Searches for non-SM Higgs bosons at the Tevatron

presented by

Per Jonsson

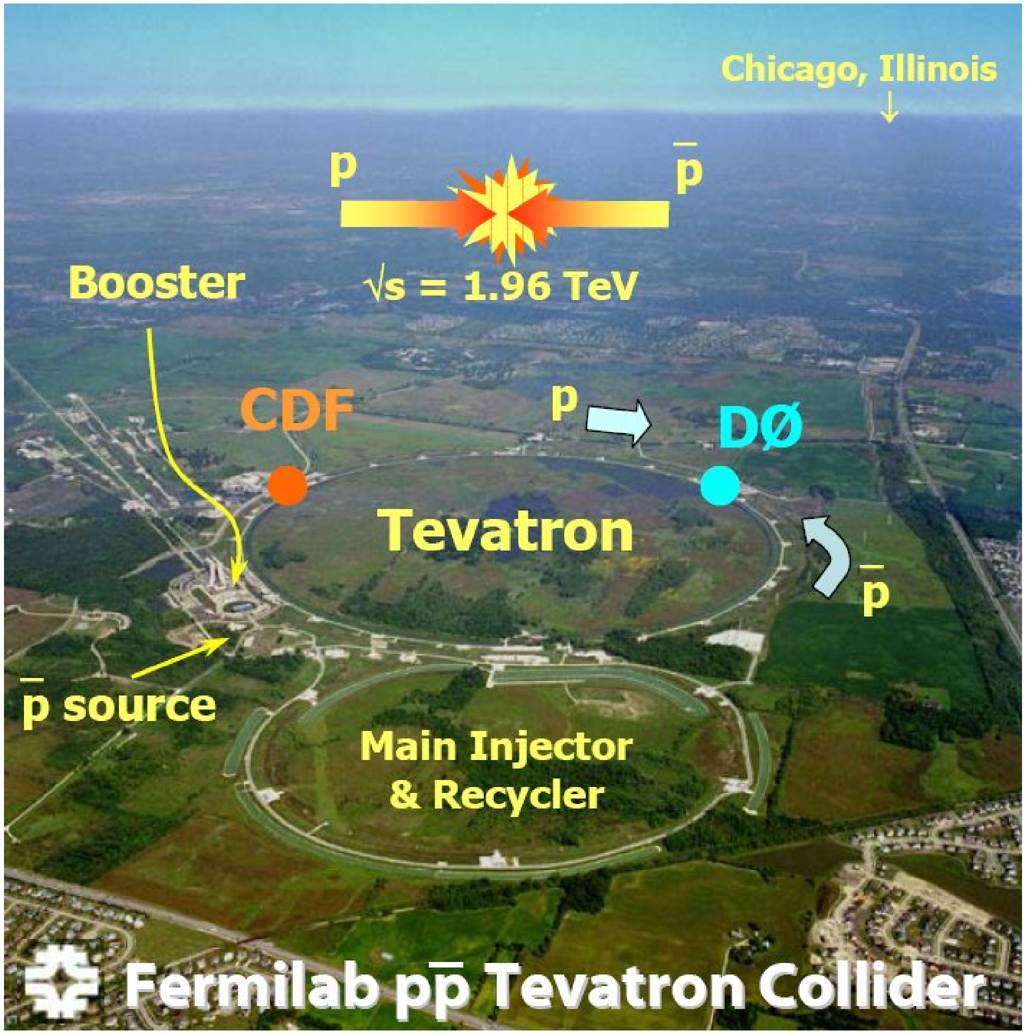
Imperial College London

On behalf of the CDF and DØ Collaborations

The 2007 Europhysics Conference on High Energy Physics
Manchester, England, July 19-25, 2007

Outline

- Introduction
  - Tevatron & experiments
- Non-SM Higgs Searches
  - Minimal Supersymmetric SM
    - tau and b ID
    - Di-tau final state (1 fb^{-1})
    - 3b/4b final states (0.9 fb^{-1})
  - Fermiophobic Higgs
    - Higgs in the 3γ + X final states (0.8 fb^{-1})
- Prospects & Conclusions



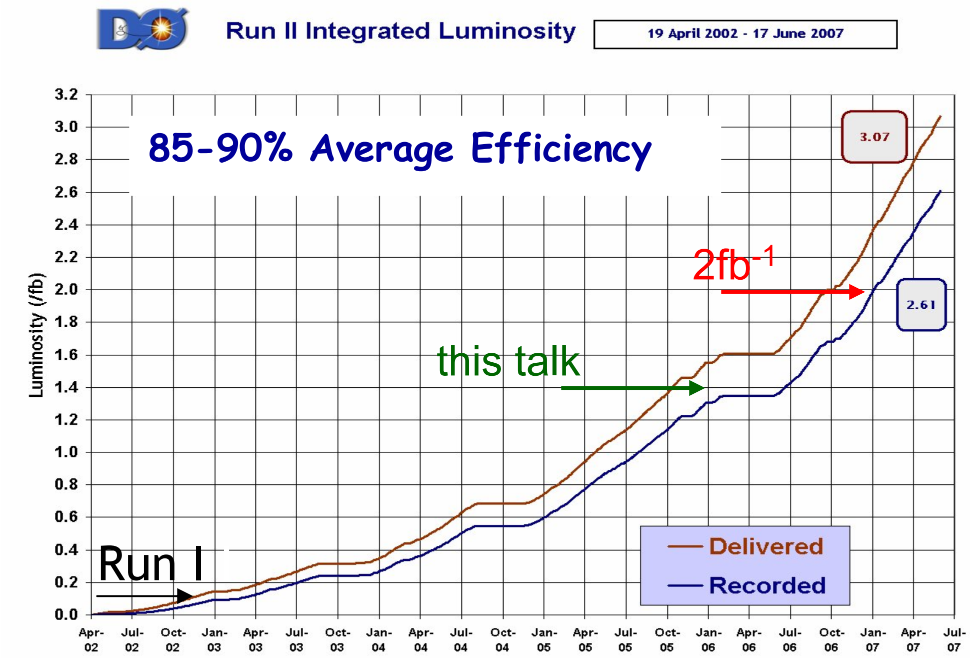
Will only cover recent results using ~1fb^{-1} (1.5fb^{-1} results are coming soon)

