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A Search for Doubly-Charged Bosons decaying to Like-Sign Dileptons at CDF with 6.1 fb^{-1}

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We present a search for pair production of doubly-charged scalars decaying to like-sign dileptons using data with an integrated luminosity of 6.1 fb^{-1}. The observed data are consistent with standard model predictions, and we set 95% CL lower limit on the scalar mass in the range 190-245 GeV/c^2, depending on the theory and the decay channel.

I. INTRODUCTION

A wide variety of models of new physics predict events with two like-sign leptons, a signature which has very low backgrounds from the standard model. Examples include supersymmetry [2], heavy neutrinos [3], same-sign top quark production [4] and fourth-generation quarks [5]. CDF examined the like-sign dilepton data in RunI [6] and in RunII in 1 fb^{-1} [7].

In this note, we present a study of the like-sign dilepton sample and search for evidence of a narrow resonance in the like-sign dilepton invariant mass spectrum.

These results supercede limits from CDF in 240 pb^{-1} [8] and are more stronger than limits from D0 in 1.1 fb^{-1} [9] by an order of magnitude

II. DATASET AND SELECTION

Events were recorded by CDF II [10, 11], a general purpose detector designed to study collisions at the Fermilab Tevatron $p\overline{p}$ collider at $\sqrt{s} = 1.96$ TeV. A charged-particle tracking system immersed in a 1.4 T magnetic field consists of a silicon microstrip tracker and a drift chamber. Electromagnetic and hadronic calorimeters surround the tracking system and measure particle energies. Drift chambers located outside the calorimeters detect muons. We examine data taken between August 2002 and September 2010, with integrated luminosity of 6.1 fb^{-1}.

The data acquisition system is triggered by e or μ candidates [12] with transverse momentum (p_T[11]) greater than 18 GeV/c. Electrons and muons are reconstructed offline and selected if they have a pseudorapidity (η[11]) magnitude less than 1.1, $p_T \geq 20$ GeV/c and satisfy the standard CDF identification and isolation requirements [12]. Jets are reconstructed in the calorimeter using the JETCLU [13] algorithm with a clustering radius of 0.4 in azimuthpseudorapidity space and corrected using the standard techniques [16]. Jets are selected if they have $p_T \geq 15$ GeV/c and $|\eta| < 2.4$. Missing transverse momentum [15] is reconstructed using fully corrected calorimeter and muon information [12].

We select events with

- A pair of isolated leptons of the same electric charge.
- The leading lepton must have $p_T > 20$ GeV/c, $|\eta| < 1.1$.
- The sub-leading must have $p_T > 10$ GeV/c, $|\eta| < 1.1$.
- The two leptons must come from the same primary vertex
- The dilepton invariant mass $m_{\ell\ell}$ must be at least 25 GeV/c^2.
- We reject events which have two OS leptons in the Z window, $m_{\ell\ell} \in [86, 96]$.
- We reject events which have two SS electrons in the Z window, $m_{\ell\ell} \in [86, 96]$.

III. BACKGROUNDS

Backgrounds to the like-sign dilepton signature with real like-sign leptons are rare in the SM; they are largely from WZ and ZZ production.

The dominant background comes from events in which the second lepton is due to the semi-leptonic decay of a b- or c-quark meson, largely from W+jets production or $t\bar{t}$ production with semi-leptonic decays. This ("fake") background is described using a lepton misidentification model from inclusive jet data applied to W+jet events.

The second largest source of background comes from processes which produce electron-positron pairs; either the electron or positron emits a hard photon leading to an asymmetric conversion (e.g. $e^-_{hard} \rightarrow e^-_{soft}\gamma \rightarrow e^-_{soft}e^-_{soft}e^+_{hard}$) and the reconstruction of an same-charge pair. The major contributions via this mechanism are from Z/γ^*+jets and $t\bar{t}$ production with fully leptonic decays.

