield

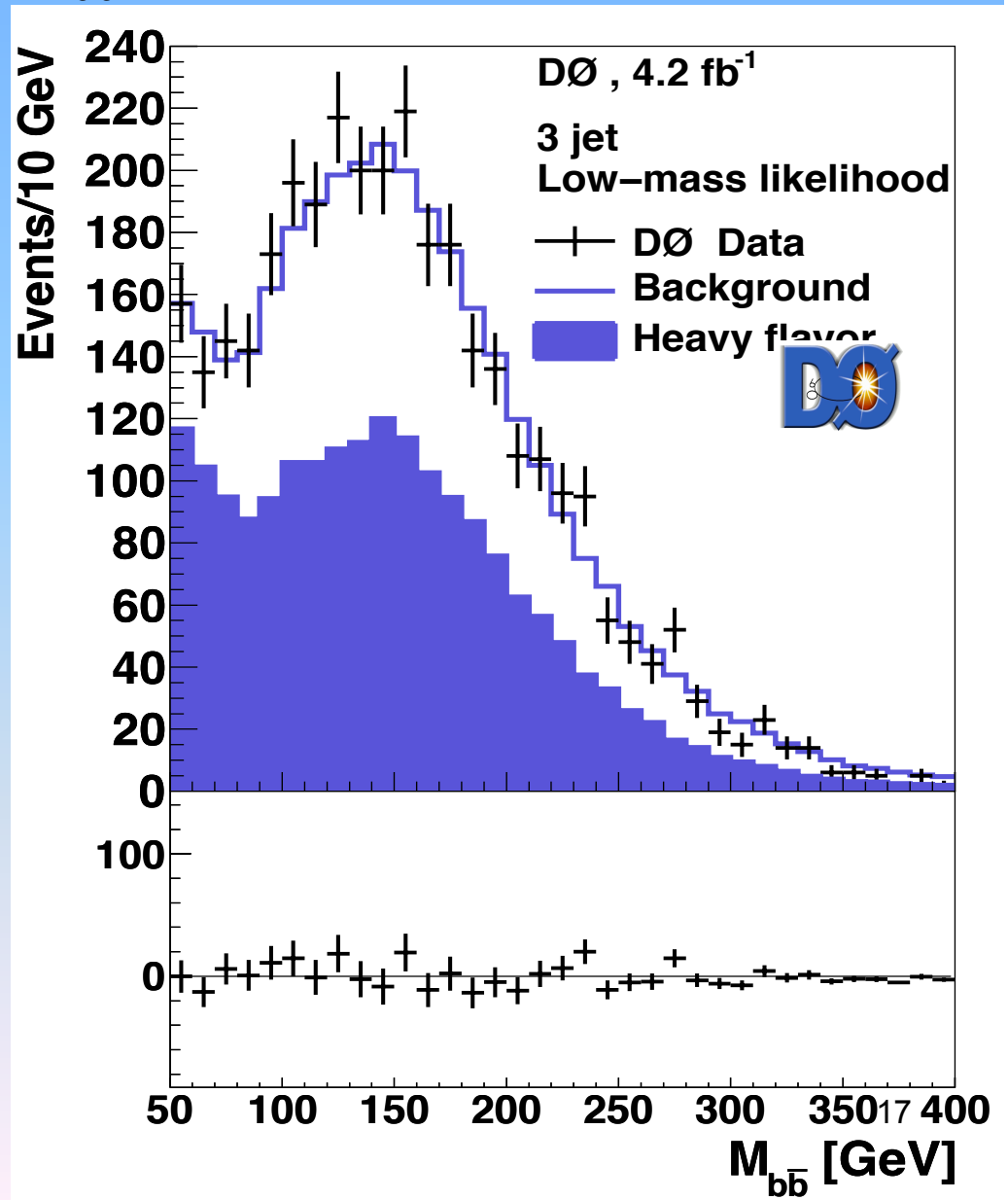
Best limits obtained in scenarios with μ < 0 (loop enhancements): sensitivity tanβ = 60



DØ 3b

Check background prediction: M_{bb} for D<0.12





Invariant mass of the two leading jets m_{bb} in triple-tagged events

Also Derive background shape from double-tagged sample

Uses two 6 dimensional likelihood discriminant, D: $\Delta\eta_{jj}$,$\Delta\phi_{jj}$, etc. for low (90-130) and high mass ϕ

