Imperial College London

Search for Supersymmetric Neutral Higgs Bosons at the Tevatron

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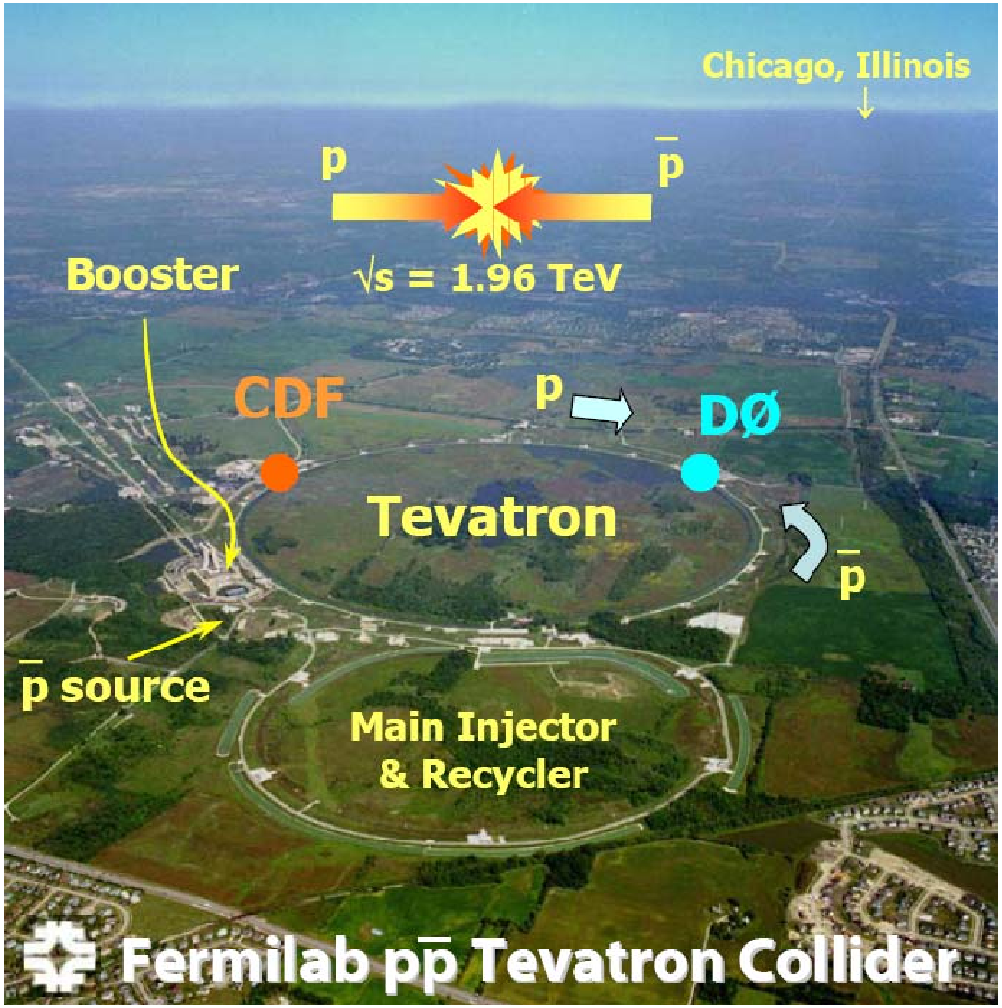
On behalf of the CDF and DØ Collaborations

Outline

- Introduction
  - Tevatron & experiments
- Neutral SUSY Higgs Searches
  - Minimal Supersymmetric SM
  - Fermiophobic Higgs
- Prospects & Conclusions

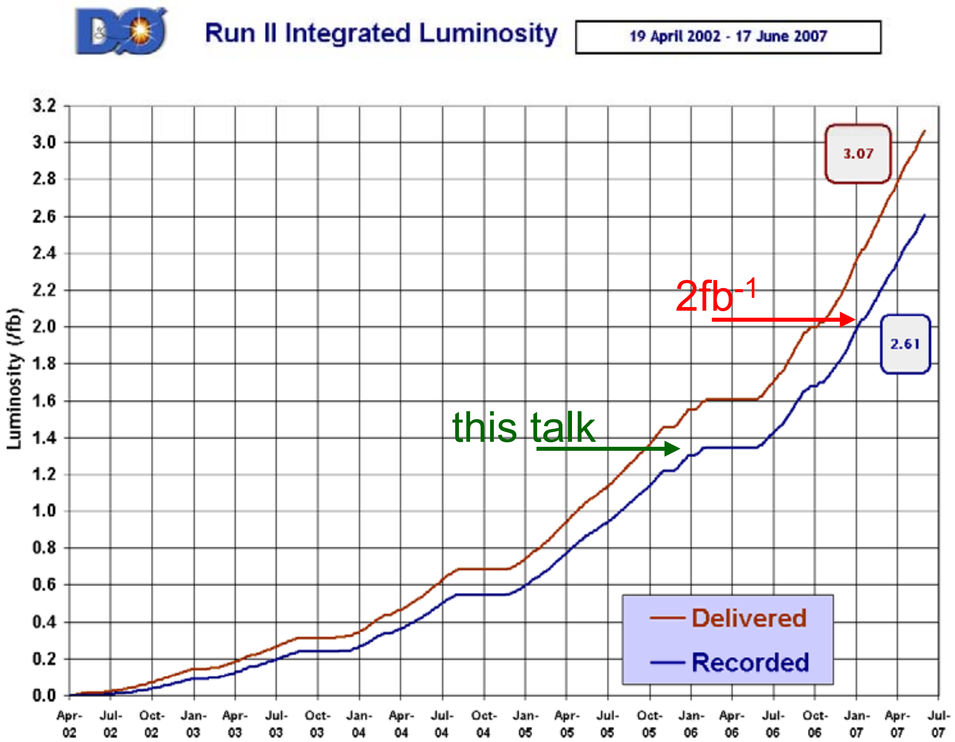


[Thanks to all my Tevatron colleagues]