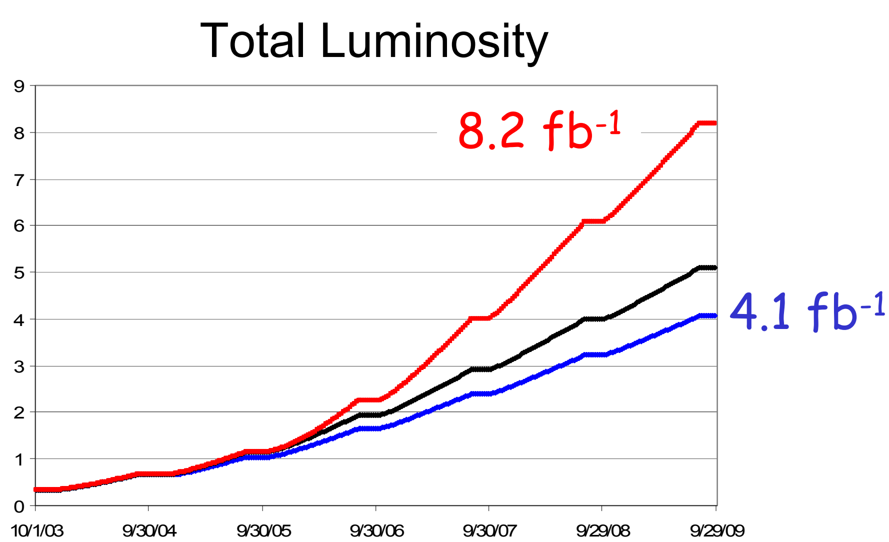
[Thanks to all Tevatron colleagues]

Tevatron Performance

Tevatron continues to perform well

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

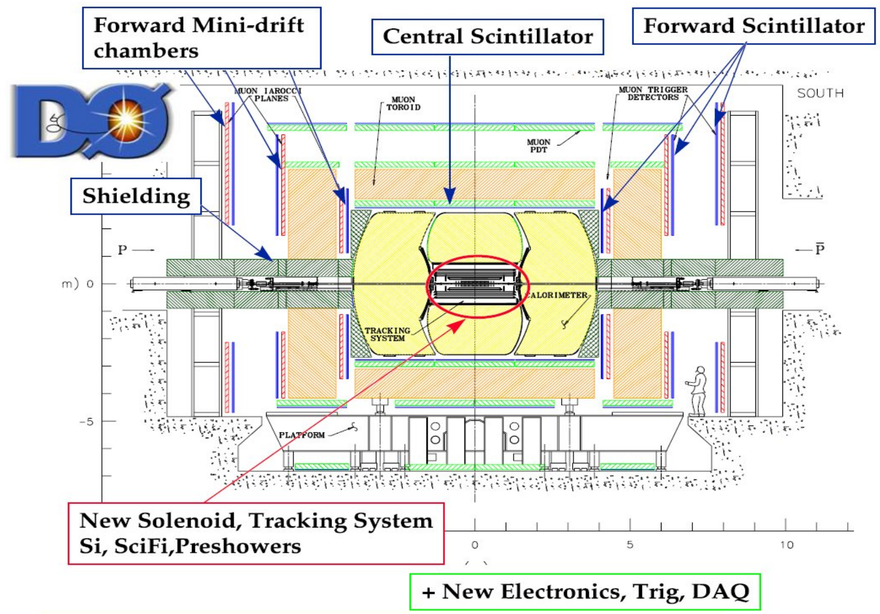


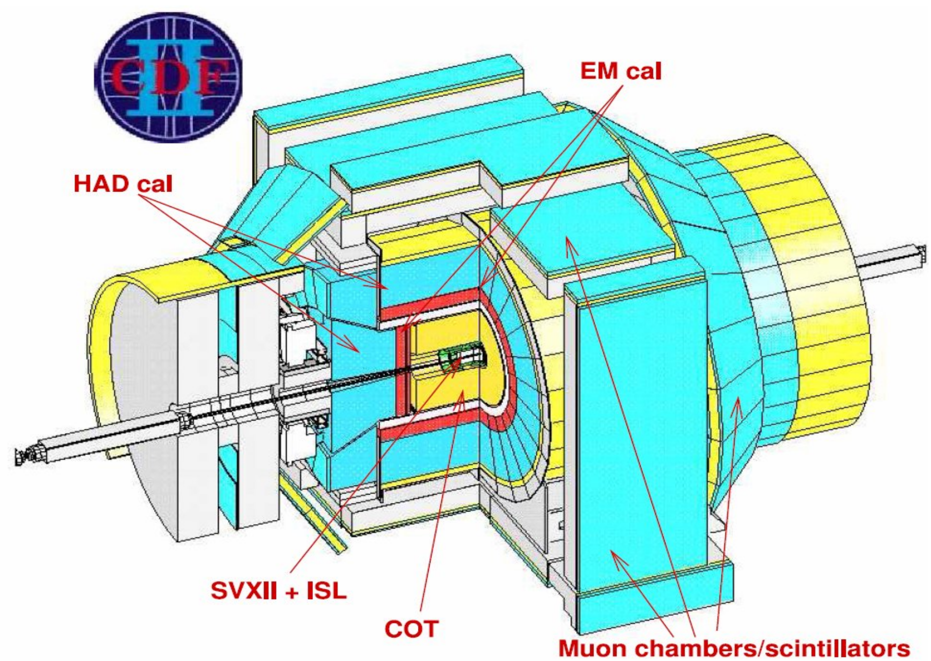


- Performance matching design integrated luminosity of ~8fb^{-1} by 2009

CDF and DØ experiments

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





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

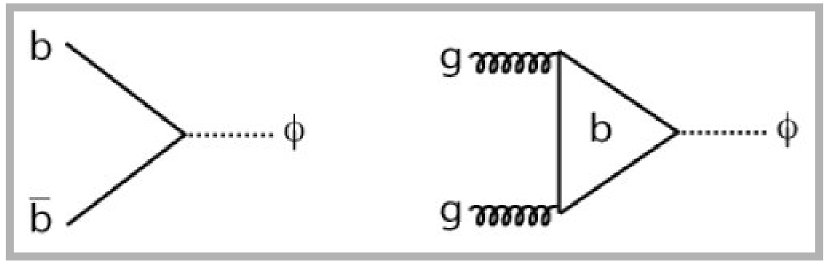
Higgs bosons in the MSSM

- In MSSM have 2 Higgs doublets
  - H_u (H_d) couple to up- (down-) type fermions
  - Ratio of their VEV's: $\tan\beta = \langle H_u\rangle / \langle H_d\rangle$
  - 5 Higgs particles after the EWSB: h, H, A, H^+, H^-
  - h has to be light: $m_h <\sim 140$ GeV
  - At tree level, 2 independent parameters: m_A and $\tan\beta$

- At large tan β:
  - Coupling of A, h/H to down-type fermions, e.g. *b*-quark, enhanced wrt SM
    $\rightarrow$ production amplitude $\sim\tan\beta$ $\rightarrow$ production cross section $\sim\tan^2\beta$
  - h/H & A (denoted by ϕ) ~degenerate in mass $\rightarrow$ further increase in cross-section
- For low & intermediate masses
  - Br ($\phi \rightarrow \tau\tau$) ~10%, Br ($\phi \rightarrow bb$) ~90%