DØ 3b

Largest deviation @ 120 GeV/c^2

No significant excess observed

Set limits on σ x BR

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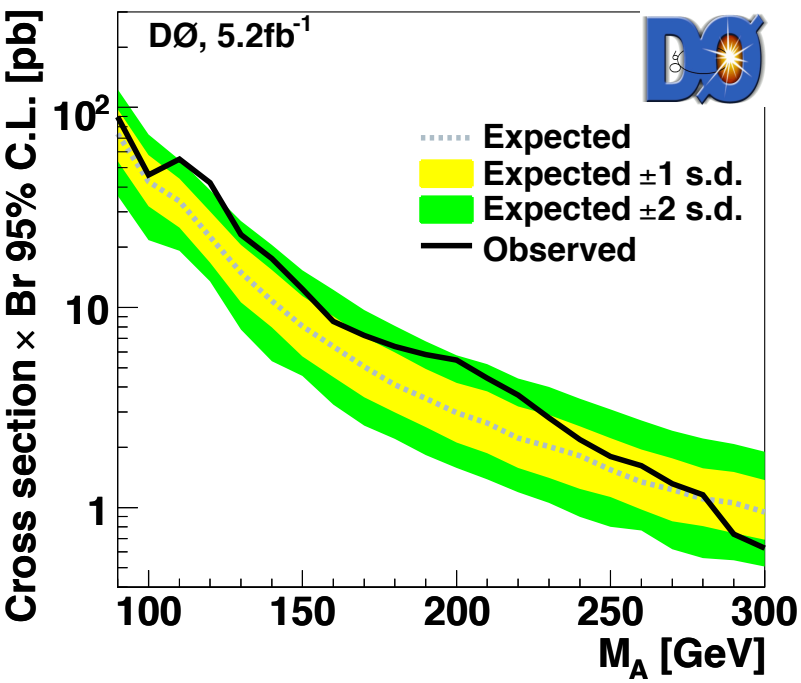
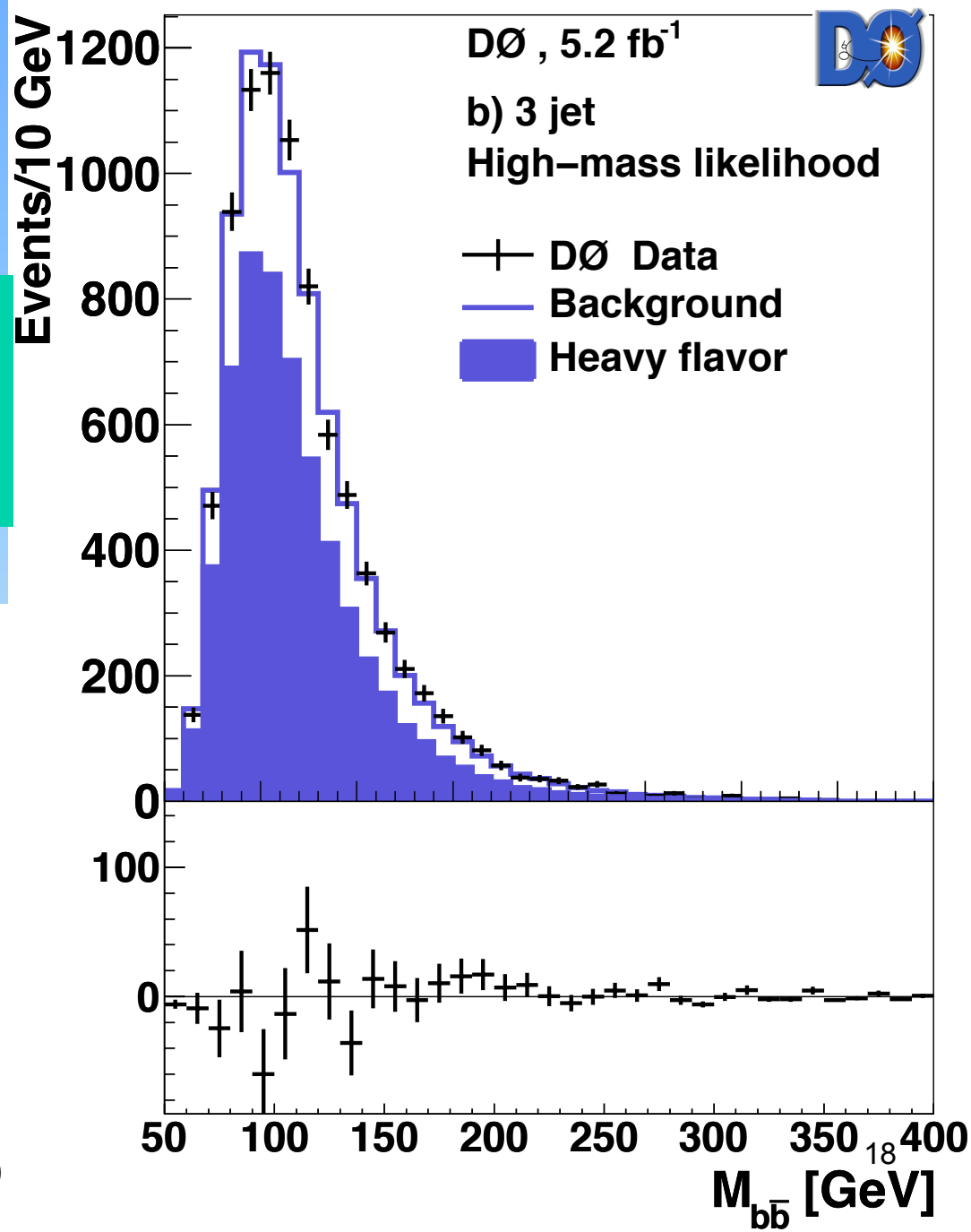
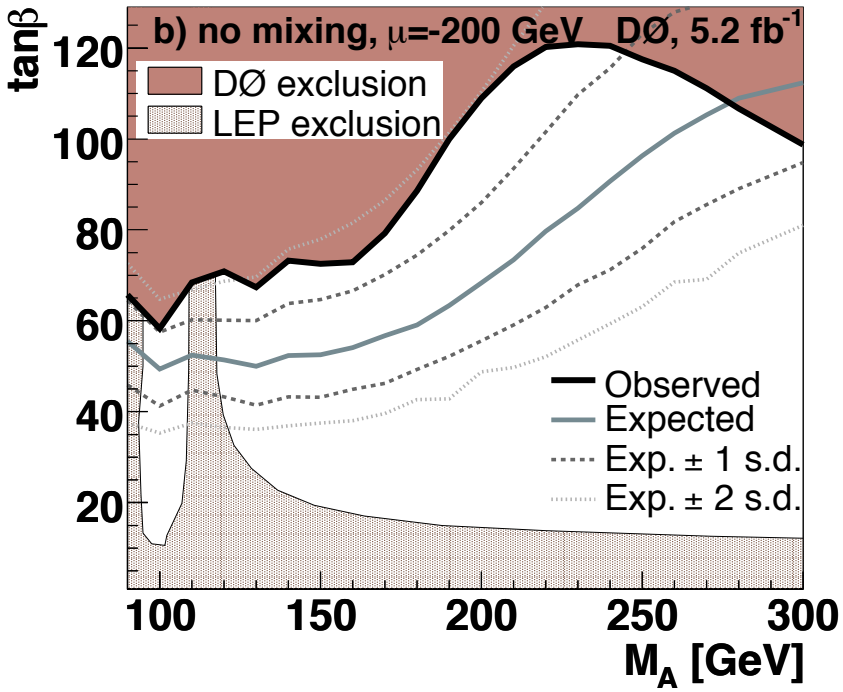
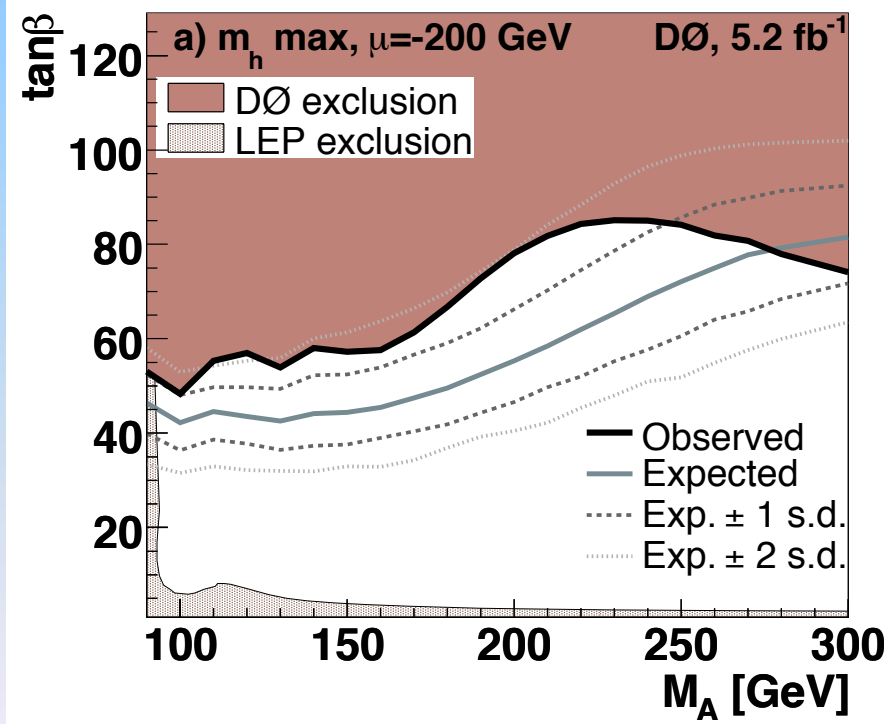




D0 3b: MSSM Interpretation

Excluded tanβ ~ 50 at lowest, 120 at 225. Sensitive to tanβ ~ 45

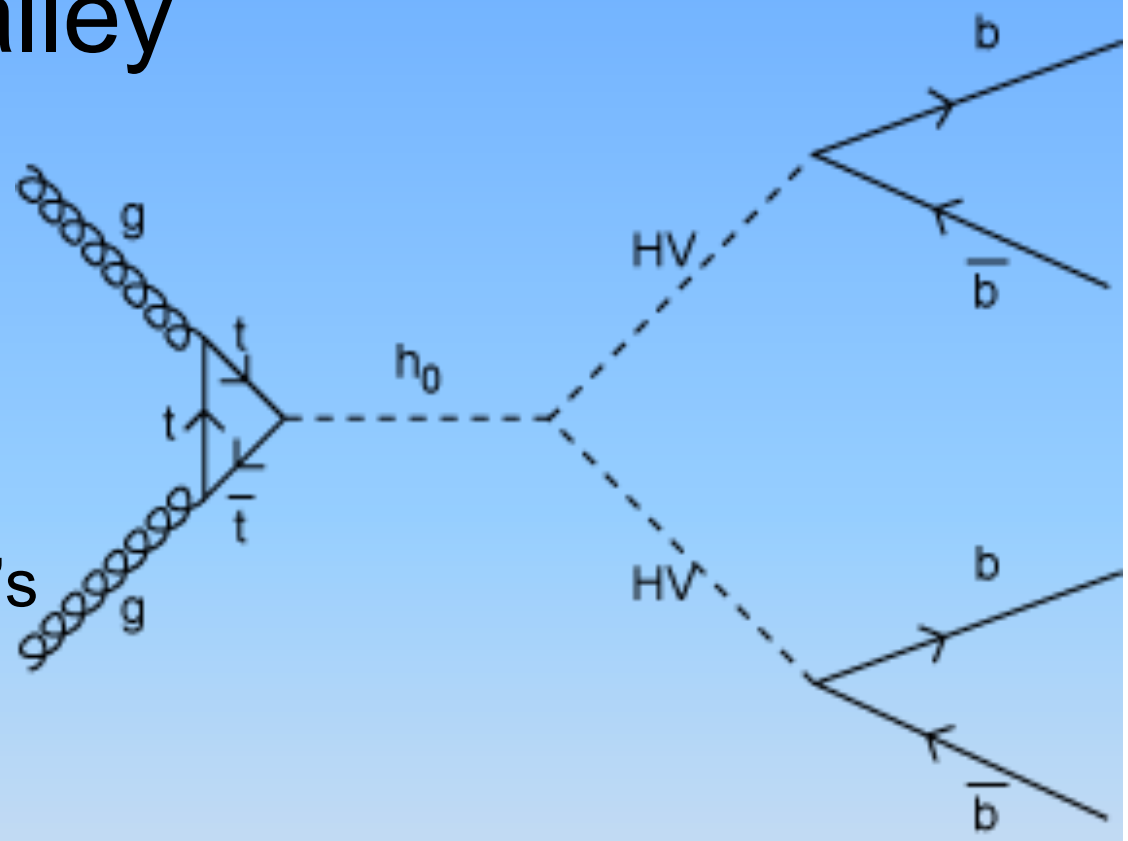




CDF Hidden Valley

New

Higgs decays to HV
particle with $c\tau \sim 1$ cm:
modified Vertexing
Each HV decays to two b's
A 4b final state: require 3
Trigger, Calibration as for
MSSM bbb



