Search for Higgs Bosons Beyond the Standard Model at the Tevatron

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Outline

Run II results

1. $b\bar{b}\phi(\rightarrow b\bar{b})$, $\phi = h/H/A$
2. $gg, b\bar{b} \rightarrow A(\rightarrow \tau\tau)$
3. $h \rightarrow \gamma\gamma$
4. $\gamma^{\star}/Z^0 \rightarrow H^{++}H^{--} \rightarrow l^+l^+l^-l^-$
5. quasi-stable $H^{\pm\pm}$

Preliminary results. All limits are given with 95% C.L.

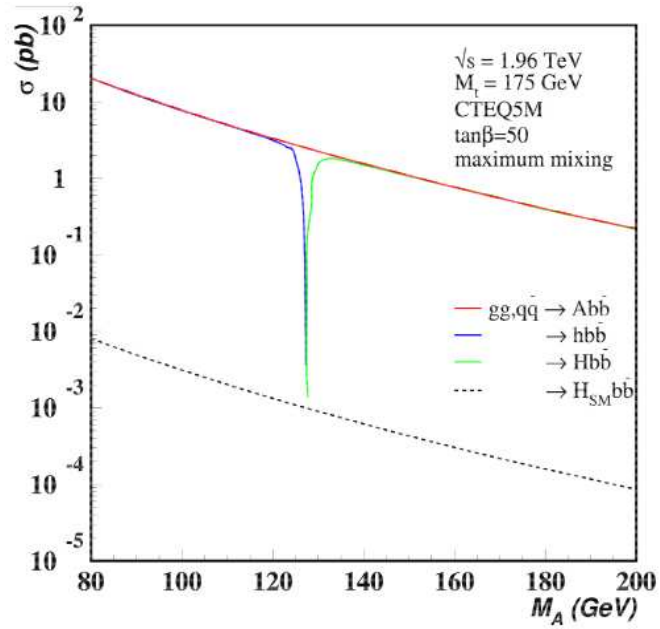
MSSM Neutral Higgs Bosons

MSSM:

- 5 physical Higgs bosons ϕ=(h^0, H^0, A^0, $H^{\pm}$)
- At tree-level: 2 free parameters (M_A, tanβ)

Production:

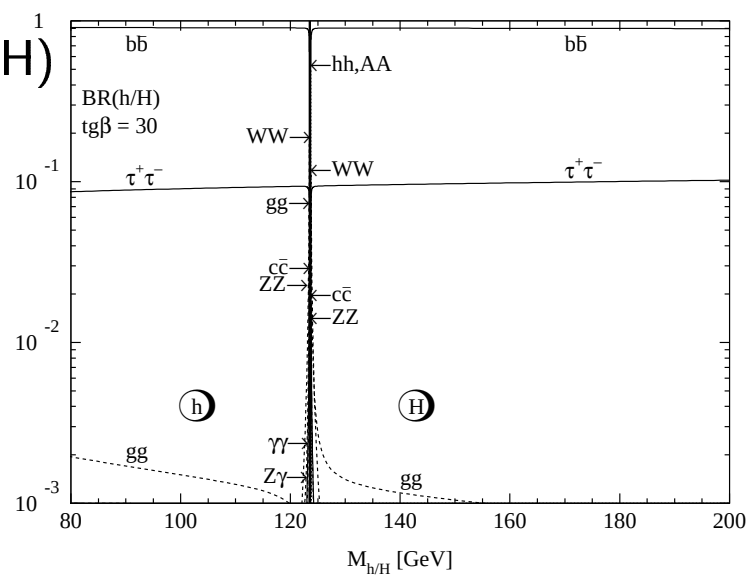
- Enhancement of the coupling to down-type quarks ($tan\beta$) over SM
- Neutral Higgs bosons: production cross-sections scale as $tan^2\beta$



Decay: (high tanβ)

- BR($h/H/A \to b\bar{b}$) $\sim$ 90%
- BR($h/H/A \to \tau\tau$) $\sim$ 10%

BR(h/H)



$b\bar{b}\phi(\rightarrow b\bar{b})$ DØ Search (1)

Don't distinguish between A and h/H (simultaneous production)

Backgrounds:

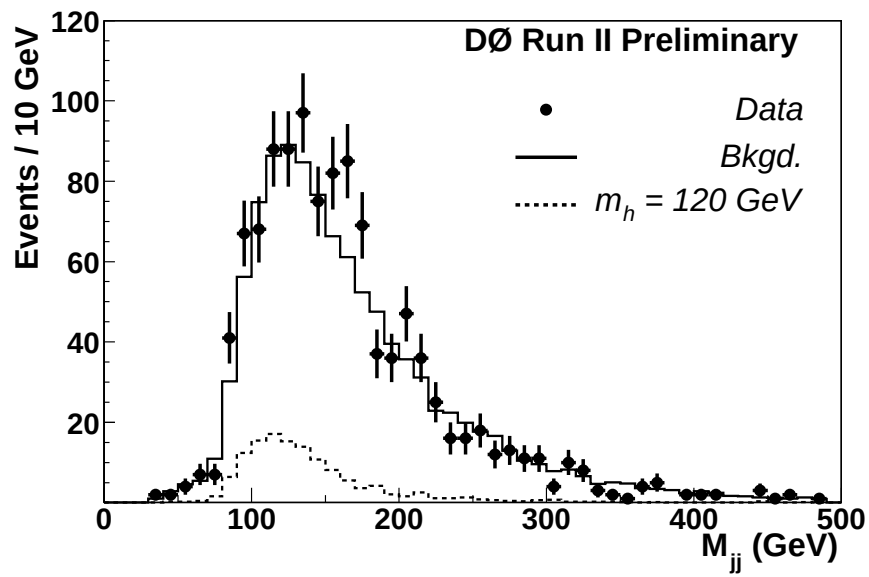
Multijets production (4j, 2b+2j, 4b), Z($b\bar{b}$)+jets, $t\bar{t}$