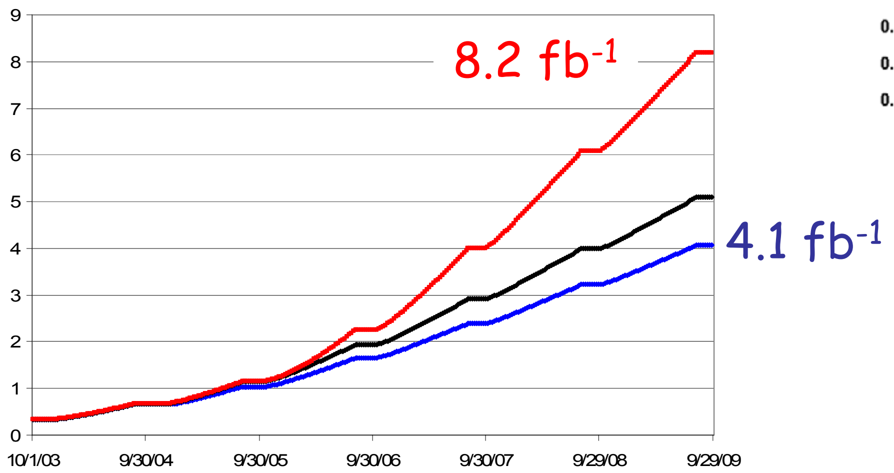
Tevatron Performance

Tevatron continues to perform well

- Over 3fb^{-1} delivered to each experiment
- Peak luminosities of ~3 x10^{32}



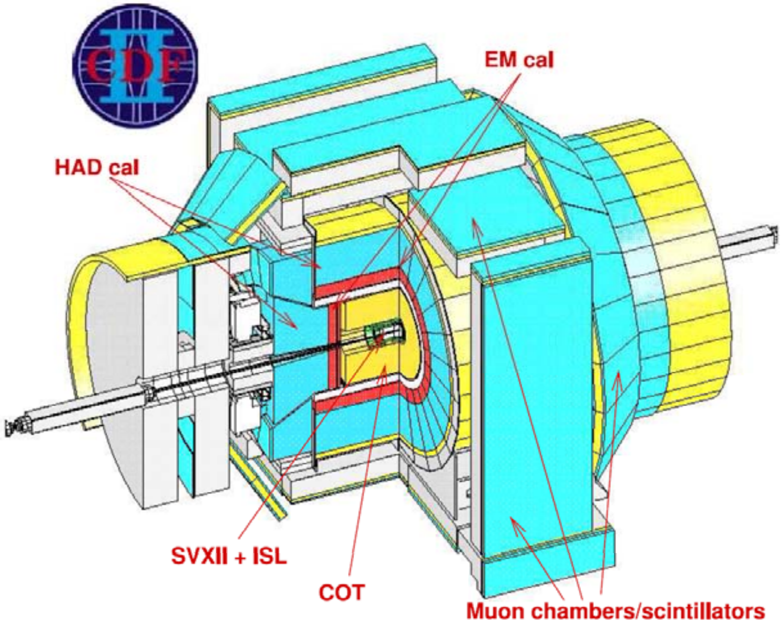
Total Luminosity



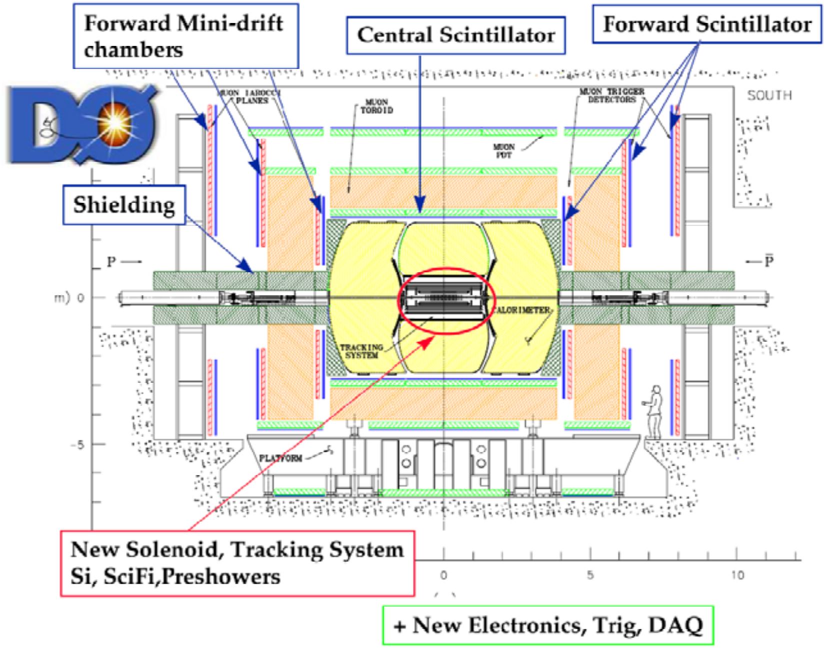
- Performance matching design integrated luminosity of ~7-8fb^{-1} by 2009

CDF and DØ experiments

- Both detectors extensively upgraded for Run IIa
  - New silicon vertex detector
  - New tracking system
  - Upgraded μ chambers



- CDF: New plug calorimeter & ToF



- DØ
  - New solenoid & preshowers
  - **Run IIb: New inner layer in SMT & L1 trigger**

Neutral SUSY Higgs

- Introduction

- Minimal Supersymmetric Standard Model (MSSM)
  - Introduction
    - Analysis Tools
  - Neutral Higgs bosons (ϕ) searches

    $\phi \rightarrow \tau\tau$

    $b\phi \rightarrow b\tau\tau$

    $b\phi \rightarrow bbb$

- Fermiophobic Higgs

- Prospects & Conclusions

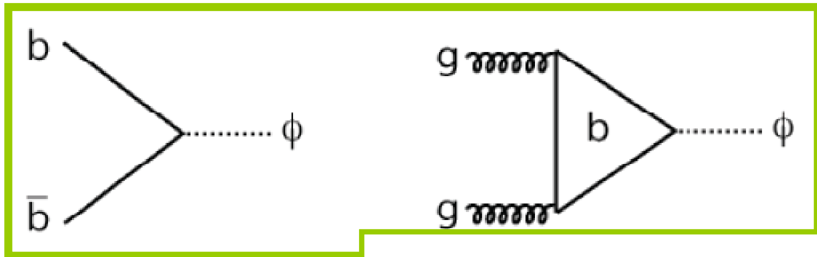
Higgs bosons in the MSSM

- MSSM has 2 Higgs doublets
  - H_u (H_d) couple to up- (down-) type fermions
  - After EWSB 5 Higgs particles : **h, H, A**, H^+, H^-
    - h has to be light: m_h < ~140 GeV
  - At tree level, 2 independent parameters: m_A and tanβ
    - tanβ: Ratio of VEV's = $\langle H_u \rangle / \langle H_d \rangle$
- At large tan β:
  - Coupling of A, h/H to down-type fermions, e.g. *b*-quark, enhanced wrt SM

    $\longrightarrow$ production amplitude ~tanβ $\longrightarrow$ production cross section **~tan$^2\beta$**
  - h/H & A (denoted by ϕ) ~degenerate in mass $\longrightarrow$ further increase in cross-section
- For low & intermediate masses
  - Br ($\phi \longrightarrow$ bb) ~90%, Br ($\phi \longrightarrow \tau\tau$) ~10%

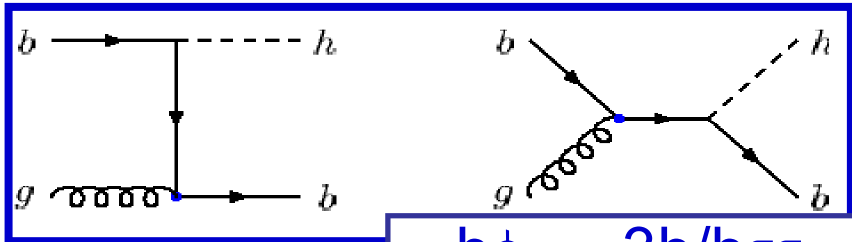
MSSM Higgs boson production

- Signatures
  - Higgs decays to 2 τ's
  - Further decays of τ's define final states

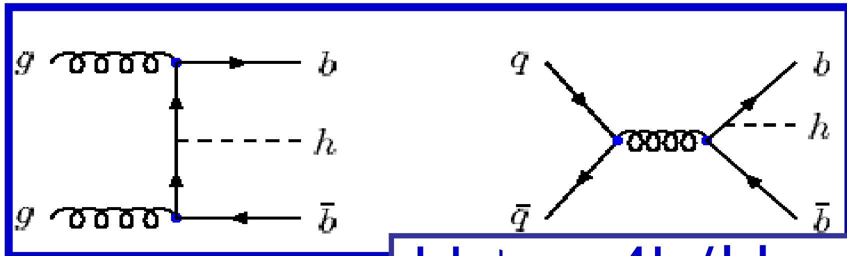


$\phi \rightarrow \tau\tau$

  - Higgs decays to 2 high p_T b-jets/2 τ's
  - 1 or 2 associated b-quarks



$b\phi \rightarrow 3b/b\tau\tau$



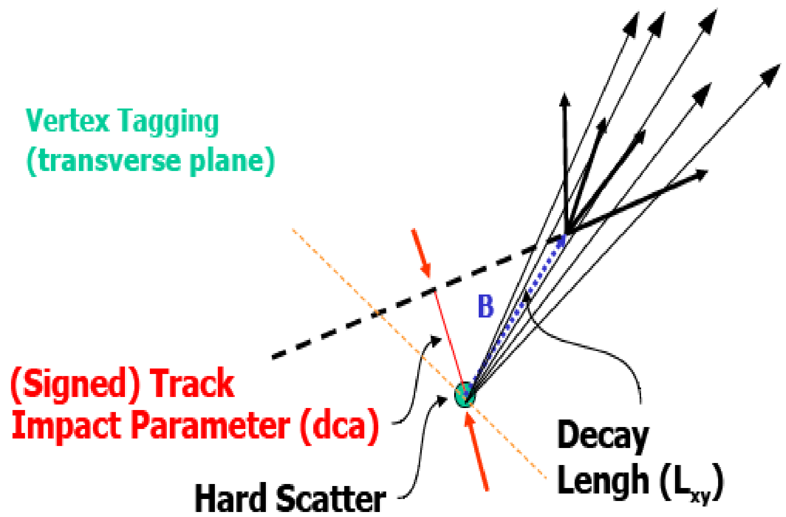
$bb\phi \rightarrow 4b/bb\tau\tau$

- Good b-jet and τ identification vital

Similar overall sensitivities $\rightarrow$ Combine

b-jet Identification

- MSSM Higgs → bb ~90% of time
  - Improves S/B by > 10
- Use lifetime information
  - Correct for MC/data differences
    - Measured at given operating points



CDF: Secondary vertex reconstruction

- Neural Net - improves purity
- Inputs: track multiplicity, p_T, vertex decay length, mass, fit

- **Loose = 50% eff, 1.5 % mis-tag**
- **Tight = 40% eff, 0.5 % mis-tag**

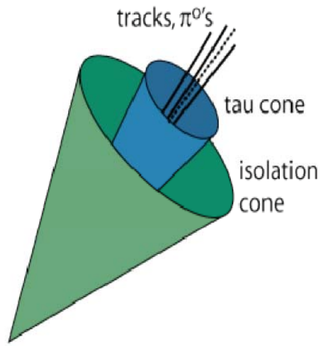
DØ: Neural Net tagger

- Secondary vertex & dca based inputs, derived from basic b-tagging tools
- High efficiency, purity

- **Loose = 70% eff, 4.5% mis-tag**
- **Tight = 50% eff, 0.5% mis-tag**

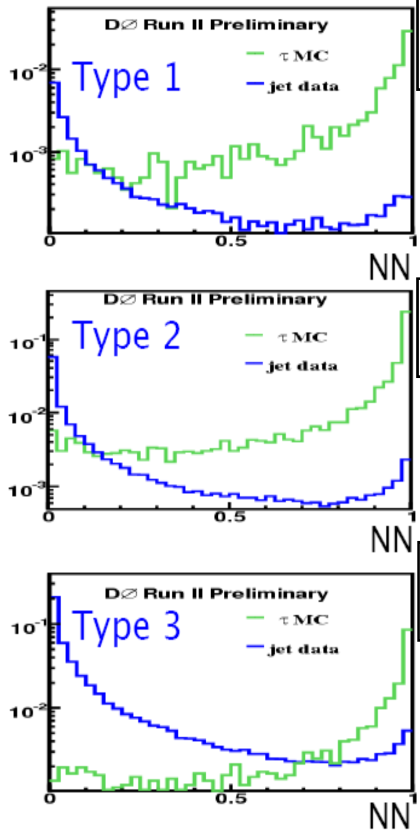
τ_{had}-Identification

- CDF: Isolation based



- Require 1 or 3 tracks, p_T > 1 GeV in the isolation cone
  - For 3 tracks 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
- Performance
  - Efficiency ~ 40-50%
  - Jet to τ fake rate ~0.001-0.005

