Searches for non-SM Higgs at the Tevatron

presented by

Per Jonsson

Imperial College London

For the CDF and D0 collaborations

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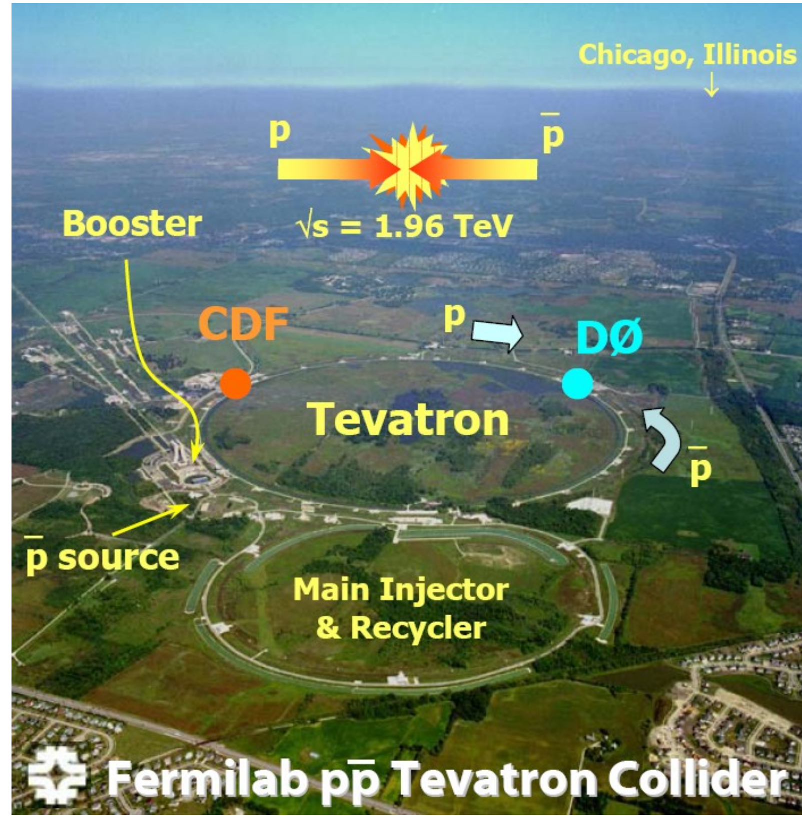
Overview

- Introduction
- MSSM Higgs:
  - Neutral Higgs bosons
  - Charged Higgs bosons
- NMSSM Higgs
- NLLP→$b\bar{b}$
- Outlook



Tevatron continues to perform well

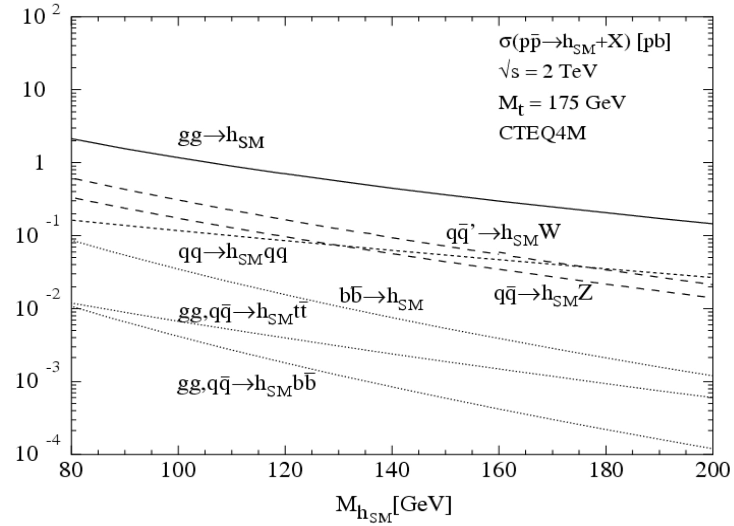
~ 6.9 fb^{-1} delivered luminosity

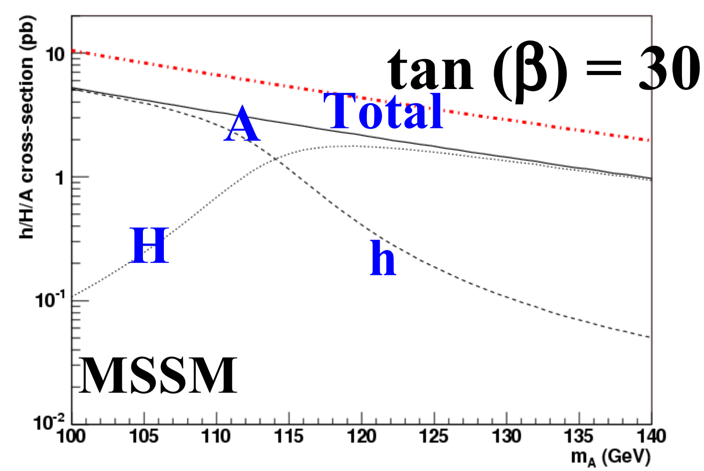
Peak initial lumi $3.5x10^{32}$ $cm^{-2}s^{-1}$

Expect 10 fb^{-1} at end of RunII

MSSM Higgs sector

- Two Higgs doublets
  - 5 physical Higgs bosons
  - 3 neutral (h,A,H=ϕ)
  - 2 charged ($H^{\pm}$)
- Higgs sector described at tree level by two parameters:
  - m_A – mass of A
  - tanβ – ratio of vacuum expectation values
  - Other parameters enter via radiative corrections
- Coupling of neutral Higgs to b-quarks enhanced by tanβ:
  - Production enhanced by $\tan^2\beta$

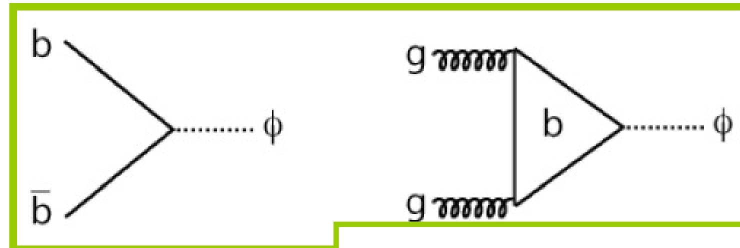




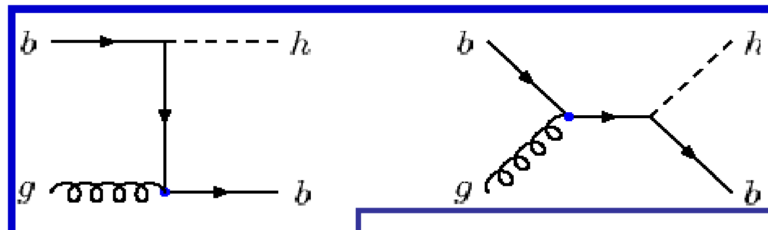
Neutral MSSM Higgs Searches

Search for Higgs decays:

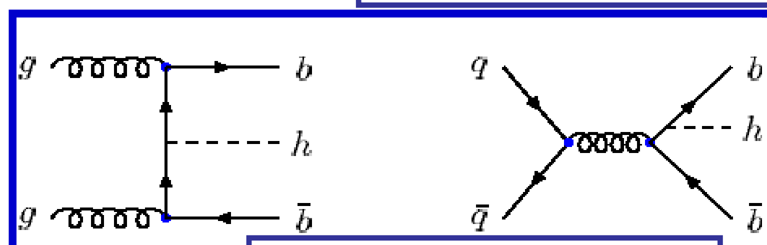
- $h \rightarrow \tau\tau$
  - relatively clean signature
  - low BR ~10%
- $(b)bh \rightarrow (b)bbb$
  - large multi-jet backgrounds
  - high BR ~90%
- $(b)bh \rightarrow (b)b\tau\tau$
  - additional sensitivity at low m_A
  - reduced $Z \rightarrow \tau\tau$ background