Estimates of the backgrounds from Z/γ^*+jets processes are made with PYTHIA normalized to data in opposite-sign events. The detector response for both Z+jets and $t\bar{t}$ processes is evaluated using CDFSIM, where, to avoid double-counting, the same-charge leptons are required to originate from the W or Z decays rather than from misidentified jets.

The dominant systematic uncertainty is due to uncertainty in the lepton misidentification model. Additional uncertainties are due to the jet energy scale [16], contributions from additional interactions, and descriptions of initial and final state radiation [17] and uncertainties in the parton distribution functions [18, 19].

IV. OBSERVED DATA

A. Event Yield

Table I shows the observed and predicted event yields.

B. Event Kinematics

Figures 1-3 show kinematic distributions of observed and predicted same-sign lepton events.

V. SIGNAL

We use a generic signal for H^{++} in which the charged Higgs may be a member of a singlet, doublet or triplet [1]. We assume the Higgs decays 100% to charged leptons, which is slightly dependent on the couplings, but at low masses is quite reasonable.

TABLE I: Predicted and observed event yields in same-sign lepton events.

CDF RunII Preliminary $\int \mathcal{L}dt = 6.1$ fb^{-1}				
Process	Total $\ell\ell$	$\mu\mu$	ee	$e\mu$
$t\bar{t}$	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0
$Z \rightarrow ee$	15.7 ± 2.7	0.0 ± 0.0	15.7 ± 2.7	0.0 ± 0.0
$Z \rightarrow \mu\mu$	8.7 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	8.7 ± 2.0
$Z \rightarrow \tau\tau$	2.2 ± 0.9	0.0 ± 0.0	1.3 ± 0.6	1.0 ± 0.6
WZ	24.7 ± 1.3	7.0 ± 0.4	5.1 ± 0.3	12.7 ± 0.7
WW	0.2 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.0
ZZ	3.5 ± 0.2	0.9 ± 0.1	0.8 ± 0.1	1.7 ± 0.1
$W(\rightarrow e\nu)\gamma$	7.8 ± 1.7	0.0 ± 0.0	7.8 ± 1.7	0.0 ± 0.0
$W(\rightarrow \mu\nu)\gamma$	7.8 ± 1.7	0.0 ± 0.0	0.0 ± 0.0	7.8 ± 1.7
$W(\rightarrow \tau\nu)\gamma$	0.6 ± 0.4	0.0 ± 0.0	0.3 ± 0.3	0.3 ± 0.3
Fakes	51.6 ± 24.2	8.2 ± 5.3	22.1 ± 8.9	21.3 ± 10.6
Total	123.0 ± 24.6	16.1 ± 5.4	53.3 ± 9.5	53.6 ± 10.9
Data	145	14	66	65

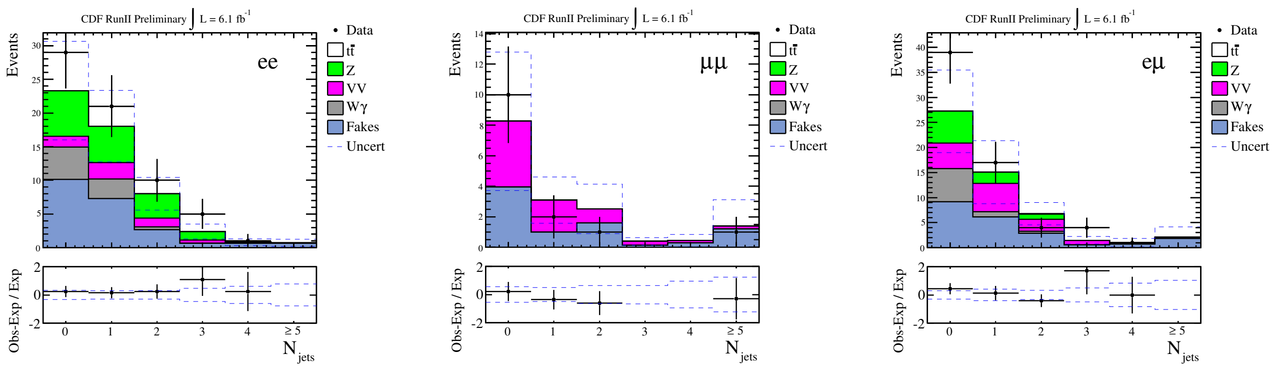

FIG. 1: Distribution of jet multiplicity in observed same-sign dilepton events and expected backgrounds.

