Physics with Tau Leptons at CDF

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for the CDF Collaboration

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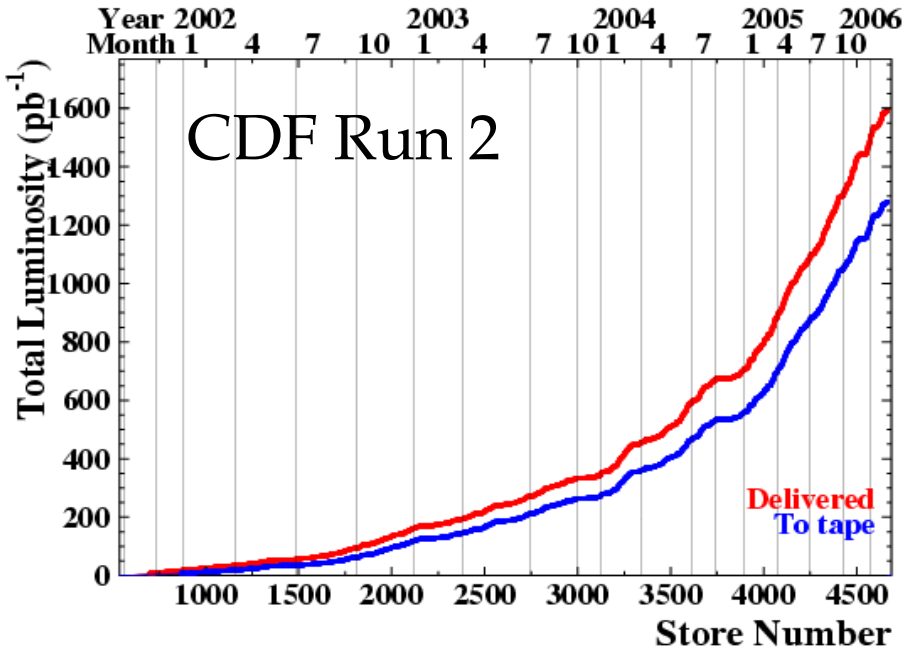
Tau Physics at the Tevatron

Data set:

>1 fb^{-1} of $\sqrt{s}$ = 1.96 TeV

$p\bar{p}$ collisions

Tau results: 0.2 - 1 fb^{-1}



Final states studied:

$\tau_h\tau_l$: Z, Higgs, Z′ production

τll: SUSY chargino + neutralino production

$\tau\tau ll$: Doubly-charged Higgs

$\tau\nu l\nu jj$: $t\bar{t}$ production, top decays to charged Higgs

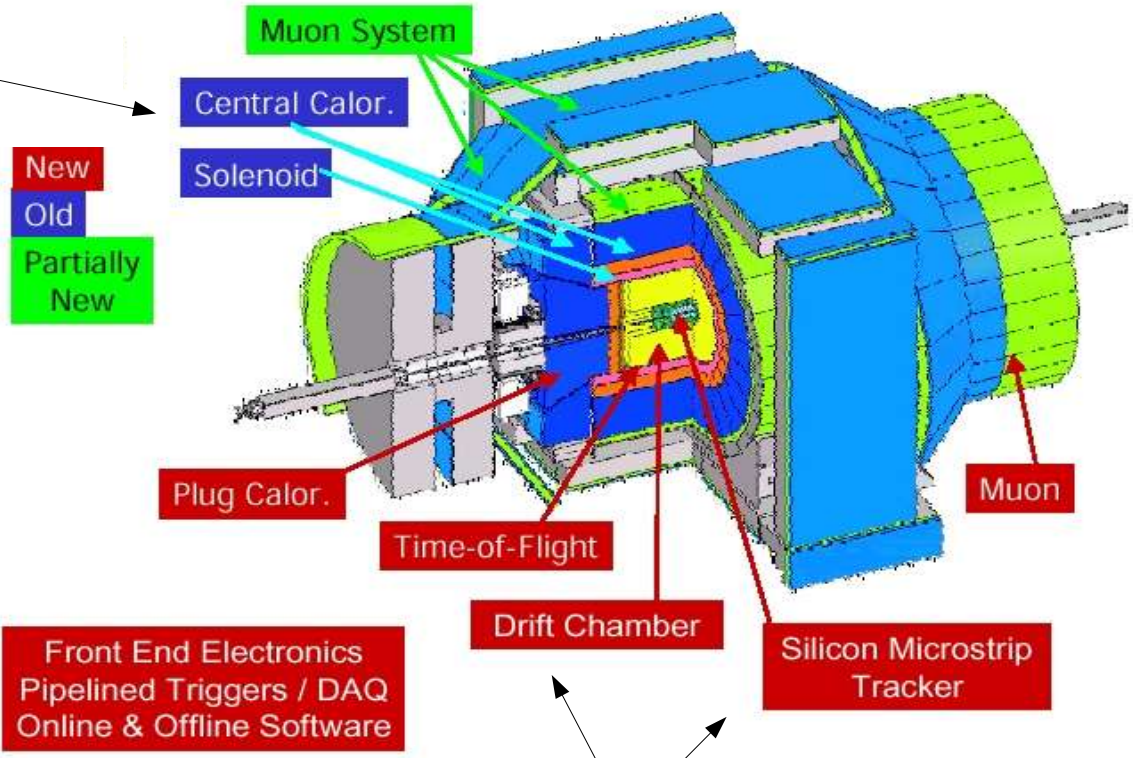
Increasing complexity

Trigger and identify tau's over wide momentum range

CDF Detector

Electromagnetic calorimetry includes finely-segmented strips and wires at shower maximum (~1 mm resolution)

Intrinsic energy resolution for Z→ee: < 2 GeV



Triggers include tracking with isolation

Tracking system (drift chamber + silicon microstrips) measure charged particles with high efficiency and high resolution

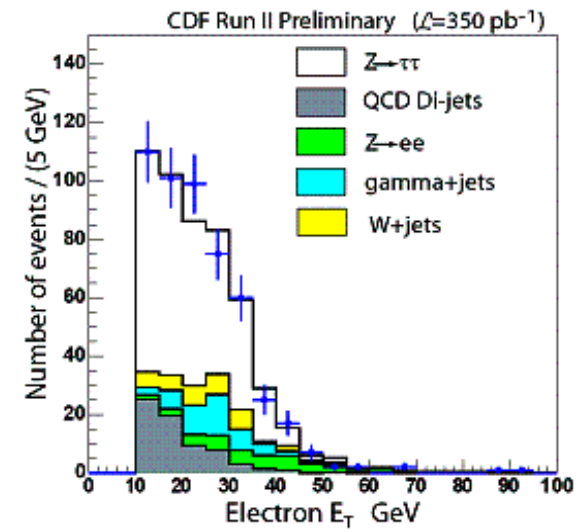
Standard Model Physics: $Z \rightarrow \tau\tau$

Goal:

* Establish tau trigger and reconstruction methods for O(40 GeV) taus

Measurement:

* 350 pb^{-1} of $Z \rightarrow \tau_h \tau_e$ candidates



Trigger:

τ_e: Electron contains ~1/3 of E_τ ($\tau \rightarrow e\nu_e\nu_\tau$)

Require E_T > 10 GeV electromagnetic cluster

96.5% efficient

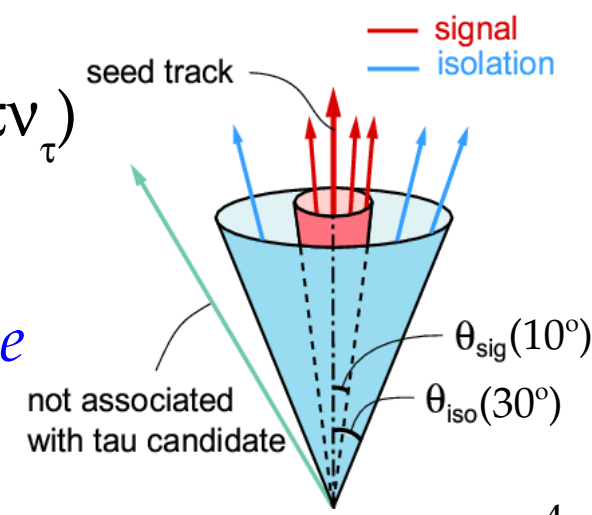
τ_h: Charged hadron contains ~1/5 - ½ of E_τ ($\tau \rightarrow n\pi\nu_\tau$)