$\phi \rightarrow \tau\tau$



$b\phi \longrightarrow 3b/b\tau\tau$

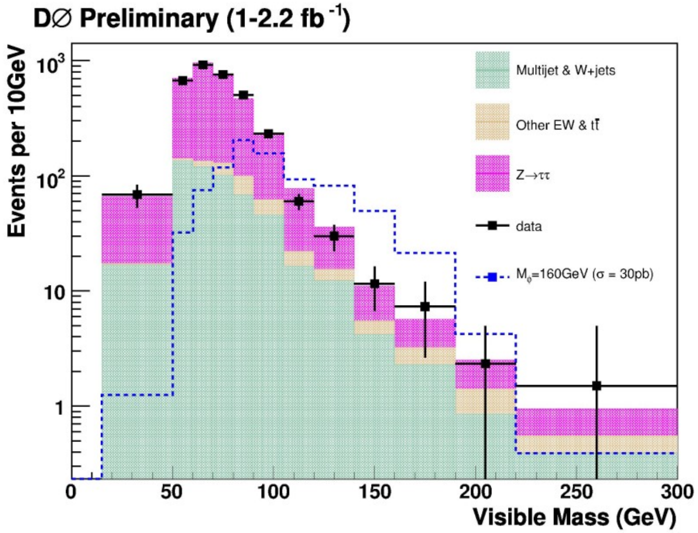


$bb\phi \longrightarrow 4b/bb\tau\tau$

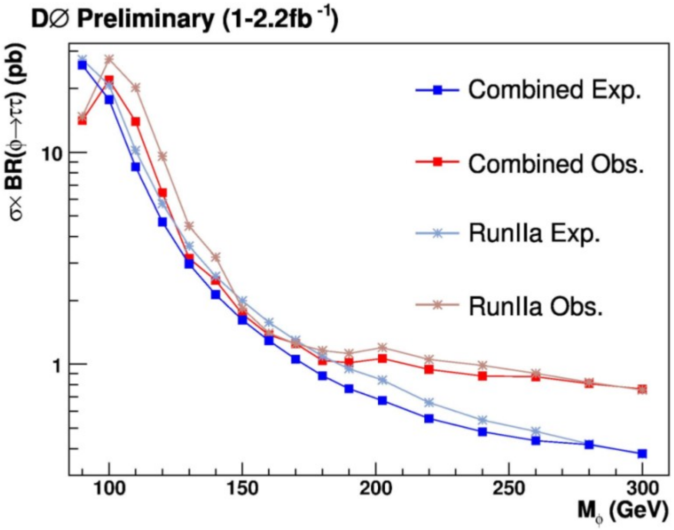
Good b and tau identification vital

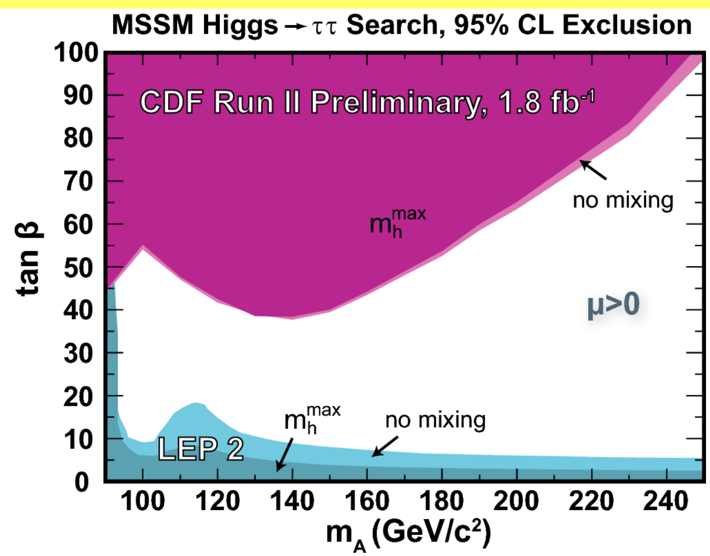
Similar overall sensitivities $\rightarrow$combine

Neutral Higgs: h→ττ

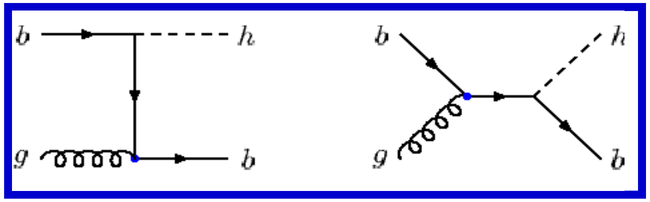


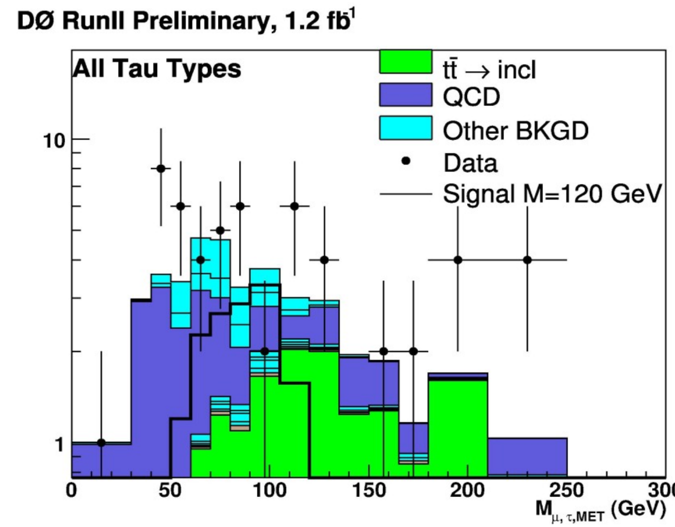
- Isolated electron or muon + hadronic tau or electron + muon
- Main backgrounds: Z→ττ, multi-jets, W+jets, Z→ee/μμ, di-bosons
- Mvis used to derive cross section limits



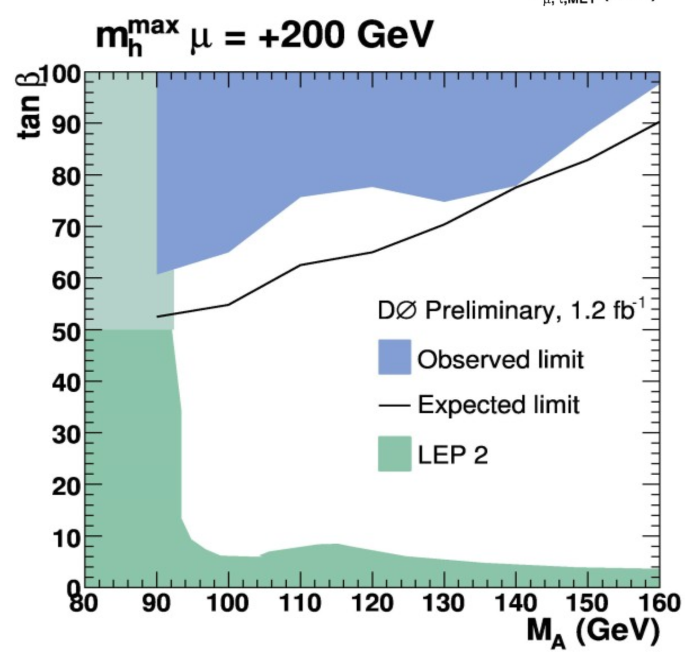


Neutral Higgs: $bh \rightarrow b\tau\tau$





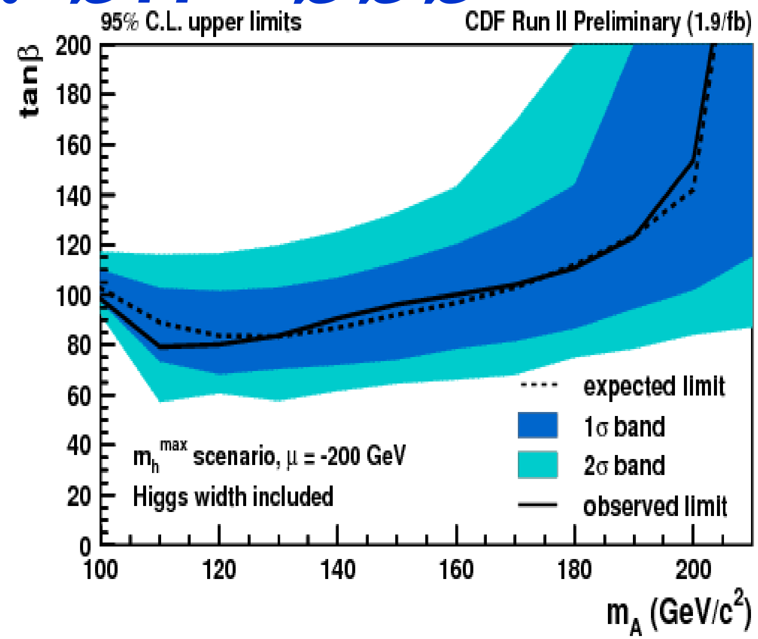
- Search in $\mu\tau_{had}$ channel ($1.2fb^{-1}$)
  - isolated muons + opposite sign hadronic tau
  - at least one b-tagged jet