VI. LIMITS

We fit for the signal cross-section using a binned maximal-likelihood fit. We set frequentist limits using the unified ordering prescription.

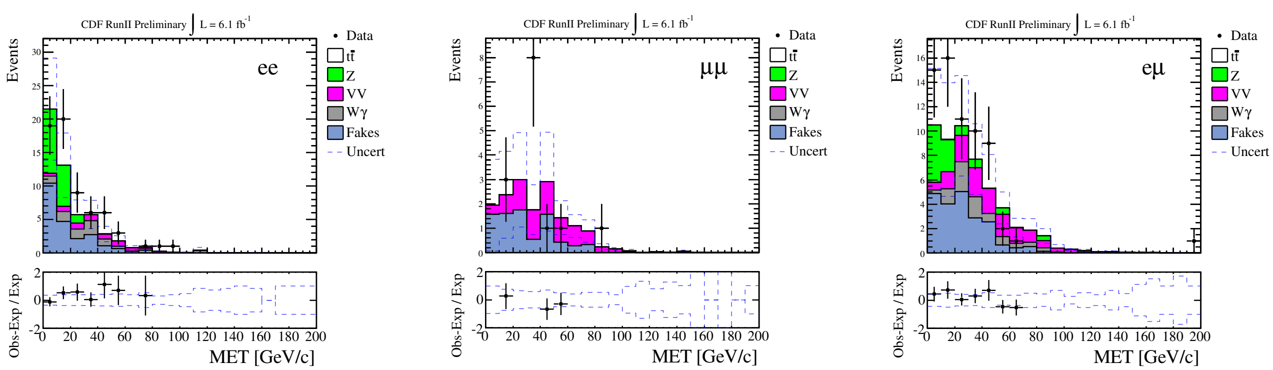

FIG. 2: Distribution of missing transverse energy in observed same-sign dilepton events and expected backgrounds.

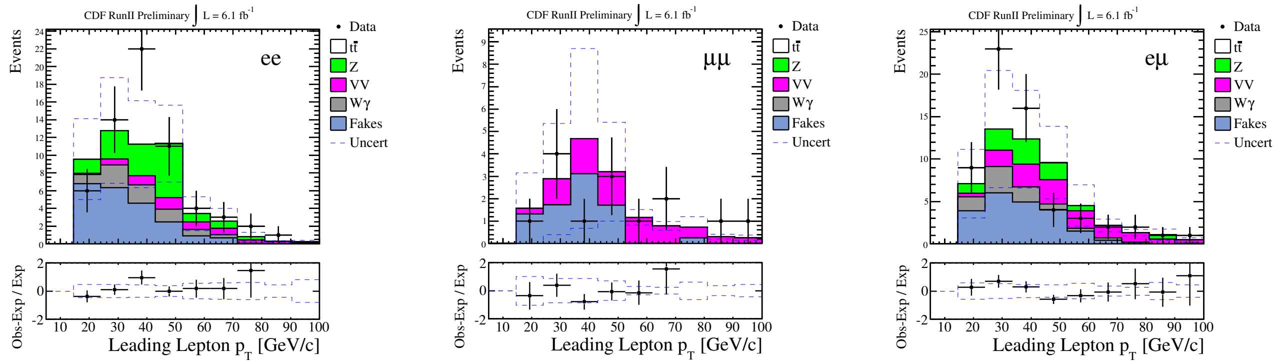

FIG. 3: Distribution of leading lepton p_T in observed same-sign dilepton events and expected backgrounds.