Require: *p_T > 5 GeV seed track*

No p_T > 1.5 GeV tracks in isolation cone

Track separated from electron

95.6% efficient



NIM A 518 (2004)

Anatomy of a Tau

Hadronic energy ($\pi^{\pm}$):

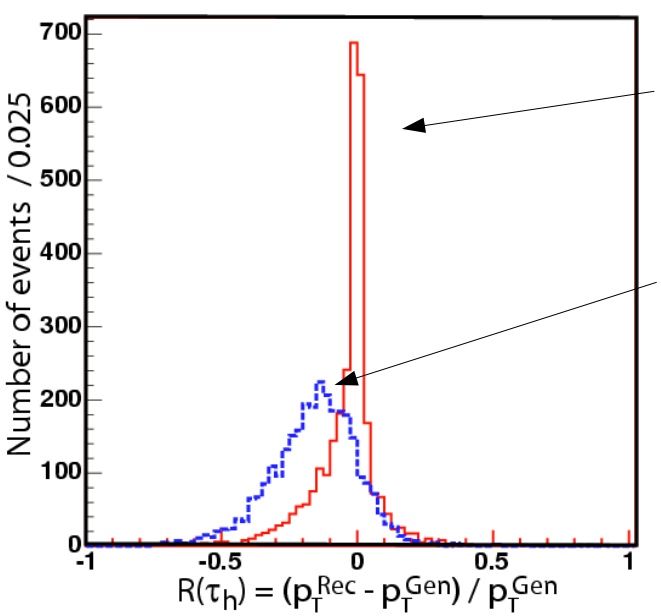
Narrow energy cluster:
~0.3 x 0.5 in η-ϕ space

Electromagnetic energy (π^0):

Resolved $\pi^0 \rightarrow \gamma\gamma$ at
EM shower maximum

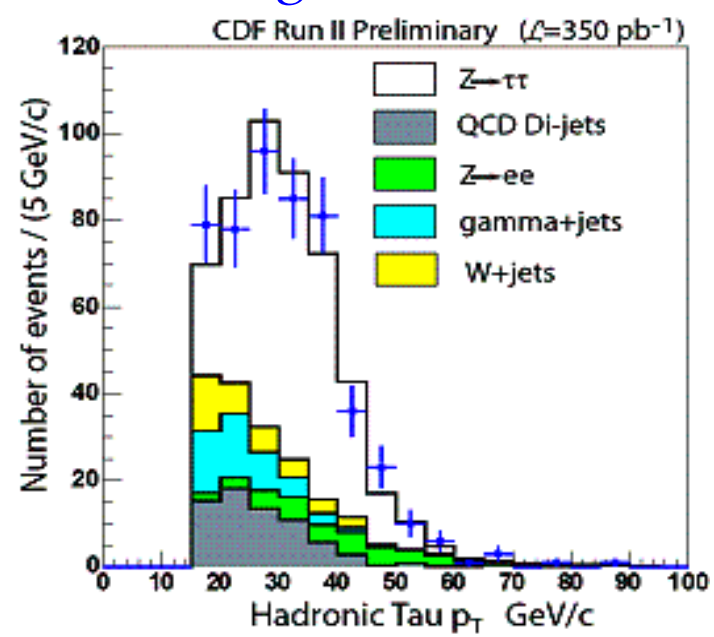
Charged track:

Measure energy using high-resolution tracker and electromagnetic calorimeter



Track + EM resolution

Calorimeter resolution



Tau Identification

Identification: 60% efficiency

π^0 candidates in isolation cone have < 0.6 GeV

95% efficient

No tracks in isolation cone

81% efficient

Require minimum hadronic energy

93% efficient

Signal cone (shrinks at high E_T):