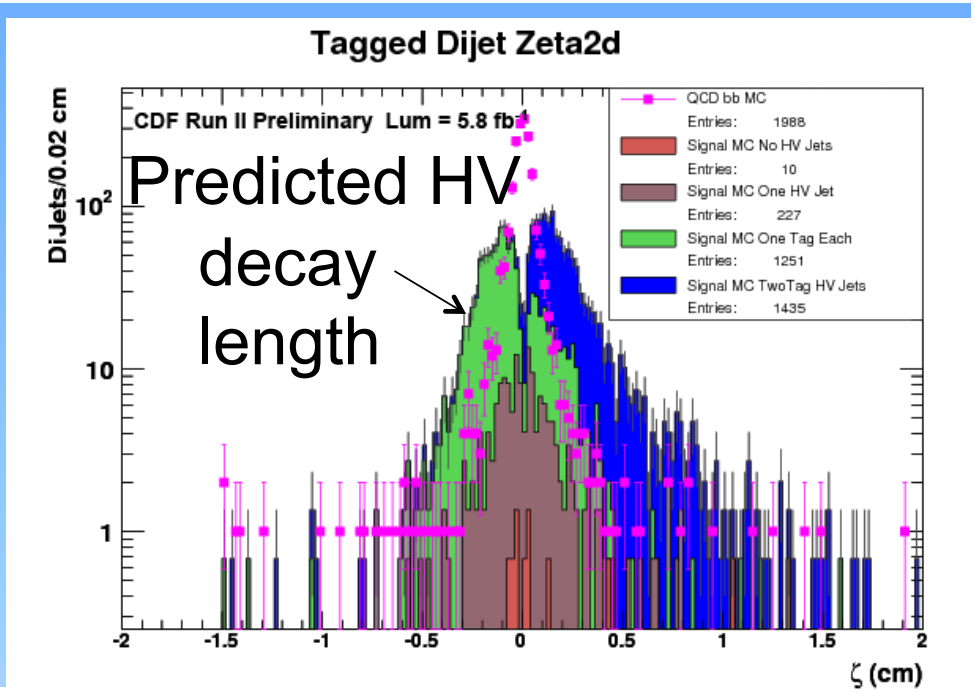
Cut on variables based on reconstructed vertex:
ζ: HV decay length
Ψ: Jet Impact Parameter

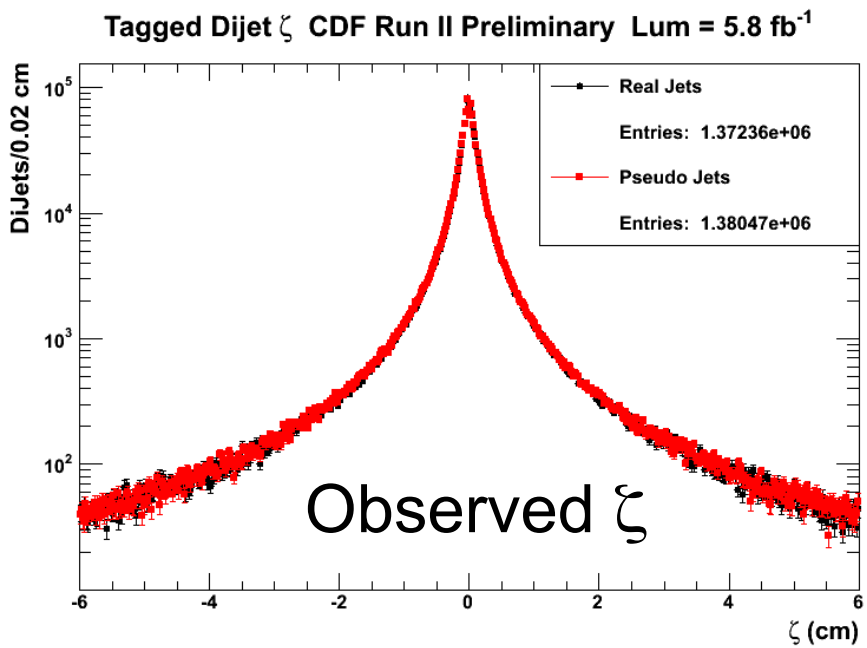
Signal: $\zeta,\psi > 0$, QCD bb Background $\zeta,\psi \sim 0$

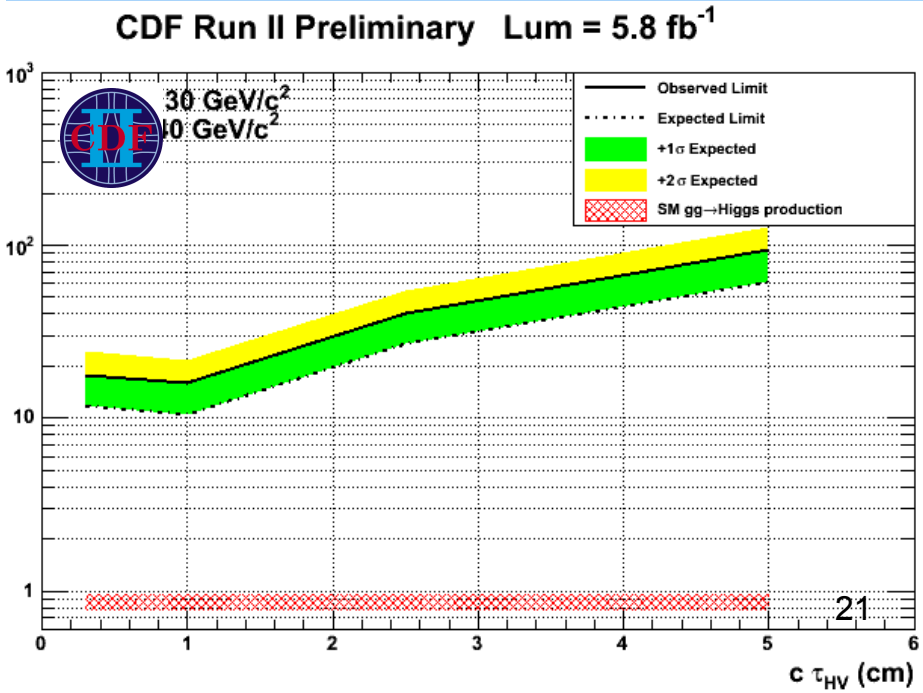
CDF Hidden Valley

New

Results: 1 event, 0.3-0.5 expected; show for various lifetimes, Higgs masses, and HV particle masses





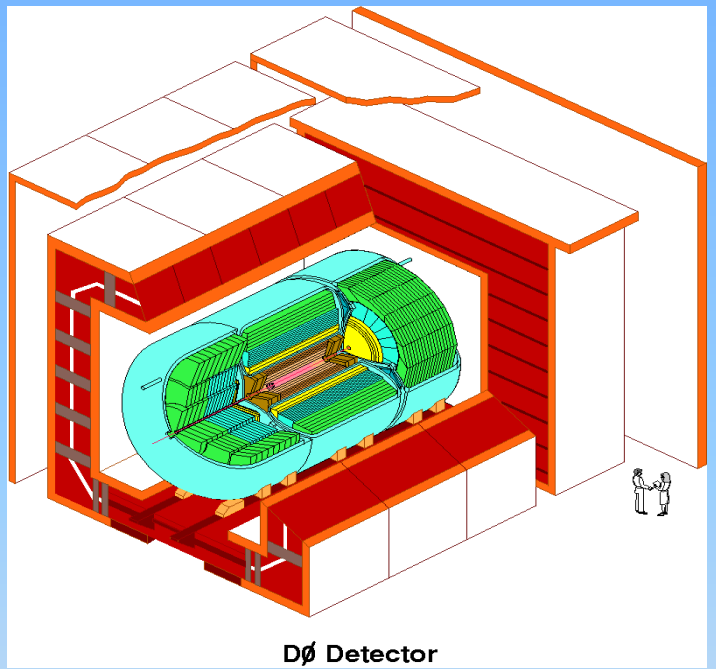


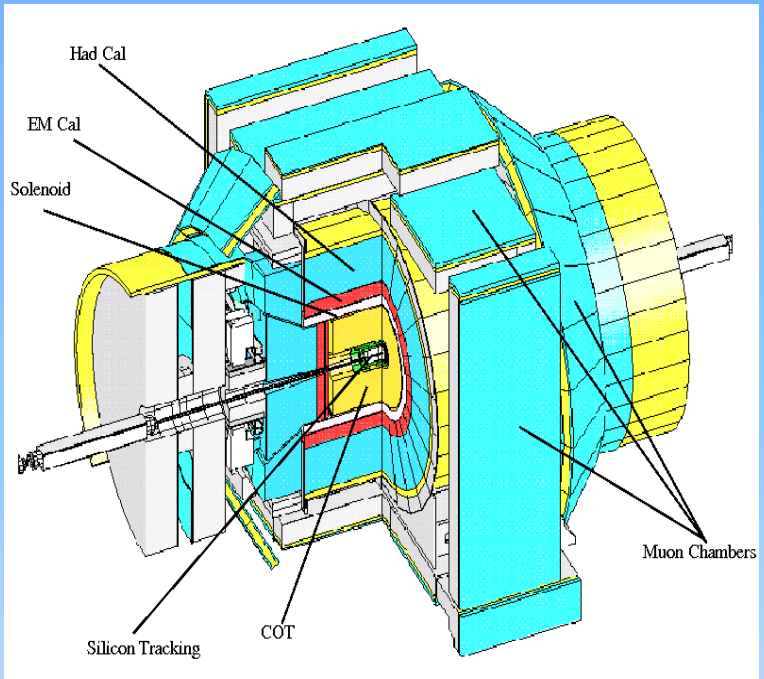
Summary

- CDF and DØ are looking hard for Higgs bosons in a variety of models beyond the standard model using advanced techniques in a harsh environment.
- Results today use 2.4-8.2 fb^{-1} MSSM: sensitive to $\tan\beta$ ~30. Full dataset, combined results could be sensitive to $\tan\beta$ ~20.
- 4th Generation excluded by CDF alone for $123 < m_H < 202$ GeV/c^2 , CDF+D0: 131-204 GeV/c^2 .
- Fermiophobic Higgs: When we find it, D0 says it has to be M_{hf}>112 GeV/c^2 (CDF M_{hf}>106 GeV/c^2)
- Hidden Valley explored but nothing seen yet: need to do more exploring.