Strategy:

- Events with $\geq$3 b-tagged jets;
- Search for a peak in the invariant di-jets mass.

Events selection:

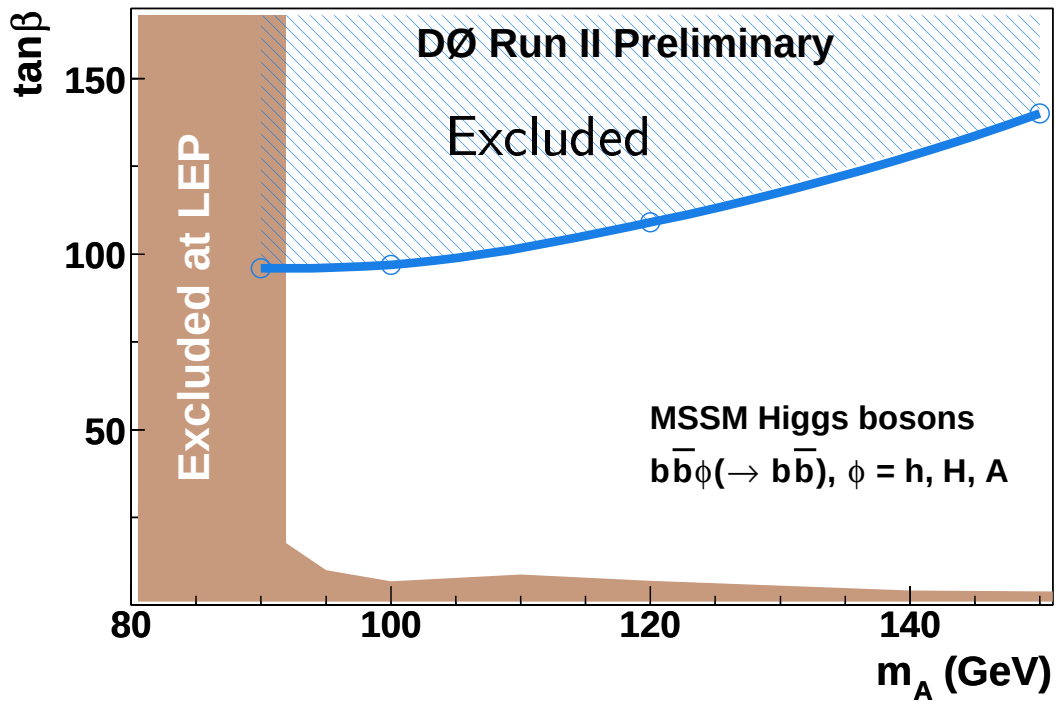
- Kinematical cuts on leading jets (E_T, η)
- Optimization for various m$_h$
  $p_T(j_{1,2,3})$=45,35,15 GeV for m$_h$=120 GeV
- $\geq$3 b-tagged jets (Secondary Vertex)
- Typical acceptances:
  $\sim$ 0.5-1.5 % (n_j $\geq$3, M$_h$=100-150 GeV)



$b\bar{b}\phi(\rightarrow b\bar{b})$ DØ Search (2)

Dataset:

Multi-jet triggers
$\mathcal{L}_{int}$=131 pb^{-1}
September 2002 - July 2003



Results:

- Absence of observed signal.
- Exclusion at 95% C.L. in the (m_A, tanβ) MSSM parameter space.

$gg, b\bar{b} \to A(\to \tau\tau)$ CDF Search (1)

Signal:

- $\tau_1 \to \nu_\tau\ e\ \nu_e,\ \ \tau_2 \to \nu_\tau\ hadrons$
- $\tau_1 \to \nu_\tau\ \mu\ \nu_\mu,\ \tau_2 \to \nu_\tau\ hadrons$

Dataset:

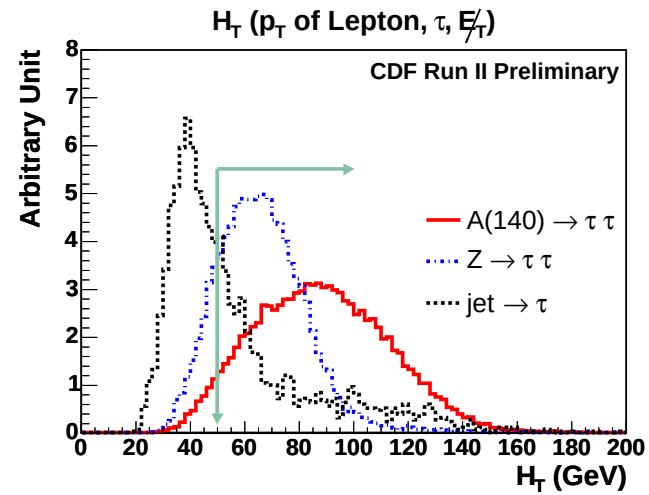
τ triggers (lepton + isolated track)
$\mathcal{L}_{int} \sim 200$ pb^{-1}
March 2002 - January 2004