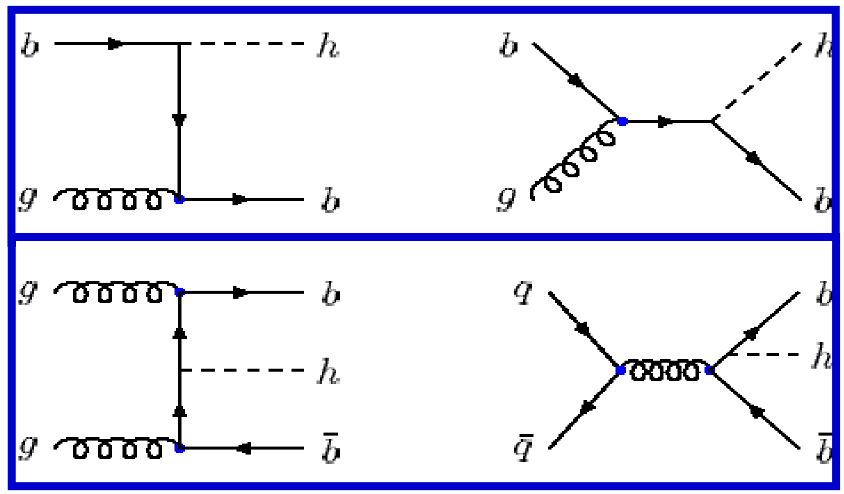
MSSM Higgs boson production

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



$\phi \to \tau\tau$

  - 2 high P_T b-jets from Higgs
  - 1 or 2 extra b-quarks
  - Search for peak in dijet invariant mass



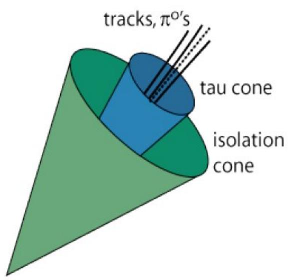
$\phi \to bb$
3b

$\phi \to bb$:
4b

Similar overall sensitivities

Tau ID at the Tevatron

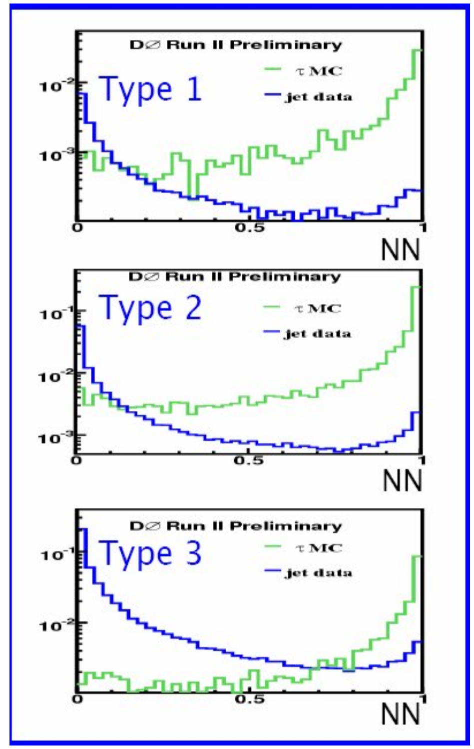
- CDF: Isolation based



- Require 1 or 3 tracks, p_T > 1GeV 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 tau fake rate ~0.001-0.005

- DØ: 3 NN's for each tau type

- Performance for pT>15 GeV



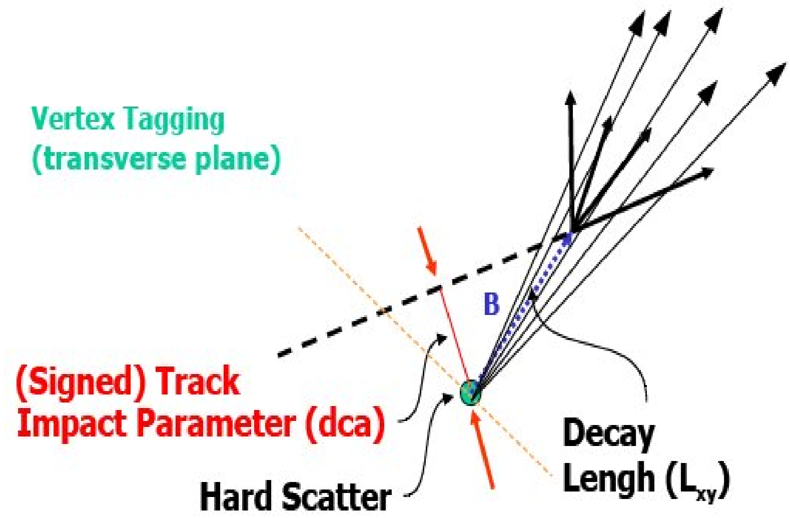
Eff(%)

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

- Validated via Z's

B-tagging

- Critical for low/medium mass $\phi \to bb$
- 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 % mistag**
- **Tight = 40% eff, 0.5 % mistag**

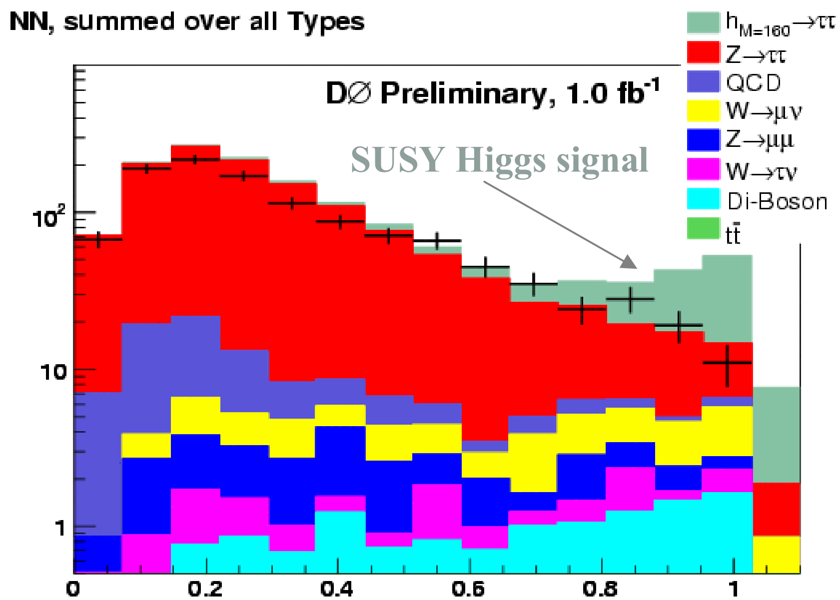
DØ: Neural Net tagger

- Secondary vertex & dca based inputs, derived from basic taggers
- High efficiency, purity