Backup

D0 and CDF Detectors

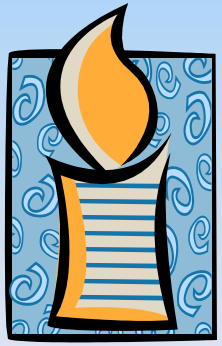


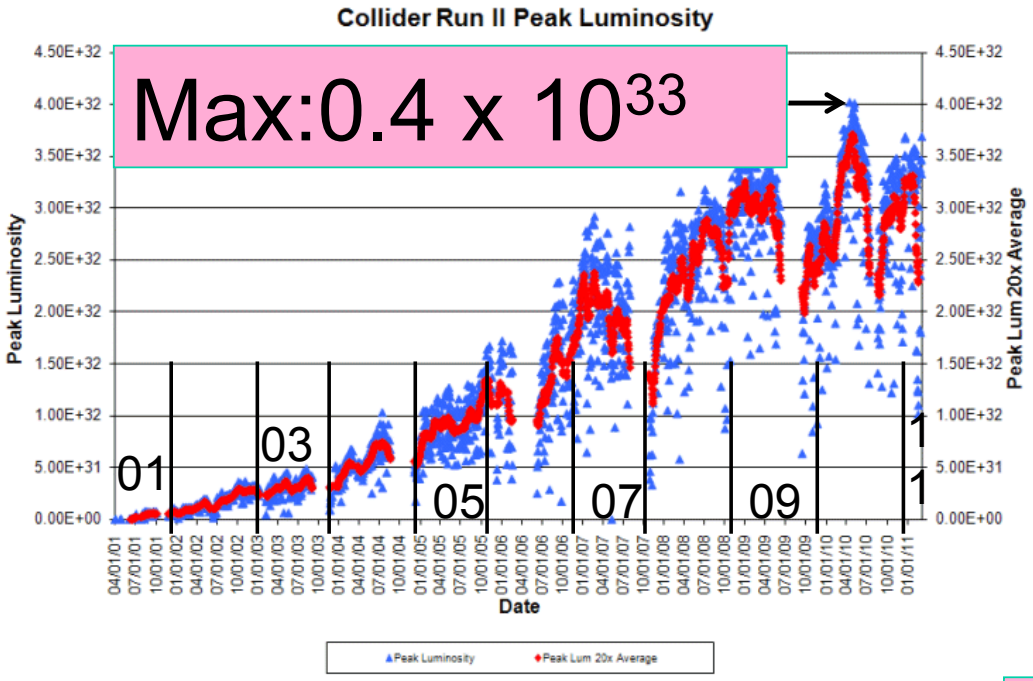


- Silicon Tracking
- Fibre Tracker
- L Ar Calo. $|\eta|<4$
- Muon: $|\eta|<2$

- Silicon Tracking
- Open drift Cell Tracker
- Scintillator Calo. $|\eta|<3.2$
- Muon coverage $|\eta|<1.5$

