Searching for Higgs Triplets at CDF

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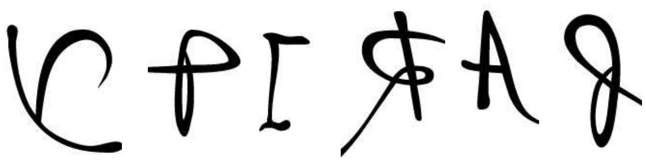


$$\begin{pmatrix} H^{++} \\ H^{+} \\ H^{0} \end{pmatrix}$$

Recent results

Future analyses

$$\begin{pmatrix} \tilde{H}^{++} \\ \tilde{H}^{+} \\ \tilde{H}^{0} \end{pmatrix}$$

Tev4LHC Higgs Workshop
Dec 14, 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

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

Non-supersymmetric left-right models

* Triplet masses typically proportional to v_R

If $v_R \approx 1$ TeV:

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

If $v_R \gg 1$ TeV:

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

Scenarios with Light Higgs Triplets

Supersymmetric left-right models

* Minimal model requires low $\upsilon_R \approx 1$ TeV, R-parity violation
* Considering nonrenormalizable (NR) terms in the superpotential allows for potential minimum with R-parity conservation
  Lead to light doubly-charged Higgs: $m_{H\pm\pm} \approx (\upsilon_R^2/M_{Pl})$
* Additional triplets with B-$L = 0$ can also result in R-parity conservation
  Lead to light doubly-charged Higgs with no lepton couplings

For seesaw $\upsilon_R \sim 10^{10}$ *GeV,* $m_{H\pm\pm} \sim 100$ *GeV*

Gauge-mediated SUSY breaking:

- Light $\widetilde{H}_R^{\pm\pm}$

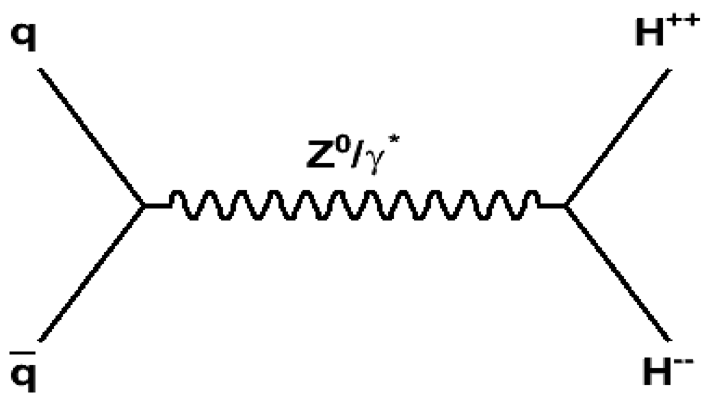
Gravity-mediated SUSY breaking:

- Light $H_R^{\pm\pm}$

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



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

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

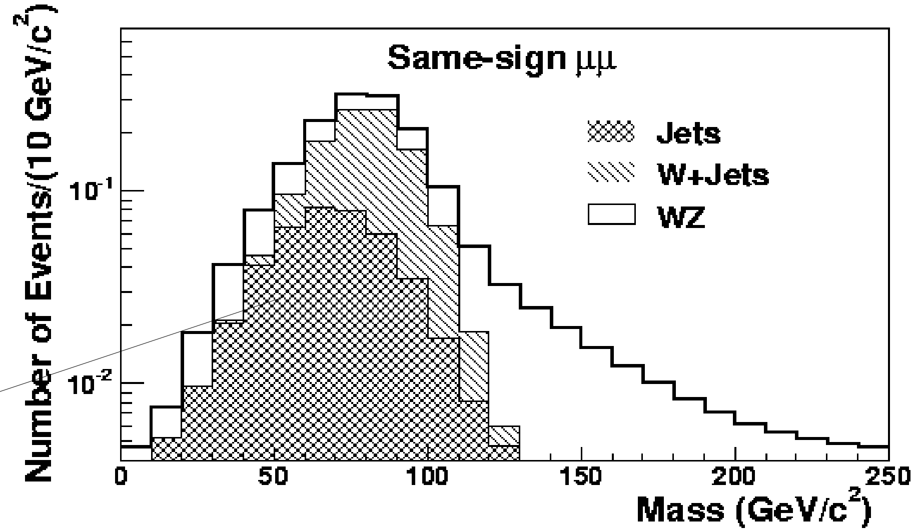
- No quark couplings due to charge conservation
- $W^{\pm}W^{\pm}$ decay constrained by ρ parameter

$$\mathcal{L}_Y = ih_{ij}(\overline{\psi}^c_{Li}\tau_2 H_L \psi_{Lj} + \overline{\psi}^c_{Ri}\tau_2 H_R \psi_{Rj})$$ ← *Violates lepton number; new quantum number: B-L*