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

Neutral MSSM Higgs → ττ

- Complementary to the φ(→bb) searches:
  - Lower branching fraction but lower backgrounds
- Main bkgs.: Z→ττ (irreducible), W+jets, Z →ee,μμ, multijet, di-boson
- DØ (μ channel only):
  - Only 1 isolated μ separated from the hadronic τ with opposite sign
  - τ identification: NN based
  - M_W < 20 GeV removes most of remaining W boson bkg.
  - Mass dependent optimized NNs to separat signal from bkg. (M^{vis}, μ and τ kinematics)

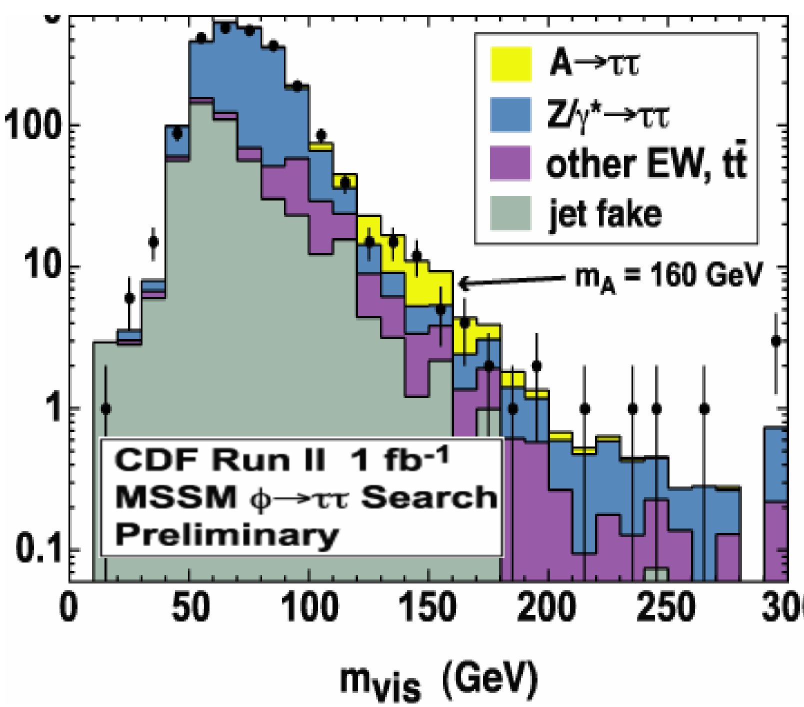


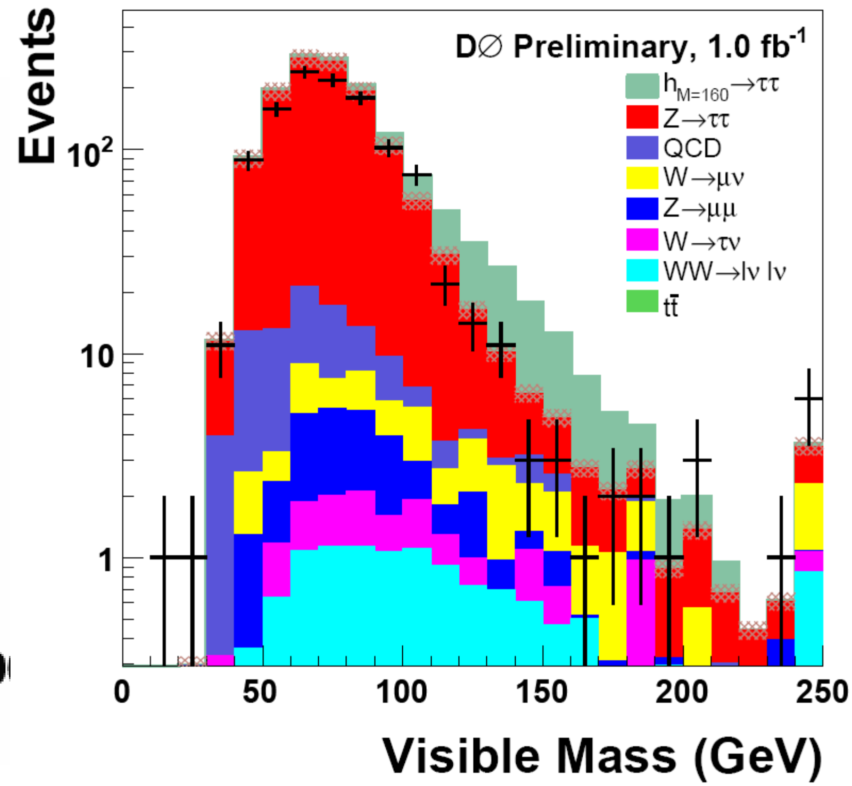
- CDF (e, μ, e+μ channels)
  - Isolated e or μ separated from hadronic τ with opposite sign
  - τ identification: Variable-size cone algorithm
  - Jet background suppression: $|p_t^l| + |p_t^{had}| + |\not{E}_T| > 55$ GeV
  - remove most of W bkg. by cutting on relative directions of the visible τ decay products and missing E_T

