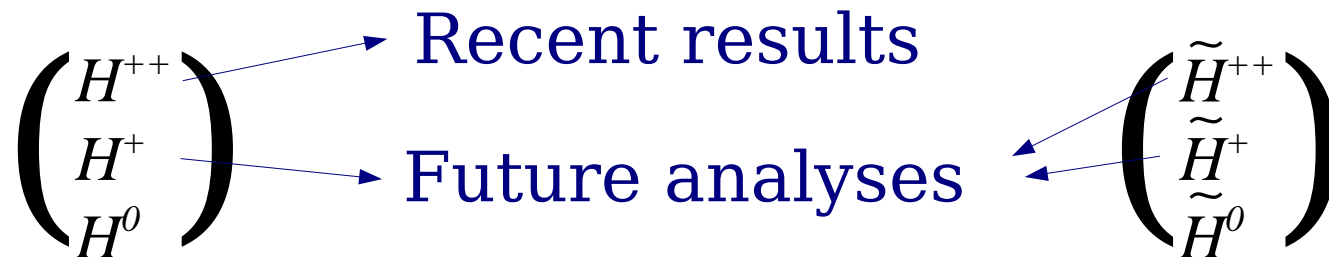


Searching for Higgs Triplets at CDF

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CPiFAq



CERN Non-SM Higgs Workshop
Dec 1-2, 2004

Why Higgs Triplets?

Natural expansion of Higgs sector

* frequently arise in models with additional gauge groups

→ Little Higgs

Increases scale of divergences by ~ 10

→ Left-right symmetric ($SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_c$)

Restore parity symmetry to weak force at scale v_R

See-saw mechanism for light ν masses

Left-right model phenomenology well studied

* Excellent reference model for searches



Scenarios with Light Higgs Triplets

Non-supersymmetric left-right models

* Triplet masses typically proportional to v_R

If $v_R \approx 1 \text{ TeV}$:

- Triplets could be observable at CDF
- Simplest see-saw mechanism not valid
(but could still apply: e.g. add sterile neutrinos)

If $v_R \gg 1 \text{ TeV}$:

- Observable triplets requires scalar potential parameter tuning
- See-saw mechanism applicable

$$\begin{pmatrix} H_R^{++} \\ H_R^+ \\ H_R^0 \end{pmatrix} \quad \begin{pmatrix} H_L^{++} \\ H_L^+ \\ H_L^0 \end{pmatrix}$$

Scenarios with Light Higgs Triplets

Supersymmetric left-right models

- * Require additional Higgs multiplets or higher-dimensional operators (HDO) in the superpotential
- * HDO lead to light doubly-charged Higgs: $m_{H^{++}} \approx (v_R^2/M_{\text{Pl}})$
See-saw suggests $v_R \sim 10^{10}$ GeV, so $m_{H^{++}} \sim 100$ GeV

Gauge-mediated SUSY breaking:

- ♦ Light $\tilde{H}_R^{\pm\pm}$

Gravity-mediated SUSY breaking:

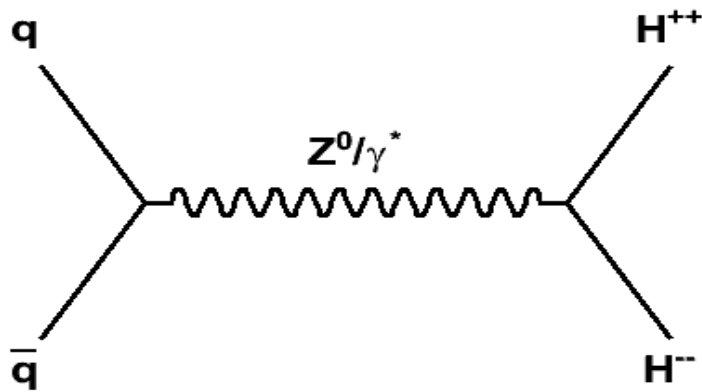
- ♦ Light $H_R^{\pm\pm}$

Also: HDO models require R-parity conservation

Doubly Charged Higgs Search at CDF

$p\bar{p}$ production cross section dominated by Z/γ exchange

- * Completely determined by weak coupling
- * W Higgstrahlung cross section depends on v_L ,
constrained by the ρ parameter to be small



$$\sigma(m_{H_L^{++}} = 100 \text{ GeV}) = 0.12 \text{ pb}$$

Expect H^{++} to decay exclusively to leptons

- * No quark couplings due to charge conservation
- * $W^\pm W^\pm$ decay constrained by ρ parameter

$$\mathcal{L}_Y = ih_{ij} (\psi_{Li}^c \tau_2 \bar{H}_L \psi_{Lj} + \psi_{Ri}^c \tau_2 \bar{H}_R \psi_{Rj})$$

