



Search for the MSSM Higgs boson in $p\bar{p}$ collisions at DØ

presented by

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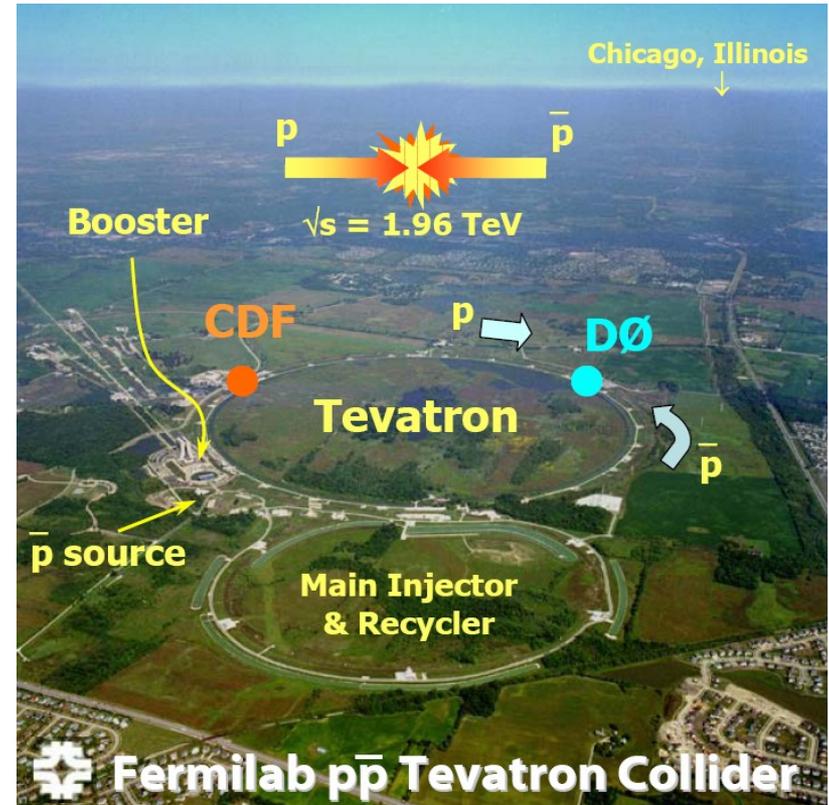
Imperial College London

For the DØ collaboration

XIX International Workshop on Deep-Inelastic Scattering and
Related Subjects,

Newport News, VA USA, April 11-15, 2011

- Introduction
- MSSM Higgs:
 - Neutral Higgs bosons
 - $\phi \rightarrow \tau\tau$
 - $b\phi \rightarrow bbb$
 - $b\phi \rightarrow b\tau\tau$
 - Combinations
 - Prospects
- Conclusions



Tevatron continues to perform well
> 10.5 fb⁻¹ delivered luminosity

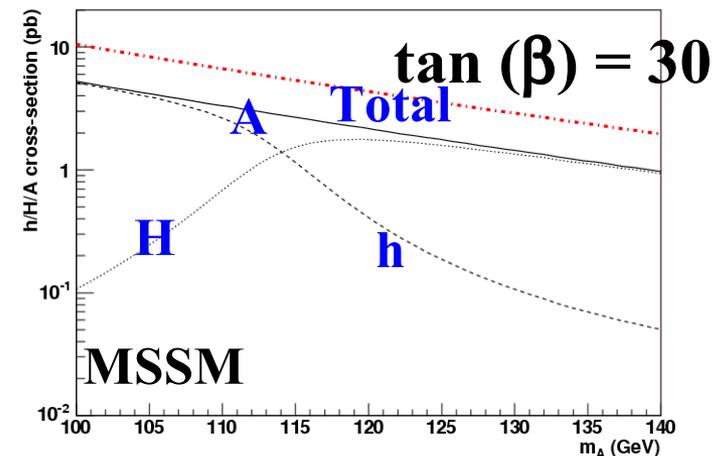
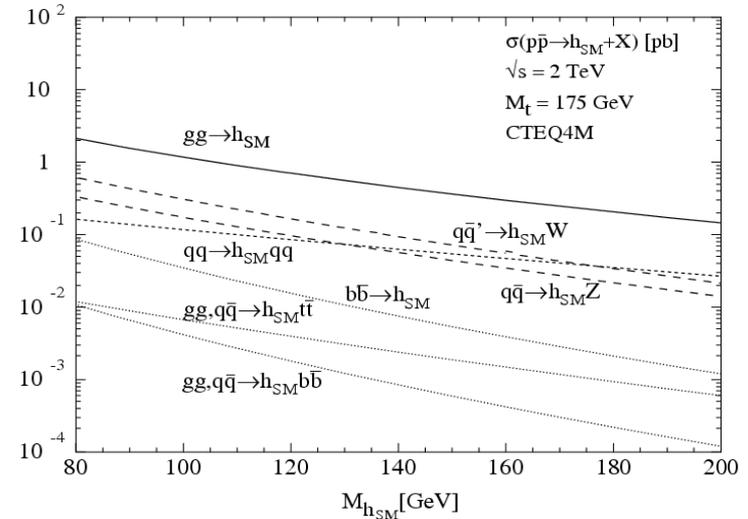
In this talk: results up to 5.2 fb⁻¹

[Thanks to all my Tevatron colleagues]



MSSM Higgs sector

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





Neutral MSSM Higgs Searches

3 channels best suited to benefit from enhanced b-quark coupling:

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

relatively clean signature

low BR ~10%

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

reduced $Z \rightarrow \tau\tau$ background

additional sensitivity at low m_A

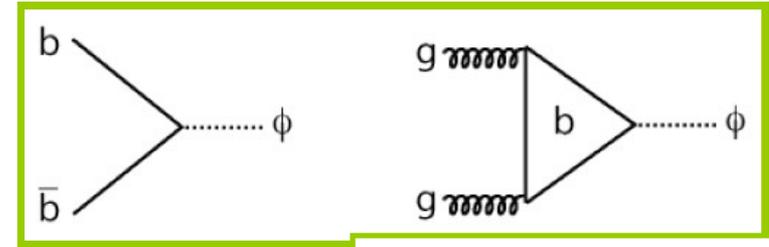
$$(b)b\phi \rightarrow (b)bbb$$

large multi-jet backgrounds

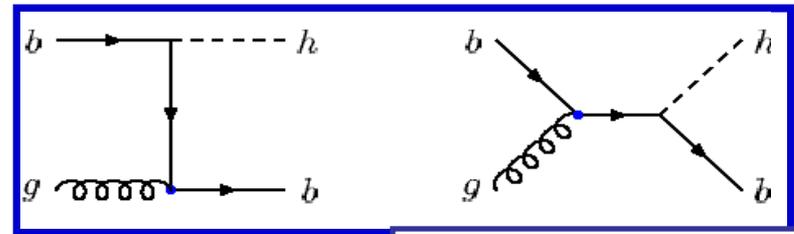
high BR ~90%

Good b and tau identification vital

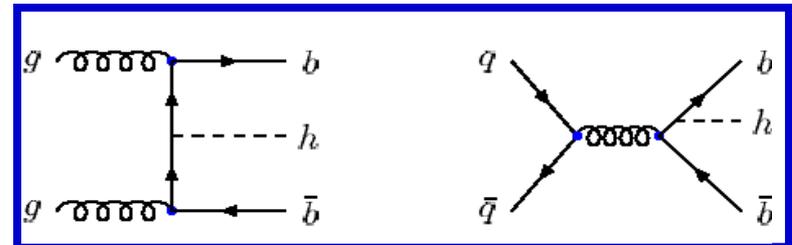
Similar overall sensitivities \rightarrow combine



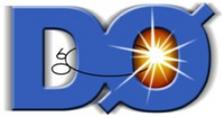
$$\phi \rightarrow \tau\tau$$



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



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

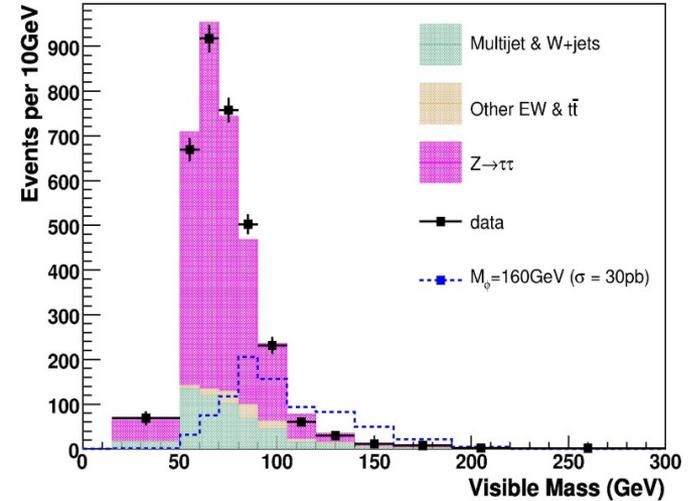


$$\phi \rightarrow \tau\tau$$

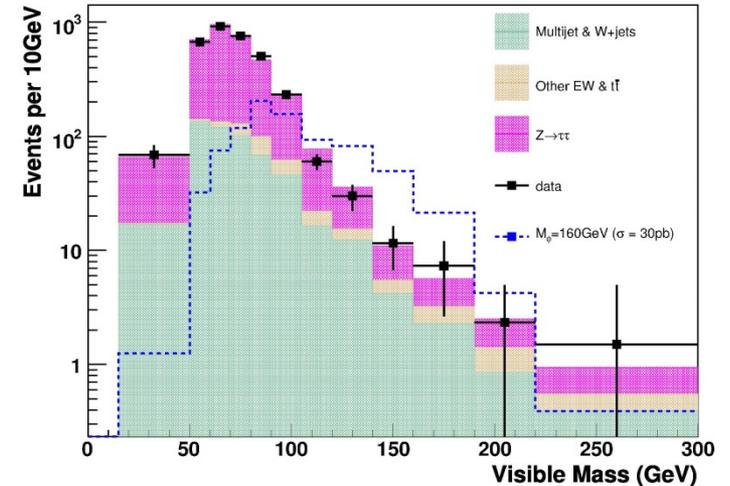
Three possible search channels:

- $\tau\tau_{\mu \text{ had}}, \tau\tau_{e \text{ had}}, \tau\tau_{e \mu}$ channels
- Isolated muon or electron + hadronic tau or electron + muon with opposite sign
- Main backgrounds: $Z \rightarrow \tau\tau$ (irreducible), multi-jets, W +jets, $Z \rightarrow ee/\mu\mu$, di-bosons
- Visible mass used to derive cross section limits

DØ Preliminary (1-2.2 fb⁻¹)



DØ Preliminary (1-2.2 fb⁻¹)





Neutral MSSM Higgs: Imperial College London

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

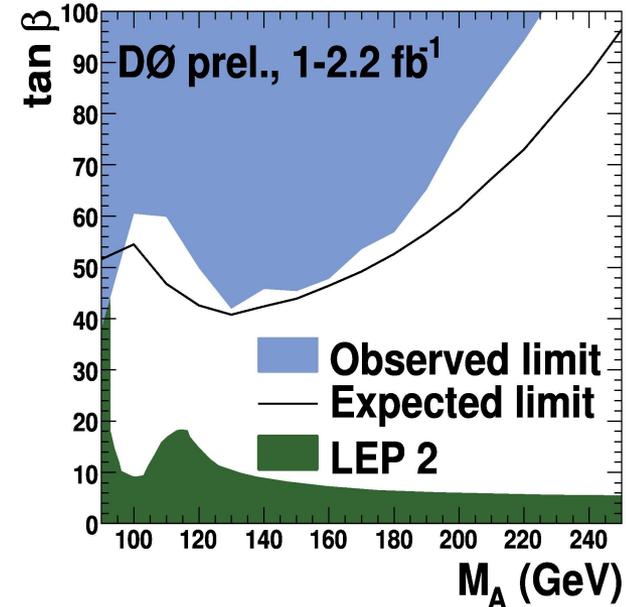
$\tau_\mu \tau_{had}$: 2.2 fb⁻¹ Summer 2008

Combined with published 1 fb⁻¹ channels :