Neutral MSSM Higgs → ττ

- CDF: 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

eτ,μτ channel

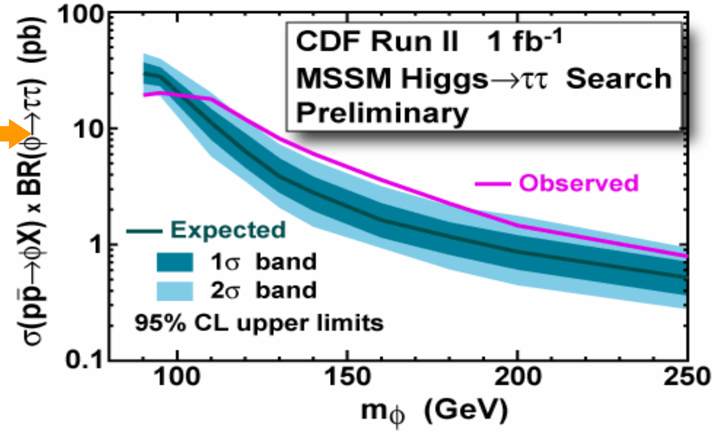


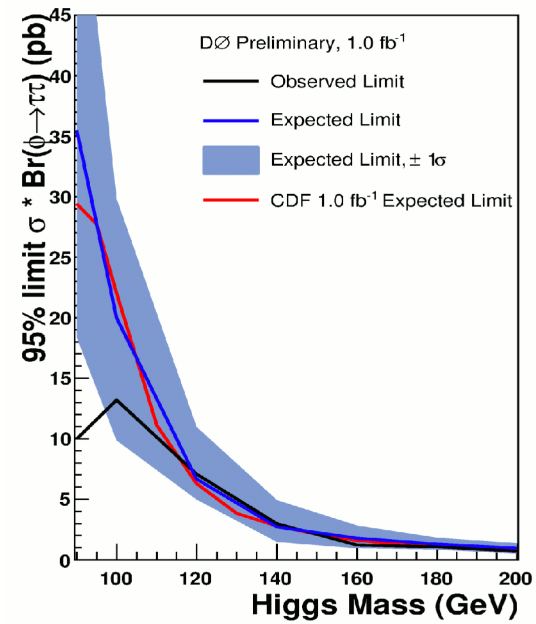


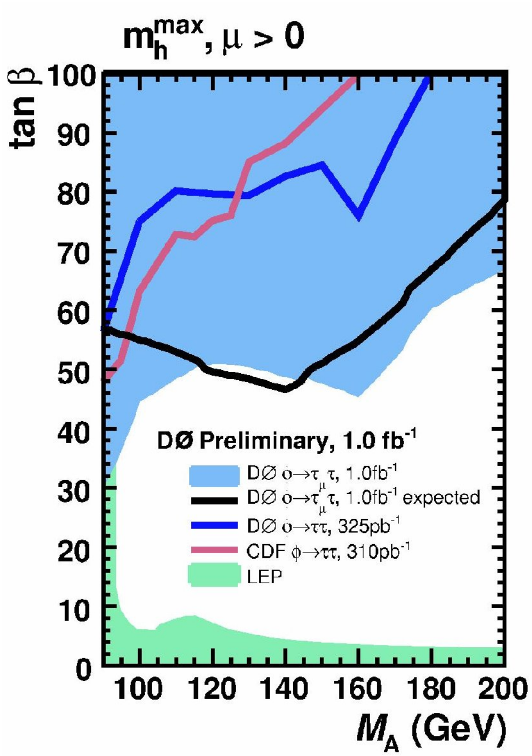
- DØ: Cross-section limits: NNs for the different tau types

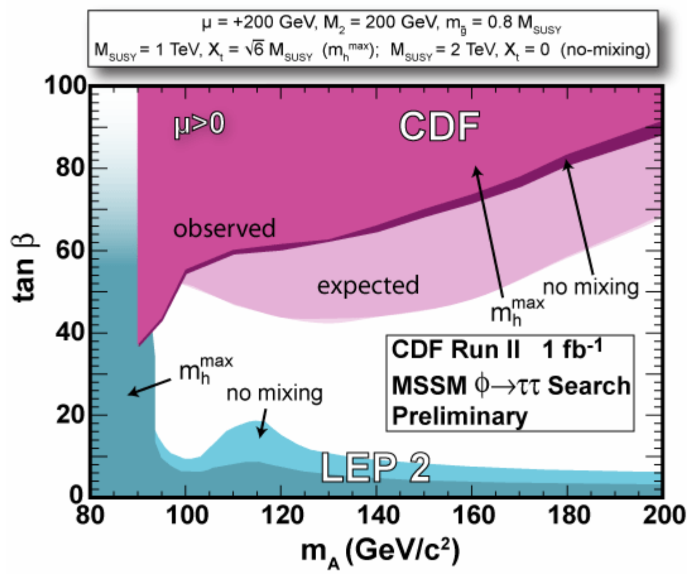
Neutral MSSM Higgs → ττ

- Proceed to set limits
- σ x Br (φ →ττ)
- MSSM parameter space









- Use no-mixing & m_h^{max} benchmark scenarios
- $90 < m_A < 200$ GeV, tanβ > 40-60 excluded

Neutral MSSM Higgs → bb + b[b]

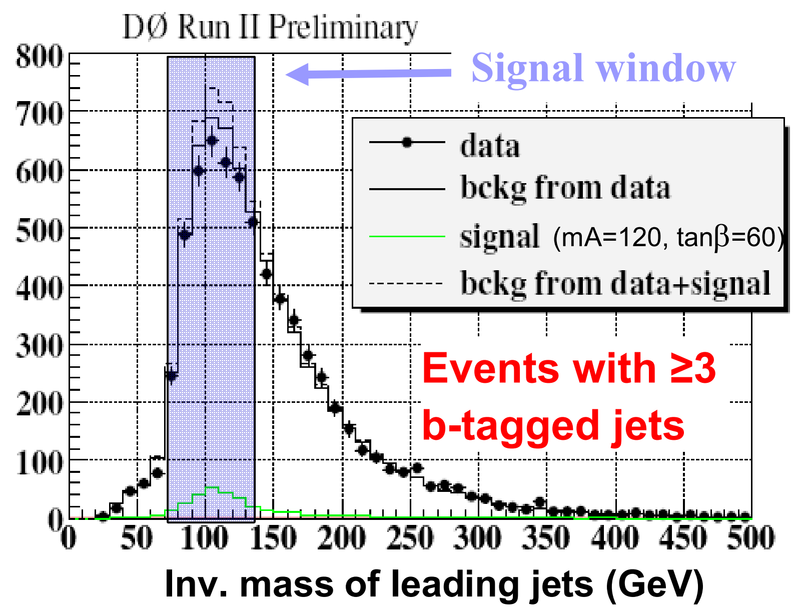
- DØ: ICHEP '06
- ϕ → bb swamped by QCD bckg
- Look for associated b and ϕ → bb

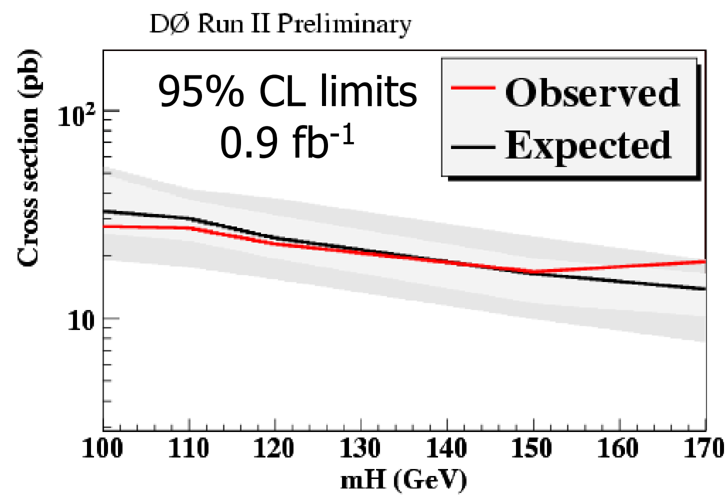
- ≥ 3 b-tagged jets: p_T> 40, 25, 15 GeV
  - Invariant mass of 2 leading jets peaks at Higgs mass