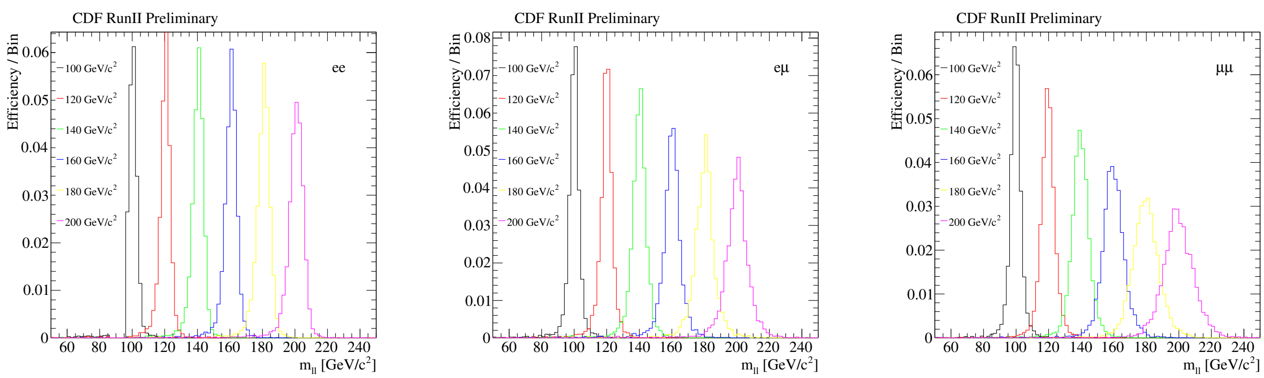

FIG. 4: Reconstructed $\ell^{\pm}\ell^{\pm}$ mass in ee (left), $e\mu$ (center), and $\mu\mu$ (right) events for varying m_H.

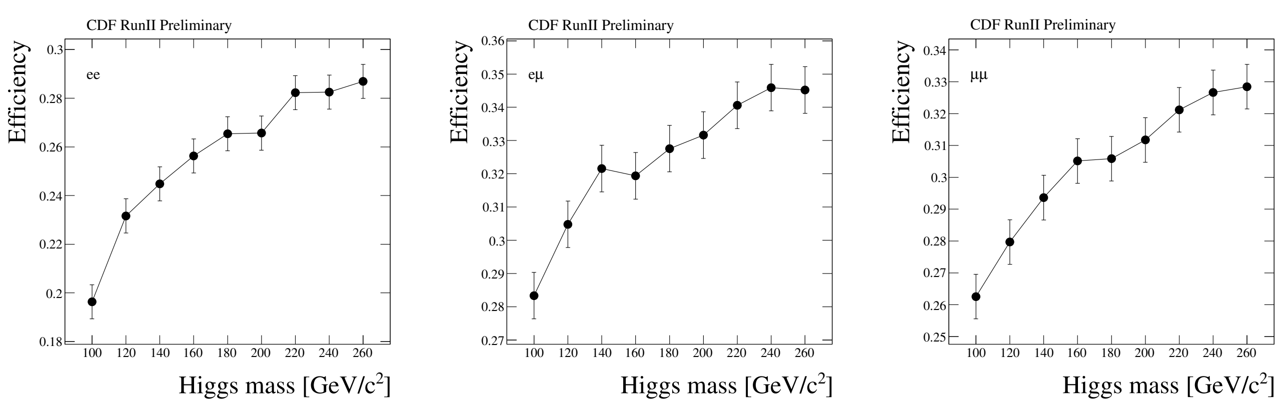

FIG. 5: Reconstruction efficiency versus Higgs mass in ee (left) $e\mu$ (center), and $\mu\mu$ (right) events.