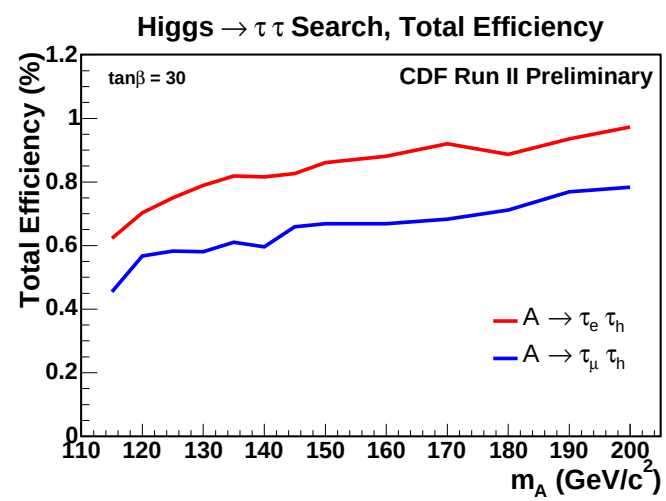
Background:

multi-jet events, $W \to l\nu$, $Z \to ll$

Selection:

- τ identification: isolation outside candidate cone (calorimeter + tracker) + N$_{tracks}$
- $\hat{H}_T = |p_T^{vis}(\tau_1)| + |p_T^{vis}(\tau_2)| + E_T^{miss}$
- direction(τ decay products, E$_T^{miss}$)
- Z boson mass veto (ee,$\mu\mu$)





$gg, b\bar{b} \to A(\to \tau\tau)$ CDF Search (2)

Remaining background:

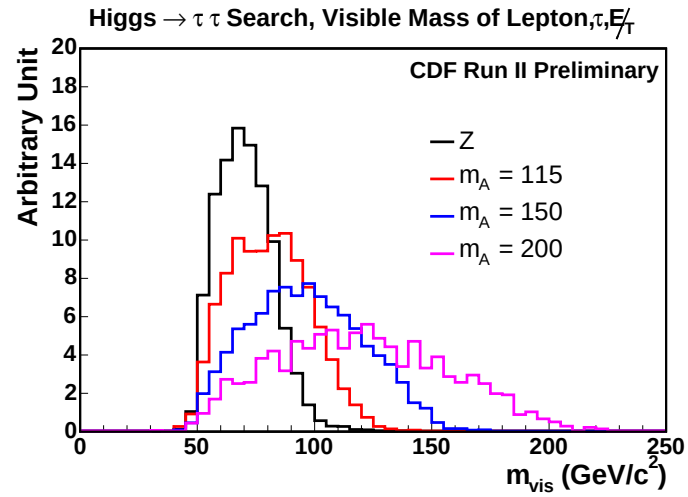
N_{exp}(total)	263.6 $\pm$ 30.1
$N_{exp}(Z \to \tau\tau)$	236.4 $\pm$ 29.5
N_{obs}	236

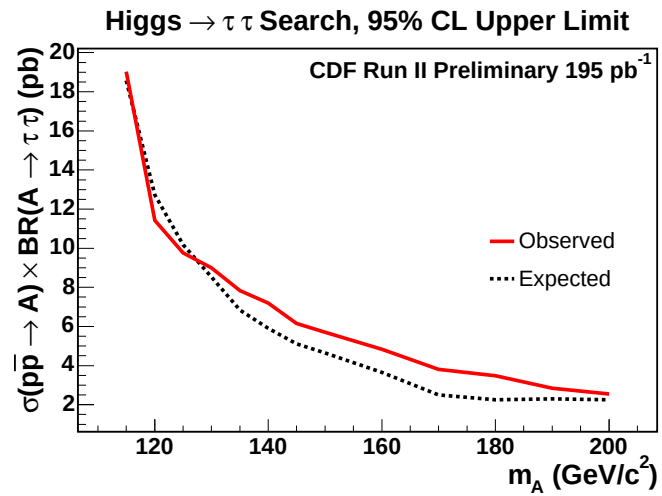
Main systematics:

- jet $\to \tau$ fake rate: 30%
- τ identification: 10%

Limits:

- Binned likelihood fit on mass-like discriminating variable $m_{vis}(l, \tau_h^{vis}, E^{miss})$
- No evidence of signal.
- 95% C.L. upper limit on $\sigma\times$ BR.