- DØ: 3 NN's for each τ type
  - Validated via Z's



$\tau^{\pm} \rightarrow \pi^{\pm} \upsilon$

$\tau^{\pm} \rightarrow \pi^{\pm} \pi^{0} \upsilon$

$\tau^{\pm} \rightarrow \pi^{\pm} \pi^{\pm} \pi^{\pm} (\pi^{0}) \upsilon$

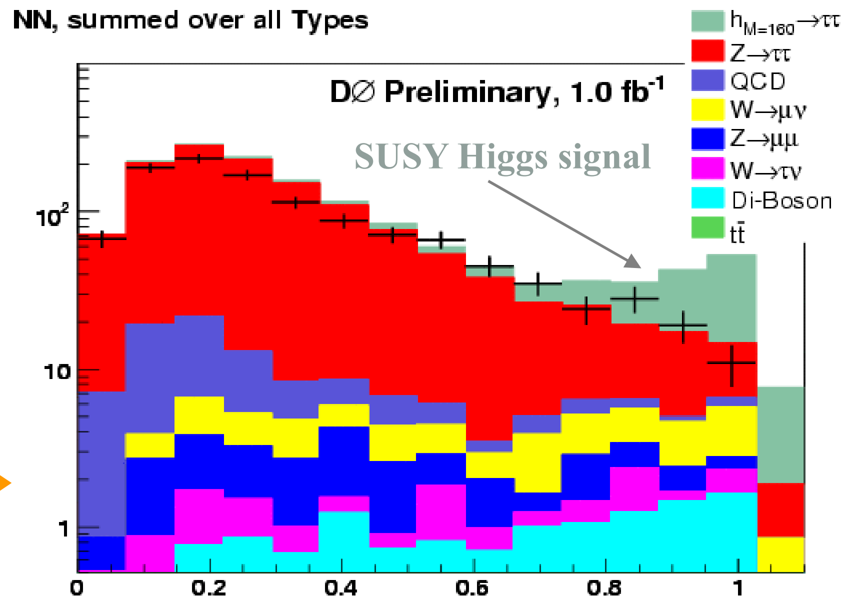
Eff

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

Neutral MSSM Higgs $\rightarrow \tau_l \tau_{had/l}$

- Main bkgs.: $Z \rightarrow \tau\tau$ (irreducible), multi-jet, W+jets, $Z \rightarrow \mu\mu$, ee, di-boson

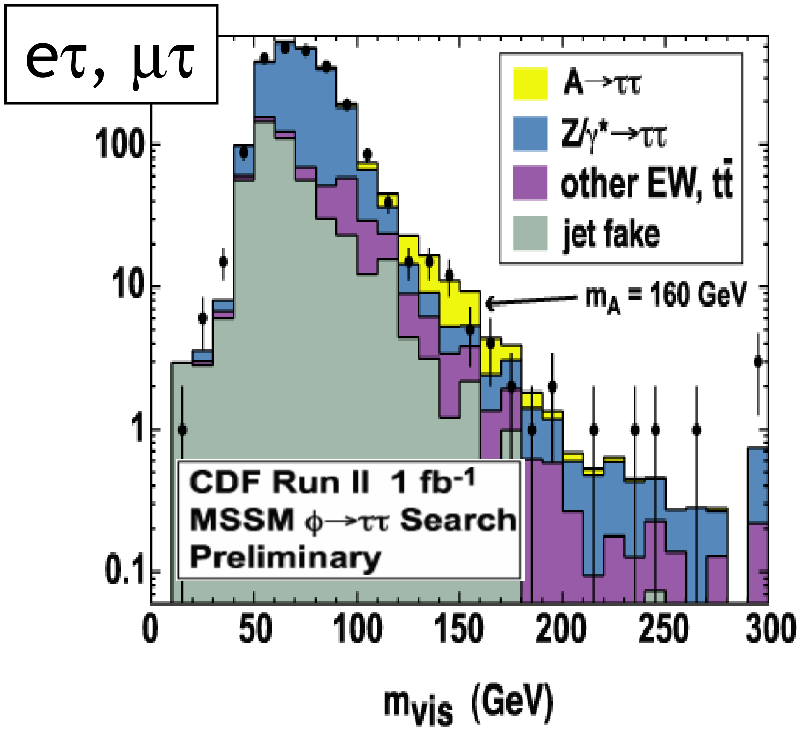
- DØ (μ channel only):
  - Only 1 isolated μ separated from hadronic τ with opposite sign
  - m_W < 20 GeV removes most of remaining W+jets bkg.
  - Optimized NNs to separate signal from bkg.

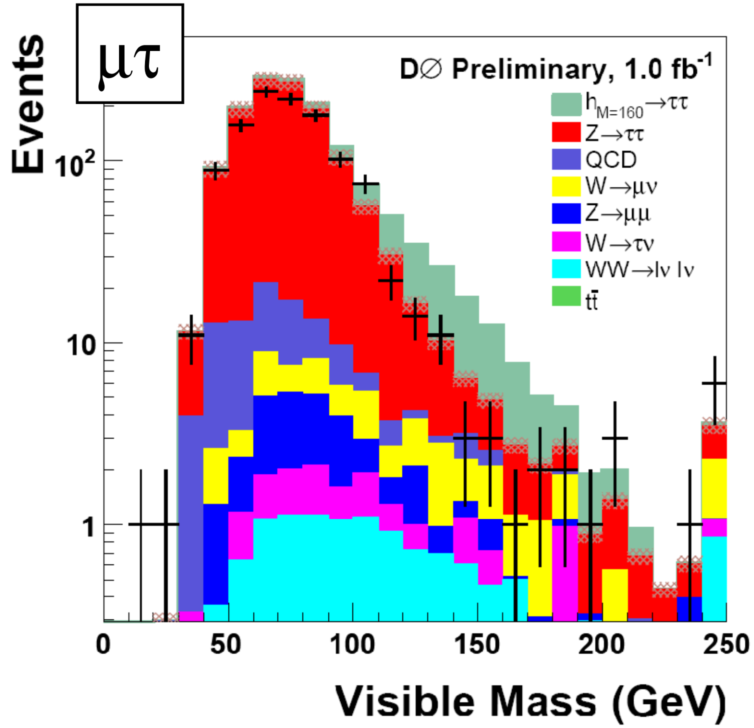


- CDF (μ, e, e+μ channels)
  - Isolated e or μ separated from hadronic τ with opposite sign
  - Multi-jet background suppression: $|p_t^l| + |p_t^{had}| + |\not{E}_T| > 55$ GeV
  - Cut on relative directions of the visible τ decay products and missing E_T removes W+jets bkg.

Neutral MSSM Higgs → $\tau_l\tau_{had}$

- CDF: Cross-section limits - derived from m_{vis} distribution
  - Observed limits weaker than expected due to an excess in data sample, but significance ≤ 2σ once all search channels & windows considered