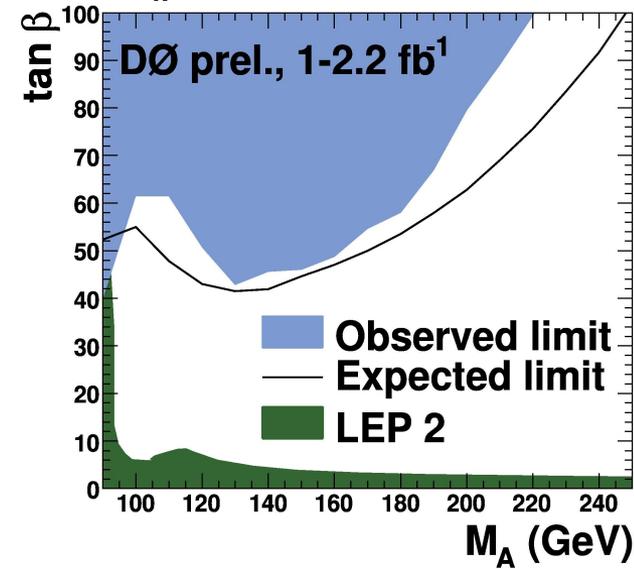
$\tau_\mu \tau_{had}$, $\tau_e \tau_{had}$, $\tau_e \tau_\mu$ [Phys. Rev. Lett. 101, 071804 (2008)]

- 5.4 fb⁻¹ publication imminent

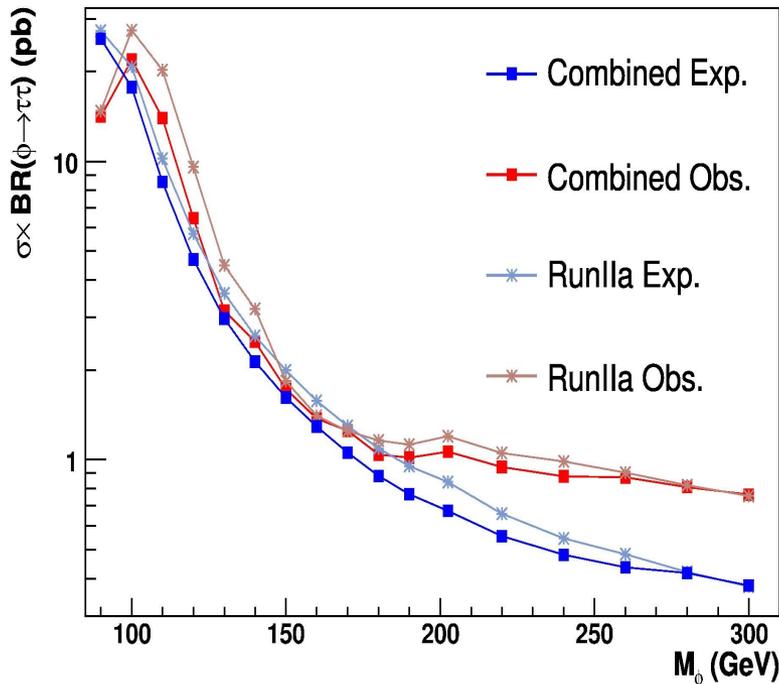
No-mixing, $\mu = +200$ GeV

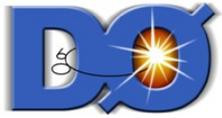


m_h^{max} , $\mu = +200$ GeV



DØ Preliminary (1-2.2fb⁻¹)

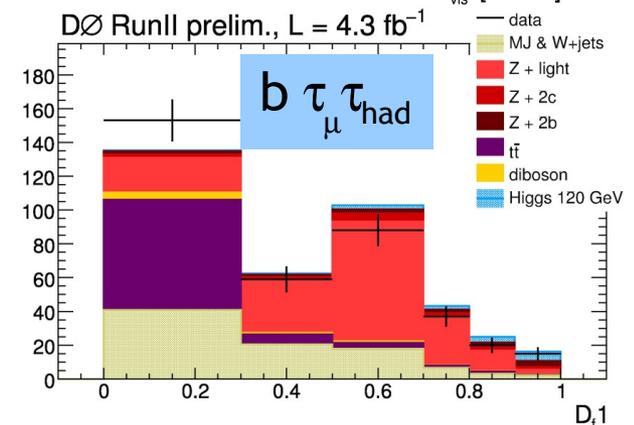
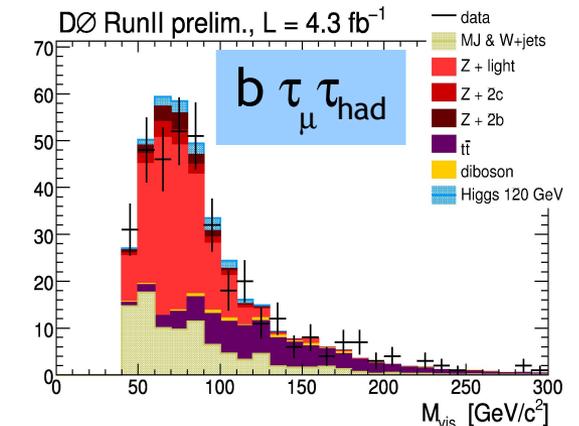
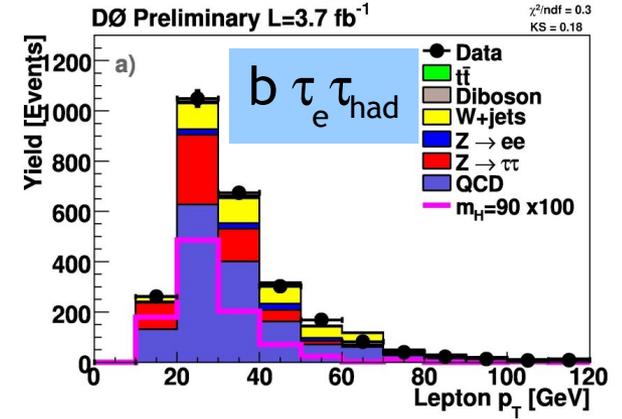




Neutral MSSM Higgs:

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

- Search in $b\tau_l\tau_{had}$ channel
- Lower branching ratio than bbb
 - Cleaner final state
 - Similar sensitivity
 - e: Prelim. 3.7 fb^{-1}
 - μ : Published 2.7 fb^{-1} [Phys. Rev. Lett. 104, 151801 (2010)]
Prelim. 4.3 fb^{-1}
- Main bkg.: $z + \text{jets}$, multi-jets, $t\bar{t}$
- Selection:
 - isolated electrons/muons + opposite sign hadronic tau
 - at least one b-tagged jet
 - Multivariate classifiers (MVAs) trained vs $Z+\text{jets}/t\bar{t}/\text{multi-jets}$

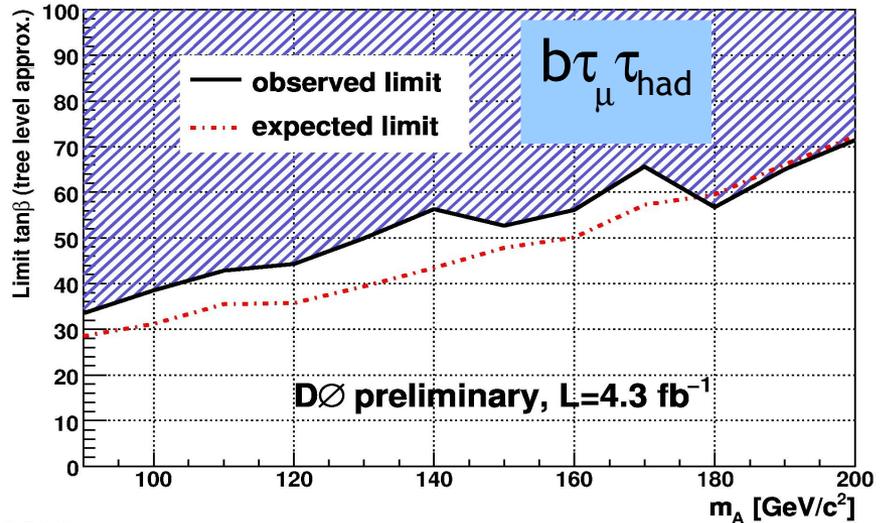
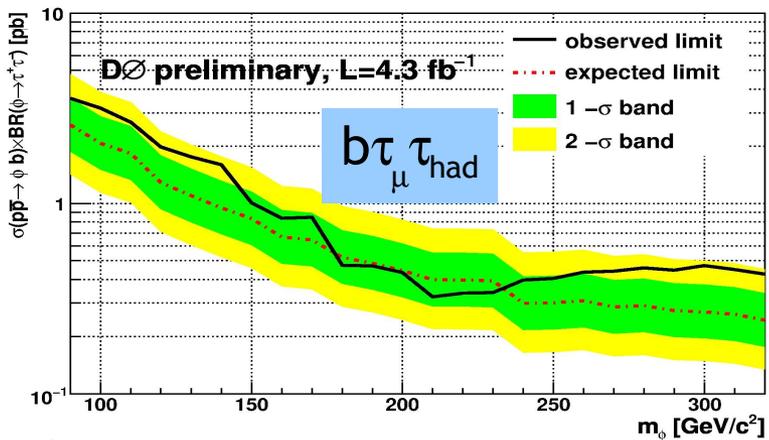
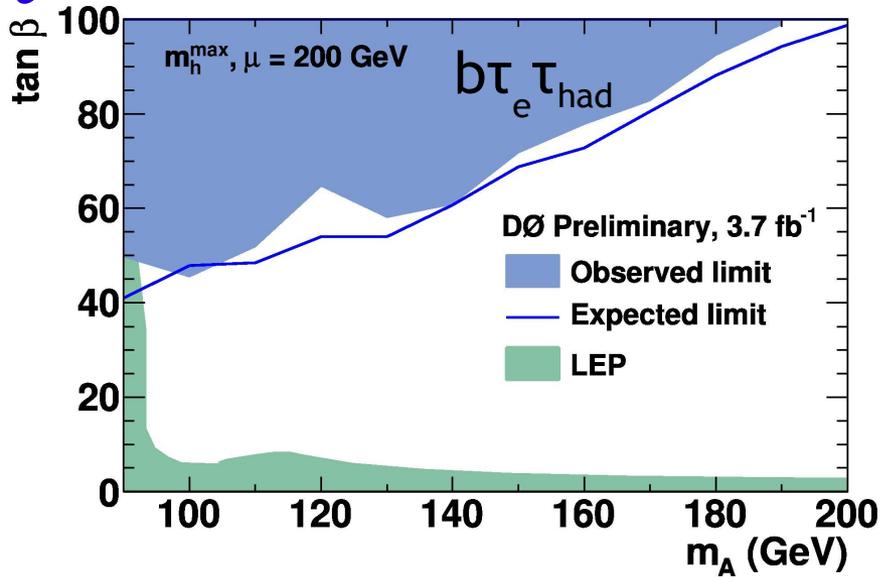


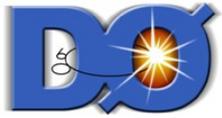


$b\phi \rightarrow b\tau\tau$

- Set limits

- Discriminant output used in setting limits
- $\sigma \times \text{BR}(\phi \rightarrow \tau\tau)$ @ 95% confidence level (CL)
- $b\tau_\mu \tau_{\text{had}}$
 - Interpreted @ tree level
 - Most sensitive Tevatron MSSM channel at low mass