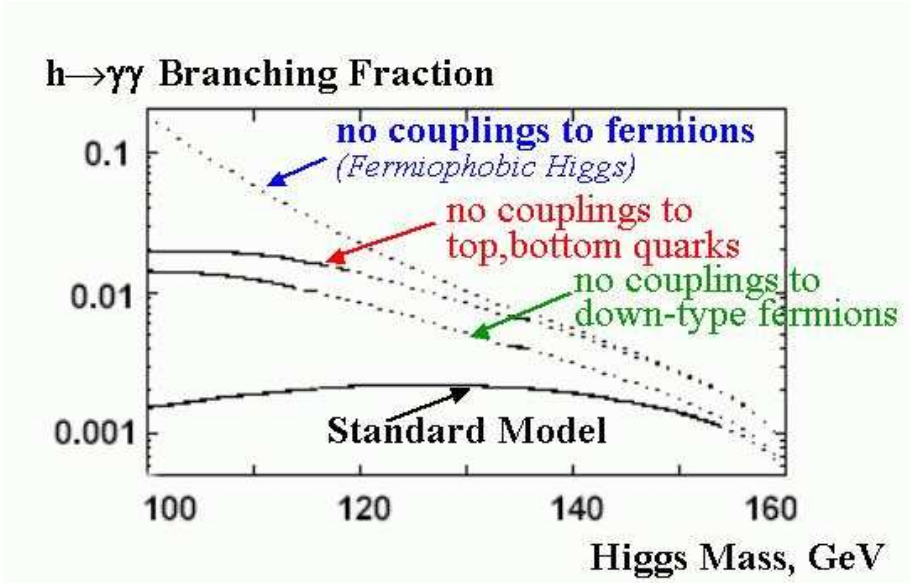




DØ Search: $h \to \gamma\gamma$ (1)

Motivation:

- SM Higgs decays: b, W, Z... γ (10^{-3}-10^{-4})
- $\sigma \times$BR($h \to \gamma\gamma$) enhanced beyond the Standard Model
- Scenarios (dominant production):
  - Fermiophobic (no coupling to fermions)
  - Topcolor (only top quark coupling)
- $\gamma\gamma$ clean signature in $p\bar{p}$ colliders



Dataset:

$\mathcal{L}_{int}$ =191 pb^{-1} (April 02 - September 03)
trigger: 2 high p_T EM objects

Events selection:

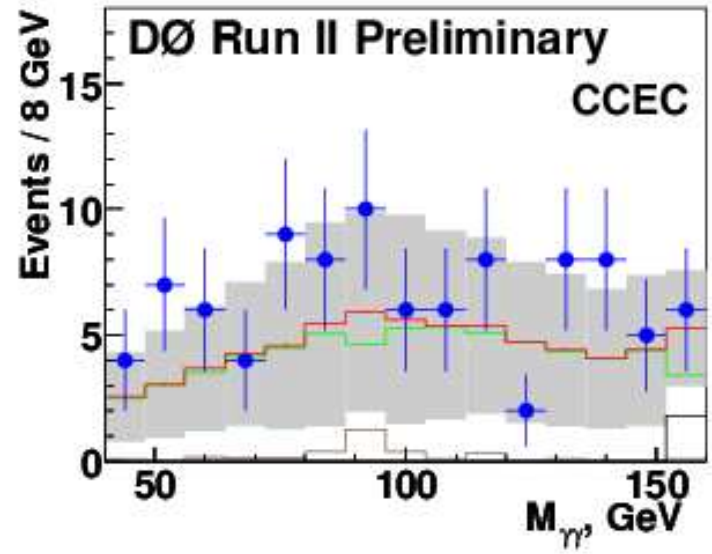
- photon ID: EM ID + no associated tracks
- $p_T(\gamma\gamma) > 35$ GeV
- 3 categories: CCCC, CCEC, ECEC; CC (central calorimeter), EC (end calorimeters)

DØ Search: $h \to \gamma\gamma$ (2)

Background events:

(derived from data)

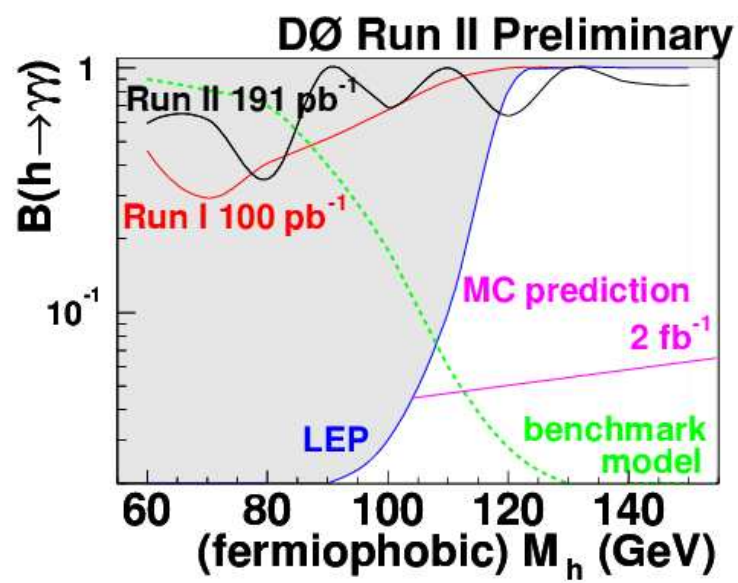
- $\gamma^\star/Z \to ee$ (e mis-identified as γ)
- direct di-photon production
- QCD events (1 γ and 1 jet or 2 jets passing γ ID criteria)