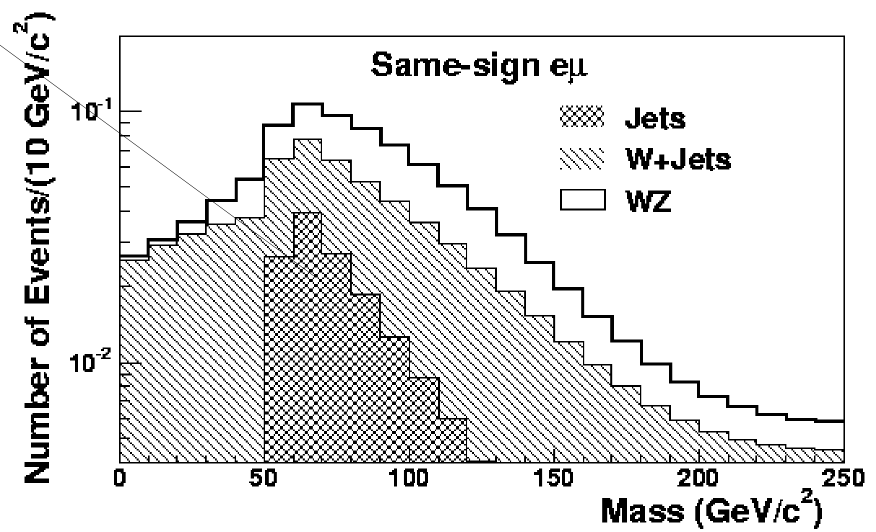
Doubly Charged Higgs Search at CDF

Search for $H^{\pm\pm}$ decays to *ee*, μμ, *e*μ

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



Low-mass background dominated by hadrons → leptons



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

Signature	Background	Data
μμ	0.8 ± 0.4	0
*e*μ	0.4 ± 0.2	0
ee	1.1 ± 0.4	1

Doubly Charged Higgs Search at CDF

Test hadron → lepton predictions using low $\not{E}_T$ (<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
$e\not{\mu} + \mu\not{e}$	2.4 ± 0.8	2
$e\not{e}$	54 ± 21	63

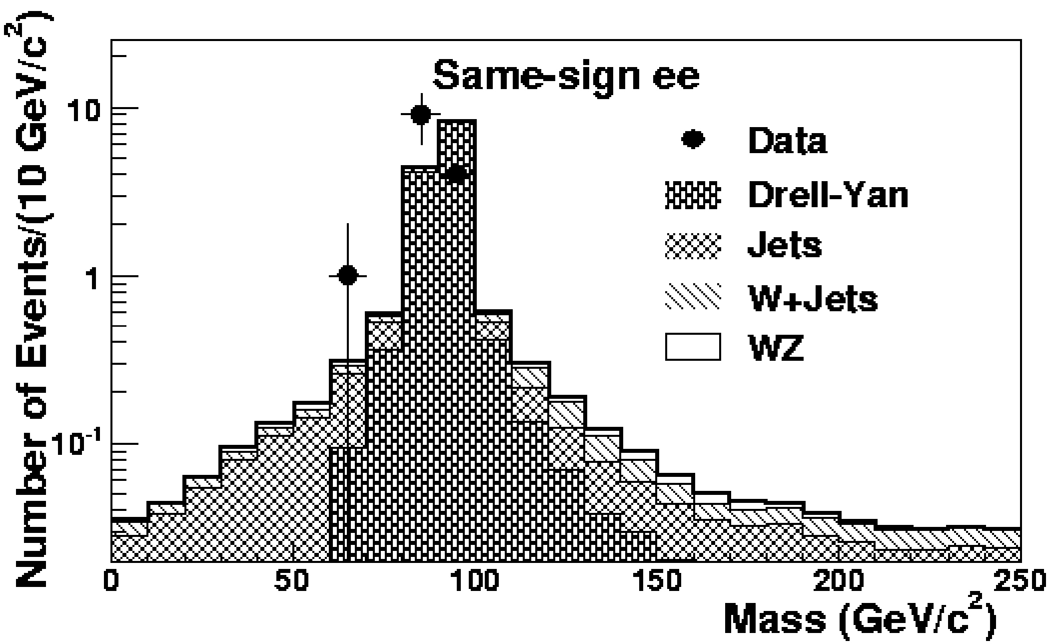
Same sign *ee* channel complicated by bremstrahlung in silicon detector