← Violates lepton number;
new quantum number: $B-L$

Doubly Charged Higgs Search at CDF

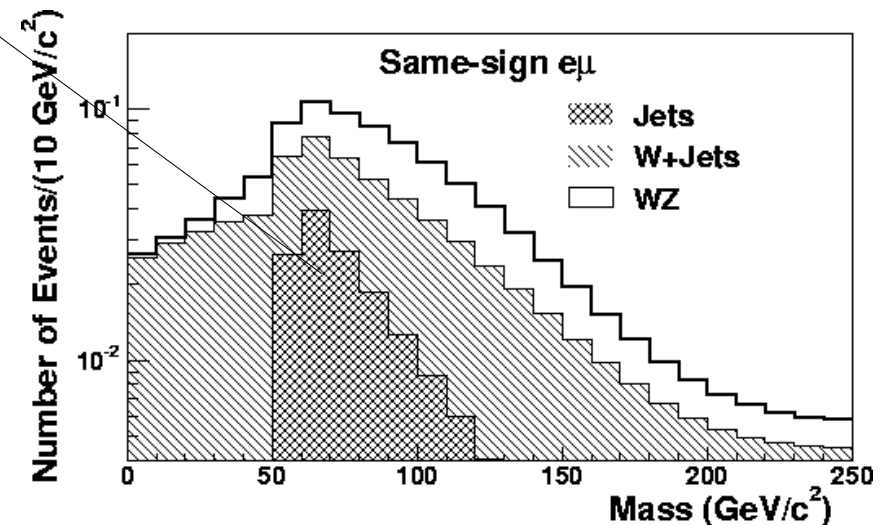
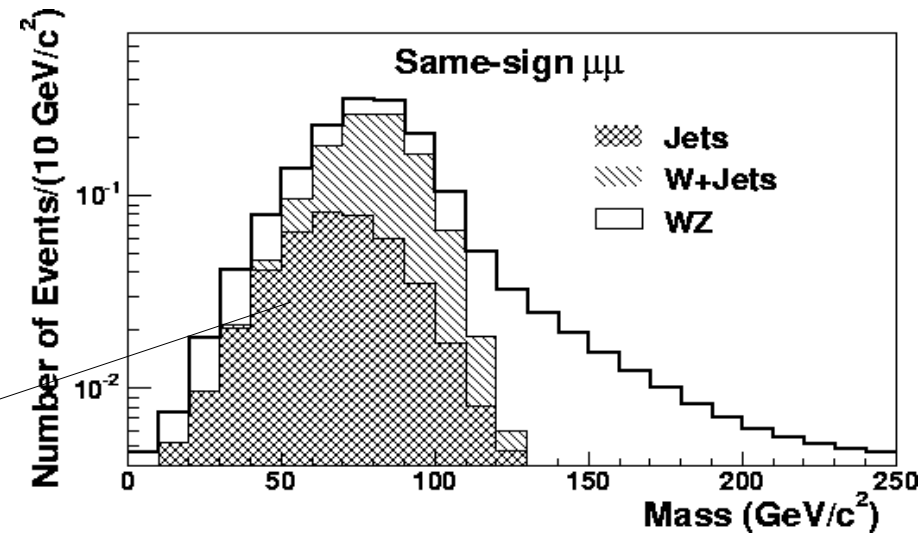
Search for $H^{\pm\pm}$ decays to ee , $\mu\mu$, $e\mu$

- * Extremely clean signatures
- * Only require one ll' pair/event
- * Excellent discovery potential

Low-mass background dominated by hadrons \rightarrow leptons

Use $m_{ll'} < 80$ GeV region to test background prediction

Signature	Background	Data
$\mu\mu$	0.8 ± 0.4	0
$e\mu$	0.4 ± 0.2	0
ee	1.1 ± 0.4	1



Doubly Charged Higgs Search at CDF

Test hadron \rightarrow lepton predictions using low E_T (<15 GeV)

same-sign events with one lepton failing identification criteria

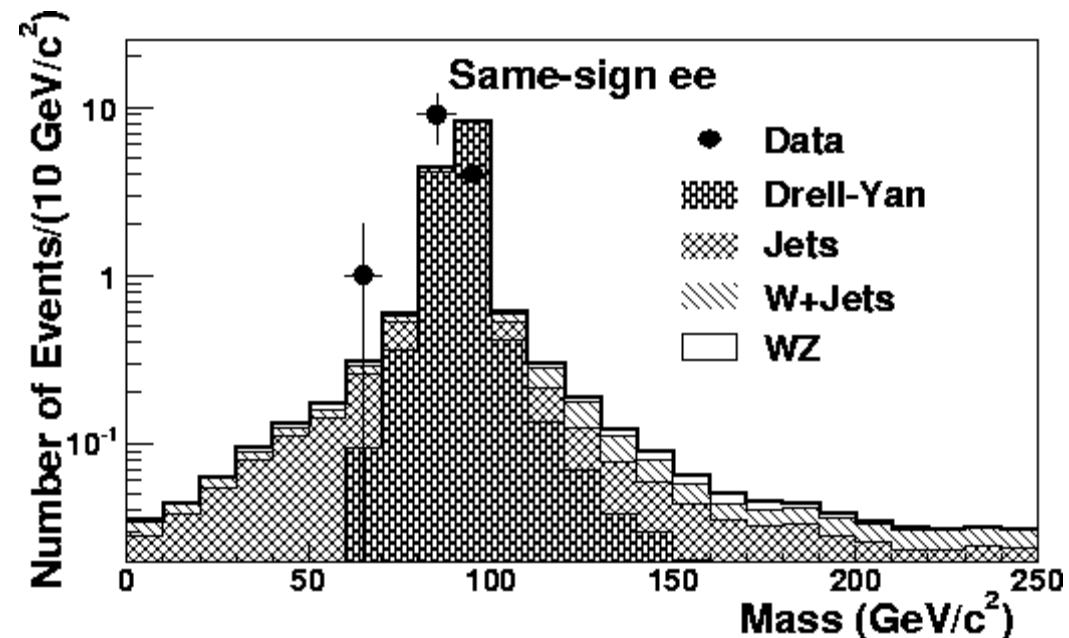
Sample dominated by dijet events

Signature	Background	Data
$\mu\mu$	7.6 ± 3.1	8
$e\mu + \mu e$	2.4 ± 0.8	2
ee	54 ± 21	63