Limits:

Counting experiment, sliding mass window ($\sim$5-10 GeV for m_h=60-150 GeV)

95% C.L. upper limit on BR($h \to \gamma\gamma$)



Main systematics:

- Background: γ mis-identification rate (30%)
- Signal: luminosity (6.5%)

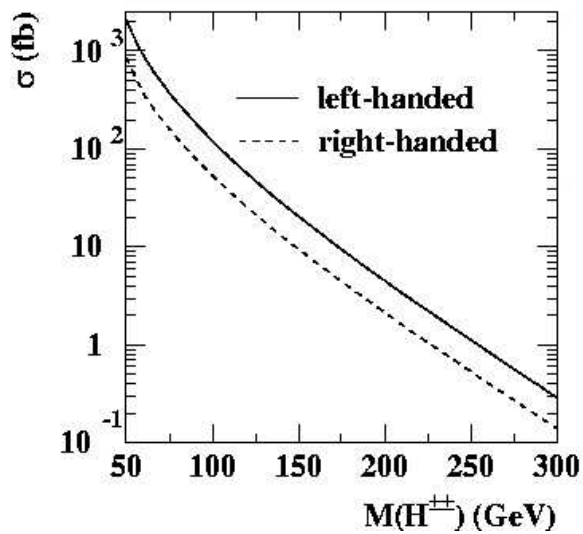
Doubly-charged Higgs

$H^{\pm\pm}$ predicted in:

- Higgs triplet models
- L-R symmetric models (M=$\mathcal{O}$(100 GeV/c^2) SUSY)

Production:

- couples to leptons, γ, W, Z, $H^{\pm}$
- $q\bar{q} \to \gamma^{\star}/Z^0 \to H^{++}H^{--}$



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$H^{\pm\pm} \to l^{\pm}l^{\pm}$:

- search for energetic isolated like-sign di-lepton (ee, $\mu\mu$, $e\mu$) pairs
- backgrounds: hadrons decaying to leptons ($b\bar{b}$), $\gamma/Z \to l^+l^-$ (γ conversion, charge mis-identification), $WZ \to l\nu + ll$, $W(\to l\nu) + jets$, cosmic rays

quasi-stable $H^{\pm\pm}$: (doesn't decay in the detector)

- search for 2 highly ionizing tracks with muon-like penetration in the detector
- backgrounds: no SM process, highly ionizing leptons and QCD jets

$H^{\pm\pm} \to \mu^{\pm}\mu^{\pm}$ DØ Search (1)

Dataset:

Inclusive di-muon data
August 2002 - June 2003
$\mathcal{L}_{int}$=113 pb^{-1}

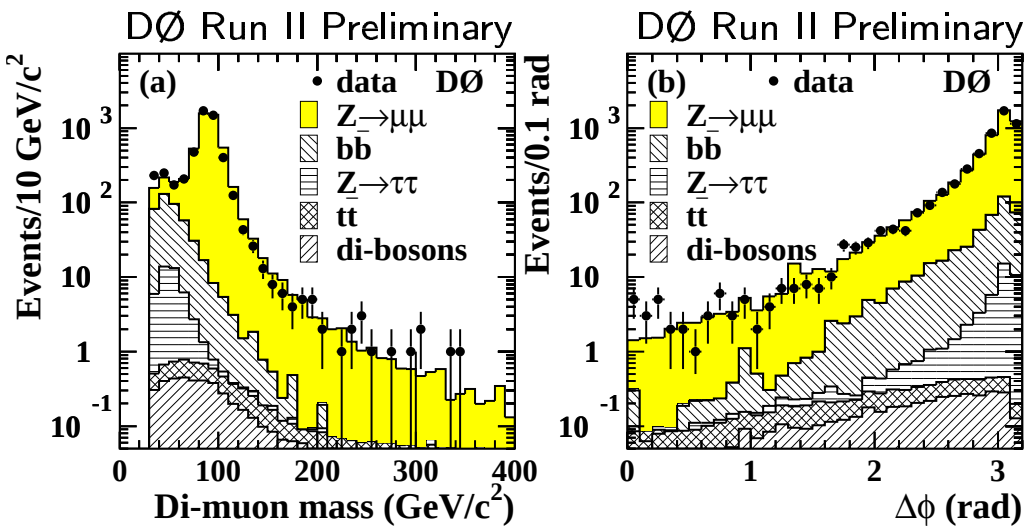
Event selection:

S1: ≥ 2 muons with $p_T > 15$ GeV

S2: Isolation (tracker + calorimeter)

S3: $\Delta\Phi(\mu_1, \mu_2) < 0.8\pi$

S4: ≥ 1 like-sign $\mu\mu$ pair



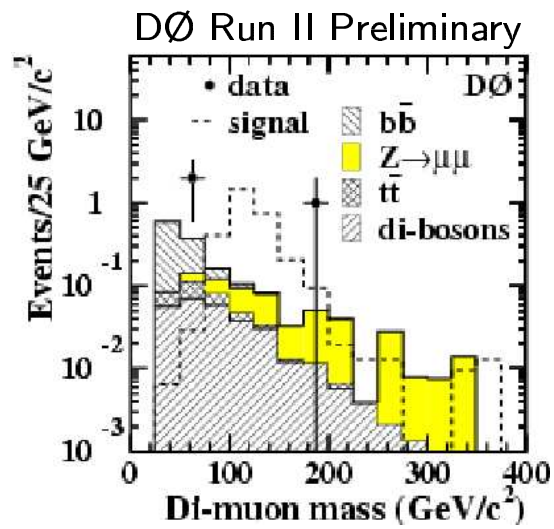
Agreement in shape and rate.