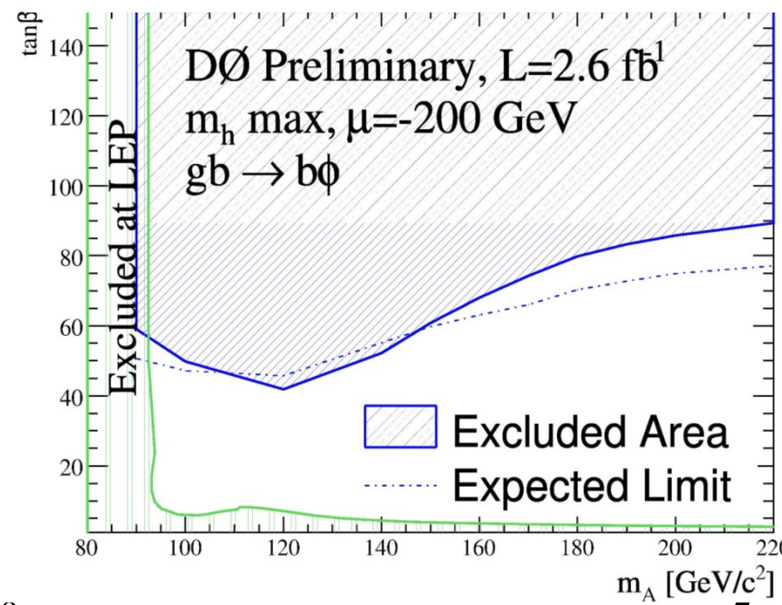


- Events selected using combination of NN($t\bar{t}$) and likelihood (multi-jet)
  - discriminant output used in setting limits

Neutral Higgs: bh→bbb

- Signal
  - At least 3 b-tagged jets
  - Peak in dijet mass spectrum
- Background
  - Multi-jet, predicted from data/MC
- CDF: 2 fb^{-1}, D0: 2.6 fb^{-1}
  - Train and cut on kinematic likelihood (D0)
  - Separate 3, 4 and 5-jet channels (D0)
  - Use dijet invariant mass to set limits in $\tan\beta$ – m_A plane
- Final limits corrected for:
  - Width: Not negligible at high tanβ
  - MSSM NLO Corrections: Strongest limits for Higgs mass term, $\mu < 0$





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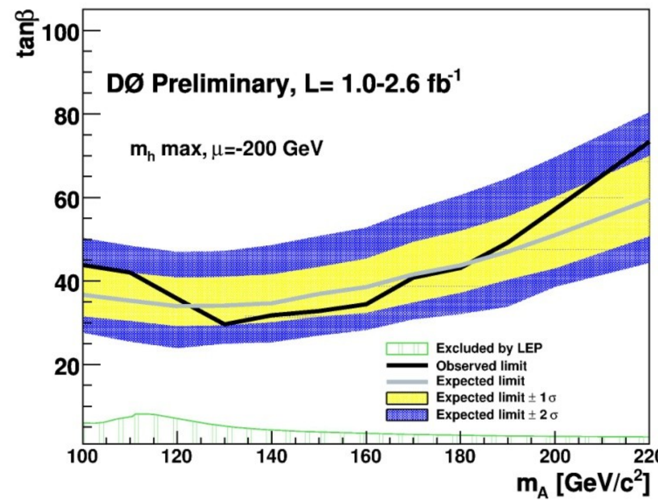
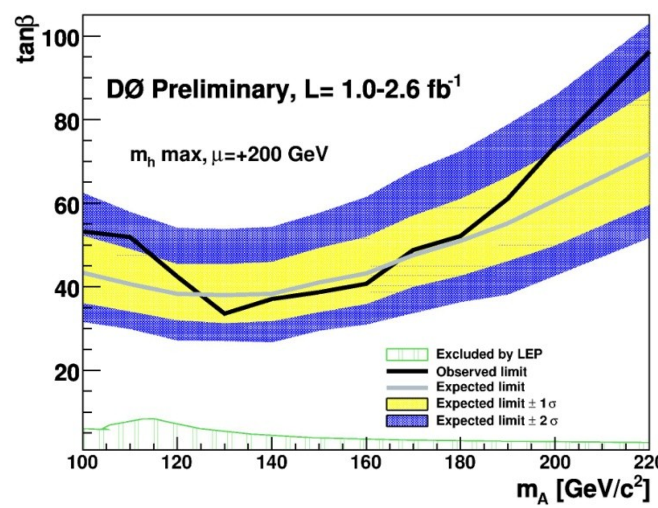
Combinations

- New result from DØ – combining three signatures in neutral Higgs searches
- 19 sub-channels using between 1.0 and 2.6 fb^{-1}
- Strongest limit on neutral MSSM Higgs in tanβ –m_A plane to date at a hadron collider
- Combinations across experiments in progress