Same sign ee channel complicated by bremsstrahlung in silicon detector

- * Bremsstrahlung can convert to two electrons, one of which has the opposite sign of the prompt electron
- * *Can result in wrong sign identification*

Drell-Yan a significant background
Search only in region $m_{ee} > 100$ GeV



Doubly Charged Higgs Search at CDF

Luminosity and acceptance key to sensitivity

** <1 event background means cross section limit is directly proportional to luminosity and acceptance*

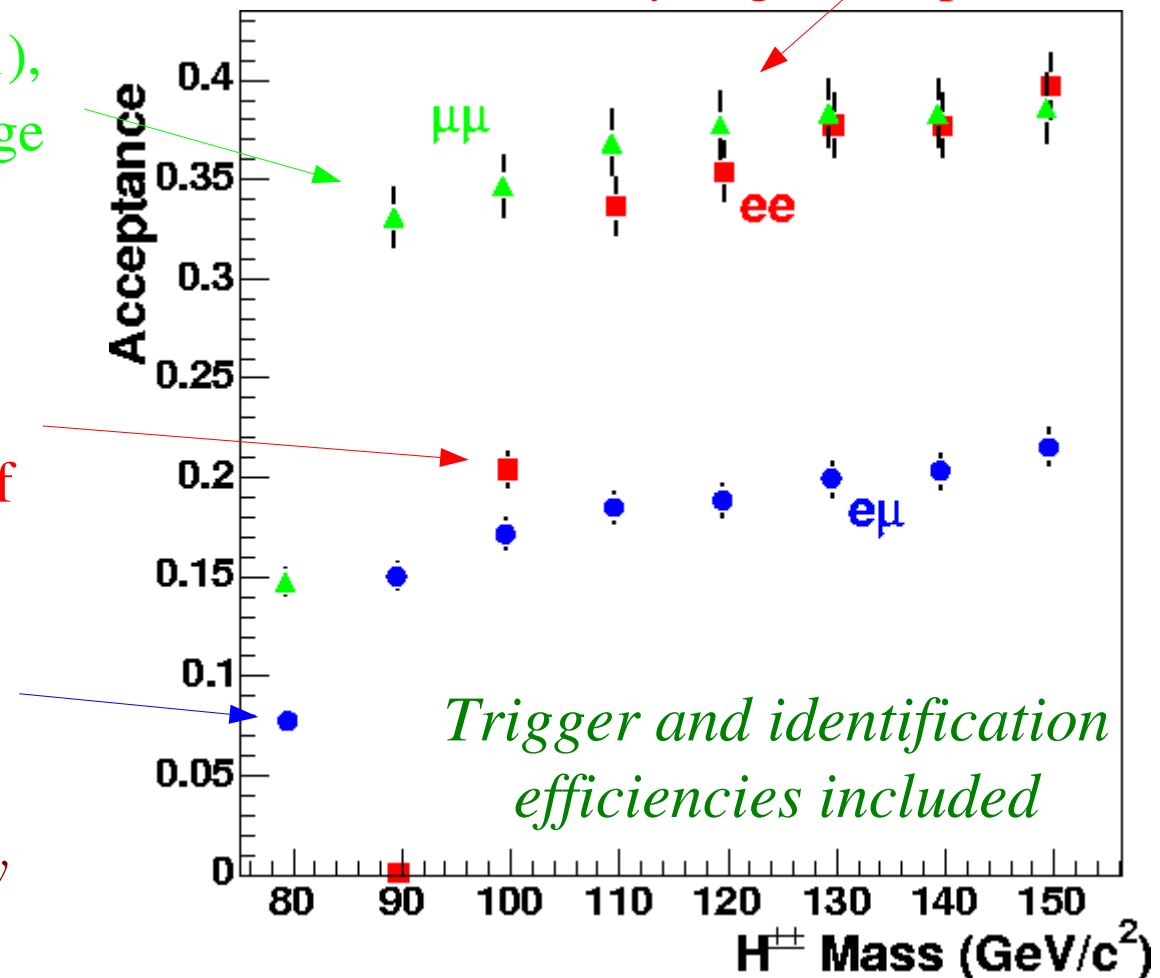
$\mu\mu$: Trigger muon has limited $|\eta| (<1)$, ϕ coverage, second muon has large coverage ($|\eta| < \sim 1.4$, all ϕ).

ee : Both electrons have large ϕ coverage, but limited $|\eta| (<1)$. Falls rapidly for $m < 100$ GeV due to cut-off

$e\mu$: Combination of limited electron and muon coverage reduces acceptance relative to ee and $\mu\mu$.

$\mathcal{L} \sim 240 \text{ pb}^{-1}$: Largest sample of any published Tevatron result!

Very high acceptances!