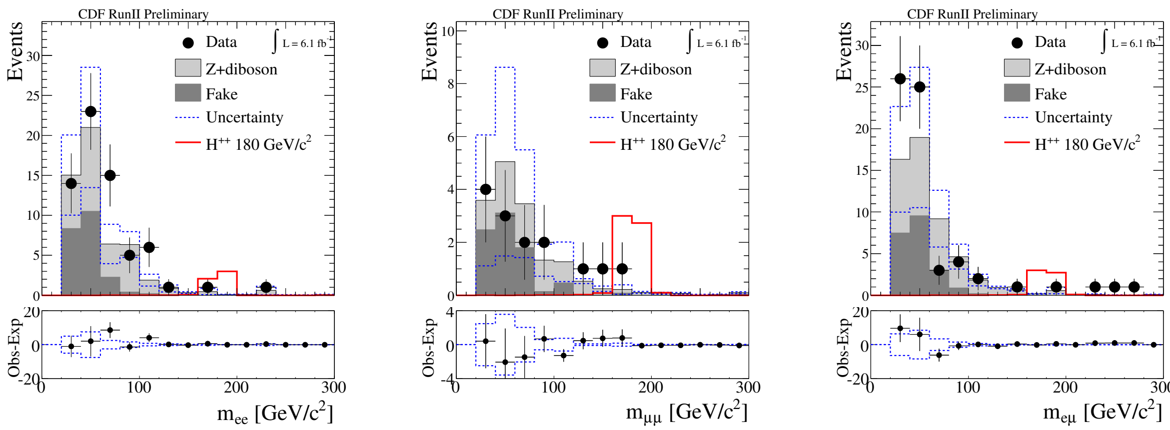

FIG. 6: Signal and backgrounds in the $ee, \mu\mu$ and $e\mu$ channels with example H^{++} signal overlaid.

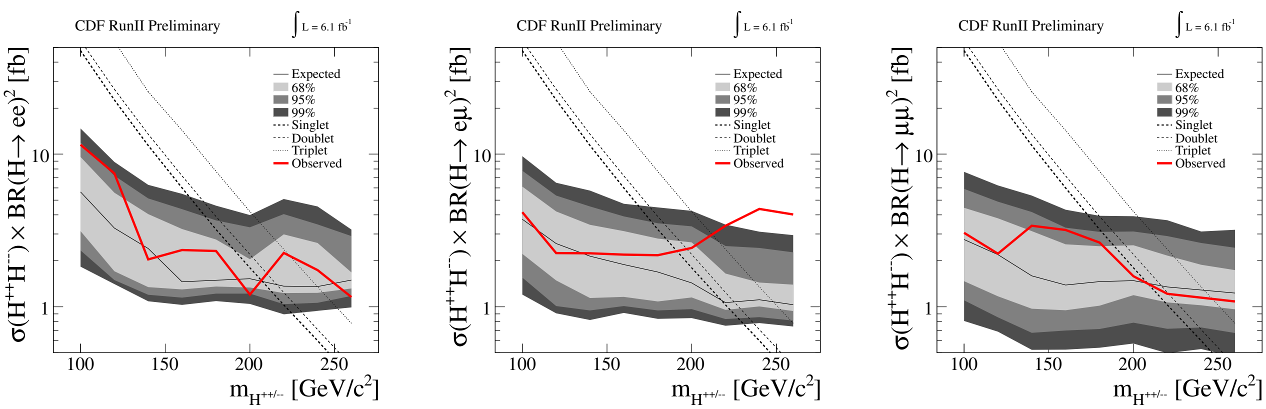

FIG. 7: Observed and expected limits compared to the theoretical predictions for the ee (top), $e\mu$ (center) and $\mu\mu$ (bottom) channels.

TABLE II: The NLO cross sections for singlet (σ_1), doublet (σ_2), triplet (σ_3) production, expected and observed 95% CL limits in the $ee, e\mu$ and $\mu\mu$ channels. All cross-sections are in femtobarns.