Signal and background rates:

Simulation corrected from measured efficiencies ($Z \to \mu\mu$).
Efficiency(signal)=(47.5±2.5)%, independent of M$_{H^{\pm\pm}}$

$H^{\pm\pm} \to \mu^\pm\mu^\pm$ DØ Search (2)

- look for excess in like-sign $\mu\mu$ invariant mass spectrum ($M_{\mu^\pm\mu^\pm} \sim M_{H^{\pm\pm}}$)
- $N_{exp} = 1.5 \pm 0.4$ events ($M_{H^{\pm\pm}} = 100$ GeV)
- 3 candidates consistent with BGD expectations.

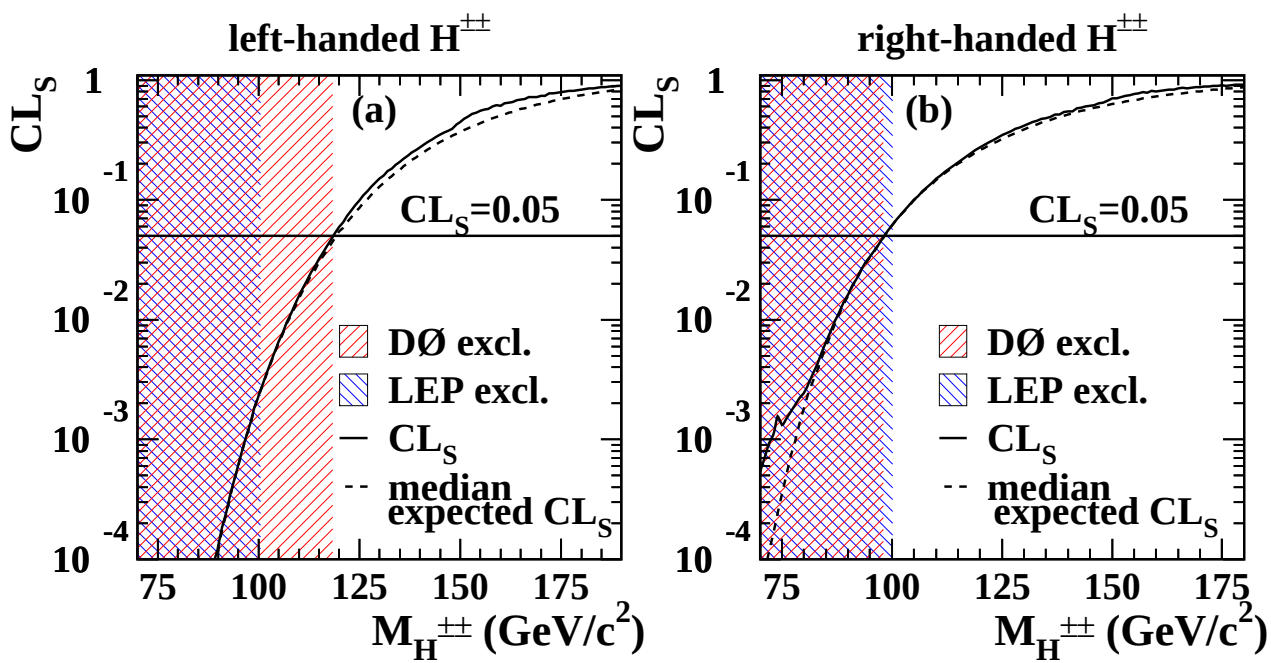


DØ mass limits:

95% C.L. upper limit on $M_{H^{\pm\pm}}$ is derived, assuming 100% BR to $\mu\mu$.

$H_L^{\pm\pm}$	118.4 GeV
$H_R^{\pm\pm}$	98.2 GeV

Accepted for PRL.