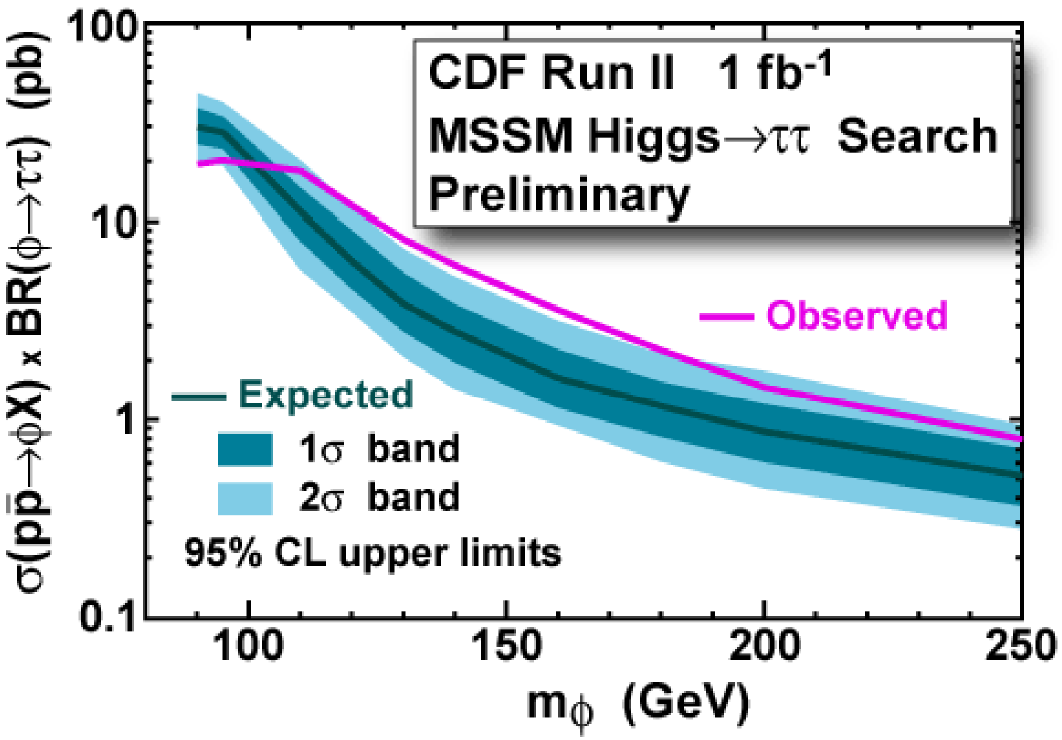


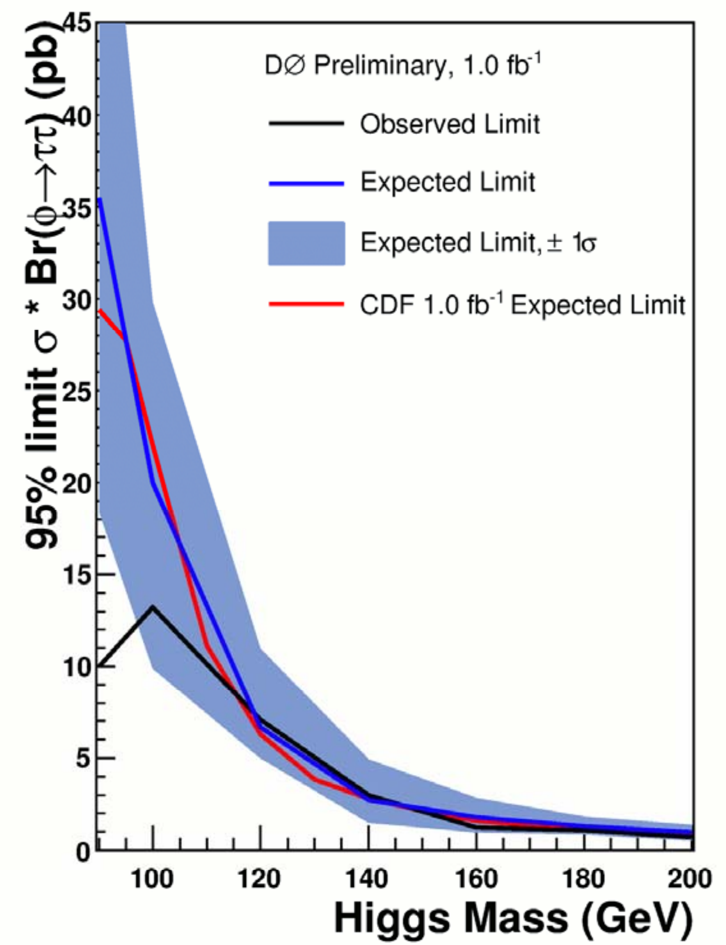


- DØ: Cross-section limits – derived from NNs for the different τ types

Neutral MSSM Higgs → $\tau_l \tau_{had}$

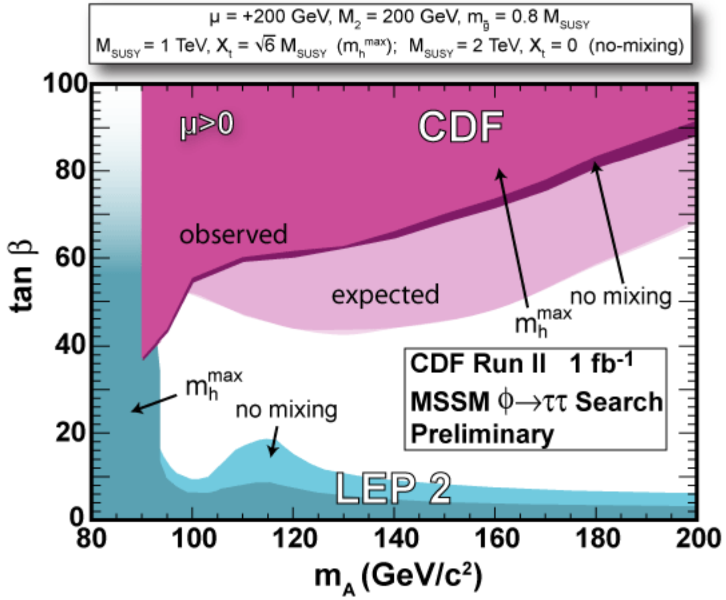
- Proceed to set limits
- σ **x** Br ($\phi \rightarrow \tau\tau$)

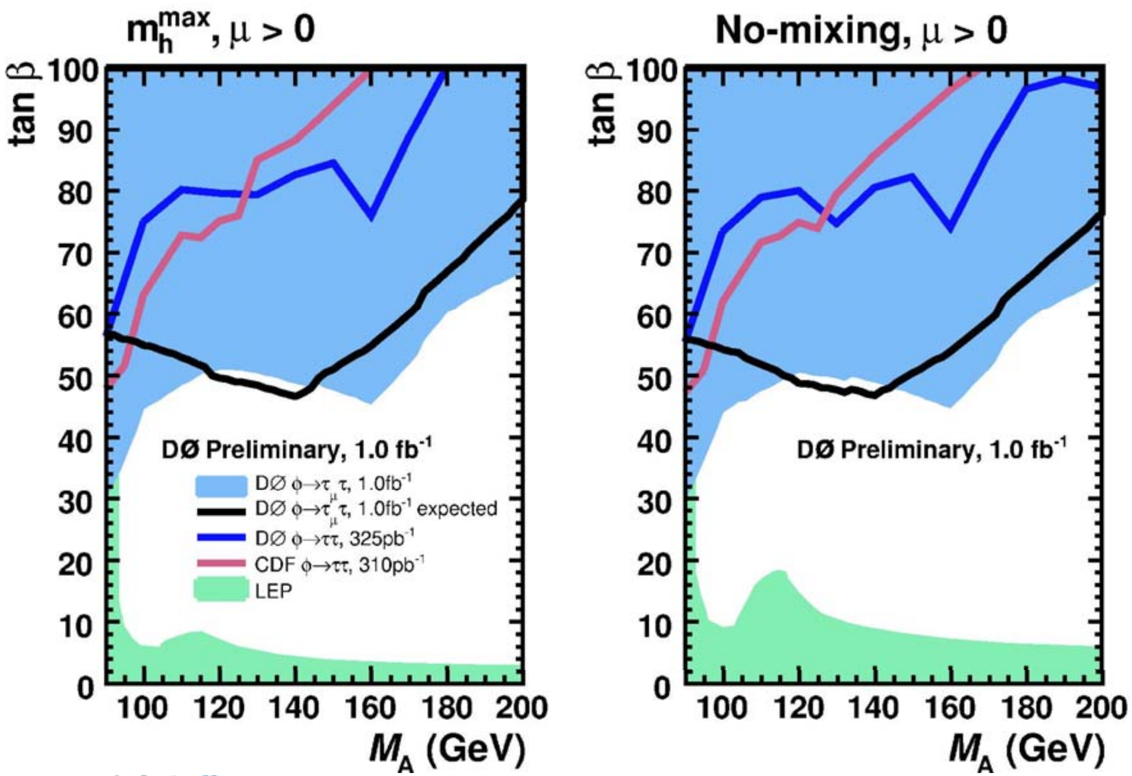


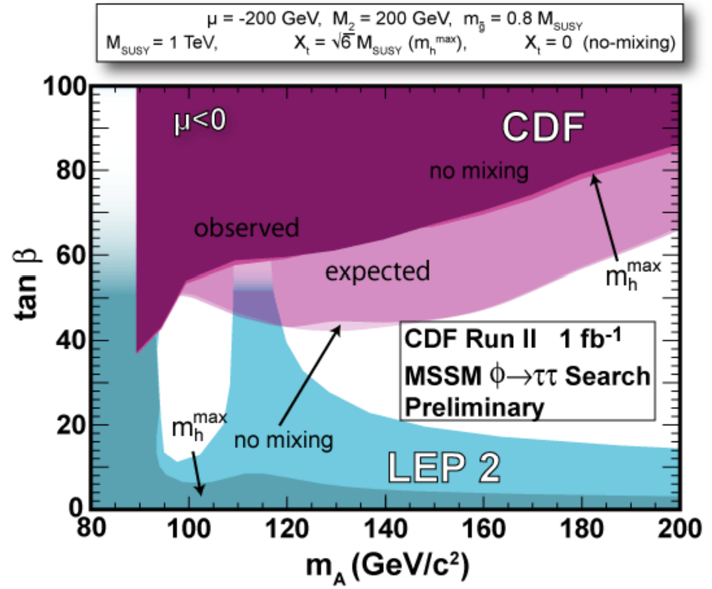


Neutral MSSM Higgs $\to \tau_l\tau_{had}$

- MSSM parameter space
  - Use no-mixing & m_h^{max} benchmark scenarios
  - $90 < m_A < 200$ GeV,
  - $\tan\beta > 40 - 60$ excluded