CDF RunII Preliminary $\int \mathcal{L}dt = 6.1$ fb^{-1}						
$M_{H^{++}}$	σ_1	σ_2	σ_3	σ^{95}_{ee}	$\sigma^{95}_{e\mu}$	$\sigma^{95}_{\mu\mu}$
100	48	55	117	12	4.2	3.1
120	23	27	55	7.4	2.3	2.2
140	11	14	26	2.0	2.2	3.4
160	6.0	7.2	14	2.4	2.2	3.2
180	3.2	3.9	7.7	2.3	2.2	2.6
200	1.8	2.2	4.2	1.2	2.4	1.6
220	1.0	1.2	2.4	2.3	3.4	1.2
240	0.60	0.71	1.4	1.7	4.4	1.2
260	0.34	0.41	0.78	1.2	4.0	1.1

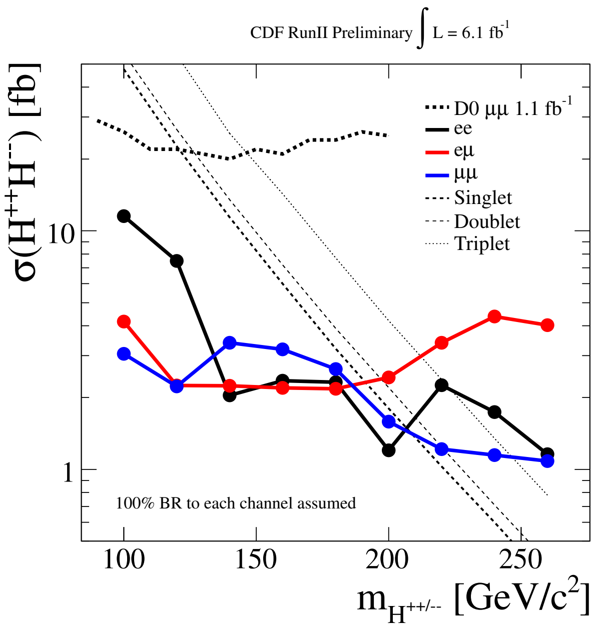

FIG. 8: Upper limits at 95% CL on the production cross-section for doubly-charged Higgs, assuming 100% branching fraction to $ee, \mu\mu$ or $e\mu$. Also shown are next-to-leading-order theoretical calculations of the cross-section, assuming the Higgs is a member of a singlet, doublet or triplet.

TABLE III: Lower limits at 95% CL on $H^{++/--}$ masses by channel, for singlet, doublet and triplet theories. All in units of GeV/c^2

CDF RunII Preliminary $\int \mathcal{L}dt = 6.1$ fb^{-1}			
	Theory		
Channel	Triplet	Doublet	Singlet
ee	225	210	205
$e\mu$	210	195	190
$\mu\mu$	245	220	205

VII. HIGH MASS EVENTS

CDF RunII Preliminary $\int \mathcal{L}dt = 6.1\ \text{fb}^{-1}$			
Run 197079 Event 2262178 $m_{\ell\ell} = 221.7$ [GeV/c^2]			
Object	P_T [GeV/c]	η	ϕ
e^-	107.7	-0.3	0.9
e^-	104.5	0.4	-2.7
Jet	22.7	0.3	-1.6
Jet	16.3	0.6	-0.7
MET	21.6	—	0.3
Run 224521 Event 27557952 $m_{\ell\ell} = 238.5$ [GeV/c^2]			
Object	P_T	η	ϕ
μ^-	100.5	1.0	0.4
e^-	71.2	-0.8	2.9
Jet	47.1	-2.2	-2.7
MET	42.5	—	-1.0
Run 233097 Event 9858845 $m_{\ell\ell} = 247.7$ [GeV/c^2]			
Object	P_T	η	ϕ
e^+	126.2	-0.2	-2.8
μ^+	119.7	-0.5	0.5
MET	18.3	—	0.1
Run 276320 Event 491354 $m_{\ell\ell} = 267.8$ [GeV/c^2]			
Object	P_T	η	ϕ
μ^+	140.5	0.5	1.2
e^+	127.0	0.6	-1.9
MET	10.0	—	-1.9

VIII. CONCLUSIONS

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