Doubly Charged Higgs Search at CDF

No events observed in signal regions

Set 95% C.L. cross section \times BR limits

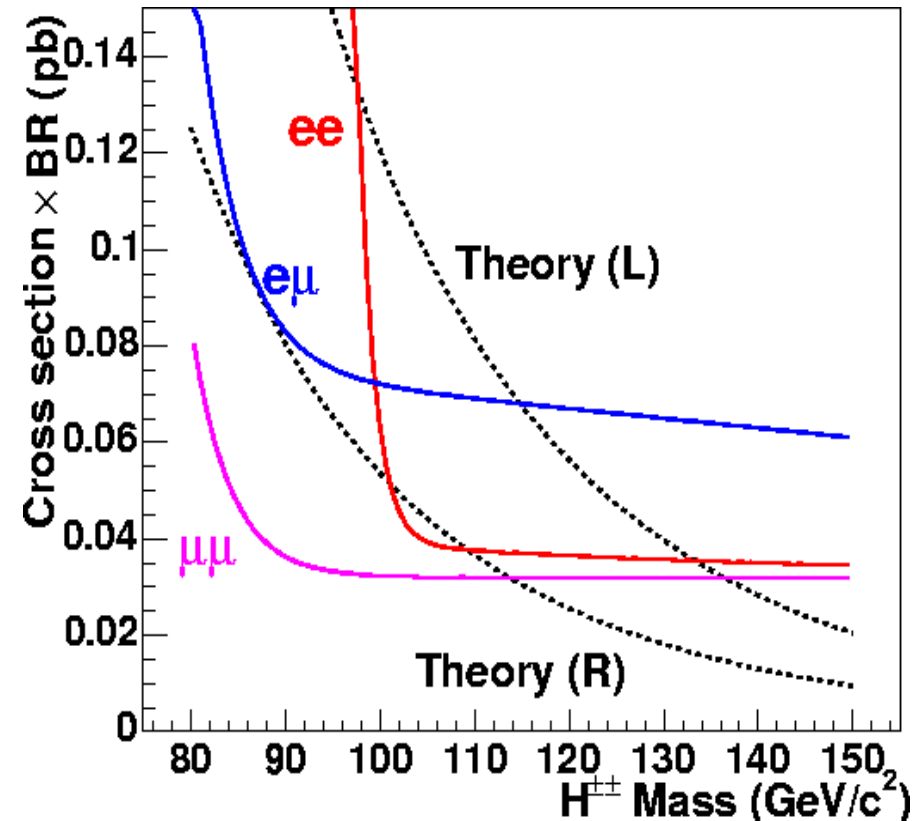
Assuming exclusive decays to a given channel, set mass limits:

$$H_L^{\pm\pm} \rightarrow \mu\mu: m > 136 \text{ GeV}$$

$$H_L^{\pm\pm} \rightarrow e\mu: m > 115 \text{ GeV}$$

$$H_L^{\pm\pm} \rightarrow ee: m > 133 \text{ GeV}$$

$$H_R^{\pm\pm} \rightarrow \mu\mu: m > 113 \text{ GeV}$$



For diagonal couplings of equal magnitude, results correspond to the following approximate limit:

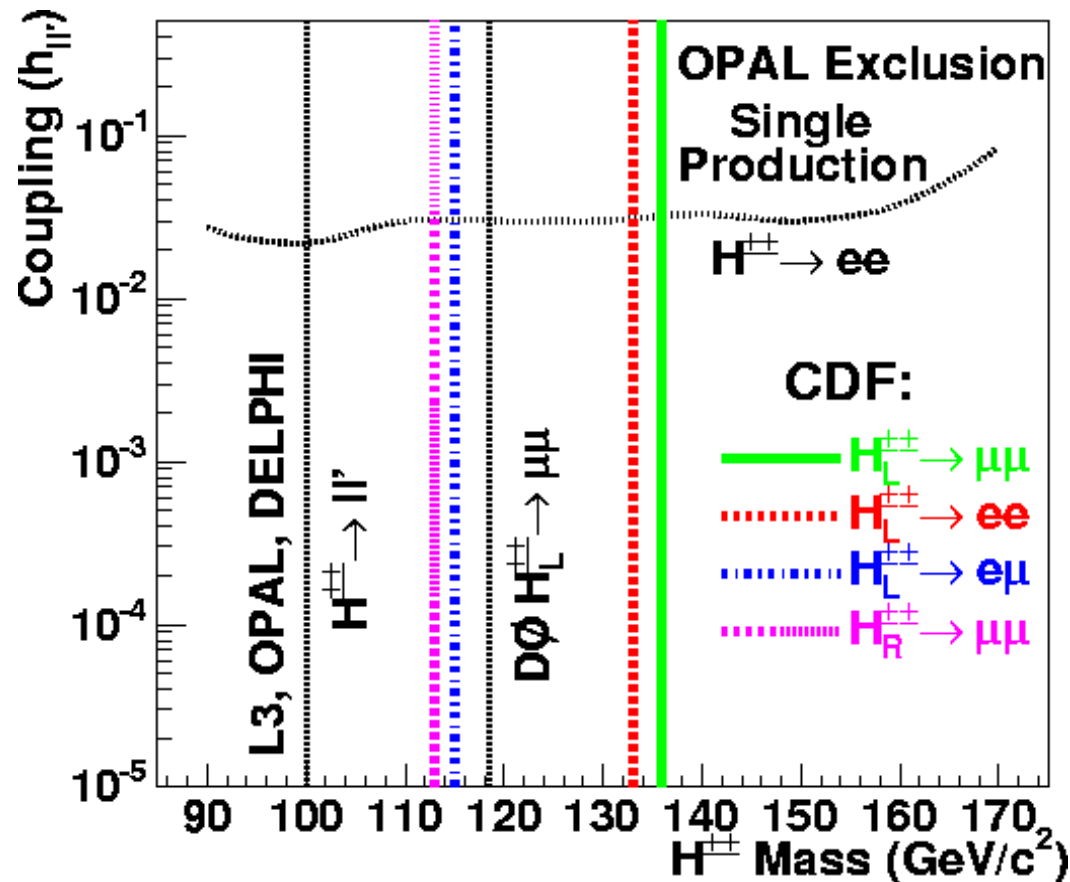
$$H_L^{\pm\pm}: m > 120 \text{ GeV}$$

Doubly Charged Higgs Search at CDF

Mass limits highest in the world for $H_L^{\pm\pm}$ in these channels

* Sensitive to a wide range of Yukawa coupling values

$$10^{-5} < \sum h_{ij} < 0.5$$



Complementary to indirect searches

h_{ij} limits for $m = 100$ GeV:

Bhabha scattering: $h_{ee} < 0.05$

$(g-2)_\mu$: $h_{\mu\mu} < 0.25$

$\mu \rightarrow 3e$: $h_{ee} h_{e\mu} < 3.2 \times 10^{-7}$

$\mu \rightarrow e\gamma$: $h_{\mu\mu} h_{e\mu} < 2 \times 10^{-6}$

*D. Acosta et al.,
PRL 93 (2004), 221802*

Doubly Charged Higgs Search at CDF

CDF has also searched for quasi-stable $H^{\pm\pm}$

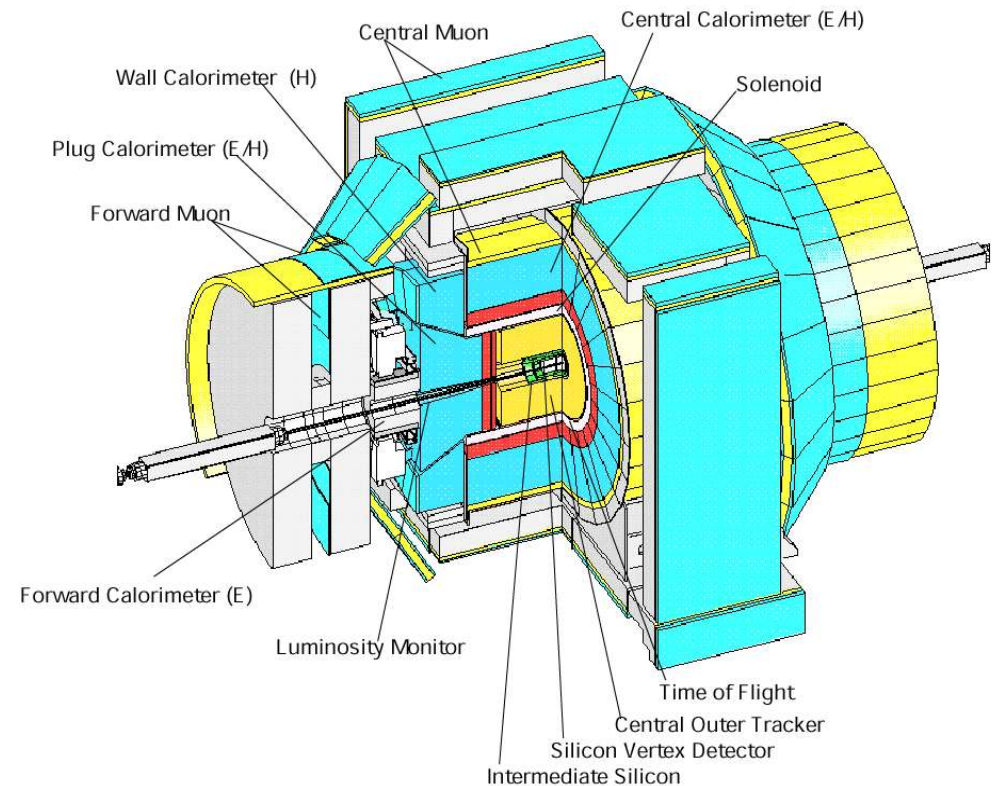
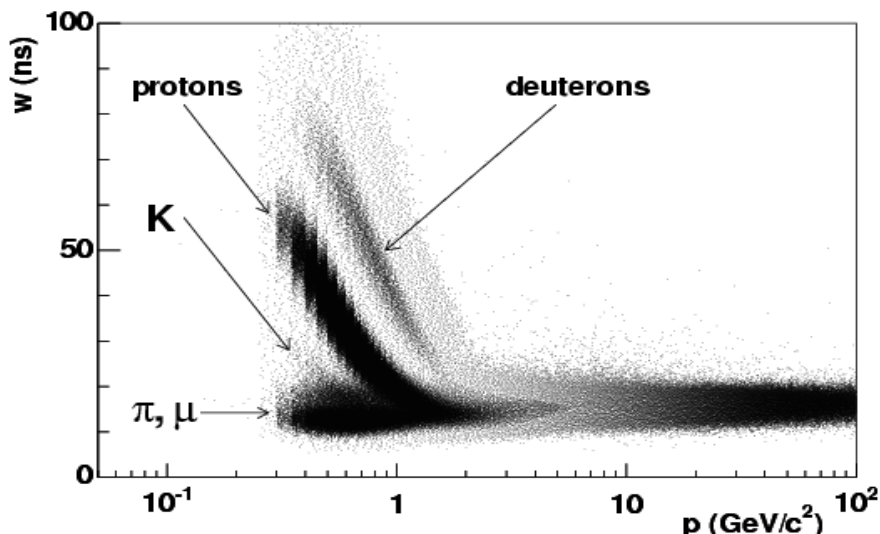
* Probes low Yukawa coupling values