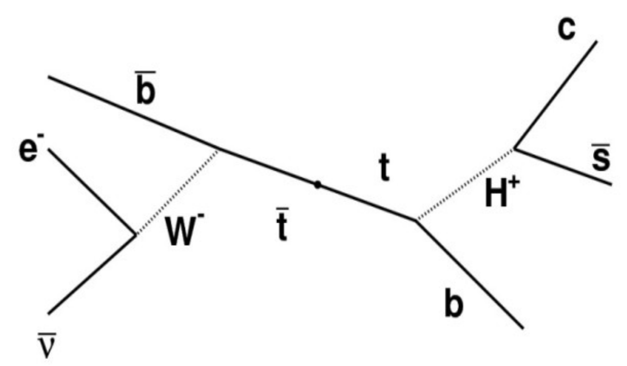


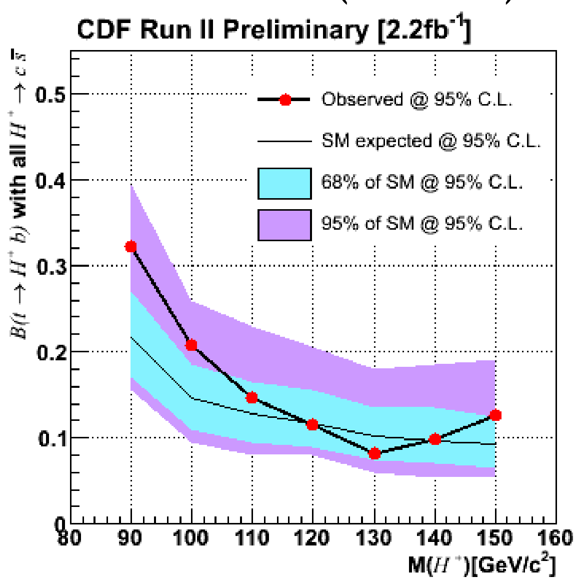
Charged Higgs → cs/ τυ

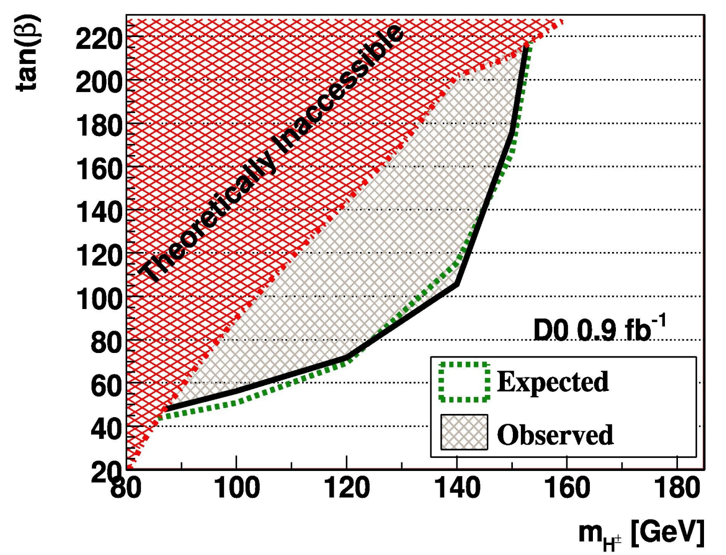
Search for H± in top decays

CDF: 2.2fb^{-1}, DØ: 0.9fb^{-1}

- Lepton + jet channel
- Di-jet mass used to set limit
  - Assume BR (H±→ cs)=1







nMSSM

Next-to-MSSM Higgs – richer model

- Two additional pseudo-scalar Higgs bosons (s and a)
- Decay h → aa dominates

If $m_a < 2m_\tau$

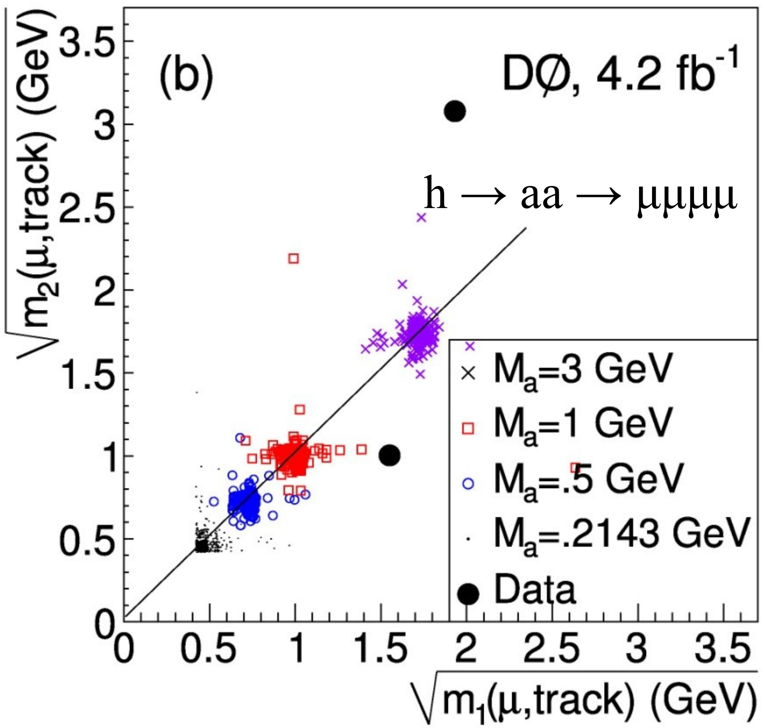
- Dominant decay: h → aa → μμμμ
  - Two pairs of collinear muons
- Limit from direct search from LEP:
  - $m_h > 82$ GeV
- Backgrounds: QCD, $Z/\gamma^* \to \mu\mu$

Event Selection:

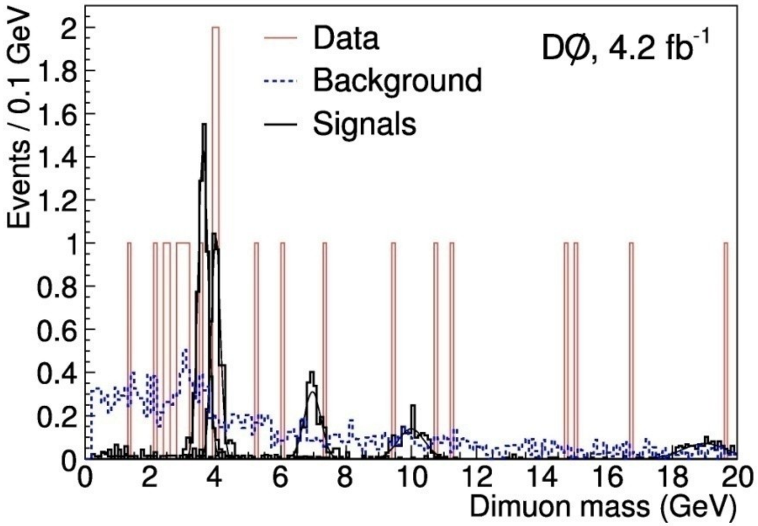
- Two muons $\Delta R(\mu,\mu) > 1$
- 'Companion' tracks $\Delta R(\mu,\text{track}) < 1$

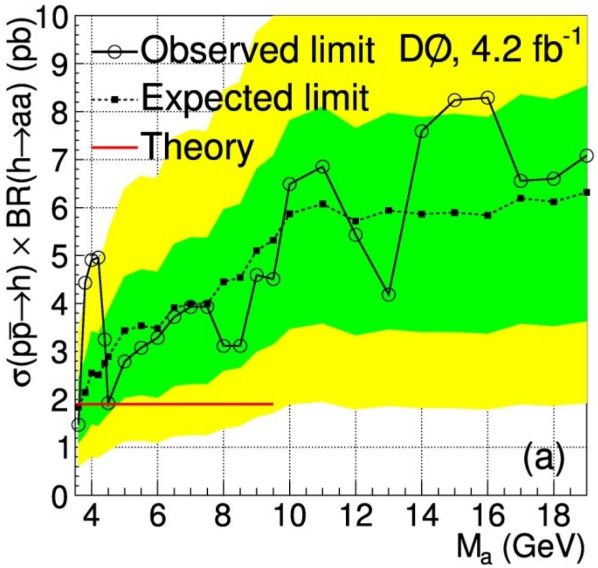
Set 95% limits in 2D mass window

- σ x BR ~ < 5 - 10 fb^{-1} for m_a= 0.2-3GeV



nMSSM





$m_a > 2m_\tau$: $h \rightarrow aa \rightarrow \mu\mu\tau\tau$

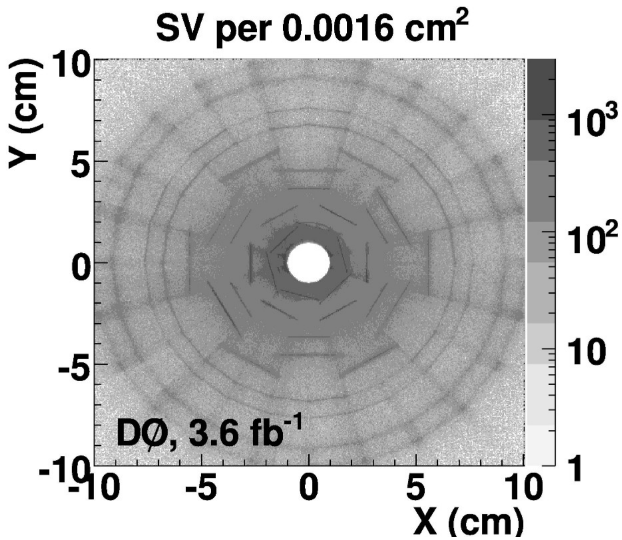
- μ decay suppressed
- τ decay dominates
- Back-to-back μ and τ pairs

- Backgrounds: QCD, Z/γ^*+jets→ μμ+jets

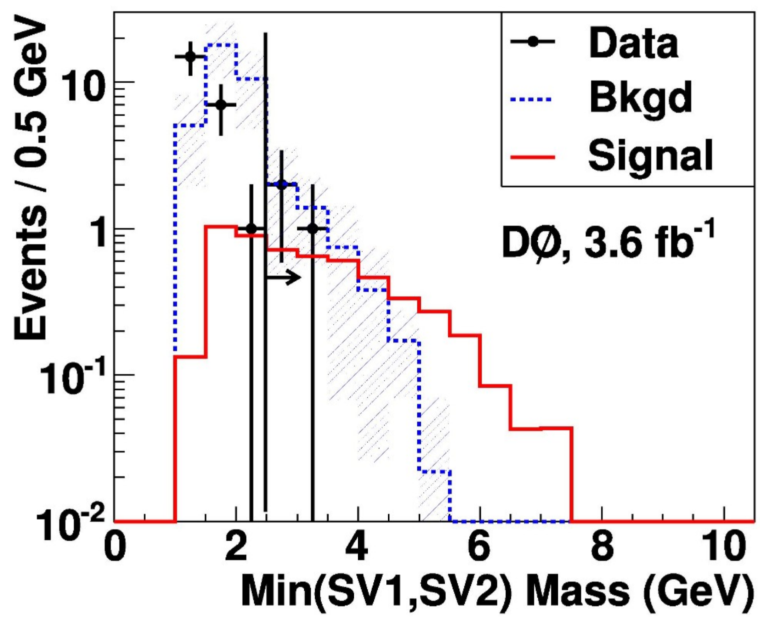
- Event Selection
  - μ pair $\Delta R(\mu,\mu) < 0.5$, $m_{\mu\mu} < 20$ GeV
  - Missing $E_T > 25$ GeV