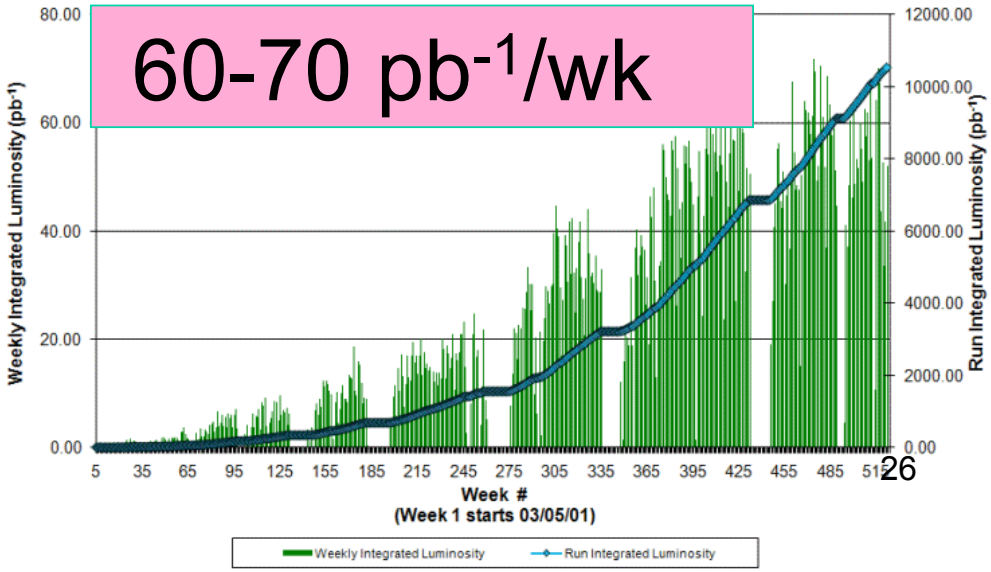
Tevatron Lumi

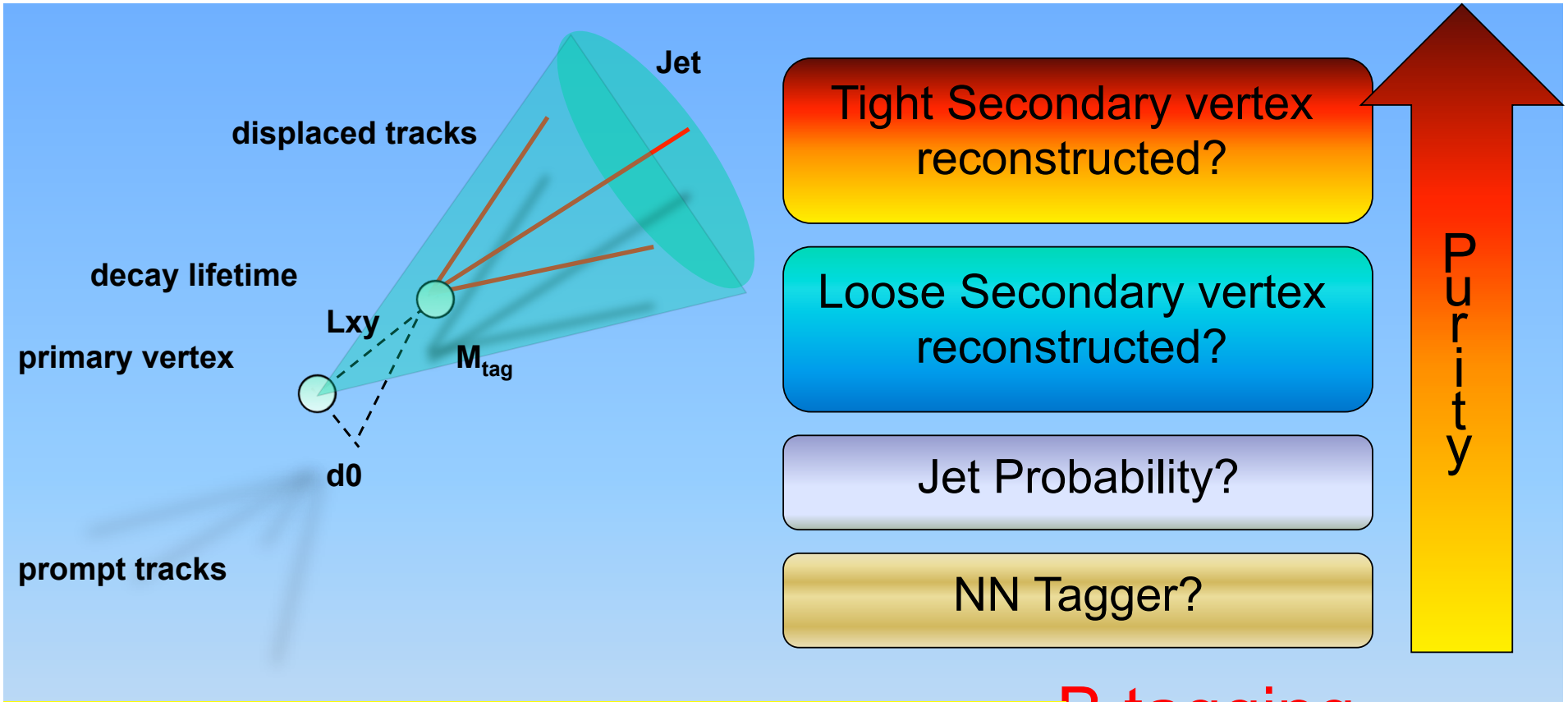




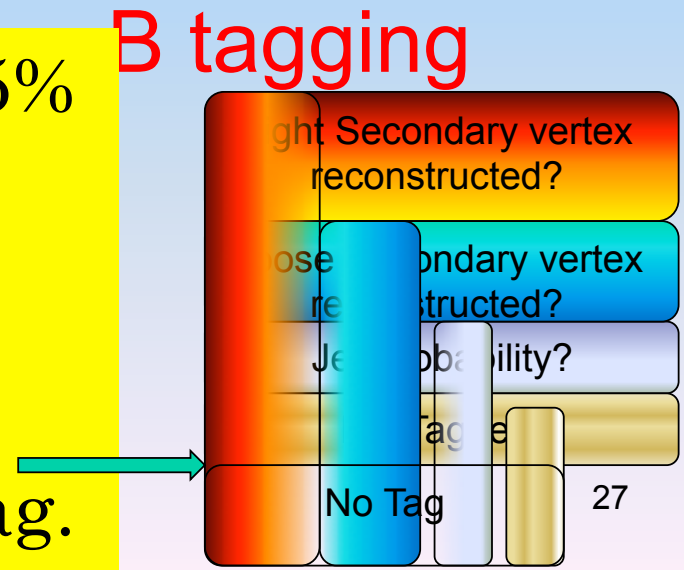
10.2 fb^{-1} Delivered

60-70 pb^{-1}/wk

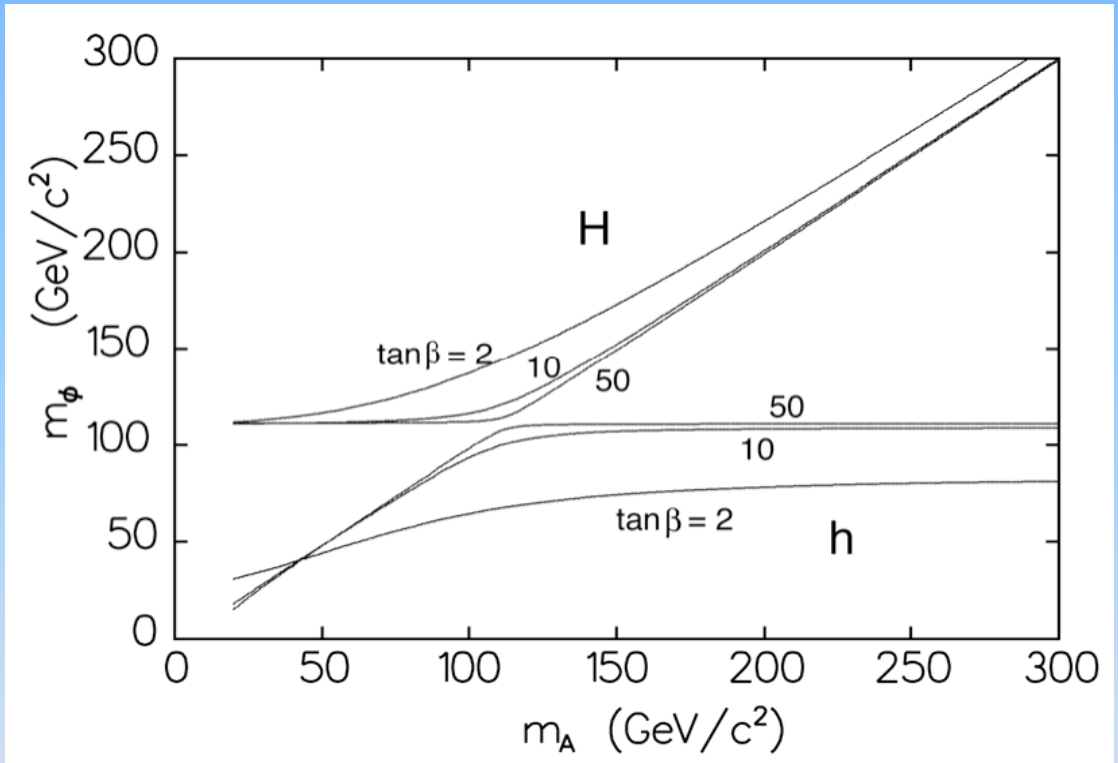




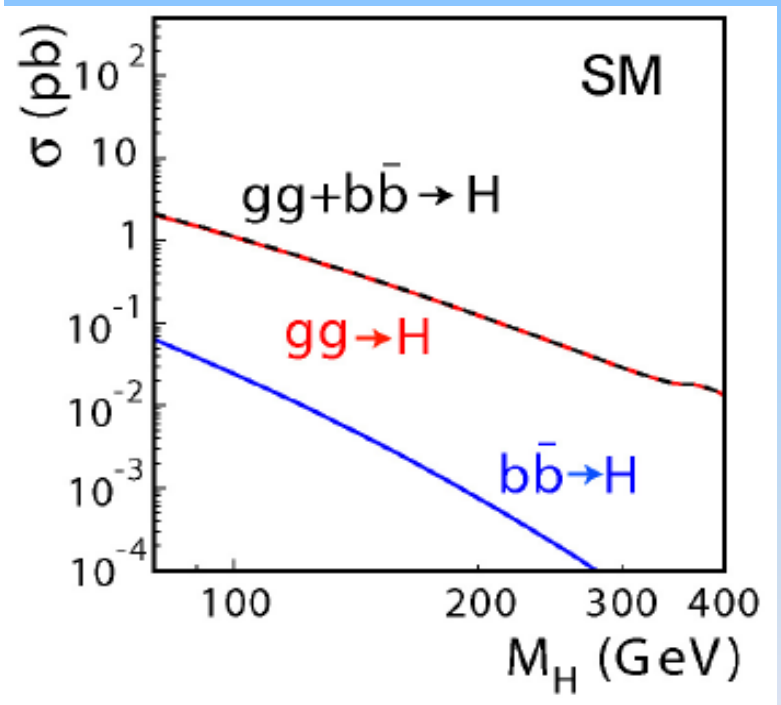
- Tag Efficiency: 50-70% b, 0.5-5% light quark
- Orthogonal event samples
- Form matrix for 2 jet: Tight-Tight, Tight-Loose… Single Tag.