- Backgrounds from data
  - Shape estimated from double-tagged dijet mass spectrum
  - Rate normalized outside signal window

- Agreement between data & predicted background → set upper limits

- Analysis being optimized



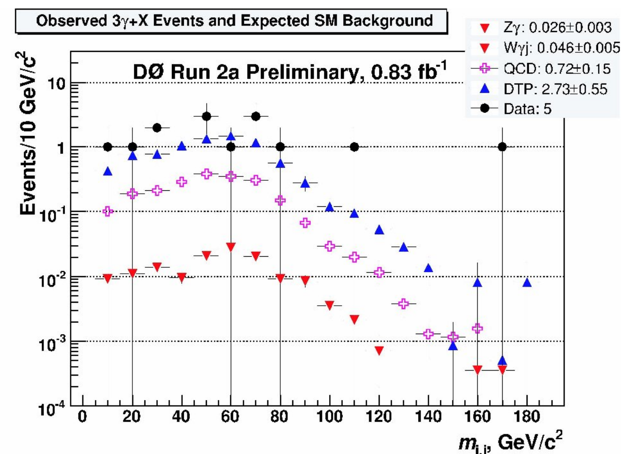


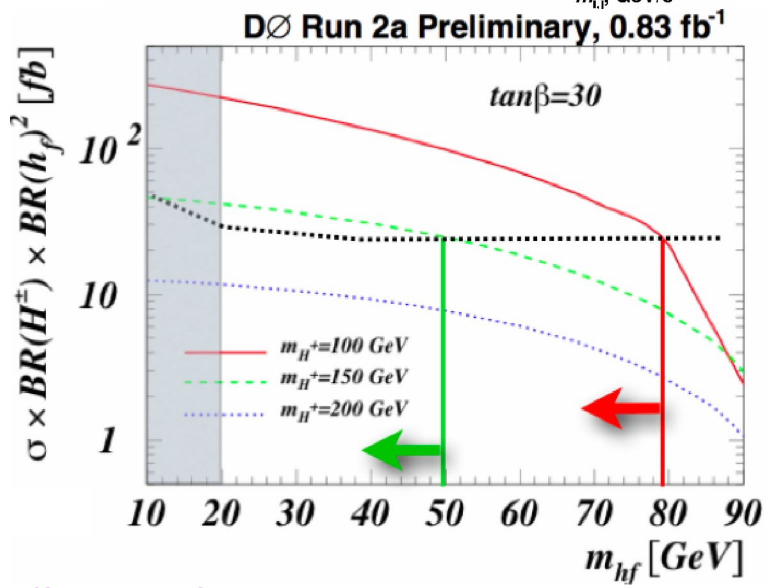
Fermiophobic Higgs → 3γ + X

- Some extensions of SM: coupling of higgs to fermions suppressed
- Sufficiently light h will decay to γγ with ~100% probability
- Search for the channel:

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

- Cuts
  - 3γ with |η|<1.1, $E_T^{1,2,3} > 30, 20, 15$ GeV
- Backgrounds
  - Jets or electrons misidentified as γ and direct 3γ production
  - Estimated from data
- $\Sigma \overline{p}_T(3\gamma) > 25$GeV
  - 0 events seen for 1.1 expected
  - 95% CL limit: σ(hH±) < 25.3fb

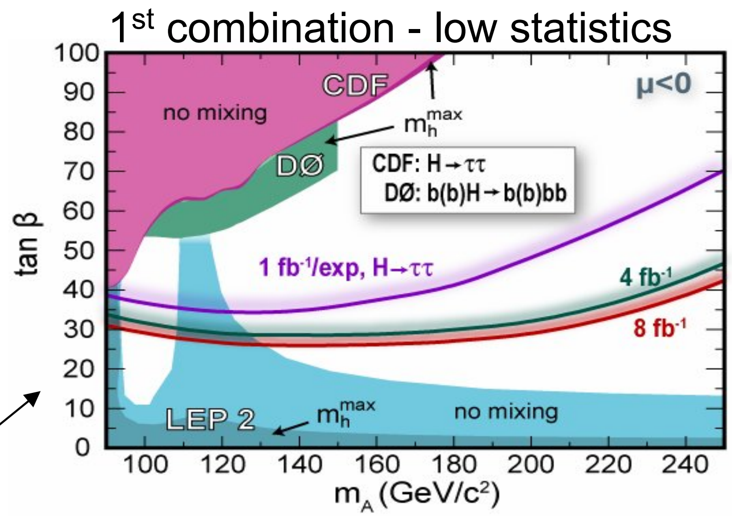


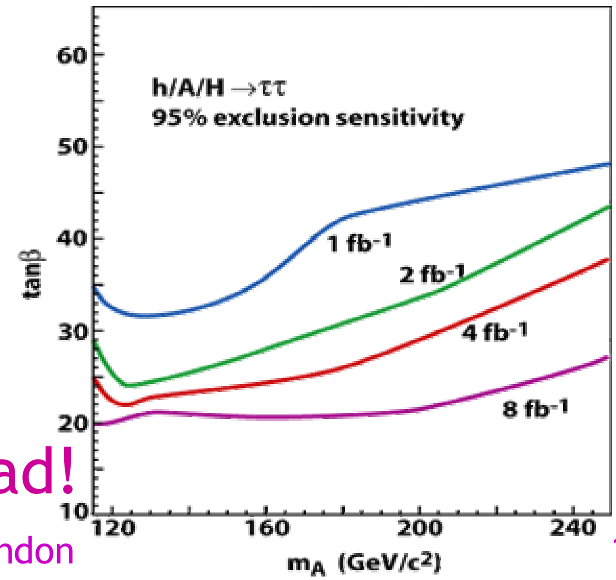


- Exclusion on mass of h_f for different charged Higgs masses (m_H±) & tanβ

Prospects & Conclusions

- Tevatron and CDF/ DØ experiments performing very well
  - Over 2.5 times more data under analysis
  - Expect up to 8 fb^{-1}/exp in Run II
- 1st results from 1fb^{-1} show very promising sensitivity
  - No signal observed, but already powerful!
- MSSM Short term:
  - New $\phi \rightarrow bb + b[b]$
    - From both experiments
  - $\phi \rightarrow bb + b[b]$, $\phi \rightarrow \tau\tau$ & $b\phi \rightarrow b\tau\tau$ (not discussed) combination
- Longer term
  - Exclude up to m_A ~250 GeV for large tanβ
  - Down to tanβ ~20 for low m_A
  - Or discovery





Very exciting times ahead!