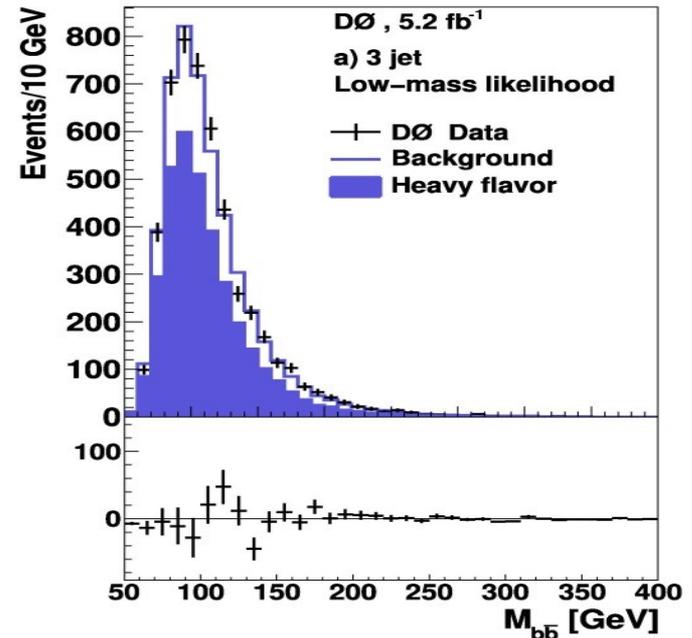
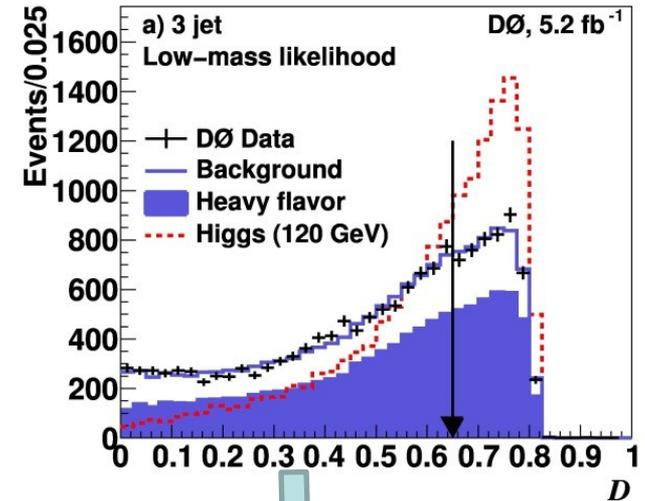


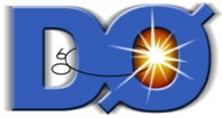


Neutral MSSM Higgs:

$$b\phi \rightarrow bbb$$

- **Signal**
 - At least 3 b-tagged jets
 - Peak in dijet mass spectrum
- **Background**
 - Heavy flavour multi-jet
 - Predicted from data/MC
- **5.2 fb⁻¹ Published 2011** [Phys. Lett. B 698, 97 (2011)]
 - Train and cut on kinematic likelihood
 - Select highest likelihood jet pairing
 - Separate 3 and 4-jet channels
- **Use dijet invariant mass to set limits**
in $\tan\beta - m_A$ plane

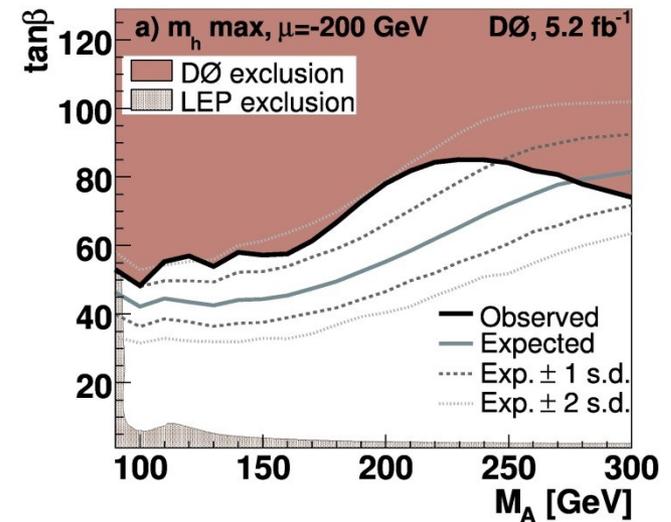
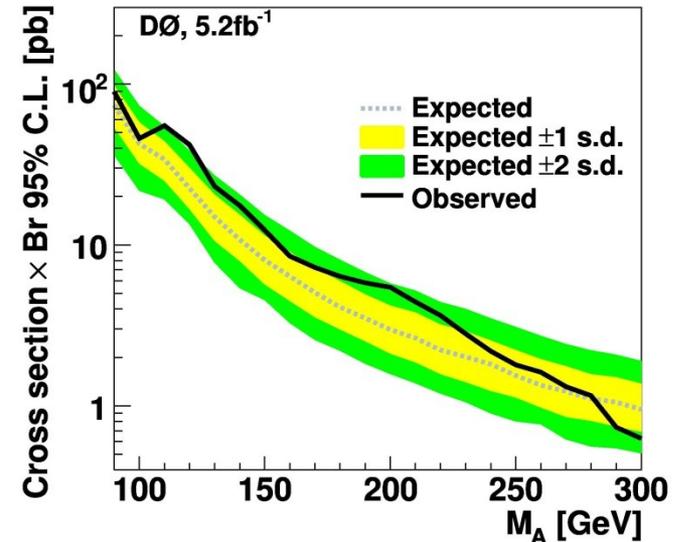




Neutral MSSM Higgs:

$$b\phi \rightarrow bbb$$

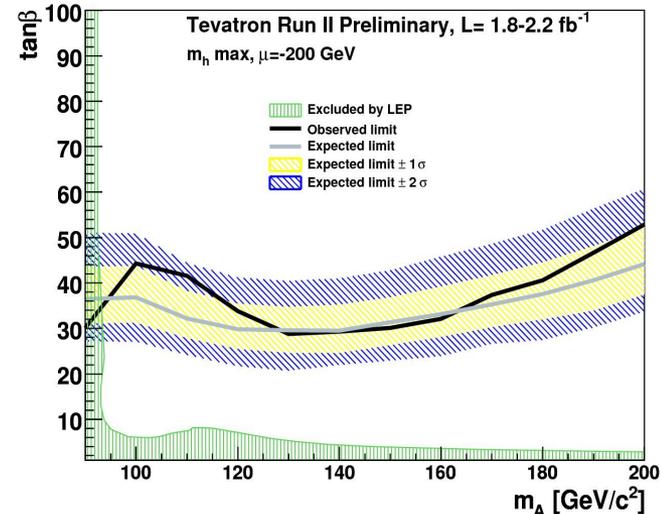
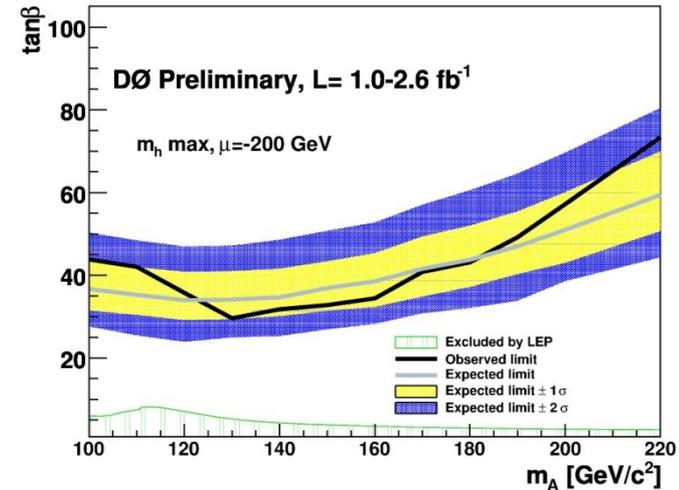
- **Set limits**
 - $\sigma \times \text{BR}(\phi \rightarrow bb)$ @ 95% confidence level (CL)
 - $90 < m_A < 300$ GeV
- **MSSM scenarios**
 - No-mixing & m_h max benchmark scenarios
- **Final limits accounted for:**
 - Width: Not negligible at high $\tan\beta$
 - MSSM NLO Corrections: Strongest limits for Higgs mass term, $\mu < 0$





Neutral MSSM Combination

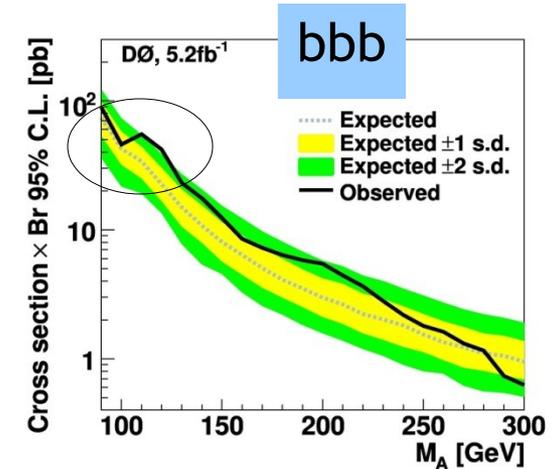
- Combining three signatures in neutral Higgs searches
 - $\phi \rightarrow \tau\tau$ (2.2 fb^{-1})
 - $b\phi \rightarrow b\tau\tau$ (1.2 fb^{-1})
 - $b\phi \rightarrow bbb$ (2.6 fb^{-1})
- 19 sub-channels using between 1.0 and 2.6 fb^{-1}
 - $\tan\beta > 30$ @ 130 GeV
- MSSM combination also across Tevatron experiments in $\phi \rightarrow \tau\tau$
arXiv:1003.3363 [hep-ex]



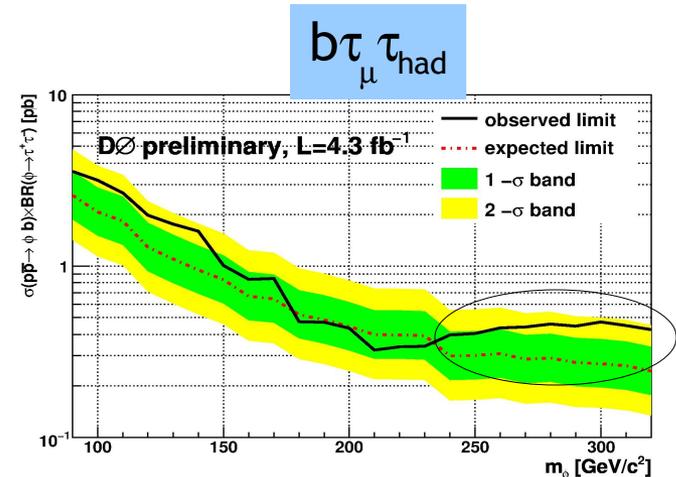


Prospects

- Probing very interesting regions
 - $> 9 \text{ fb}^{-1}$ data now available
 - Aiming for rapid inclusion into analyses
 - Stable and well developed analyses
 - Further algorithmic/analysis improvements



- Short term (early summer)
 - Updated searches ($> 8 \text{ fb}^{-1}$):
 - $b\phi \rightarrow bbb$ & $\phi \rightarrow \tau\tau$ & $b\phi \rightarrow b\tau\tau$
 - New combinations
 - Down to $\tan\beta \sim 20$ for low m_A
 - Or discovery





Conclusions

- DØ performing well
- Wide range of MSSM Higgs searches performed with up to 5.2 fb^{-1} RunII data
 - No Higgs signal observed yet, but established and sensitive analyses:
 - Potential is there
 - Probing theoretically very interesting regions
- Updated analyses
 - x2-5 more data being analysed, will include rapidly
 - Improvements in analysis techniques
 - Combinations, also across experiments
 - Expect to be sensitive beyond $\tan\beta \sim 20$
- New results with increased sensitivity in coming months!