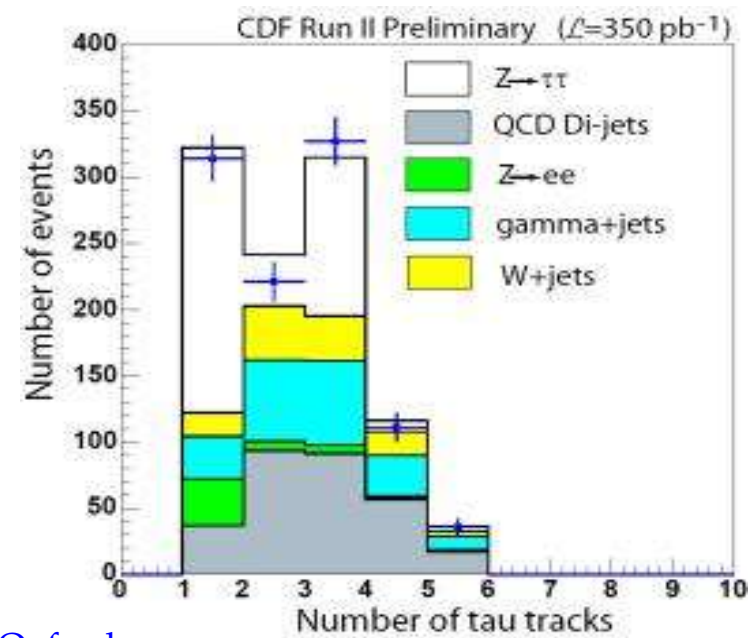
Mass of tracks + π^0s consistent with τ

Σ track charge opposite sign as e

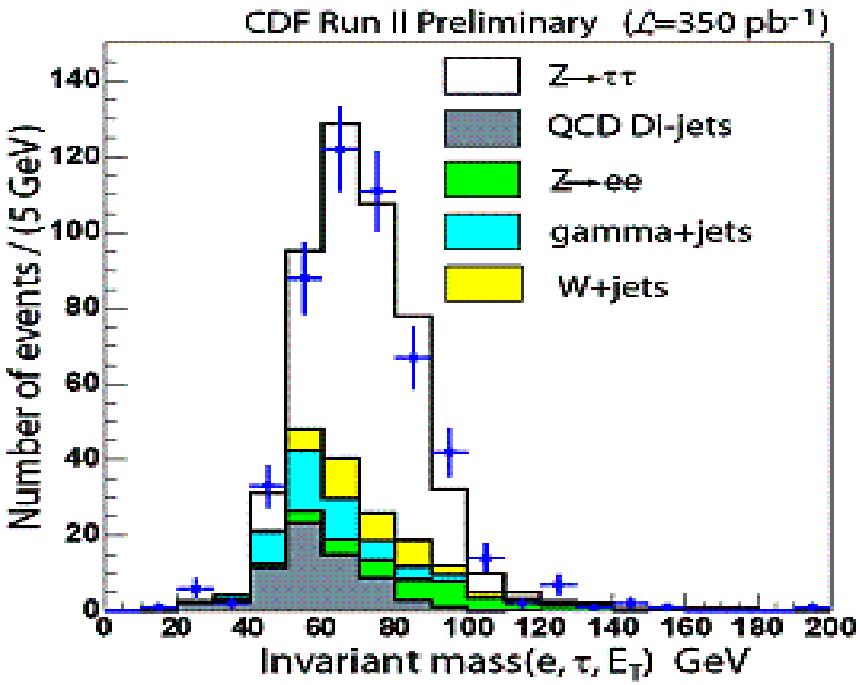
1 or 3 tracks **87% efficient**

Before opposite-sign requirement:

Good modelling of background



$Z \rightarrow \tau\tau$ Cross Section Result



Process	Yield (in number of events)
$Z \rightarrow ee$	$34.8 \pm 1.4 \pm 7.0$
W+jets	$36.6 \pm 3.5 \pm 4.9$
γ+jets	$47.8 \pm 2.2 \pm 12.0$
QCD di-jets	68.6 ± 3.6
Total:	$187.7 \pm 5.7 \pm 15.0^*$
Data	504
$Z \rightarrow \tau\tau$	$316 \pm 23 \pm 15$