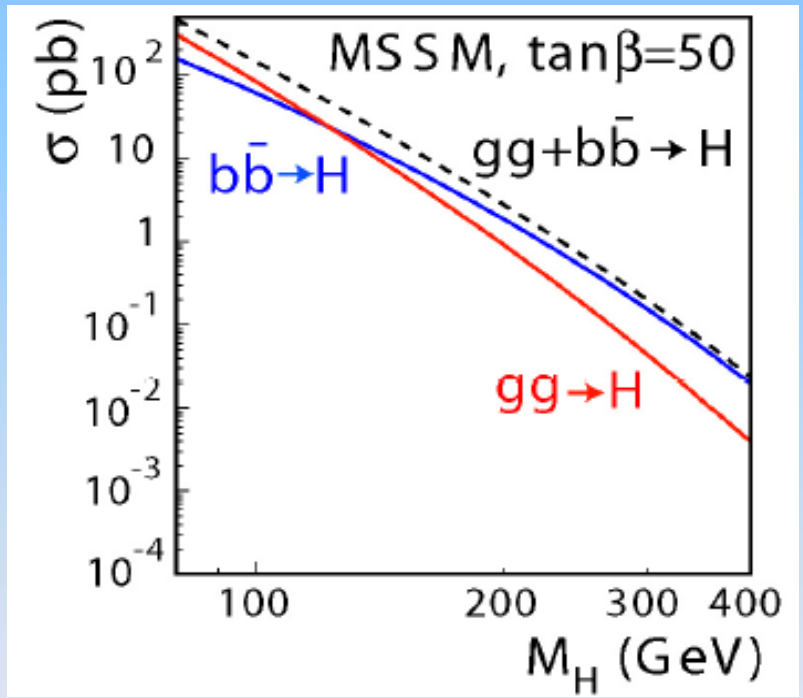


Higgs at High tanβ



Higgs at High tanβ



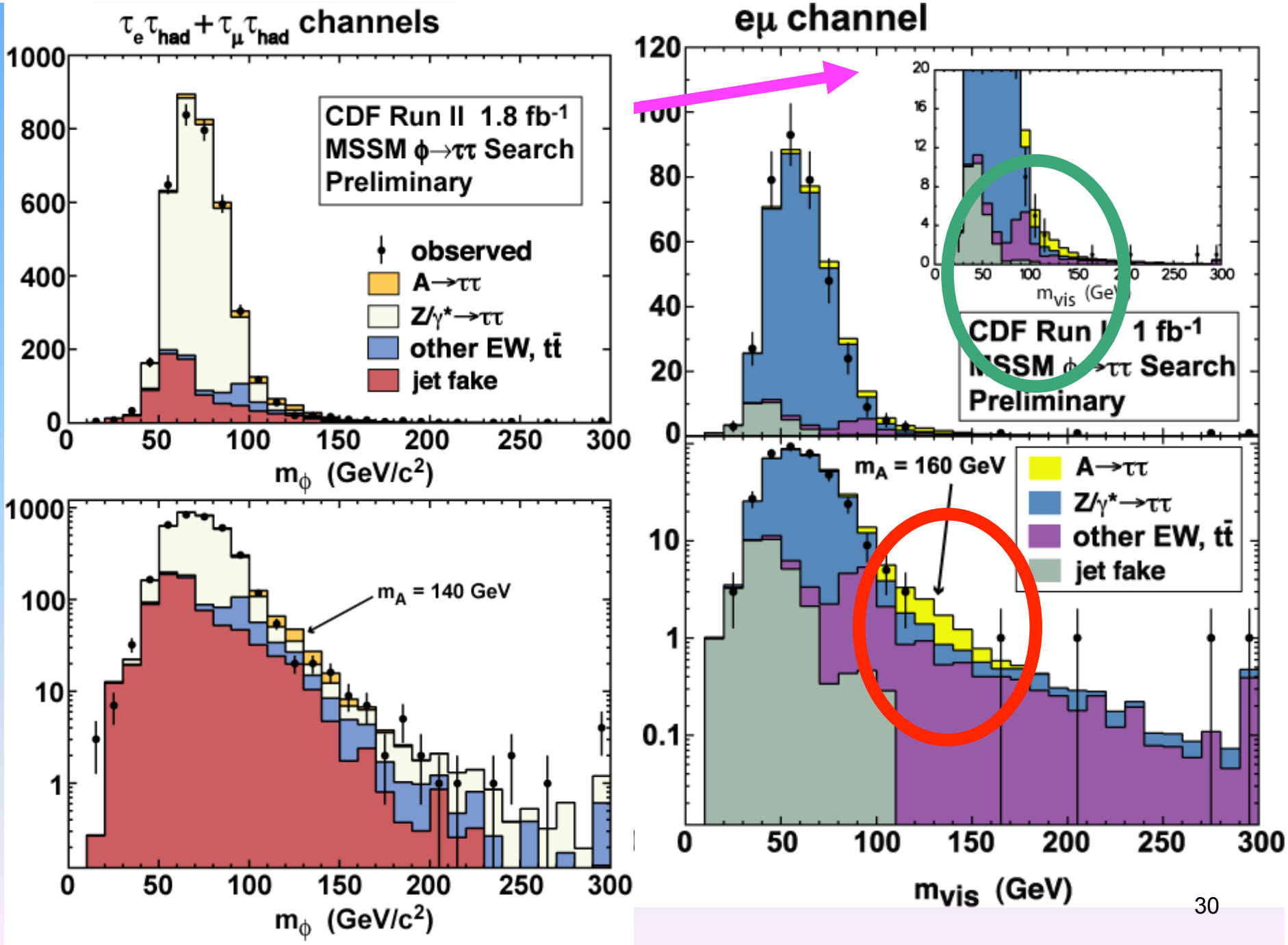


via top loop

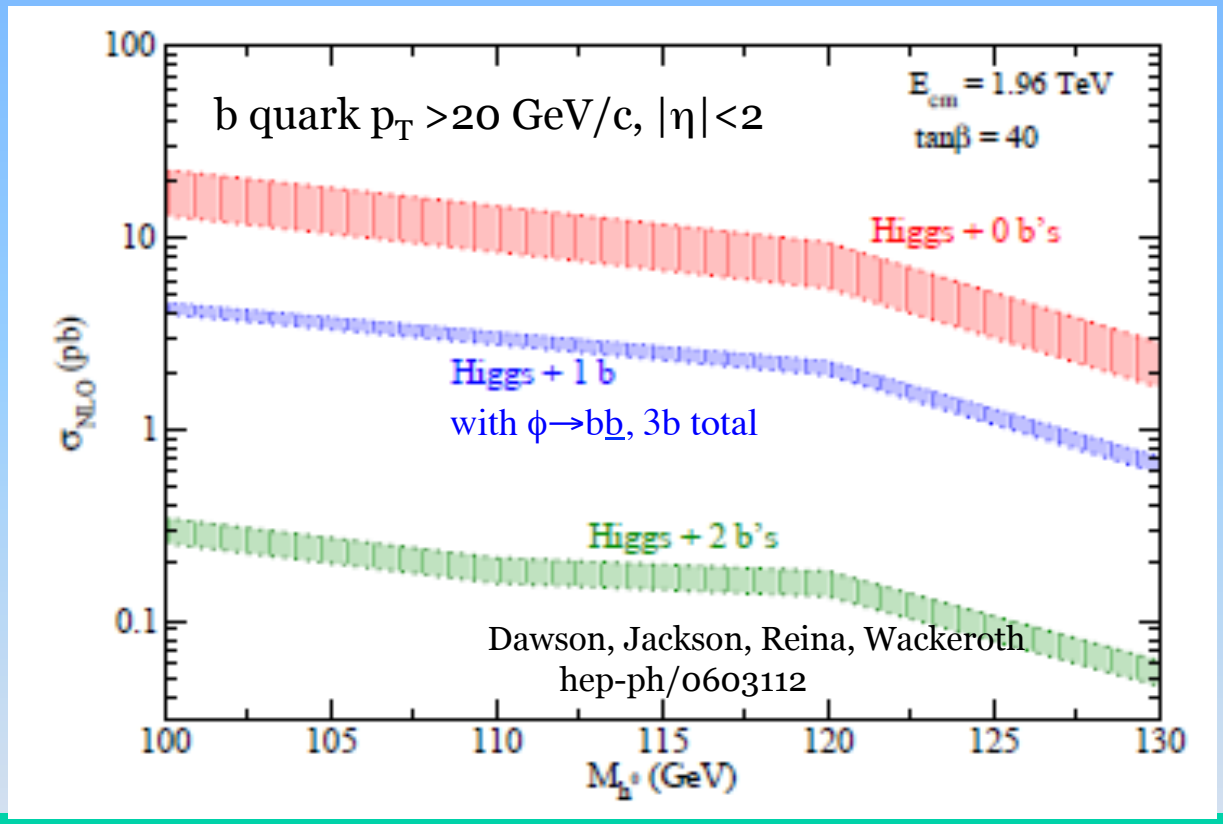
H = SM Higgs

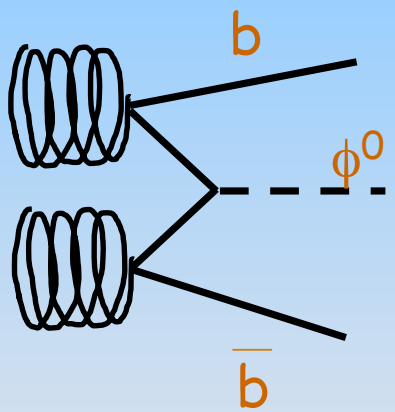
ϕ^0 = h/H/A

here, H = A or h/H


$\tau_e\tau_{had} + \tau_\mu\tau_{had}$ channels
CDF Run II 1.8 fb^{-1}
MSSM $\phi\to\tau\tau$ Search
Preliminary
observed
$A\to\tau\tau$
$Z/\gamma^*\to\tau\tau$
other EW, $t\bar{t}$
jet fake
m_ϕ (GeV/c^2)
m_A = 140 GeV
$e\mu$ channel
m_A = 160 GeV
m_{vis} (GeV)