Backup

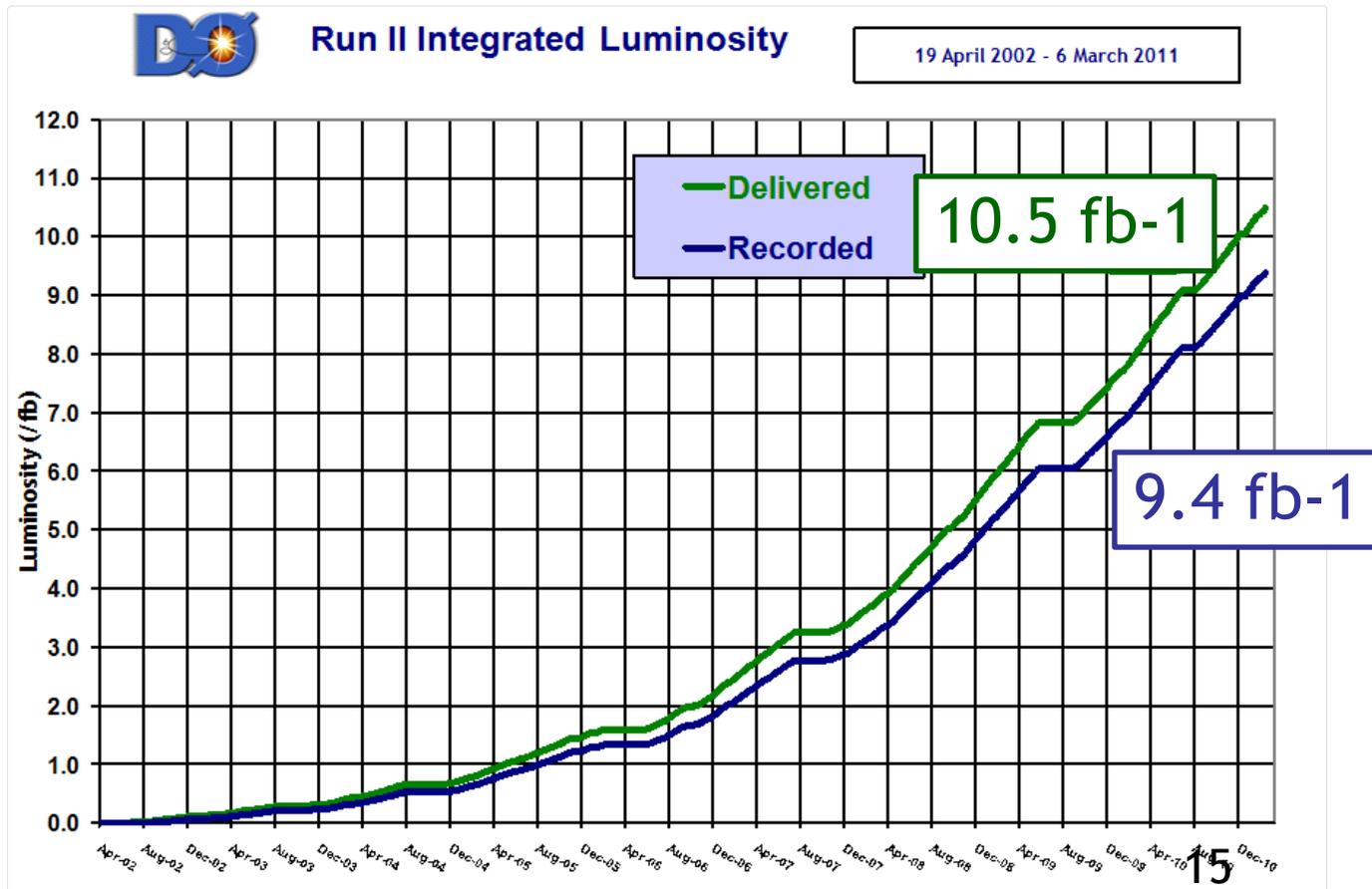
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Tevatron Performance



Tevatron continues to perform well

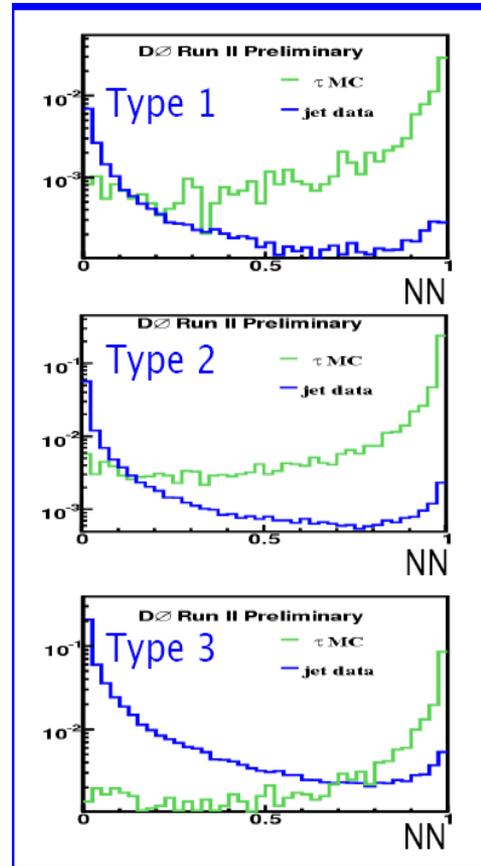
- Over 10.5 fb⁻¹ delivered to each experiment
- Deliver ~2.5 fb⁻¹ per year



Tau-Identification



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



Eff

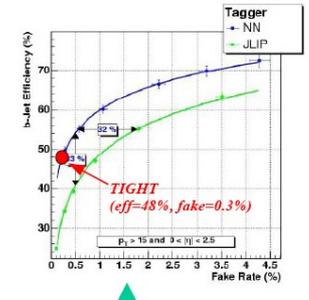
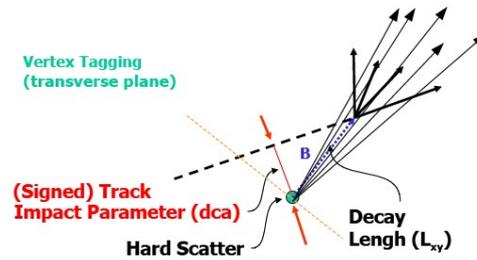
Tau Type	1	2	3
Reconstruction			
Jets	1.5	10	38
Taus	9.1	50	20
NN > 0.9			
Jets	0.04	0.2	0.8
Taus	5.8	37	13

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

b-Jet Tagging



Several mature algorithms used:
3 main categories:
 - Soft-lepton tagging
 - Impact Parameter based
 - Secondary Vertex reconstruction