* Bremstrahlung 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*

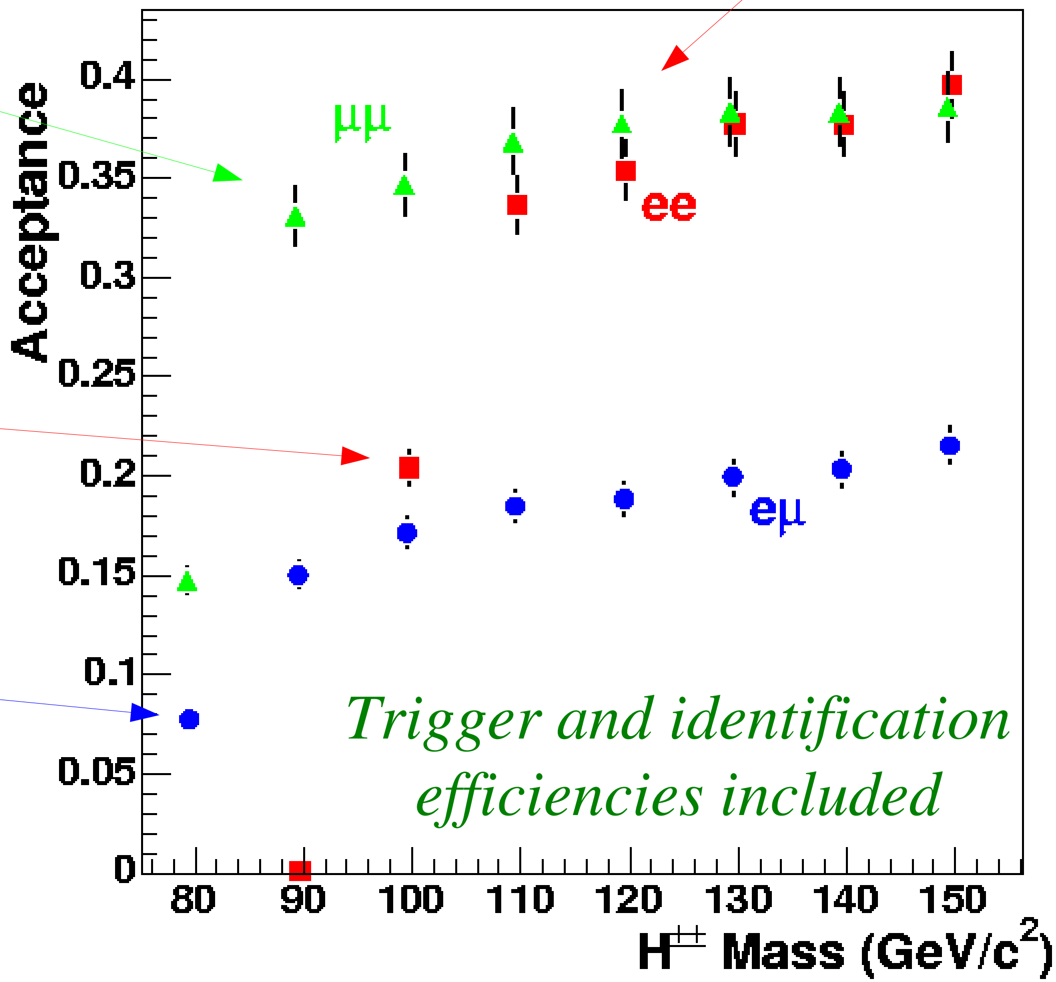
Very high acceptances!

μμ: Trigger muon has limited |η| (<1), ϕ coverage, second muon has large coverage (|η| < ~1.4, all ϕ).

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

*e*μ: Combination of limited electron and muon coverage reduces acceptance relative to *ee* and μμ.

ℒ ~ 240 pb-1: Largest sample of any published Tevatron result!