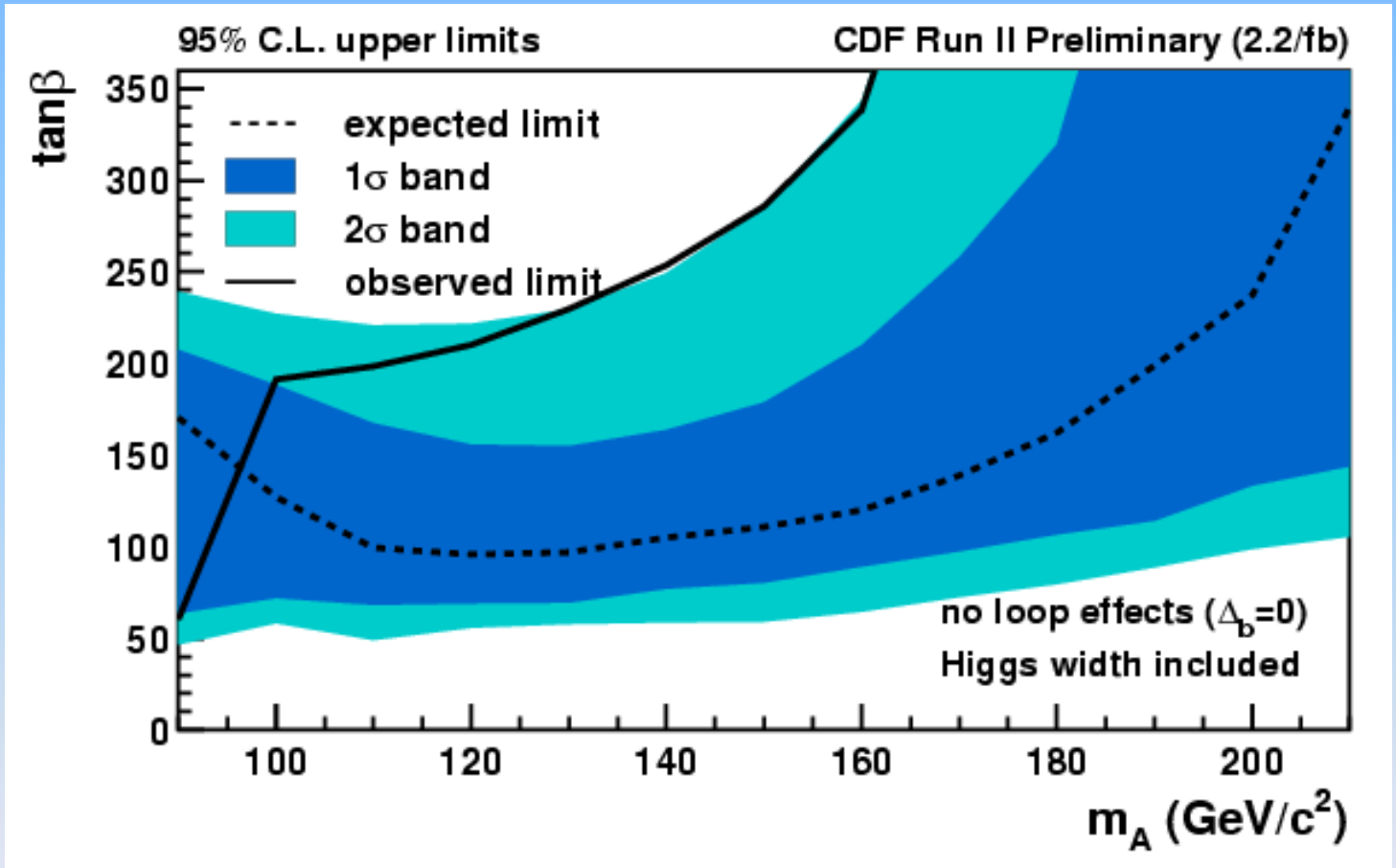
The $\phi \rightarrow b\underline{b}$ Channel



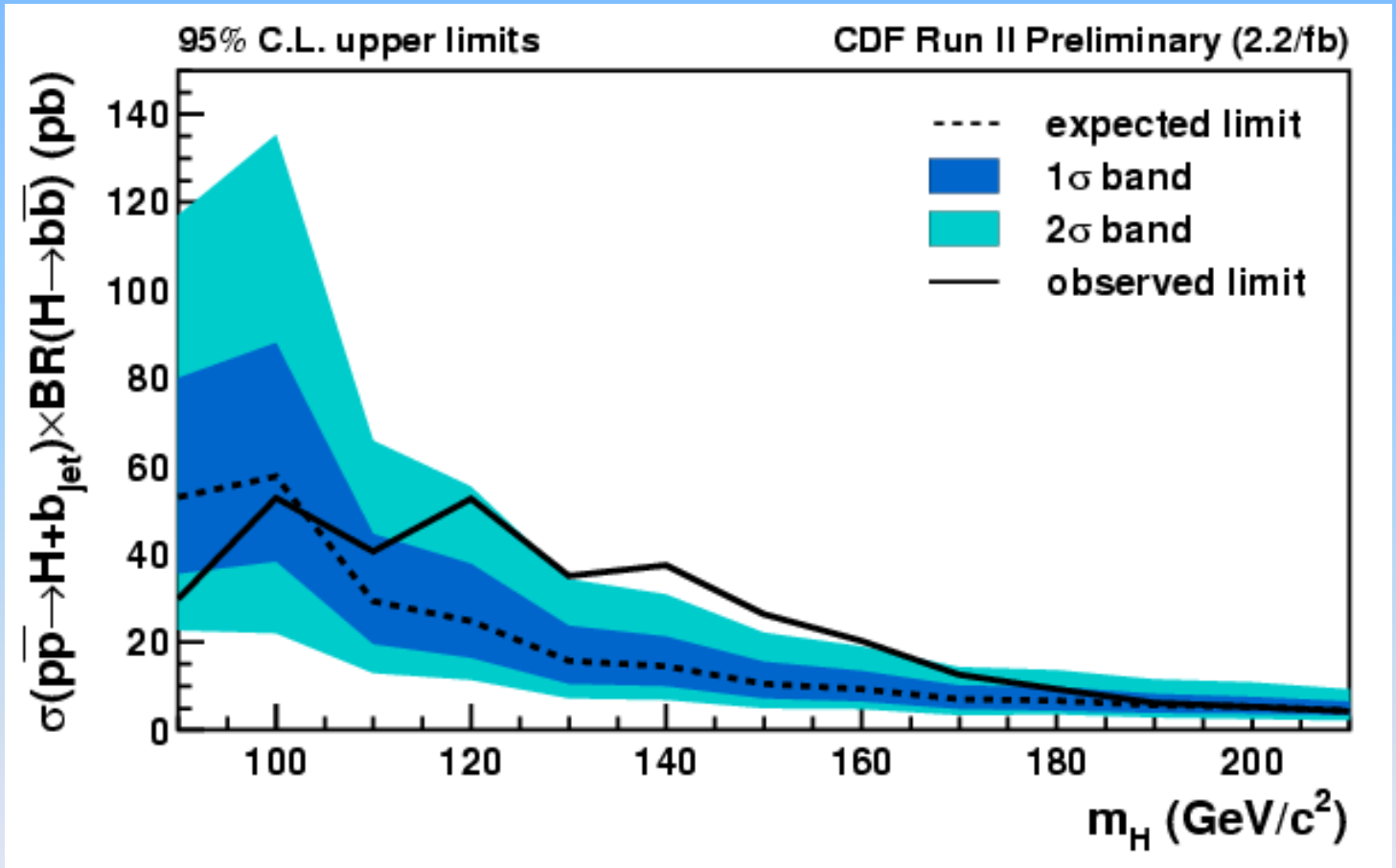


- Inclusive $H \rightarrow b\underline{b}$ is too hard due to QCD background
- Require one additional bottom quark jet besides the two from Higgs decay
  - "3b" channel best compromise between signal and background rates

CDF 3b Alternative SUSY Scenario



CDF 3b Linear Scale



Items not covered

Doubly Charged Higgs:

D0: $M(H_L^{++,--})>150$ GeV/c^2 , $M(H_R^{++,--})>127$ GeV/c^2

CDF: $M(H_L^{++,--})>133,136,115$ GeV/c^2 ($ee,e\mu,\mu\mu$), $M(H_R^{++,--})>113$ GeV/c^2 \\

CDF: LFV $e\tau,\mu\tau$: $M(H^{++,--})>114,112$ GeV/c^2 , long lived: $M(H_L^{++,--})>133$ GeV/c^2 ,

$M(H_R^{++,--})>109$ GeV/c^2 ,M(Degenerate)>146 GeV/c^2

Charged Higgs:

Direct search for decay to cs: CDF: $B(t\rightarrow H^+b)<0.1$ to 0.3

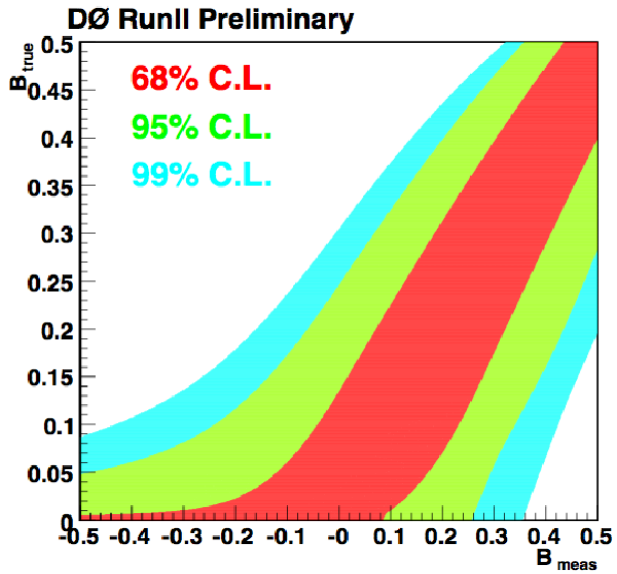
$60<m_{H+}<150$ GeV/c^2

Direct search for decay to tb -> Wbb -> lvbb: $\tan\beta$ of order 1,5,10,

$180<m_{H+}<300$ GeV/c^2, σ x Br 14 to 5 pb

General search for all H+ decays considered in top decays.