$H^{\pm\pm} \to \ell^\pm\ell^\pm$ CDF Search (1)

Inclusive search in same-sign:

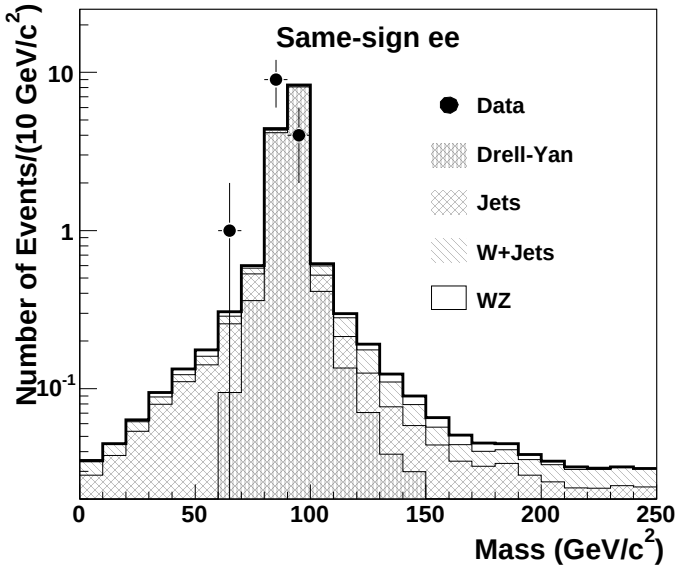
ee: 2EM trigger, central e with $E_T > 30$ GeV, $p_T(track) > 10$ GeV

$\mu\mu$: 1 μ trigger, beam-line coincident out-going μ, $p_T(track) > 25$ GeV, MIP

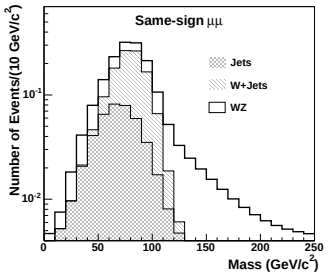
$e\mu$: 1EM trigger, central e + track match to a μ.

Efficiencies and rates:

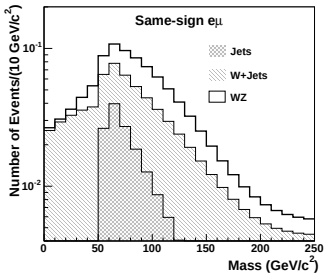
- Trigger, tracking, lepton-identification efficiencies and backgrounds are obtained from data.
- Signal kinematics and acceptances are corrected from $Z \to \mu\mu$ (simulation vs data).
  - ◇ 34% (18%) ee, $\mu\mu$ ($e\mu$)



$\mu\mu$



$e\mu$

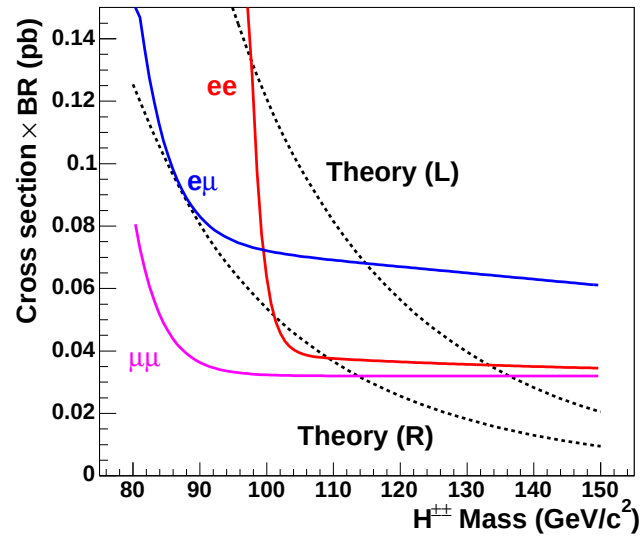


Integrated background:

$M(ll)$ /GeV	N_{obs}	N^{ee}_{exp}	$N^{\mu\mu}_{exp}$	$N^{e\mu}_{exp}$
< 80	1	1.1±0.4	0.8±0.4	0.4±0.2
$> 80 (100, ee)$	0	$1.5^{+0.9}_{-0.6}$	$0.8^{+0.5}_{-0.4}$	0.4±0.2

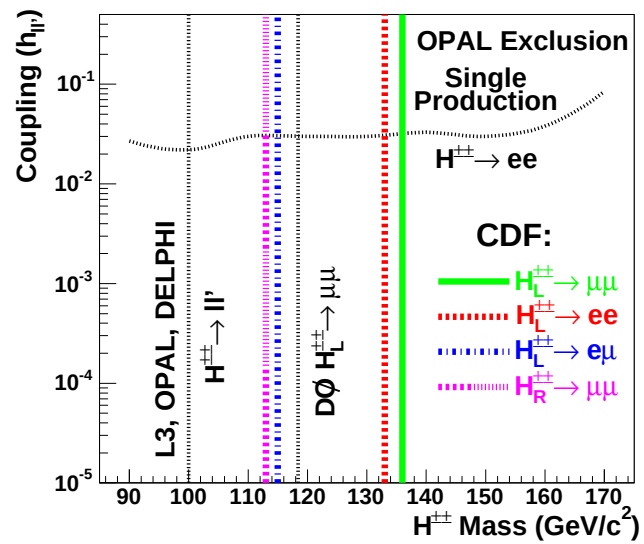
$H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}$ CDF Search (2)

- Search windows of $\pm 10\%$ of a given $M_{H^{\pm\pm}}$.
- No observed events.
  95% C.L. upper limit on the cross-section.