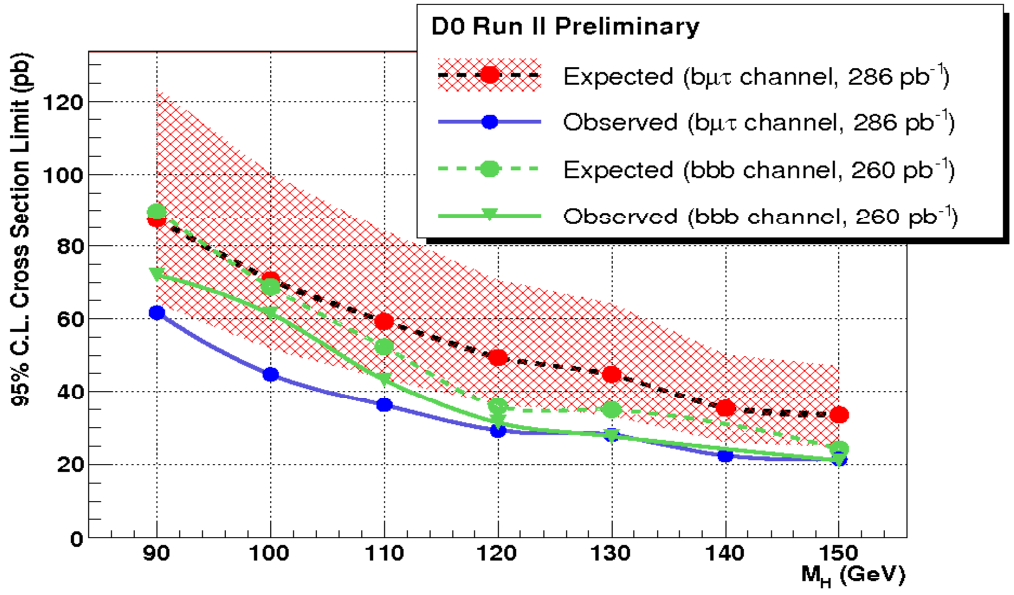






Neutral MSSM Higgs → $\tau_l \tau_{had}$ + b

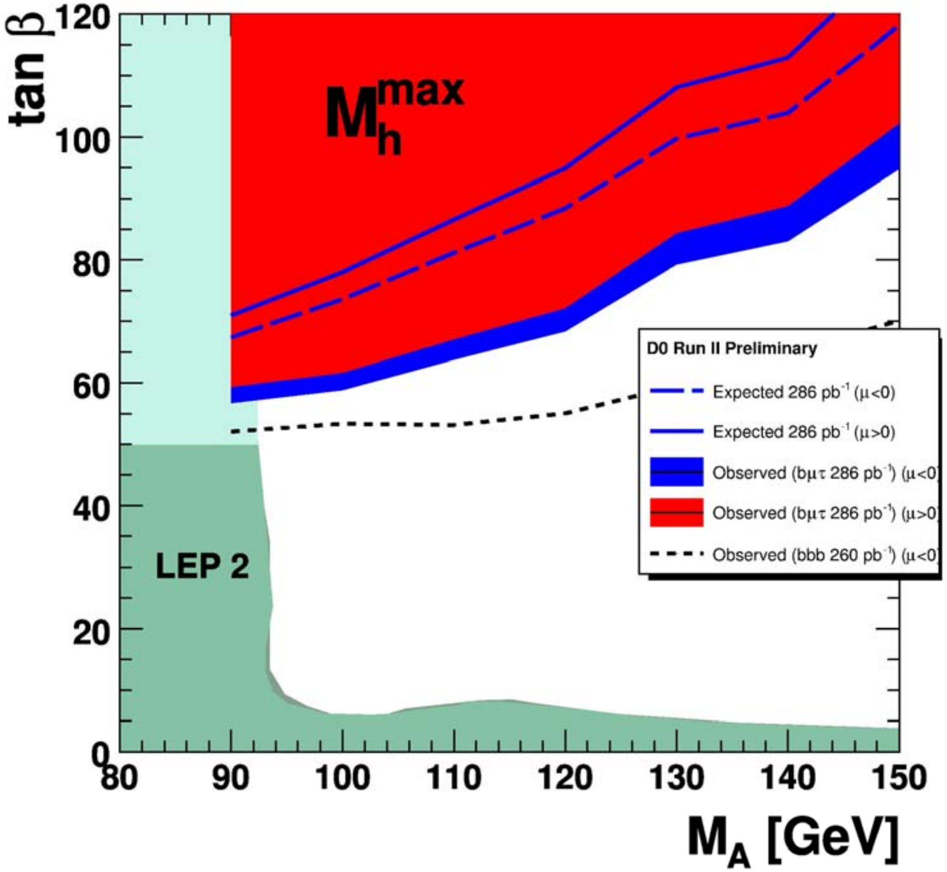
- DØ: ICHEP 2006 (344 pb^{-1})
- Main bkgs.: $Z+(b)$jets → $\tau\tau/\mu\mu+(b)$jets, multi-jet, $t\bar{t} \rightarrow bb\tau\mu$, W+jets, WW
- μ channel only:
  - 1 isolated μ separated from the hadronic τ with opposite sign
  - τ identification: NN cuts optimised for analysis
  - 1 IP b-tagged jet
  - Optimized kinematic NN to separate signal from $t\bar{t}$ bkg.

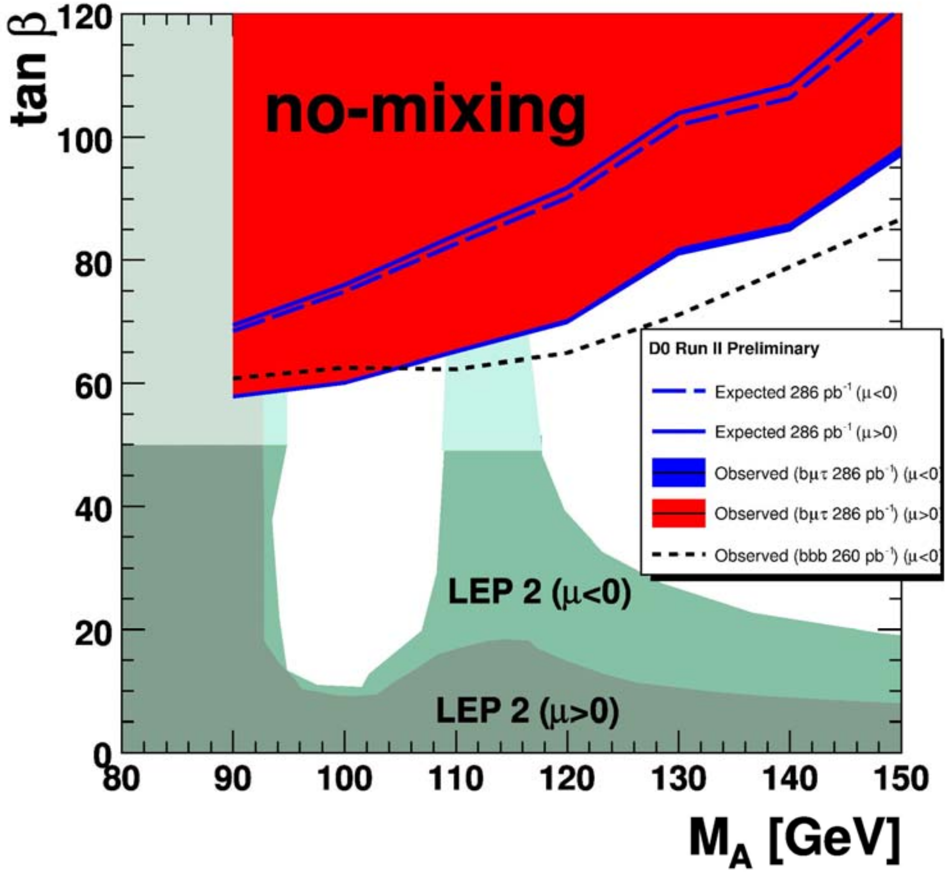


- No excess: Set Limits
  - Limits set using m_{vis}
  - Competitive with bbb channel even with 1:9 branching ratio

Neutral MSSM Higgs → $b\tau_l\tau_{had}$

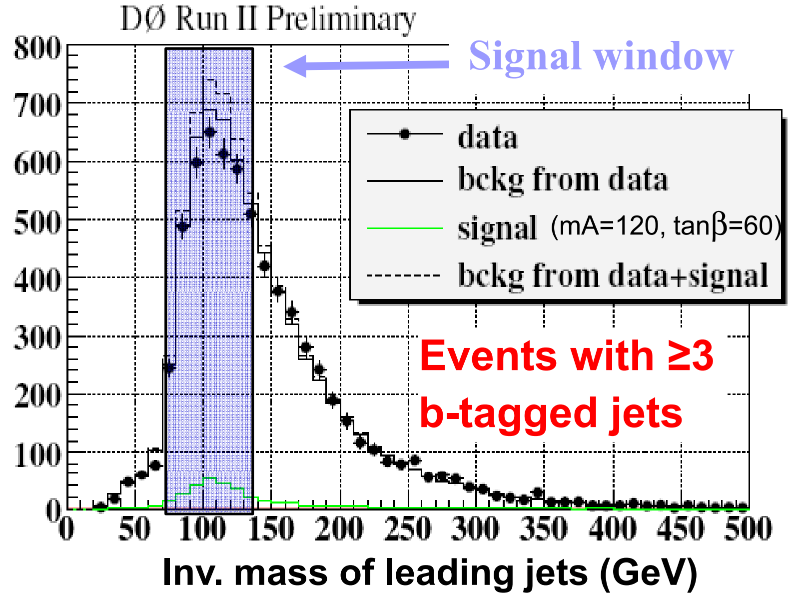
- Limits in MSSM parameter space
  - Use no-mixing & m_h^{max} benchmark scenarios