$$\Sigma h_{ij} < 10^{-8}$$

Couplings don't exist for additional triplets that conserve lepton number

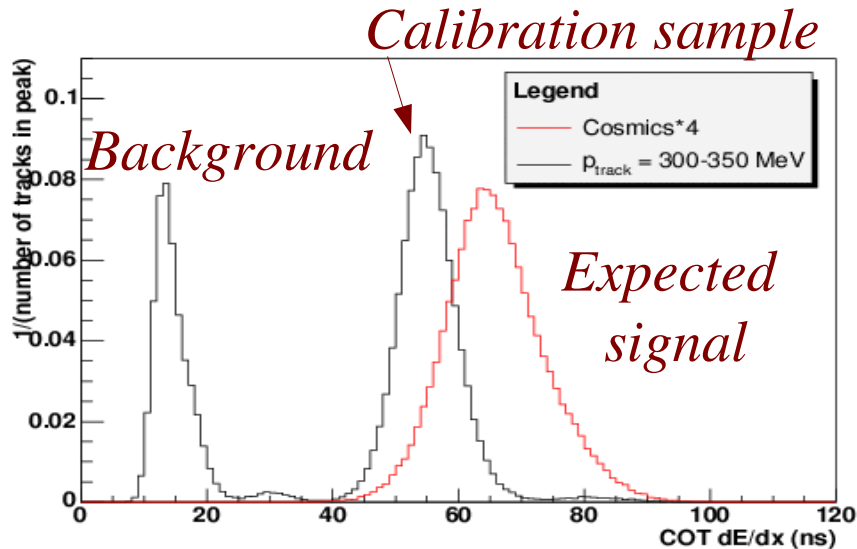
Strategy:

- Use dE/dx information from tracker
- Search for pairs of high-momentum doubly-charged tracks
- Define tight “discovery” selection including calorimeter ionization



Doubly Charged Higgs Search at CDF

dE/dx resolution provides many σ separation of signal and background



Background $< 10^{-5}$

- *Single-event discovery!*

Signal confirmation defined *a priori*

- *Require large MIP energy in calorimeter*
- *Further suppresses muon backgrounds*

Backgrounds studied with data and MC

Background	dE/dx only	dE/dx + MIP	
$Z \rightarrow \mu\mu$	$< 10^{-6}$	$< 10^{-12}$	<i>No candidates in samples used to determine acceptance</i>
$Z \rightarrow ee$	$< 10^{-6}$	$< 10^{-7}$	
$Z \rightarrow \tau\tau$	$< 10^{-9}$	$< 10^{-9}$	<i>Yields upper limits on expected background</i>
Dijets	$< 10^{-5}$	$< 10^{-6}$	

Doubly Charged Higgs Search at CDF

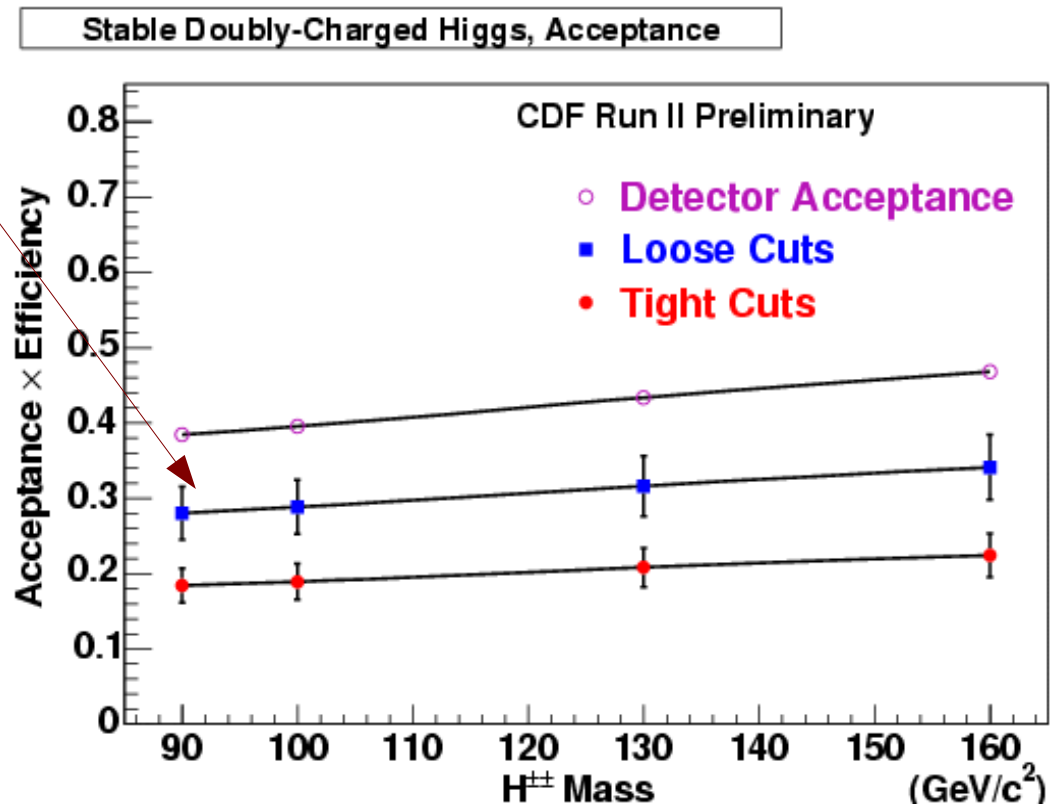
Acceptance has additional inefficiencies and uncertainties (beyond $\mu\mu$)