Set Limits @95% C.L. using di-muon mass

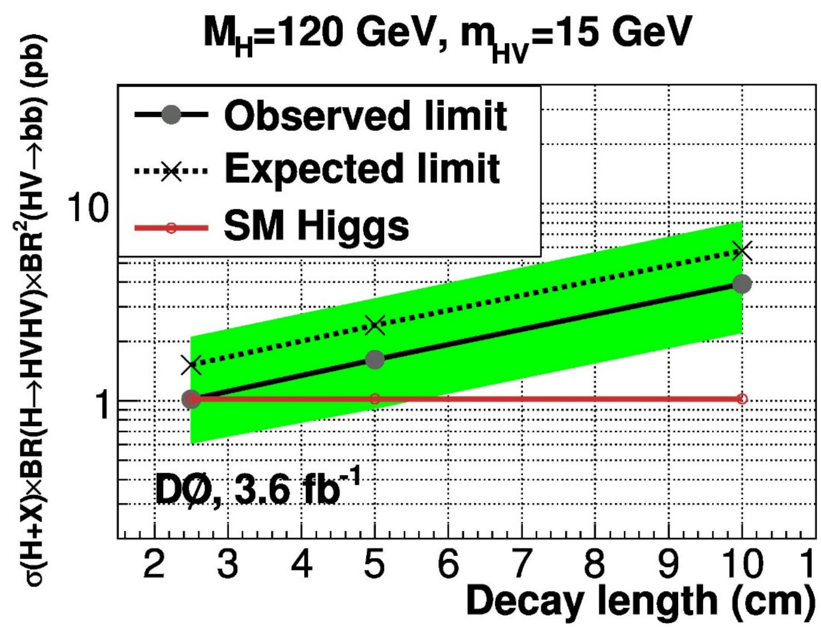
Search for NLLP→ $b\bar{b}$



- *search for pairs of displaced secondary vertices, located 1.6-20 cm from the beam axis*
- *no significant excess found*
- *interpret as a limit on SM Higgs, decaying to a pair of Hidden Valley particles (neutral and long-lived), each decaying to a b quark pair*



M_H = 120 GeV
M_{HV} = 15 GeV
L_d = 5 cm



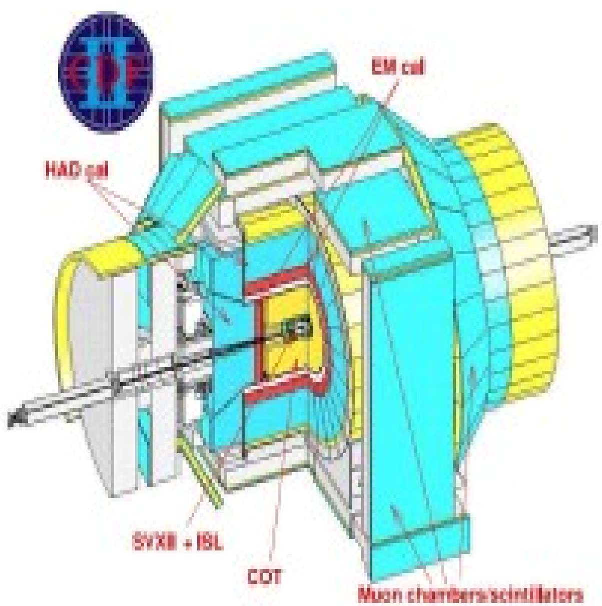
Outlook

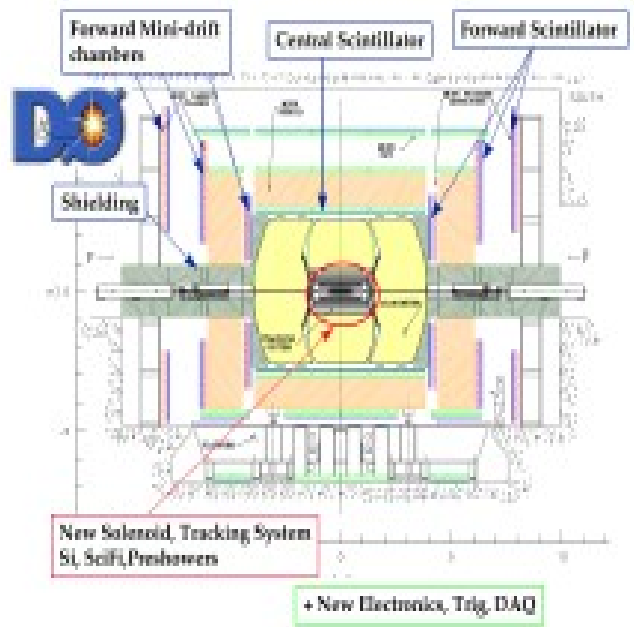
- CDF and DØ both performing well
- Wide range of BSM Higgs searches with up to $4fb^{-1}$
  - No BSM Higgs signal yet, but established and sensitive analyses:
    - Potential is there
  - More data available, will include rapidly
- Combinations across experiments underway
- New results with more data and improved analysis techniques coming soon!

Backup

CDF and D0 experiments

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



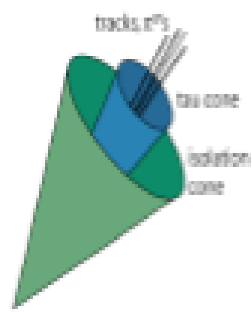


- CDF: New plug calorimeter & ToF

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

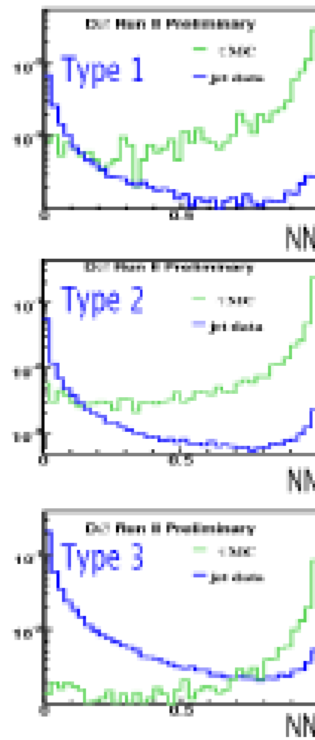
Tau identification

- CDF: Isolation based



- 1 or 3 tracks in variable size and isolation cone
- Validated via W/Z measurements
  - Efficiency ~ 40-50%
  - Jet fake rate < 1%

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



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

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

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

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

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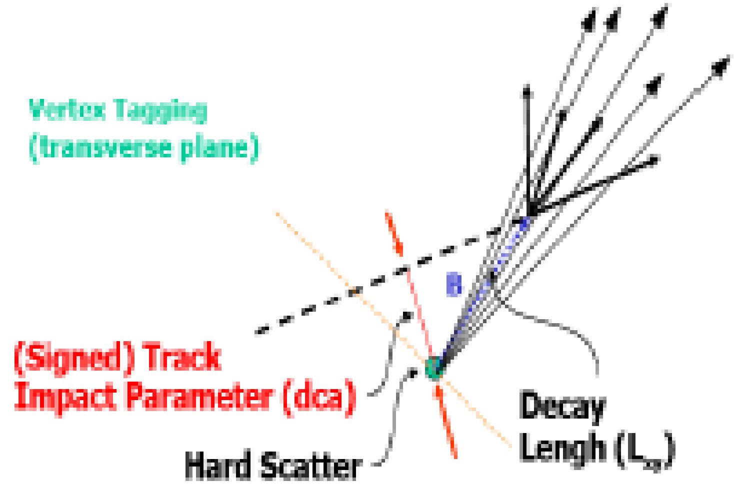
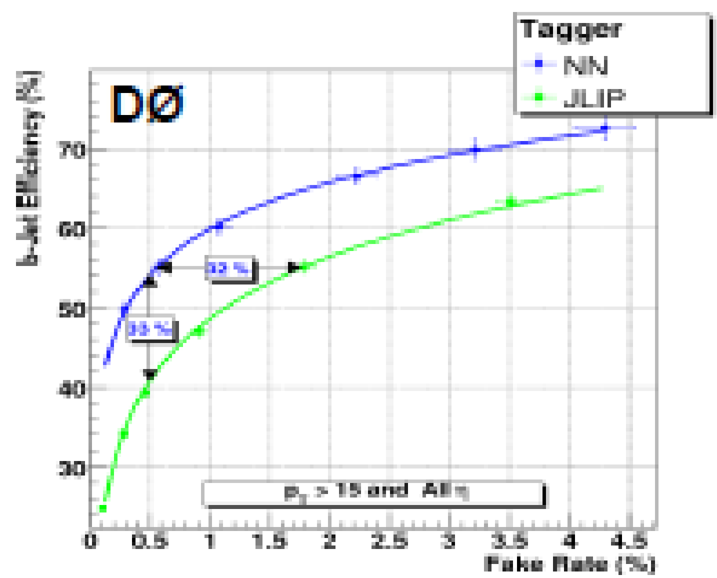
B-jet identification