Trigger and identification efficiencies included

Doubly Charged Higgs Search at CDF

No events observed in signal regions

Set 95% C.L. cross section x BR limits

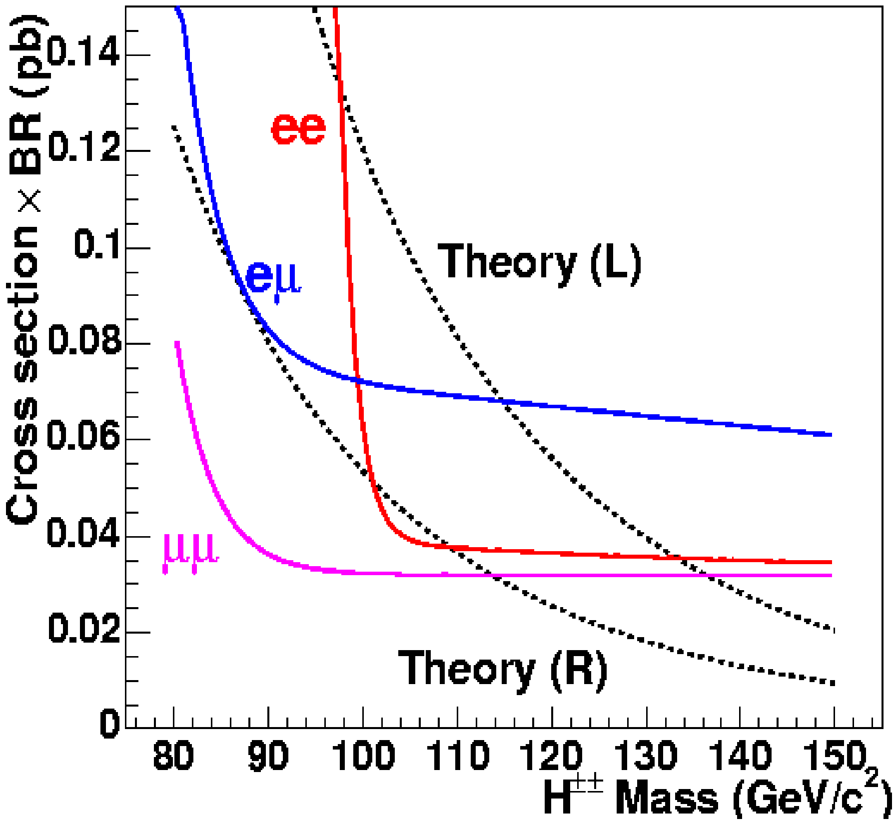
Assuming exclusive decays to a given channel, set mass limits:

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

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

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

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



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

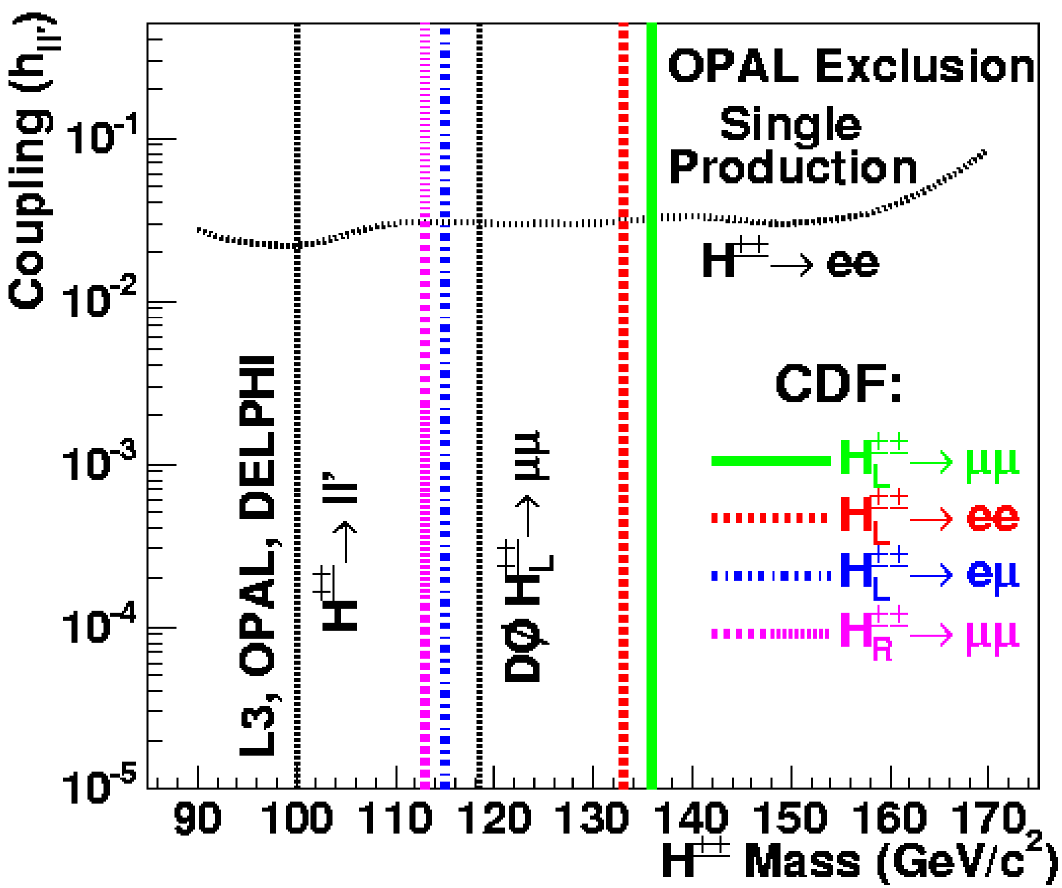
$H_L^{\pm\pm}$: $m > 120$ GeV

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

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



Complementary to indirect searches

h_{ij} limits for m = 100 GeV:

Bhabha scattering: $h_{ee} < 0.05$

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

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

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

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

Doubly Charged Higgs Search at CDF

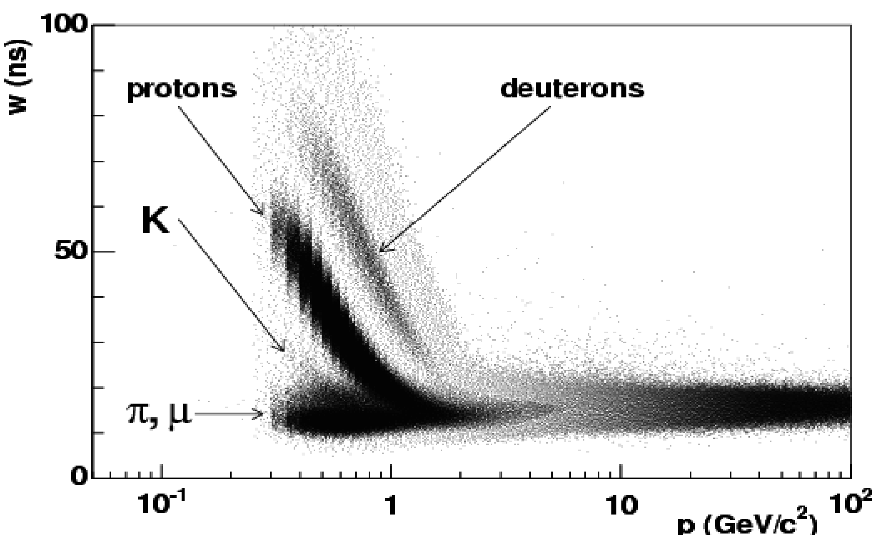
CDF has also searched for quasi-stable $H^{\pm\pm}$

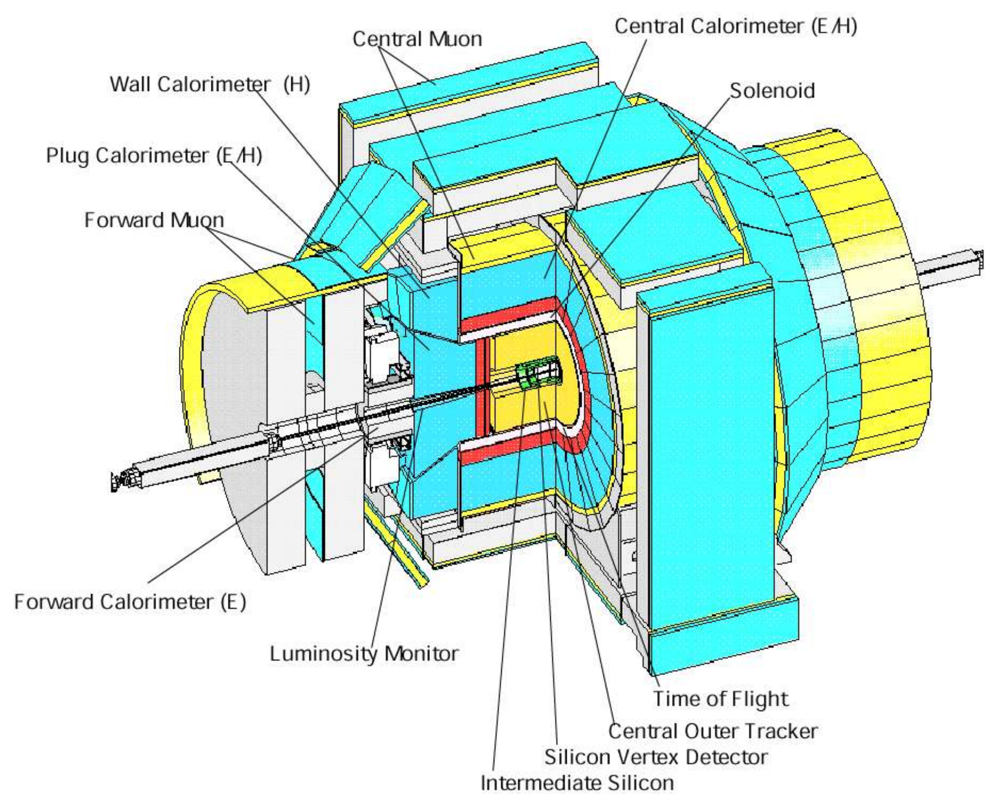
* Probes low Yukawa coupling values → *Couplings don't exist for additional triplets that conserve lepton number*