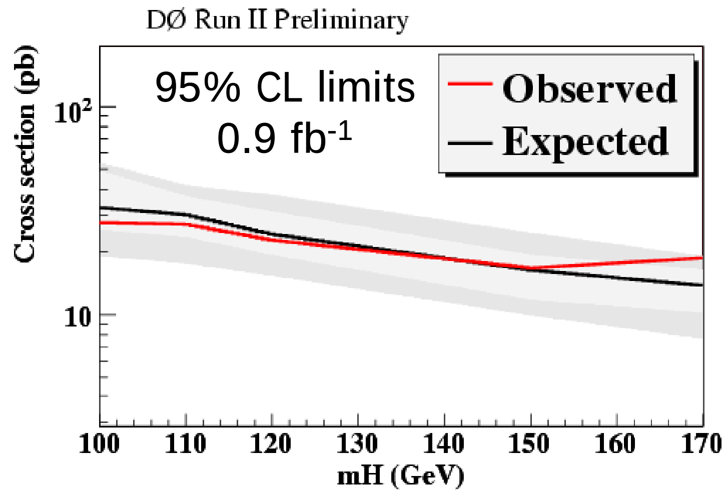




Neutral MSSM Higgs → bb + b[b]

- DØ: ICHEP '06
- ≥ 3 b-tagged jets: p_T> 40, 25, 15 GeV
  - Invariant mass of 2 leading jets peaks at Higgs mass
- Backgrounds from data
  - Shape estimated from double-tagged di-jet mass spectrum
  - Rate normalized outside signal window
- Agreement between data & predicted background → set upper limits
- Preliminary analysis being optimized
  - New version this summer





Fermiophobic Higgs

- Introduction
- Minimal Supersymmetric Standard Model (MSSM)
  - Introduction
    - *b*-jet Identification
    - τ Identification
  - Neutral Higgs bosons (ϕ) searches

    $\phi \rightarrow \tau\tau$

    $\phi \rightarrow b\tau\tau$

    $b\phi \rightarrow bbb$
- Fermiophobic Higgs
- Prospects & Conclusions

Fermiophobic Higgs $\rightarrow 3\gamma + X$

- Some extensions of SM: coupling of Higgs to fermions suppressed
  - Searches previously carried out at LEP and Tevatron

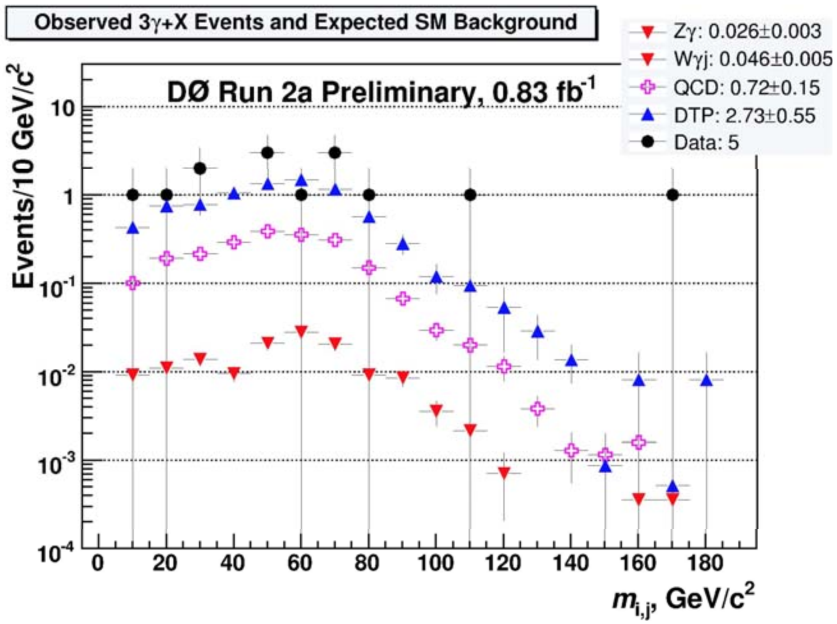
- Search channel (2 Higgs Doublet Model):

$$p\bar{p} \rightarrow h_f H^{\pm} \rightarrow h_f h_f W^{\pm} \rightarrow \gamma\gamma(\gamma) + X$$

- Backgrounds
  - Direct 3γ production (DTP)
  - Jets or electrons misidentified as γ
  - Estimated from data

- Cuts
  - 3γ with $|\eta|<1.1$, $E_T^{1,2,3} > 30, 20, 15$ GeV
  - $H_T(3\gamma) > 25$GeV
    - Rejects 3-particle events

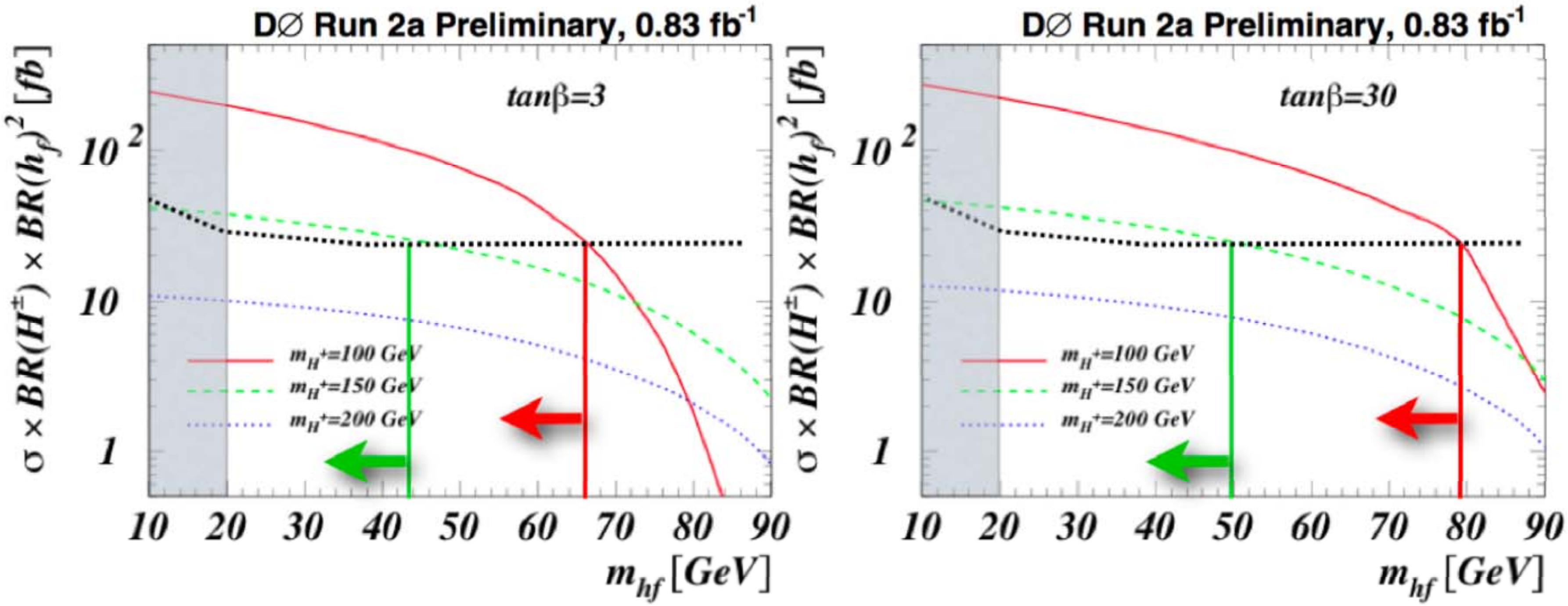
- 0 events seen for 1.1 expected



Fermiophobic Higgs $\rightarrow 3\gamma + X$

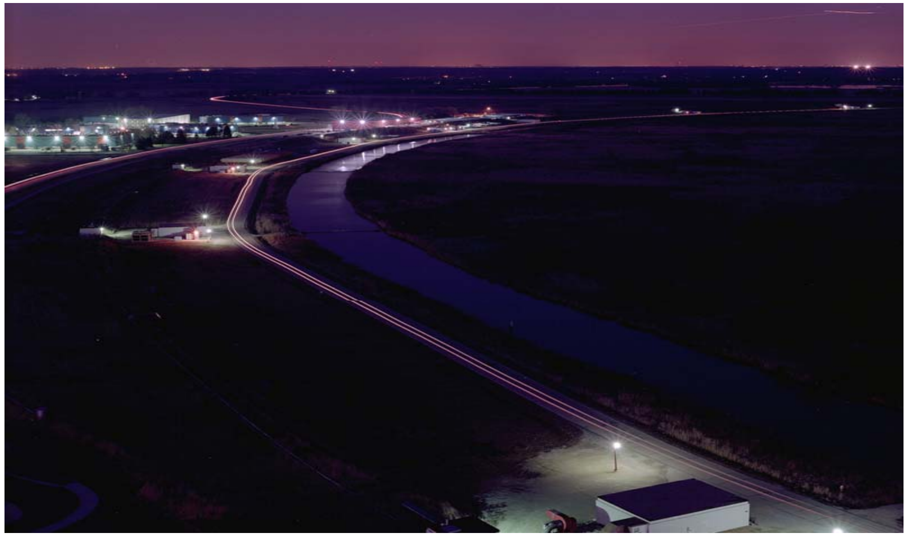
- No excess, set limits:
  - 95% CL limit: $\sigma(hH^{\pm}) < 25.3$fb