- 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
- Neutral network increases purity
- 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 ➡
- Tight = 50% eff, 0.5% mis-tag

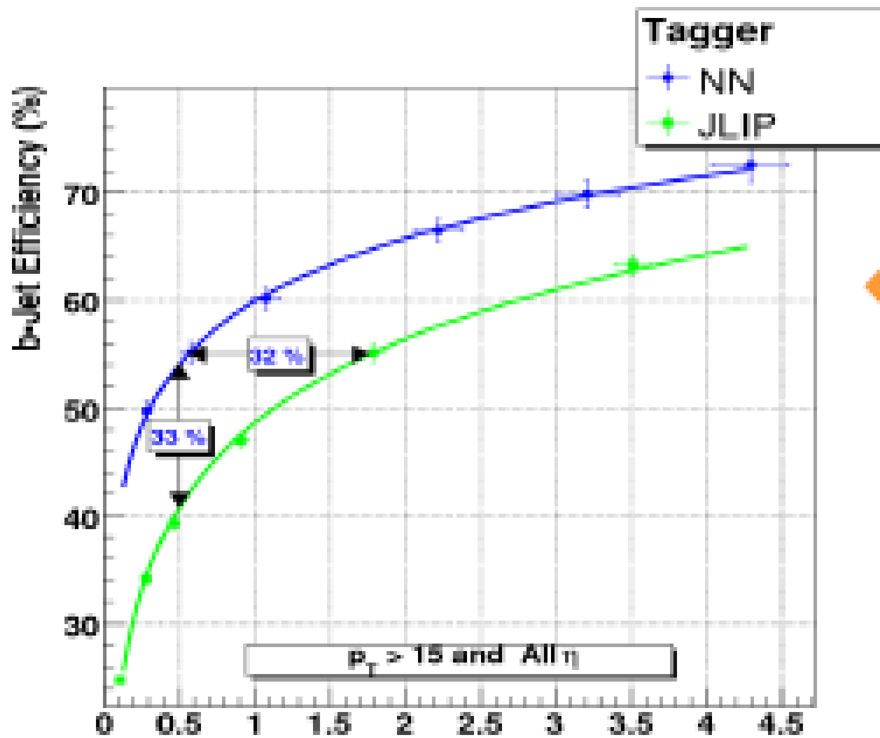


D0 b-tagging

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



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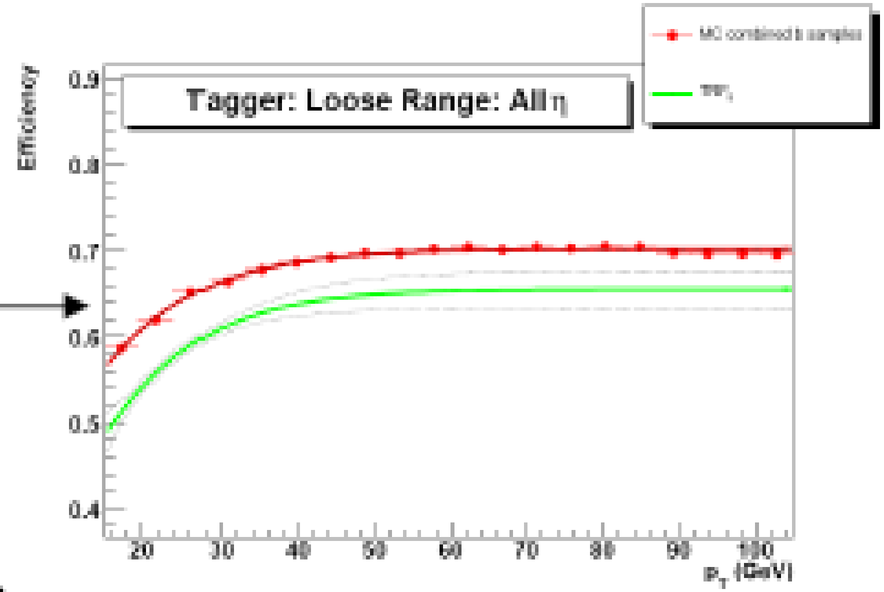
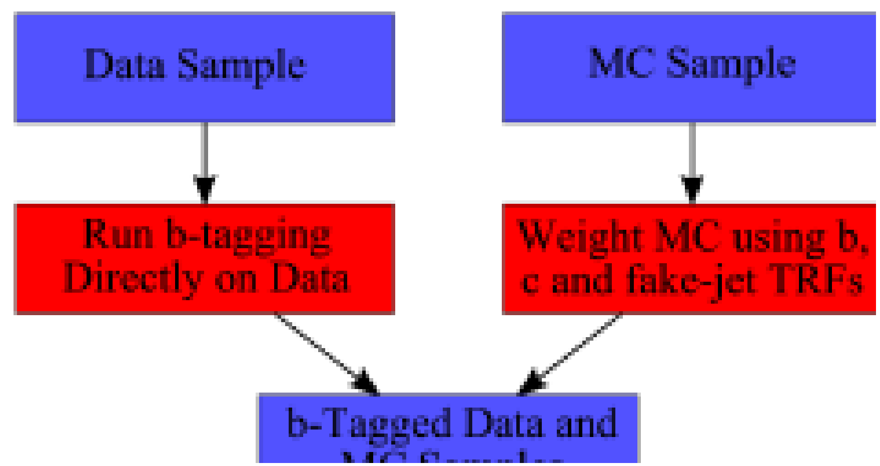
B-tagging-(D0) certification