Prospects & Conclusions

Backup slides

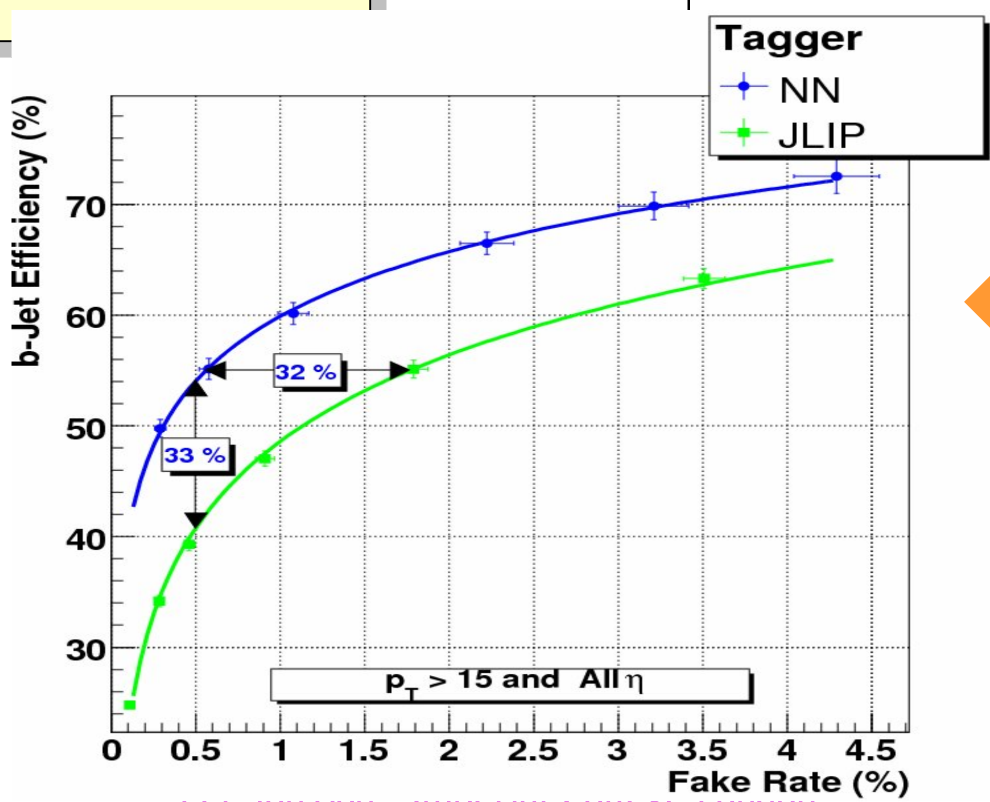
DØ B-tagging

Several mature algorithms used:

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

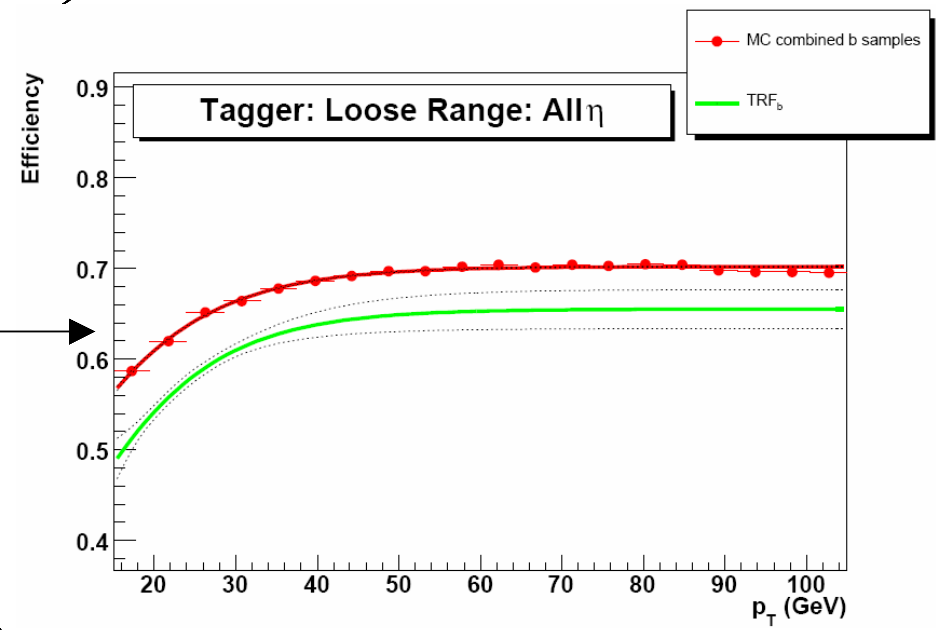
Combine in Neural Network:

- 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

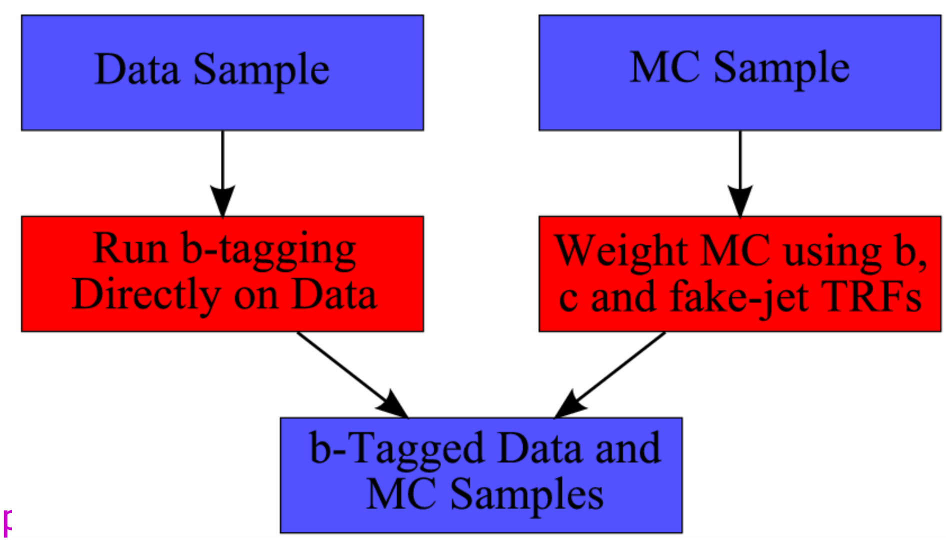


B-tagging – (DØ) Certification

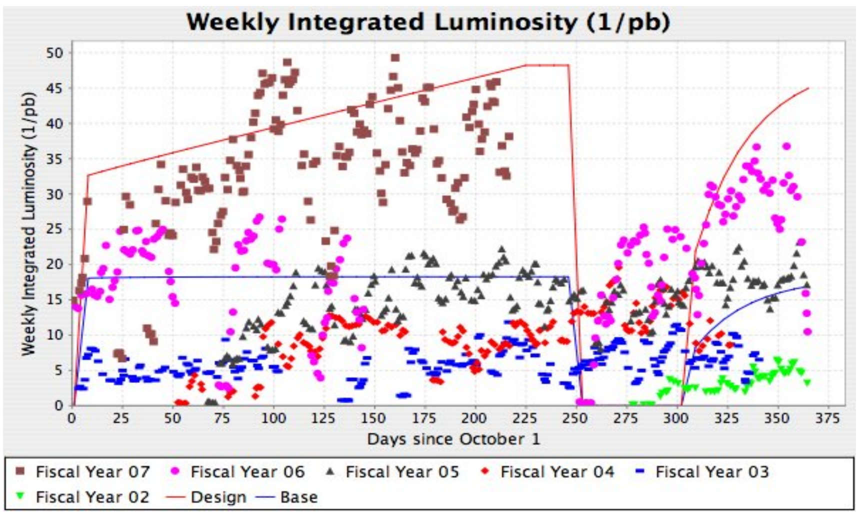
- Have MC / data differences - particularly at a hadron machine
  - Measure performance on data
    - Tag Rate Function (TRF) Parameterized efficiency & fake-rate as function of p_T and η
  - Use to correct MC b-tagging rate

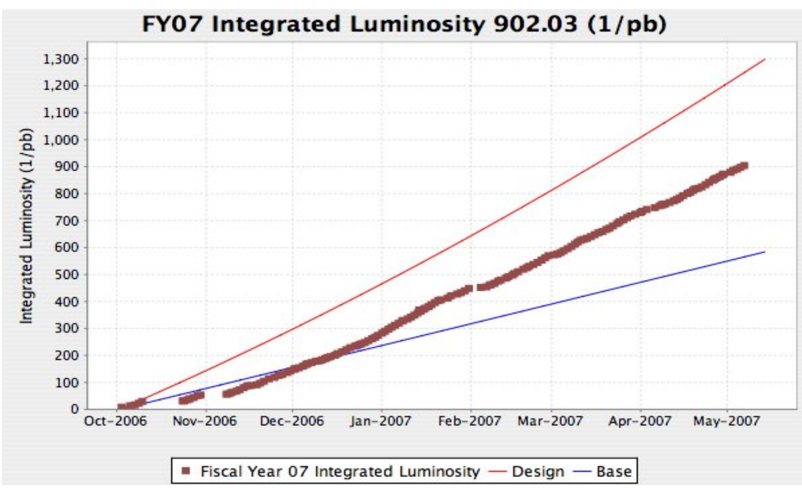


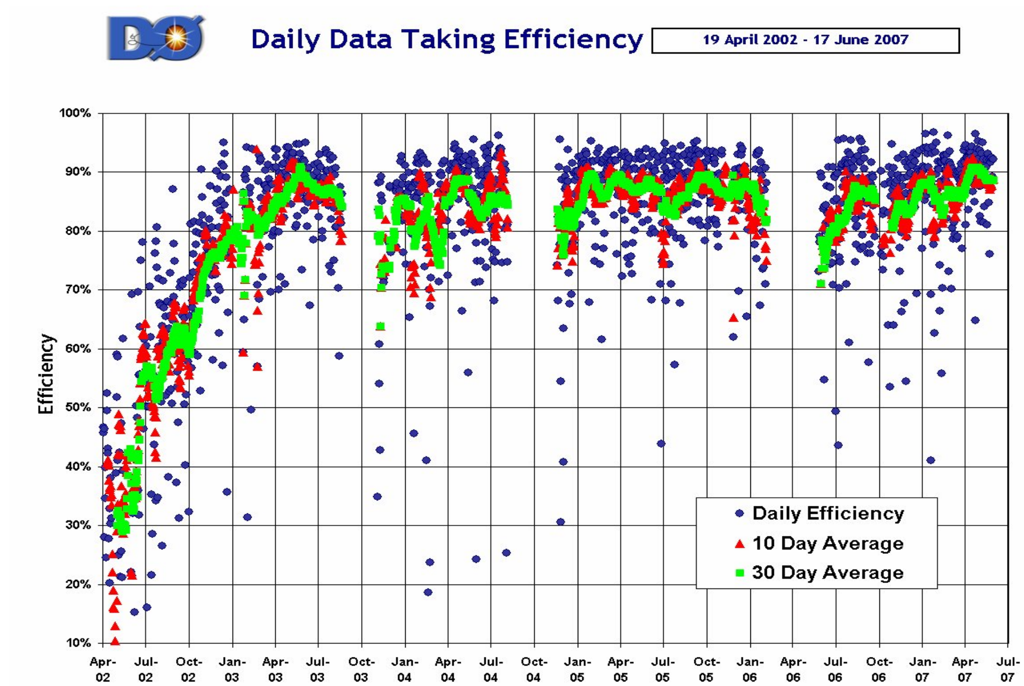
- b and c-efficiencies
  - Measured using a b-enriched data sample
- Fake-rate
  - Measured using QCD data



Tevatron & DØ


Weekly Integrated Luminosity (1/pb)
Weekly Integrated Luminosity (1/pb)
Days since October 1
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)
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
Daily Efficiency
10 Day Average
30 Day Average

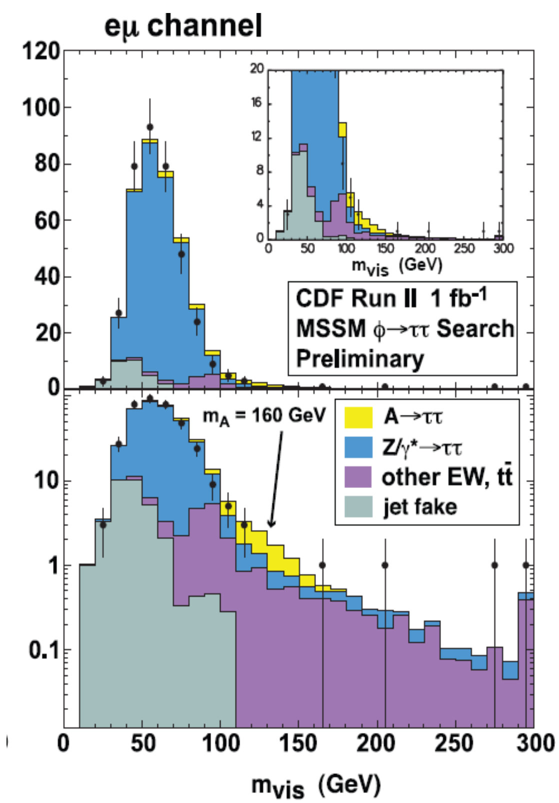
MSSM benchmarks

- 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)

- 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 → small mass for h**

	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

CDF - MSSM Higgs → ττ



No excess seen in this channel

MSSM evolution