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

Strategy:

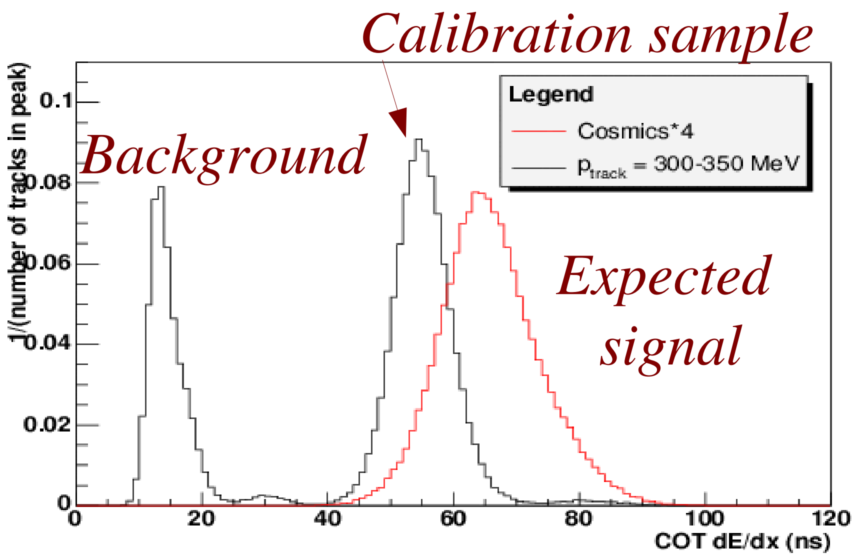
- *Use dE/dx information from tracker*
- *Search for pairs of high-momentum doubly-charged tracks*
- *Define tight "discovery" selection including calorimeter ionization*





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}
$Z \rightarrow ee$	< 10^{-6}	< 10^{-7}
$Z \rightarrow \tau\tau$	< 10^{-9}	< 10^{-9}
Dijets	< 10^{-5}	< 10^{-6}

No candidates in samples used to determine acceptance

Yields upper limits on expected background

Doubly Charged Higgs Search at CDF

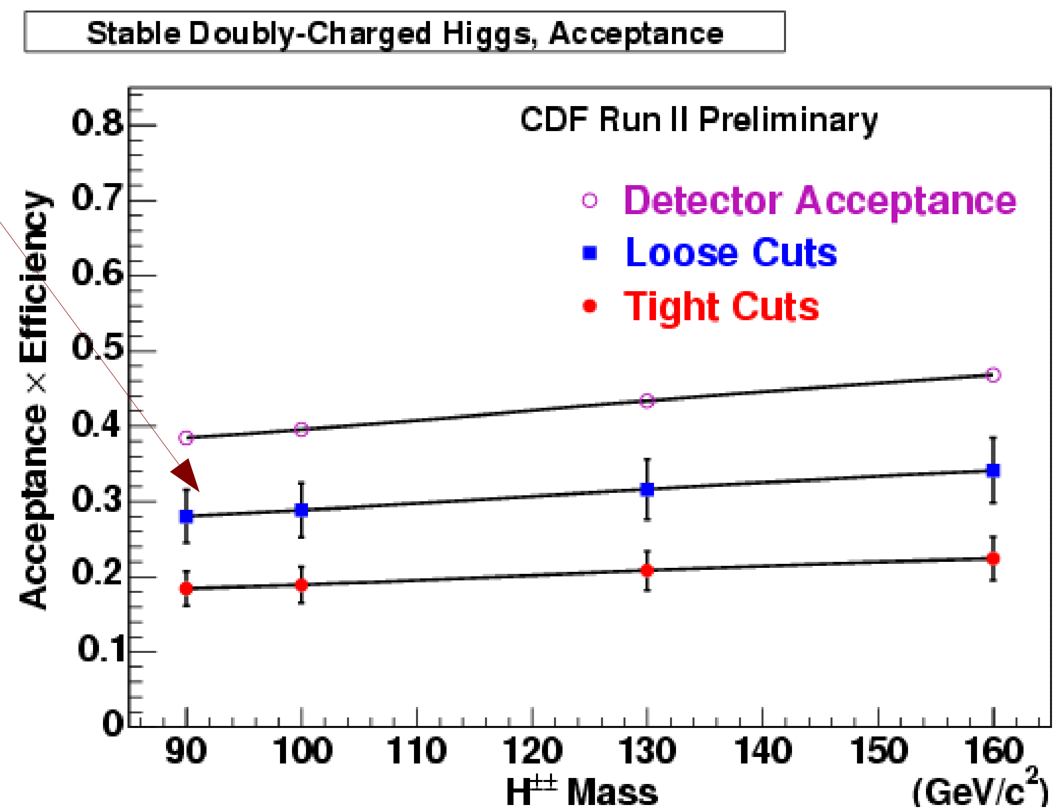
Acceptance has additional inefficiencies and uncertainties (beyond μμ)