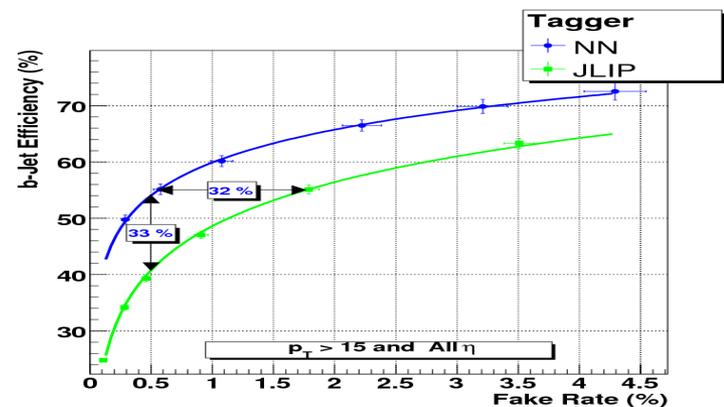
Combine in Neural Network:
 • vertex mass
 • vertex number of tracks
 • vertex decay length significance
 • chi2/DOF of vertex
 • number of vertices
 • two methods of combined track impact parameter significances

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**

➔

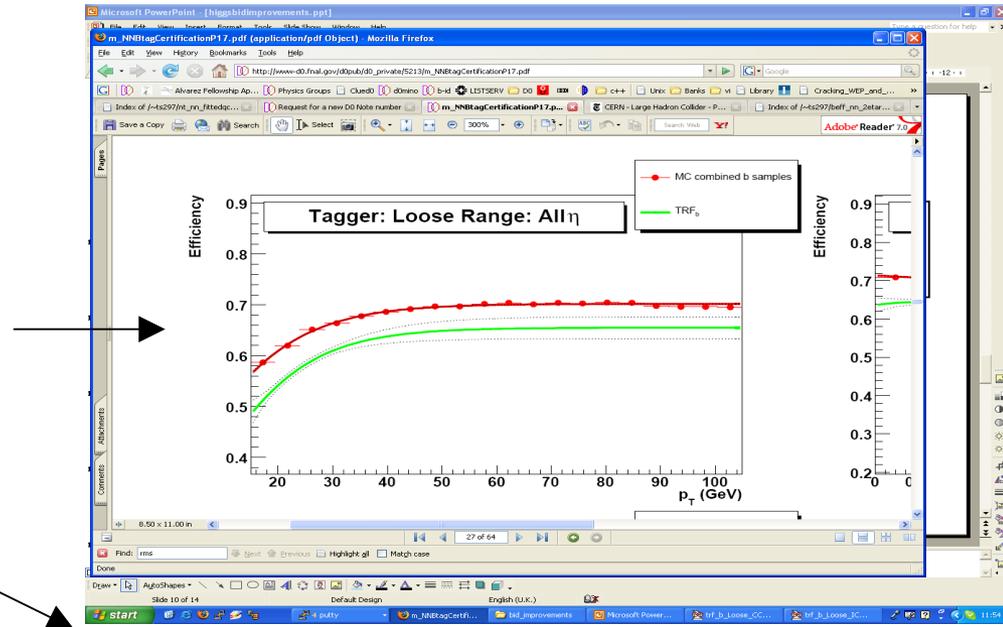
DØ



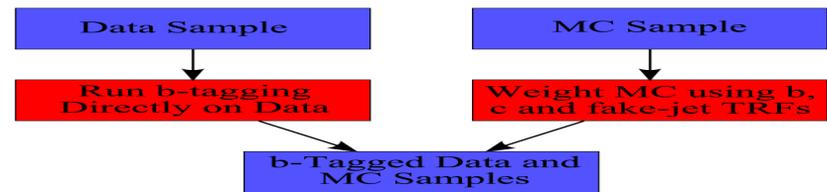
B-tagging - Certification



- 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 multi-jet 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 $\tan\beta$

- No-mixing - vanishing mixing in stop sector \rightarrow small mass

for h

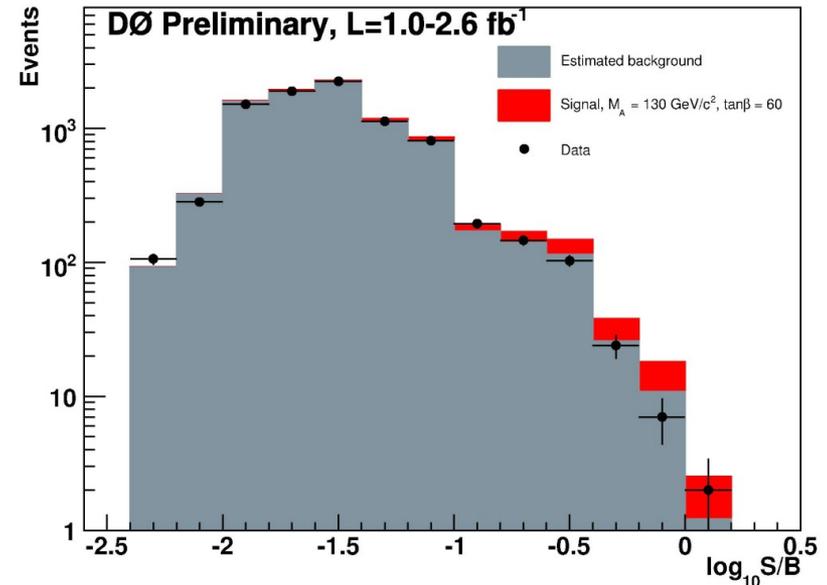
DØ MSSM Combination



- Combine three neutral Higgs searches
 - 19 sub-channels

Channel	Integrated Luminosity / fb ⁻¹		Final Variable
	Run IIa	Run IIb	
$h \rightarrow \tau_e \tau_{had}$	1.0	-	visible mass
$h \rightarrow \tau_\mu \tau_{had}$	1.0	1.2	visible mass
$h \rightarrow \tau_e \tau_\mu$	1.0	-	visible mass
$bh \rightarrow b\tau_\mu \tau_{had}$	-	1.2	1D-discriminant
$bh \rightarrow bb\bar{b}$	1.0	1.6	M_{bb}

- Large number systematic errors
 - Assumed 0 or 100% correlated
- Uses ~7 times luminosity of previous combination





Charged Higgs $\rightarrow cs/\tau\nu$

Search for H^\pm in top decays

- Dilepton, lepton + jets, lepton + tau channels
- Compare predicted/observed yields
- Published 1.0 fb^{-1} in 2009

Two models:

- Tauonic: $H^\pm \rightarrow \tau\nu$
 - MSSM: $\tan\beta > 10$
- Leptophobic: $H^\pm \rightarrow cs$