CDF mass limits:

	$\mathcal{L}_{int}$	$H_L^{\pm\pm}$	$H_R^{\pm\pm}$
ee	235 pb^{-1}	133	-
$\mu\mu$	242 pb^{-1}	136	113
$e\mu$	240 pb^{-1}	115	-



quasi-stable $H^{\pm\pm}$ CDF Search (1)

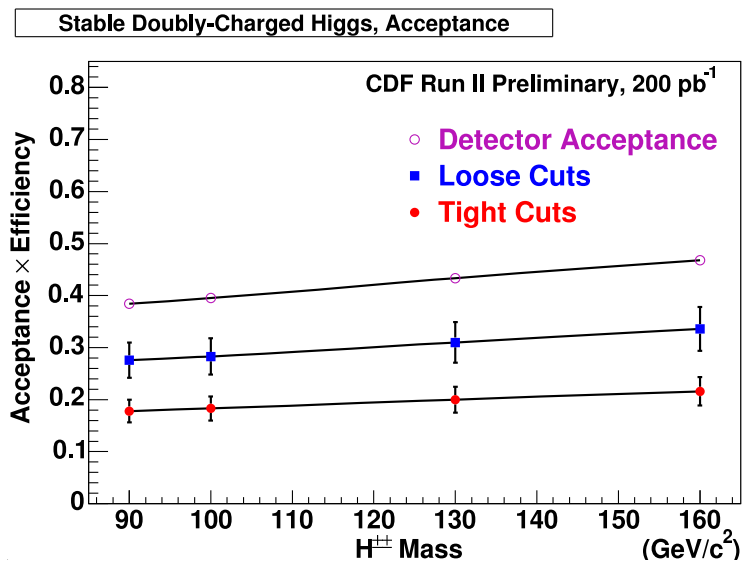
Stable charged massive particles loose energy due to ionization ($-\frac{dE}{dx} \propto z^2$).

Dataset:

Inclusive muon data
February 2002 - September 2003
$\mathcal{L}_{int}$=206 pb^{-1}

Event selection:

- Isolated μ (track) + second track ($p_T^{track} > 20$ GeV)
- Highly ionizing objects: combined dE/dx in calorimeters and tracker
  - ◇ loose cuts: mass limits
  - ◇ tight cuts: discovery



Efficiencies and rates:

- $H^{\pm\pm}$ identification efficiencies from data and applied to the simulation.
- Fake rates either from data (μ, QCD) or from simulation (e, hadronic τ)

quasi-stable $H^{\pm\pm}$ CDF Search (2)

Results:

Background dominated by mis-identified jets

	Loose	Tight
N_{exp}	$< 10^{-5}$	$< 10^{-6}$
N_{obs}	0	0

Main systematics:

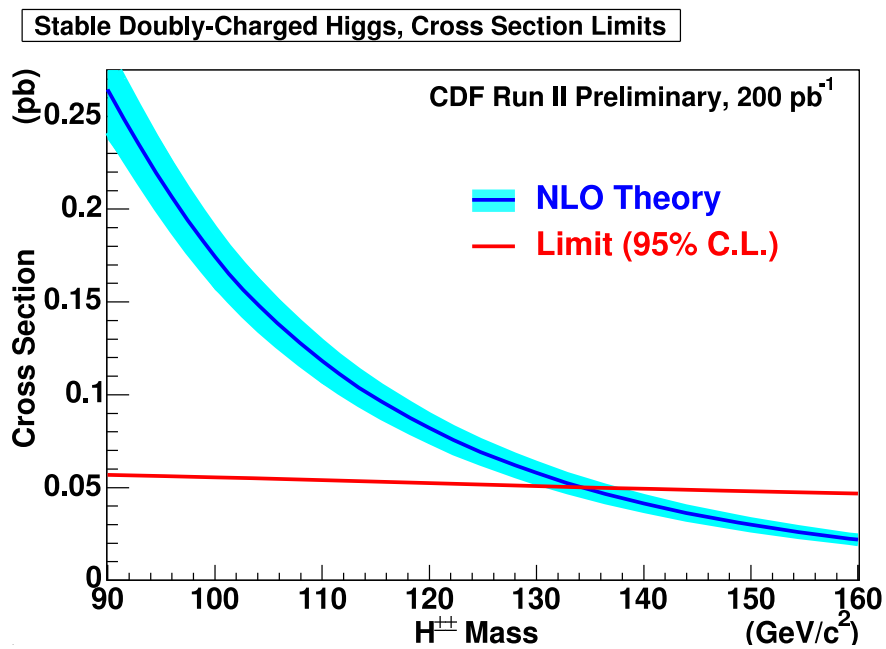
Identification efficiency (potential edge effects in $Z \to \mu\mu$): 12.4%
NNLO contributions: 7.5% (central value)

Limits:

95% C.L. cross-section limit.

Limit of 134 GeV for quasi-stable doubly charged Higgs.

LEP (DELPHI):
$M_{H^{\pm\pm}} > 97.3$ GeV



Summary

- CDF and DØ have performed several searches for non Standard Model Higgs bosons.
- Main results include:
  - ◇ MSSM neutral Higgs bosons
  - ◇ light Higgs boson $\rightarrow \gamma\gamma$
  - ◇ doubly-charged Higgs
- Limits are competitive with Run I/LEP results.
- Searches are based on a fraction of the available data ($\mathcal{L}_{int} \leq$ 200 pb^{-1}).
- More to come soon!