- 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

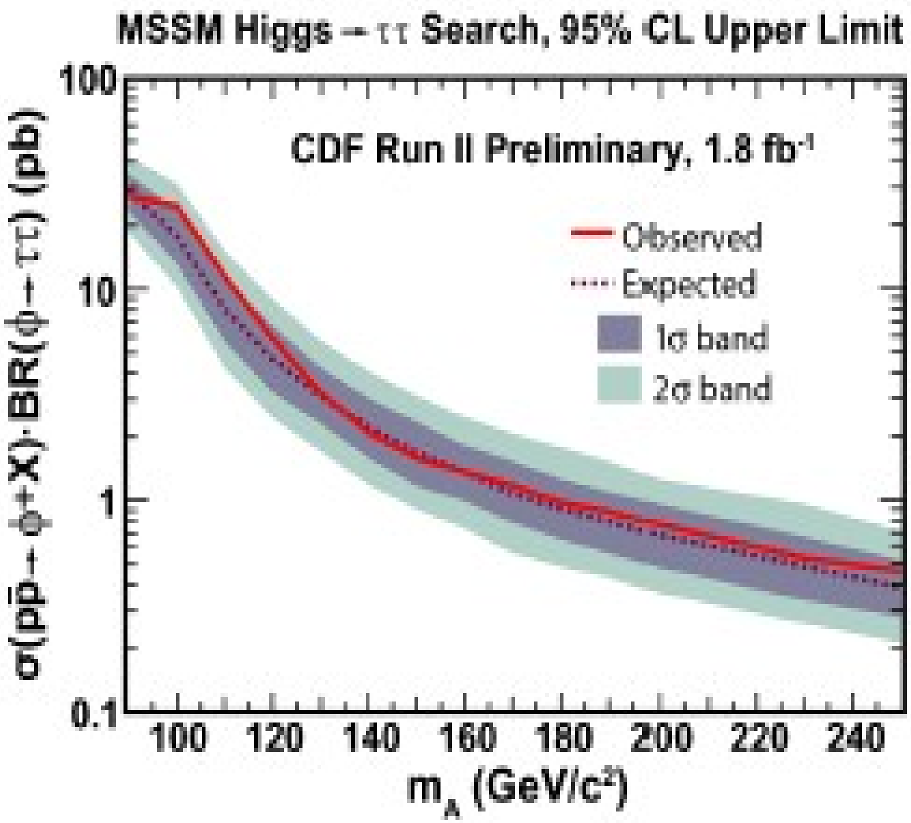


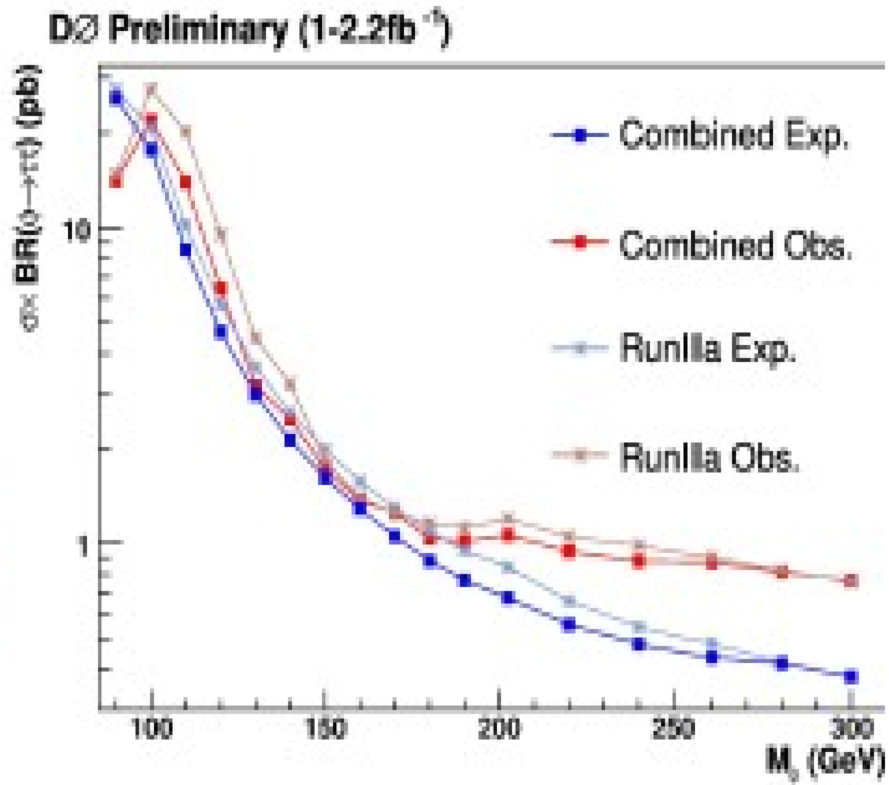
- b and c-efficiencies
  - ➢ Measured using a b-enriched data sample
- Fake-rate
  - ➢ Measured using QCD data



Neutral MSSM Higgs→ττ

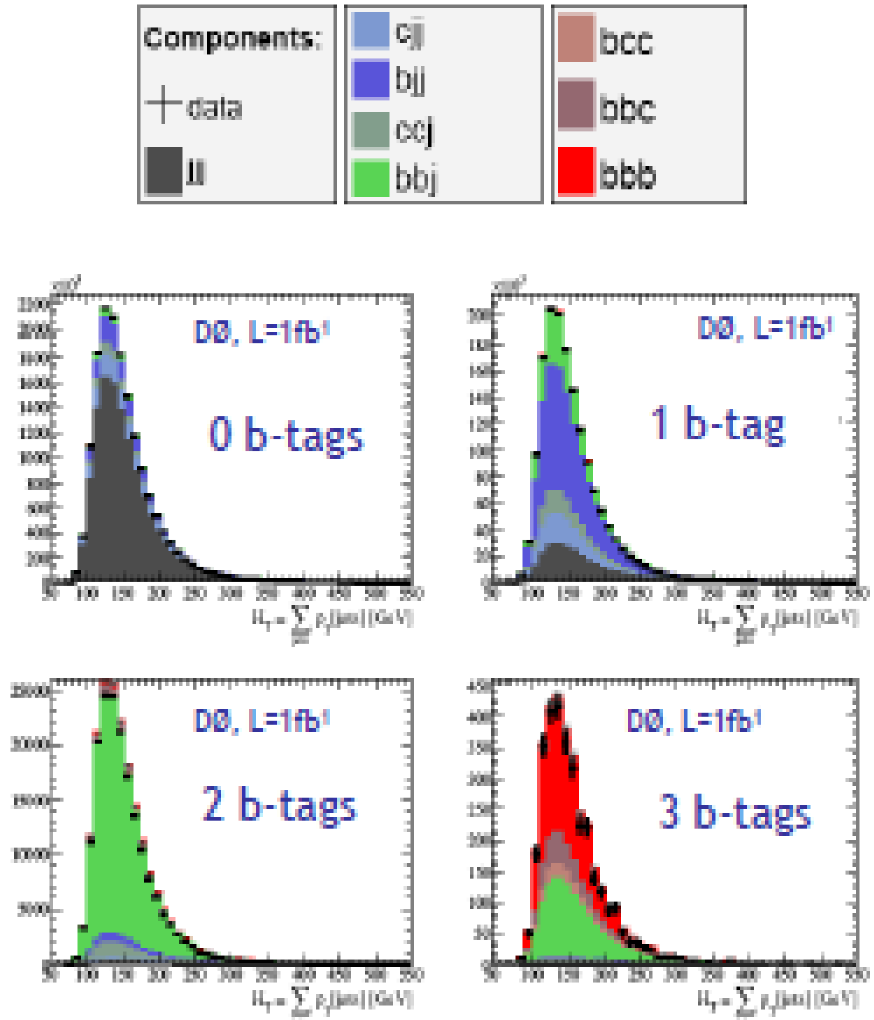
- Set limits
  - σ x Br (φ →ττ) @ 95% confidence level (CL)





Neutral MSSM Higgs → bbb

- Background Prediction
  - Large multijet background
  - Theoretical cross sections very large errors
- DØ: Sample Composition
  - Fit MC to data over several b-tagging points
- DØ: Background Shape
  - Use double b-tagged data to predict triple b-tagged background

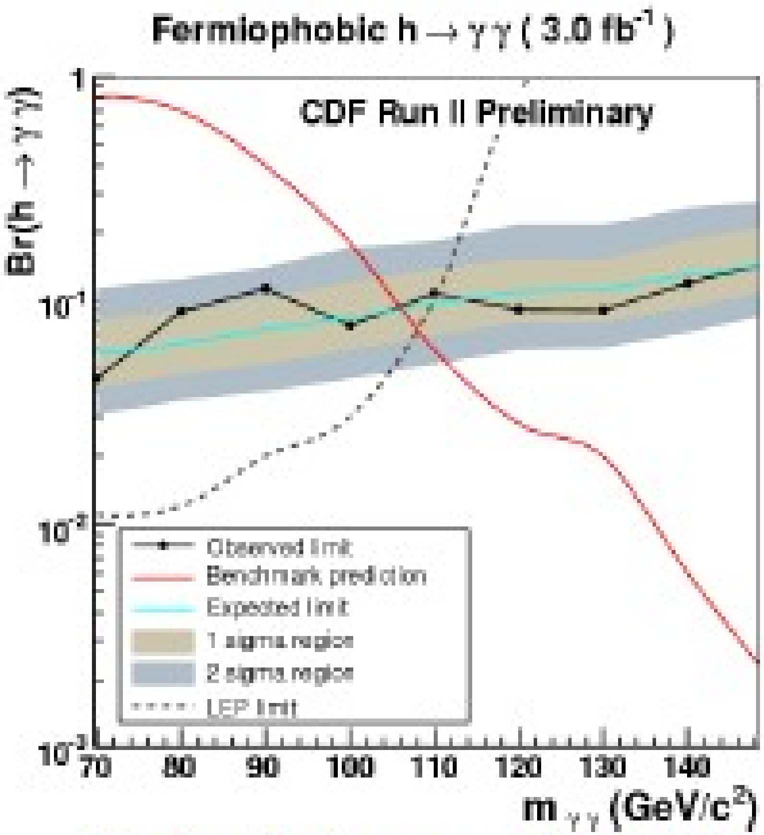


$$S^{exp}_{3Tag}(\mathcal{D}, M_{bb}) = \frac{S^{MC}_{3Tag}(\mathcal{D}, M_{bb})}{S^{MC}_{2Tag}(\mathcal{D}, M_{bb})} S^{data}_{2Tag}(\mathcal{D}, M_{bb}).$$