- Exclusion on mass of h_f for different charged Higgs masses ($m_{H^{\pm}}$) & $\tan\beta$



Prospects and Conclusions

- Introduction
- Neutral SUSY Higgs
- Prospects and Conclusions

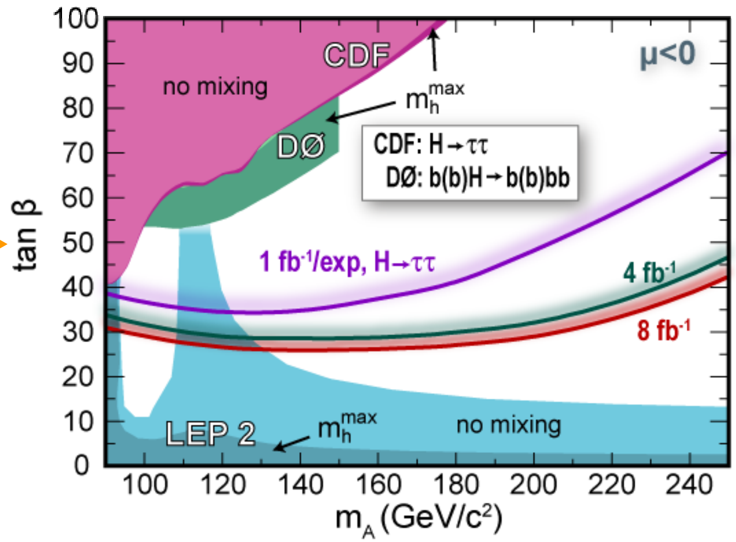


Prospects - MSSM Higgs

- 1st results from 1fb^{-1} show promising sensitivity
  - 2.5 fb^{-1} data available
  - Many algorithmic/analysis improvements

- Short term (this summer)
  - New b$\phi \rightarrow$ bb + b(b)
    - From both experiments
  - New MSSM combination
  - b$\phi \rightarrow$ bb + b(b) & $\phi \rightarrow \tau\tau$ & b$\phi \rightarrow$ b$\tau\tau$

1st combination - low statistics



- Longer term
  - Up to m_A ~250 GeV for large tanβ
  - Down to tanβ ~20 for low m_A
  - Or discovery

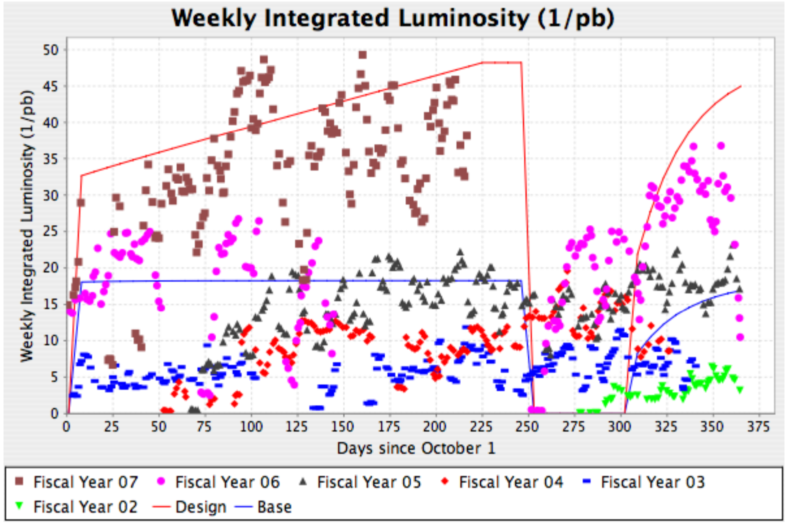
Conclusions

- Tevatron and CDF/ DØ experiments performing very well
- Wide range of SUSY Higgs searches performed by CDF & DØ with up to 1 fb^{-1} Run II data:
  - No signal observed in MSSM Higgs search, but already powerful!
- Updated CDF and DØ combinations soon
  - Rapid evolution in sensitivity
  - Over 2.5 times more data under analysis

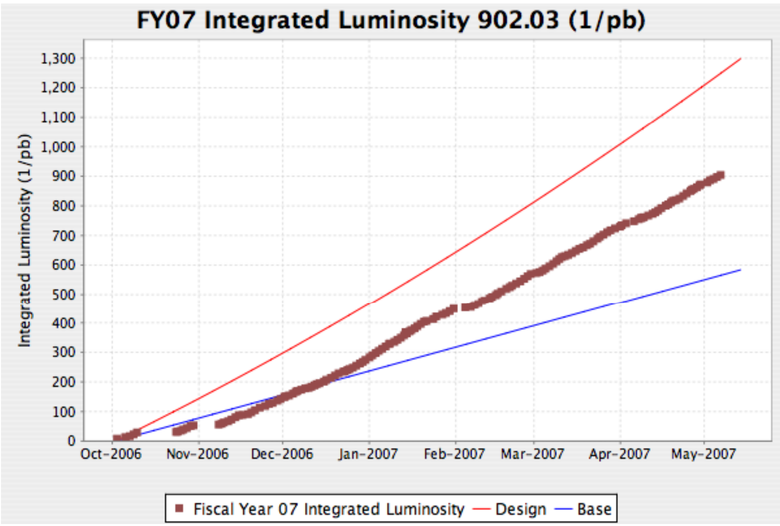
Very exciting times ahead!

Backup slides

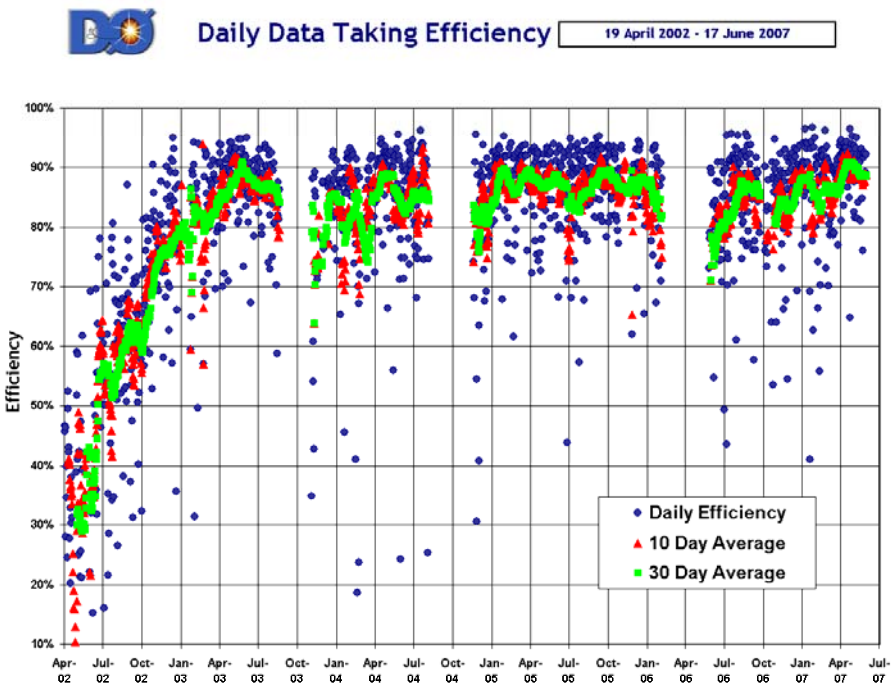
Tevatron & DØ



Weekly Integrated Luminosity (1/pb)
Weekly Integrated Luminosity (1/pb)
Days since October 1
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375
0 5 10 15 20 25 30 35 40 45 50
Fiscal Year 07
Fiscal Year 06
Fiscal Year 05
Fiscal Year 04
Fiscal Year 03
Fiscal Year 02
Design
Base



FY07 Integrated Luminosity 902.03 (1/pb)
Integrated Luminosity (1/pb)
0 100 200 300 400 500 600 700 800 900 1,000 1,100 1,200 1,300
Oct-2006 Nov-2006 Dec-2006 Jan-2007 Feb-2007 Mar-2007 Apr-2007 May-2007
Fiscal Year 07 Integrated Luminosity
Design
Base



Daily Data Taking Efficiency
19 April 2002 - 17 June 2007
Efficiency
10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Apr-02 Jul-02 Oct-02 Jan-03 Apr-03 Jul-03 Oct-03 Jan-04 Apr-04 Jul-04 Oct-04 Jan-05 Apr-05 Jul-05 Oct-05 Jan-06 Apr-06 Jul-06 Oct-06 Jan-07 Apr-07 Jul-07
Daily Efficiency
10 Day Average
30 Day Average