Charged Higgs



CDF : use dilepton, l+jets (single and double-tagged), and lepton+tau σ's

Consider $H^+ \rightarrow \tau\nu$, $c\underline{s}$, $t^*\underline{b}$, $W^+b\underline{b}$

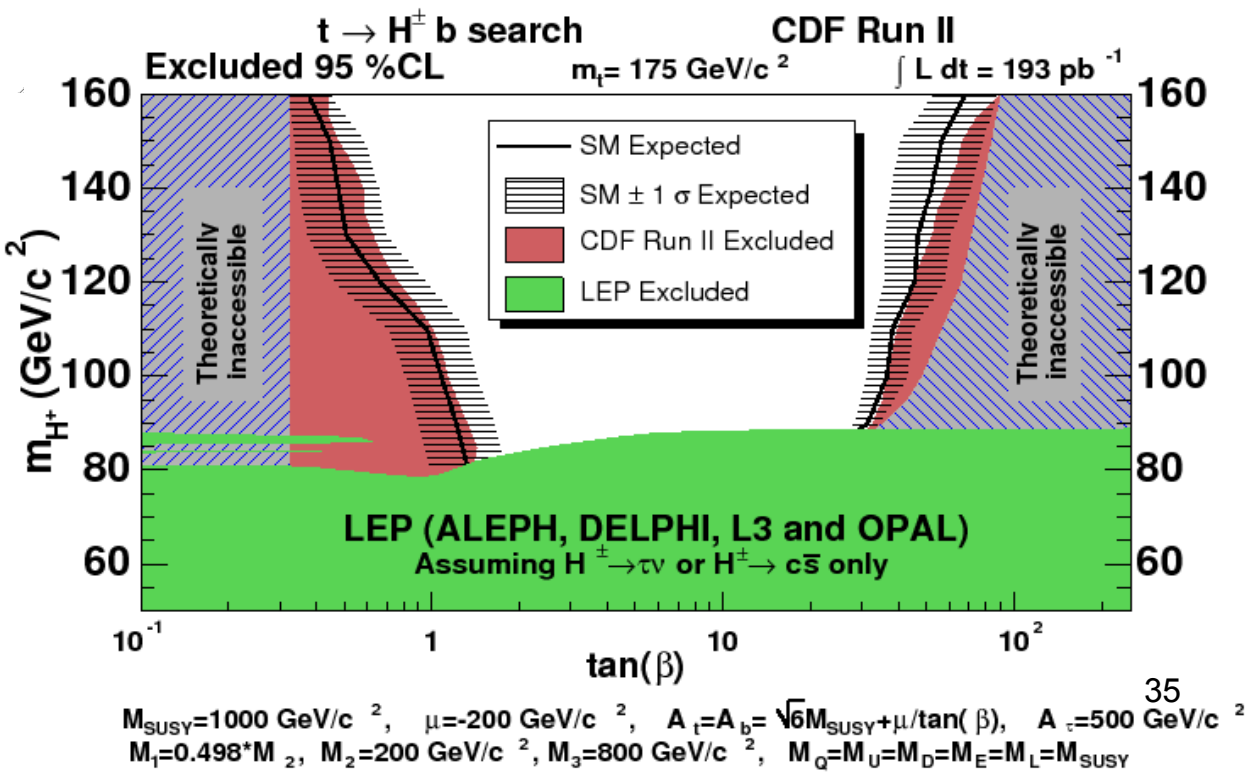
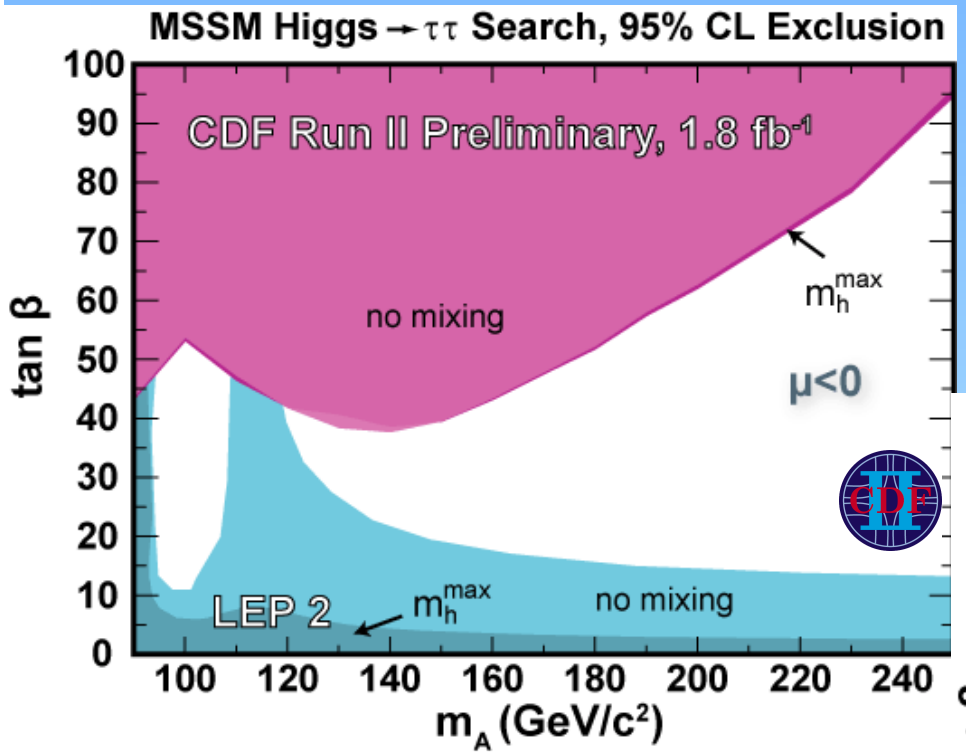
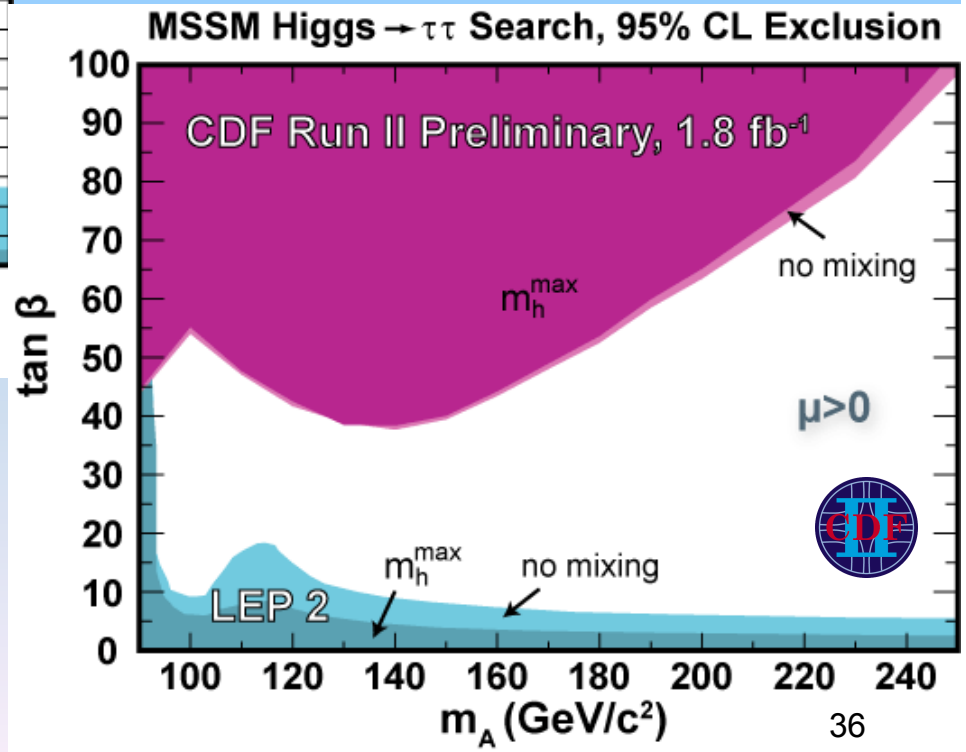
Map out allowed and excluded regions in m_{H+} vs $\tan\beta$ using CPsuperH and CDF simulation to predict effects on top σ's

Search in top decays

$t \rightarrow H^+b$

DØ : ration of cross sections l+jets/dilepton

BR($t \rightarrow H^+b$) < 0.35 @ 95% CL (for $H^+ \rightarrow c\underline{s}$)



CDF ττ MSSM Intepretation