- * Fraction of $H^{\pm\pm}$ with β too small to reconstruct tracks
- * Multiple scattering affecting track matching to muon track segment
- * Ionization affecting calorimeter isolation requirements

Acceptance reduced relative to $\mu\mu$:

- * *Both $H^{\pm\pm}$ must be central, with reconstructed tracks*
- * *Additional track cuts and inefficiencies*
- * *Still > 30%*

$\mathcal{L} \sim 200 \text{ pb}^{-1}$



Doubly Charged Higgs Search at CDF

Left and right cross sections combined

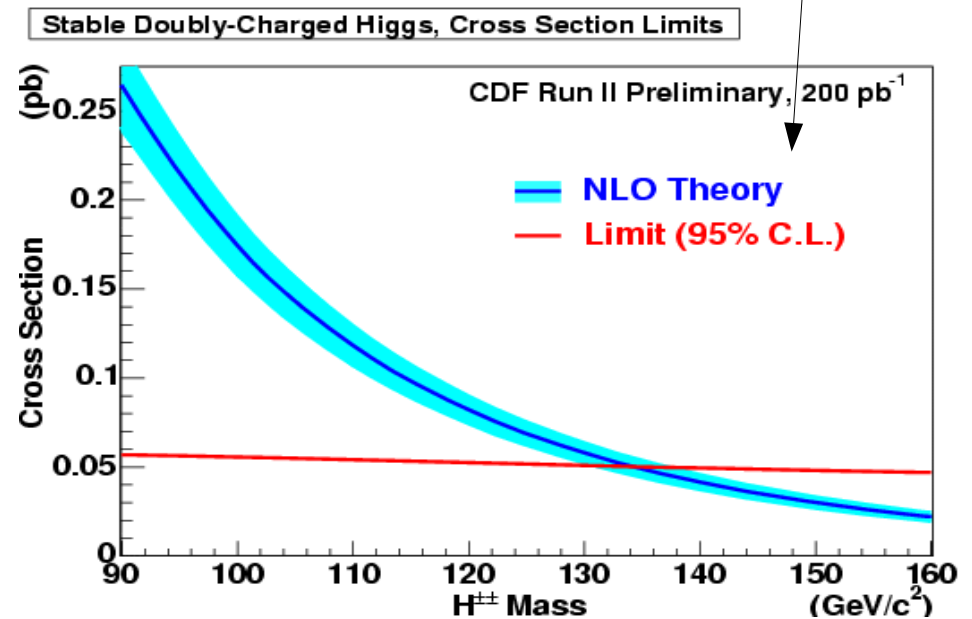
No events observed in data

Set 95% C.L. cross section limit

Infer mass limits:

$$H_L^{\pm\pm}: m > \sim 125 \text{ GeV}$$

$$H_R^{\pm\pm}: m > \sim 100 \text{ GeV}$$



Limits similar to $\mu\mu$ and ee decay channels

Sensitivity will improve with order of magnitude increase in luminosity:

$$H_L^{\pm\pm}: m \sim 200 \text{ GeV}$$

$$H_R^{\pm\pm}: m \sim 170 \text{ GeV}$$

Ongoing $H^{\pm\pm}$ Search at CDF

Same-sign tau decays

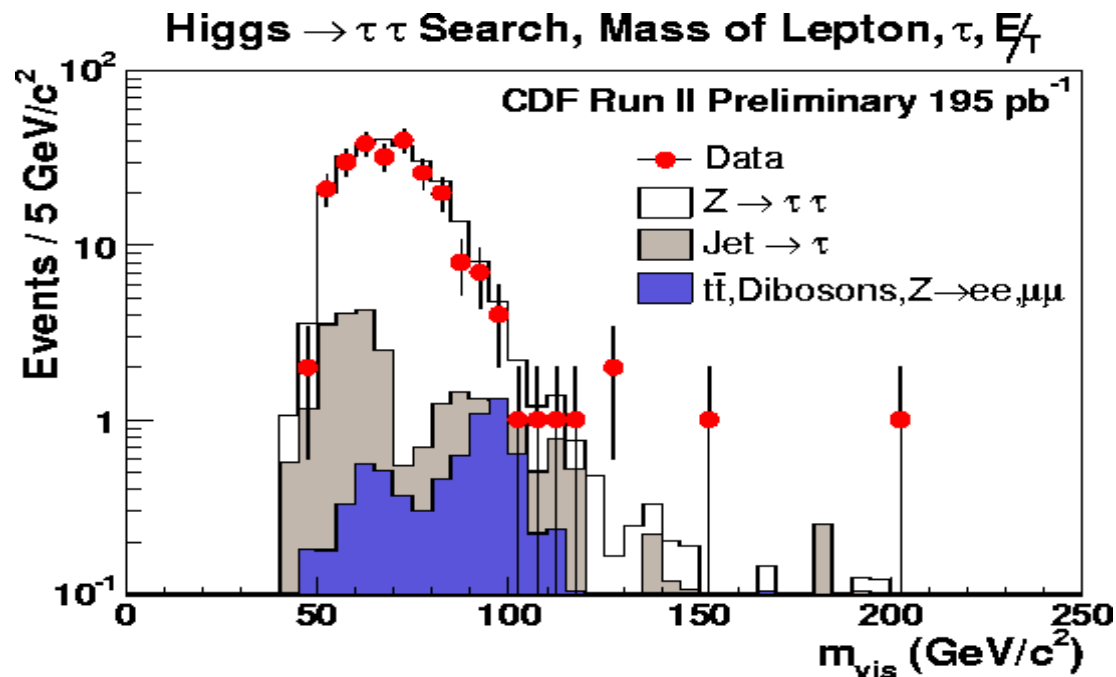
Experimentally challenging:

- * Cannot fully reconstruct invariant mass
- * Hadronic tau decays difficult to detect

Phenomenologically interesting:

- * $h_{\tau\tau}$ coupling the least constrained

Many problems solved in $H^0 \rightarrow \tau\tau$ search:



Studying issues of sign identification

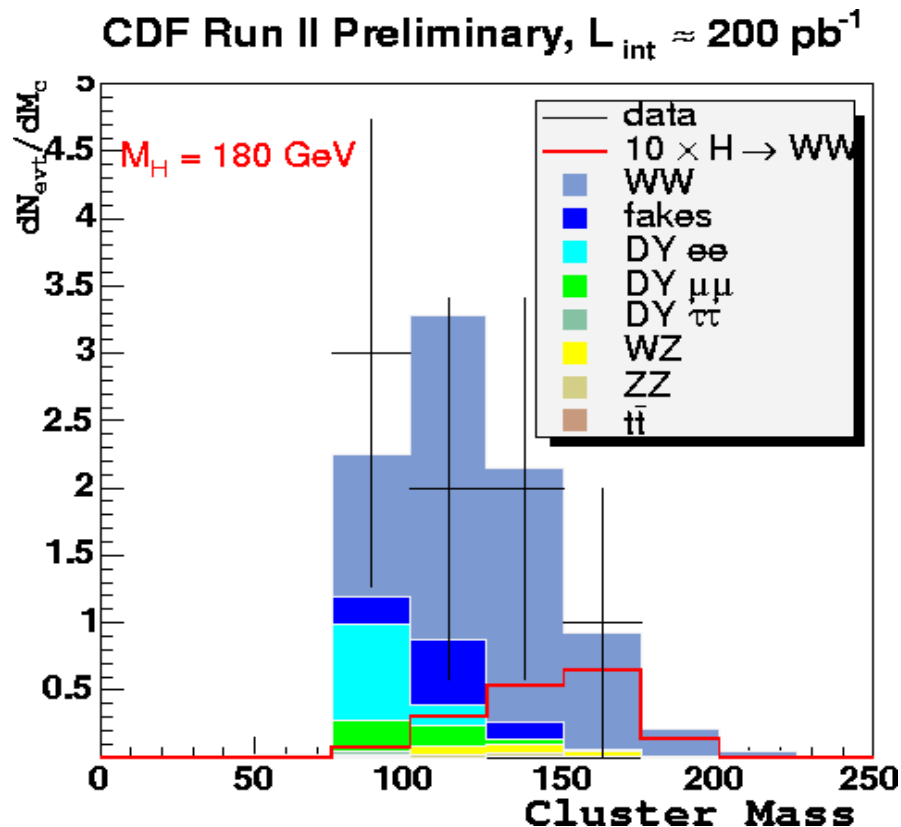
Determining backgrounds for same-sign sample

Other Possible Triplet Searches at CDF

H^\pm :

- * Experimentally accessible
- * No quark couplings if no mixing with Higgs doublet

Same final state as $H^0 \rightarrow WW$ search



*Can reoptimize for leptons
from H^\pm decays*

*NLO cross section would help
in sensitivity determination*

Other Possible Triplet Searches at CDF

$\tilde{H}^{\pm\pm}, \tilde{H}^\pm$:

- * Existing searches have sensitivity
- * Signatures depend on NLSP

$$\chi_1^0: \tilde{H}^{\pm\pm} \rightarrow \tilde{l}l' \rightarrow l\tilde{\chi}_1^0 l' \rightarrow l\chi^0 \gamma \chi^0 l'$$

Final state $ll'l'\gamma\cancel{E}_T$

$$\tilde{l}: \tilde{H}^{\pm\pm} \rightarrow \tilde{l}l' \rightarrow l\chi^0 l'$$

Final state $ll'l'\cancel{E}_T$

$$\tilde{H}^\pm \rightarrow lv \rightarrow l\chi_1^0 v \rightarrow l\chi^0 \gamma \chi^0 v$$

Final state $ll\gamma\cancel{E}_T$

$$\tilde{H}^\pm \rightarrow lv \rightarrow l\chi^0 v$$

Final state $ll\cancel{E}_T$

*Need to validate MC generators,
use for optimization and
acceptance determination*

NLO cross section would help

Summary

Higgs triplets a likely component of non-SM Higgs sector

- ♦ Arise in well-motivated models

Doubly-charged Higgs searches particularly attractive

- ♦ Accessible to colliders in a number of scenarios
- ♦ Extremely clean signatures: excellent discovery potential

CDF has world's highest mass limits for long-lived $H^{\pm\pm}$ and decays to ee , $e\mu$, $\mu\mu$

- ♦ Ongoing data-taking will significantly extend sensitivity
- ♦ Still early in Run 2!

Potential for a range of additional triplet searches

- ♦ Need to determine sensitivity (cross sections, acceptances)