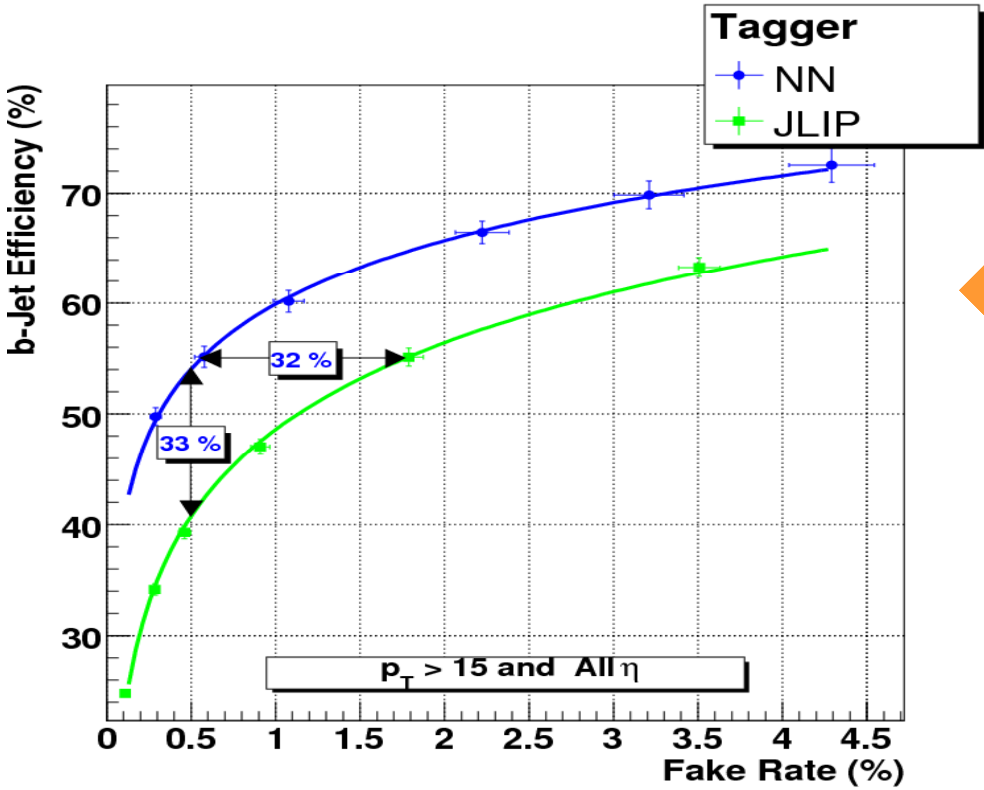
DØ B-tagging

Several mature algorithms used:

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

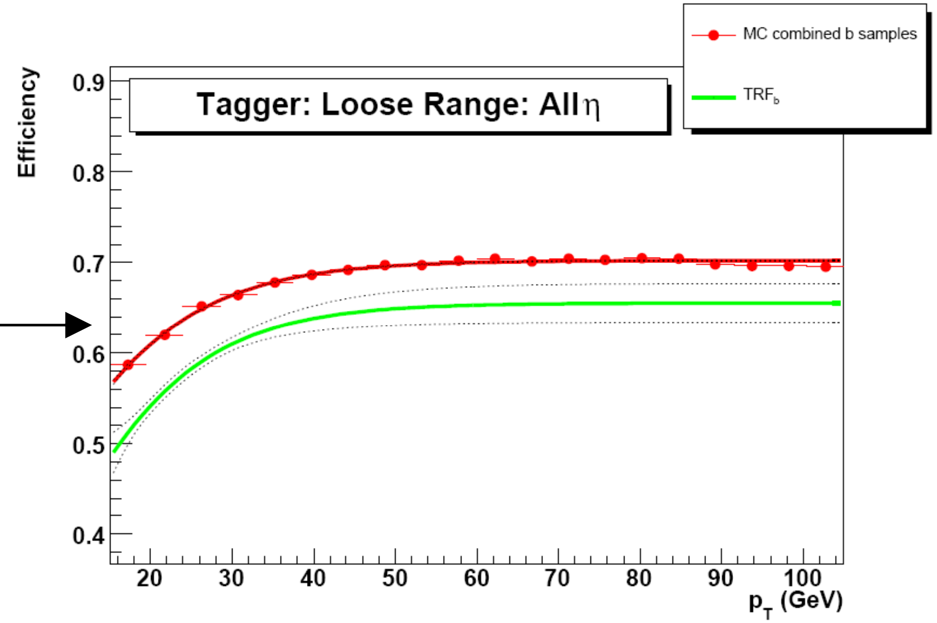
Combine in Neural Network:

- 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

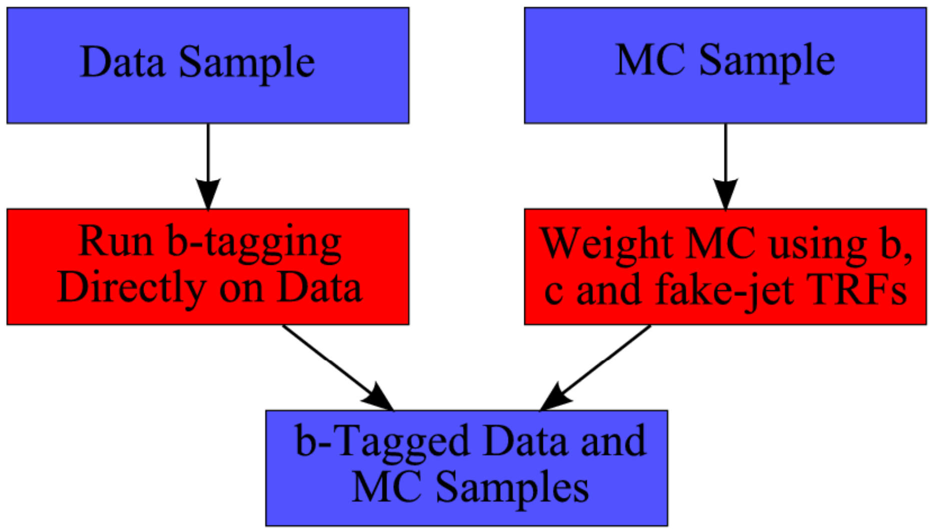


B-tagging – (DØ) Certification

- Have MC / data differences - particularly at a hadron machine
  - Measure performance on data
    - Tag Rate Function (TRF) Parameterized efficiency & fake-rate as function of p_T and η
  - Use to correct MC b-tagging rate



- b and c-efficiencies
  - Measured using a b-enriched data sample
- Fake-rate
  - Measured using QCD data



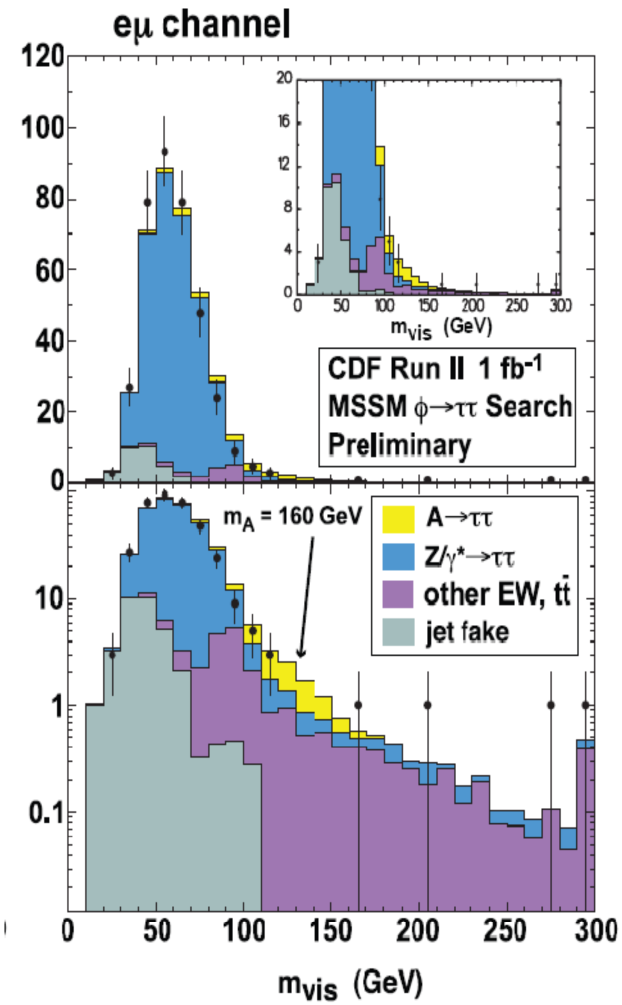
MSSM benchmarks

- Five additional parameters due to radiative correction
  - M_{SUSY} (parameterizes squark, gaugino masses)
  - X_t (related to the trilinear coupling $A_t \rightarrow$ stop mixing)
  - M_2 (gaugino mass term)
  - μ (Higgs mass parameter)
  - M_{gluino} (comes in via loops)

	m_h-max	no-mixing
M_{SUSY}	1 TeV	2 TeV
X_t	2 TeV	0
M_2	200 GeV	200 GeV
μ	±200 GeV	±200 GeV
m_g	800 GeV	1600 GeV

- Two common benchmarks
  - Max-mixing - **Higgs boson mass m_h close to max possible value for a given tanβ**
  - No-mixing - **vanishing mixing in stop sector $\rightarrow$ small mass for h**

CDF - MSSM Higgs $\rightarrow \tau_l \tau_{had}$



No excess seen in this channel

MSSM evolution