* 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 μμ:

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

$\mathcal{L}$ ~ 200 pb-1

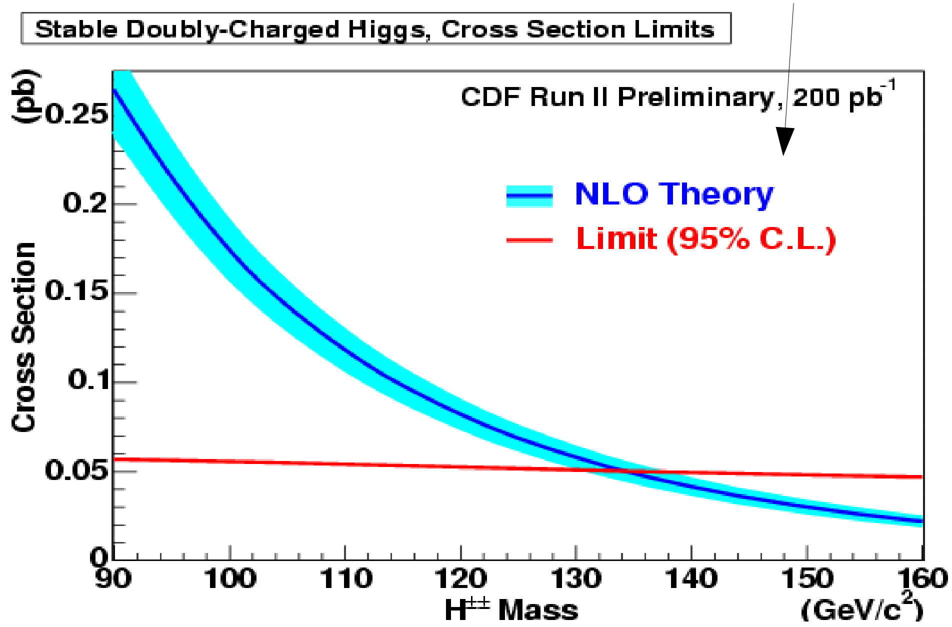


Doubly Charged Higgs Search at CDF

No events observed in data

Left and right cross sections combined

Set 95% C.L. cross section limit



Infer mass limits:

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

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

Limits similar to μμ and *ee* decay channels

Sensitivity will improve with order of magnitude increase in luminosity:

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

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

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

Same-sign tau decays

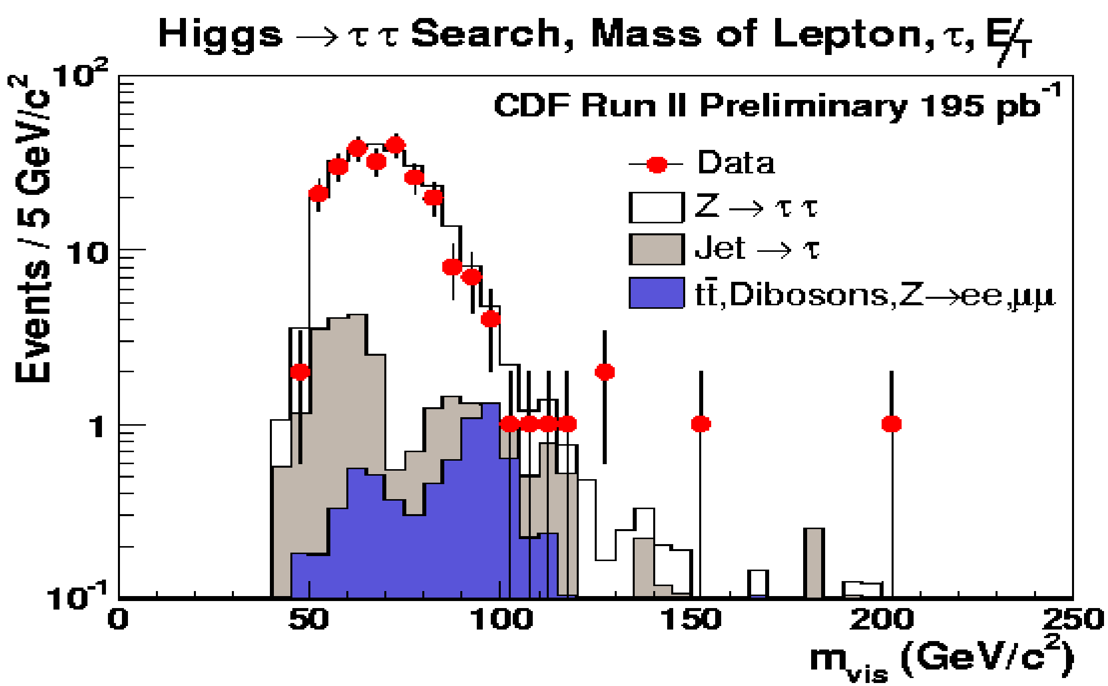
Experimentally challenging:

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

Phenomenologically interesting:

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

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



Studying issues of sign identification

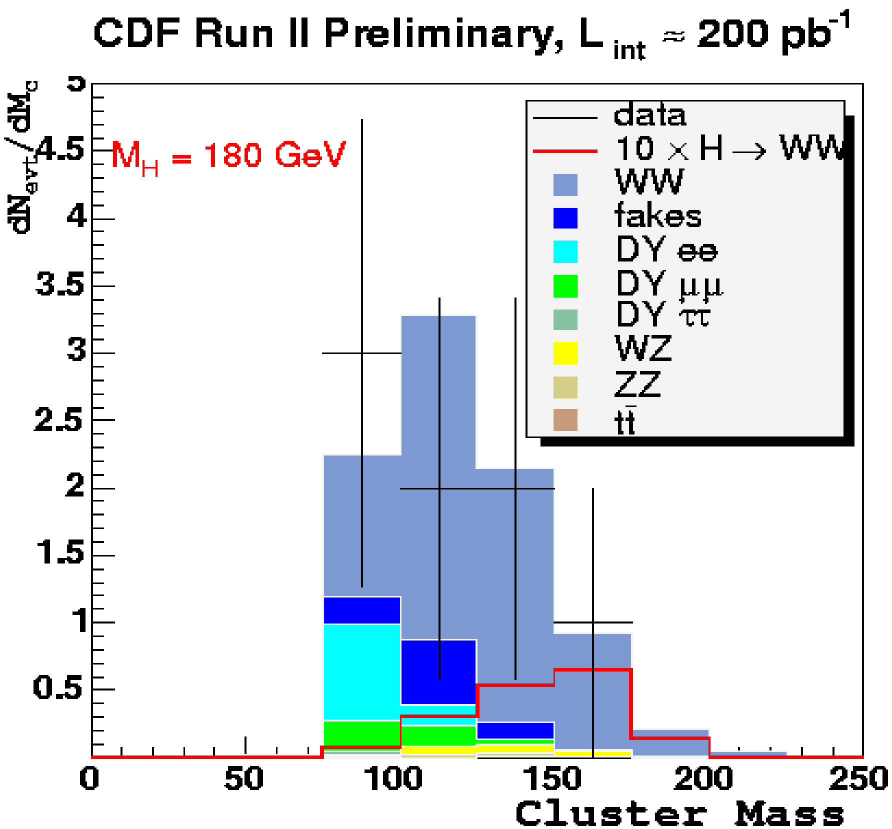
Determining backgrounds for same-sign sample

Other Possible Triplet Searches at CDF

$H^\pm$:

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

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



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

NLO cross section would help in full analysis

Other Possible Triplet Searches at CDF

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

* Existing searches have sensitivity

* Signatures depend on NLSP

χ_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 $lll'l'\gamma\gamma\not{E}_T$

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

Final state $ll\gamma\gamma\not{E}_T$

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

Final state $lll'l'\not{E}_T$

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

Final state $ll\not{E}_T$

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, eμ, μμ

- 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)