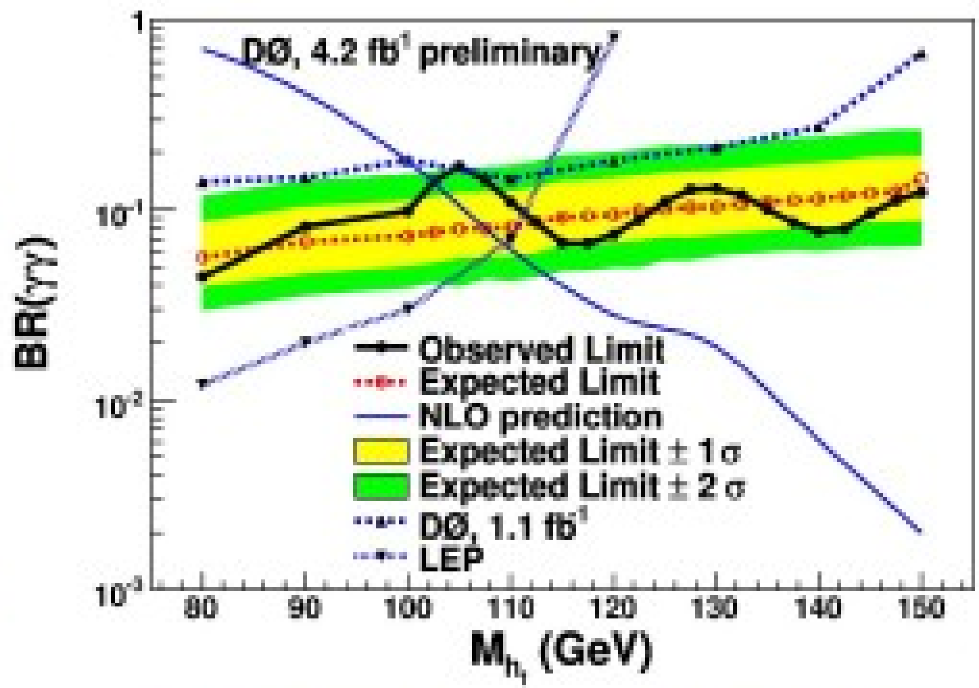
3 b-tag background — MC correction factor — 2 b-tag data

Fermiophobic Higgs→$\gamma\gamma$

- 95% CL limits on branching ratio
  - Extend sensitivity into m_{hf} > 130 GeV
    - Not accessible by LEP



Excluded m_{hf} < 106 GeV



Excluded m_{hf} < 102.5 GeV

MSSM benchmarks

Five additional parameters due to radiative correction

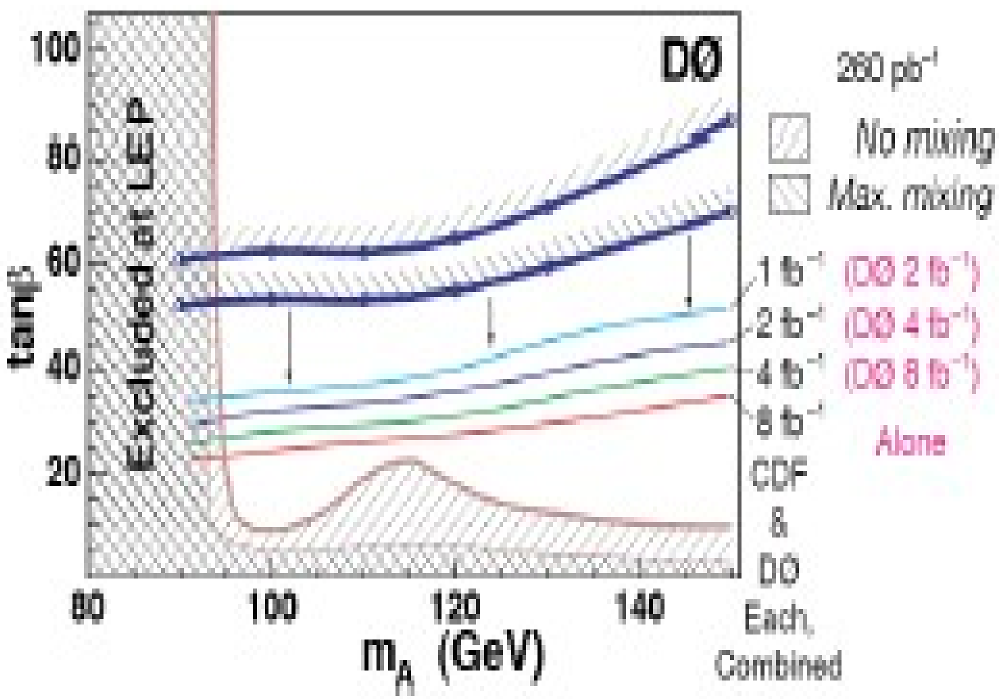
- M_{SUSY} (parameterizes squark, gaugino masses)
- X_t (related to the trilinear coupling $A_t \rightarrow$ stop mixing)
- M_2 (gaugino mass term)
- μ (Higgs mass parameter)
- M_{gluino} (comes in via loops)

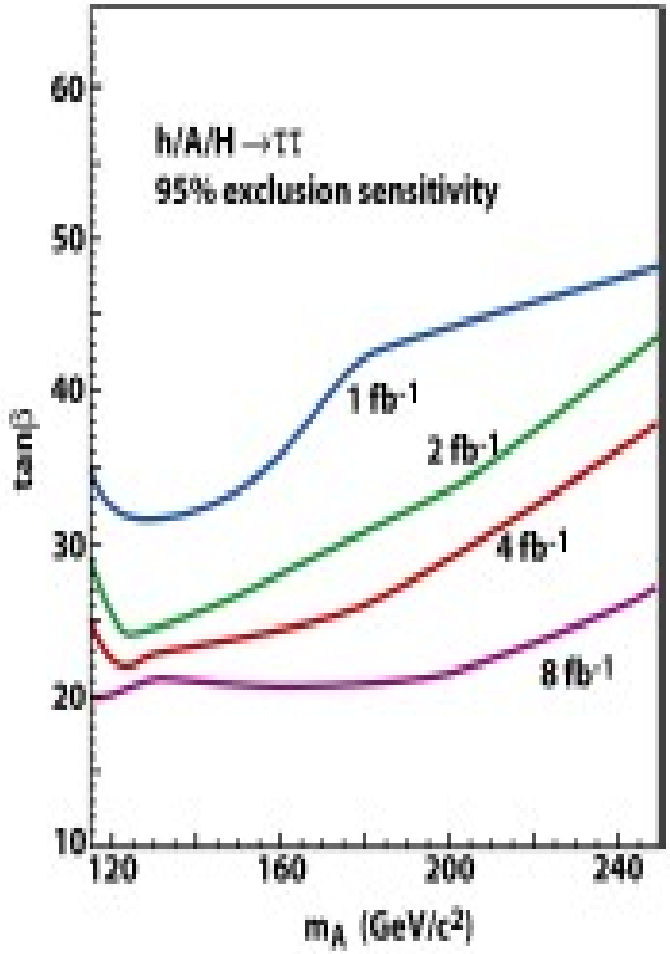
	m_h-max	no-mixing
M_{SUSY}	1 TeV	2 TeV
X_t	2 TeV	0
M_2	200 GeV	200 GeV
μ	±200 GeV	±200 GeV
m_g	800 GeV	1600 GeV

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 → small mass for h**

MSSM evolution





SM Higgs Sensitivity Projections

Can project sensitivity as a function of analyzed luminosity

- ~5.5 fb^{-1} analyzed in 2009
- ~10 fb^{-1} analyzed in 2011

Benchmark scenario:

- Assumes analysis design will remain similar to today's designs
- Assumes we achieve potential for known sources of improvement
- We expect to improve a broad range of analysis aspects including: dijet mass resolution, detector acceptance, add missing channels