>300 $Z \rightarrow \tau\tau$ events:

S/B > 3/2

	Systematic Uncertainty [%]
Signal events yield $N_{Z\rightarrow\tau\tau} = 316 \pm 23 \pm 15$	
Geometrical and kinematical acceptance (incl. PDFs)	3.0
Electron ID	1.9
Tau ID	3.0
Electron Trigger Efficiency	2.0
Tau Trigger Efficiency	2.0
Topology cuts	2.8
Background estimation	4.7
Total:	7.7
Cross-Section $\sigma(p\bar{p} \rightarrow Z)Br(Z \rightarrow \tau\tau) = 265 \pm 20(stat) \pm 21(syst) \pm 15(lumi)$ pb	

Systematic uncertainty < 8%

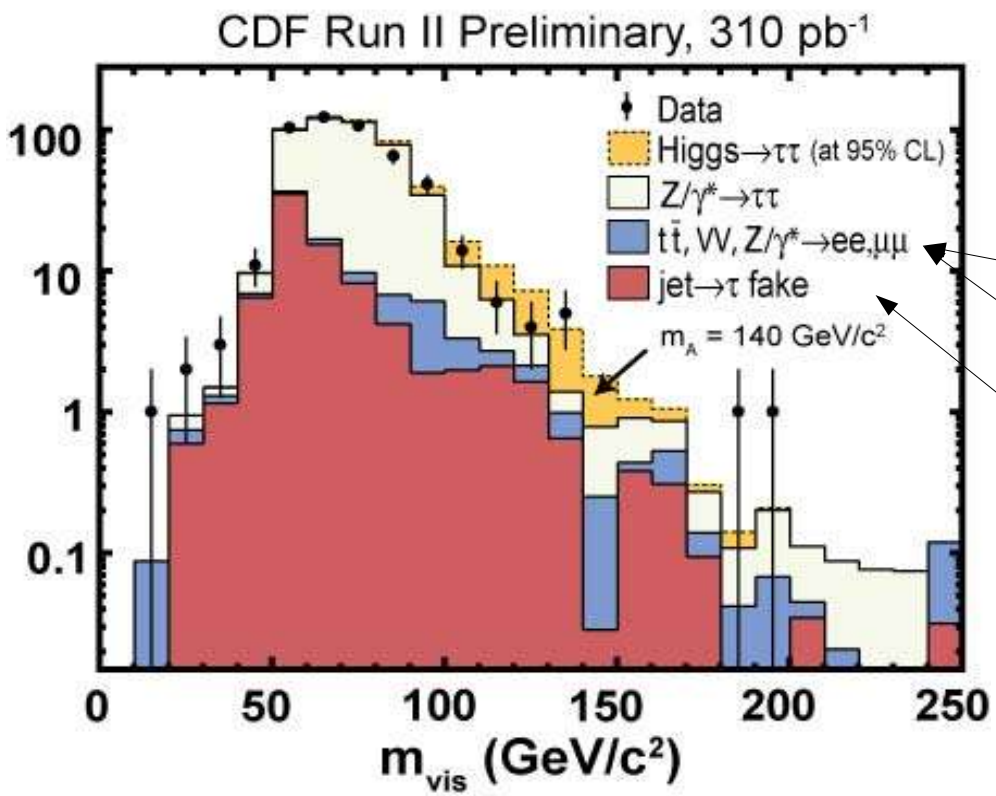
Consistent with theory (250.5 pb)

and $Z \rightarrow \mu\mu$ measurement (261 pb)

Higgs → ττ Search

Scan $\tau_h \tau_l$ mass spectrum for Higgs:

* MSSM: Higgs cross section large for high tanβ (= ratio of d/u Higgs vevs)
* LEP limits O(90 GeV)



Background reduction:

* Reject $m_{l\text{-}track}$ in Z mass region
* Require small $\not{E}_T$ opposite tau pair
* Require large total energy:

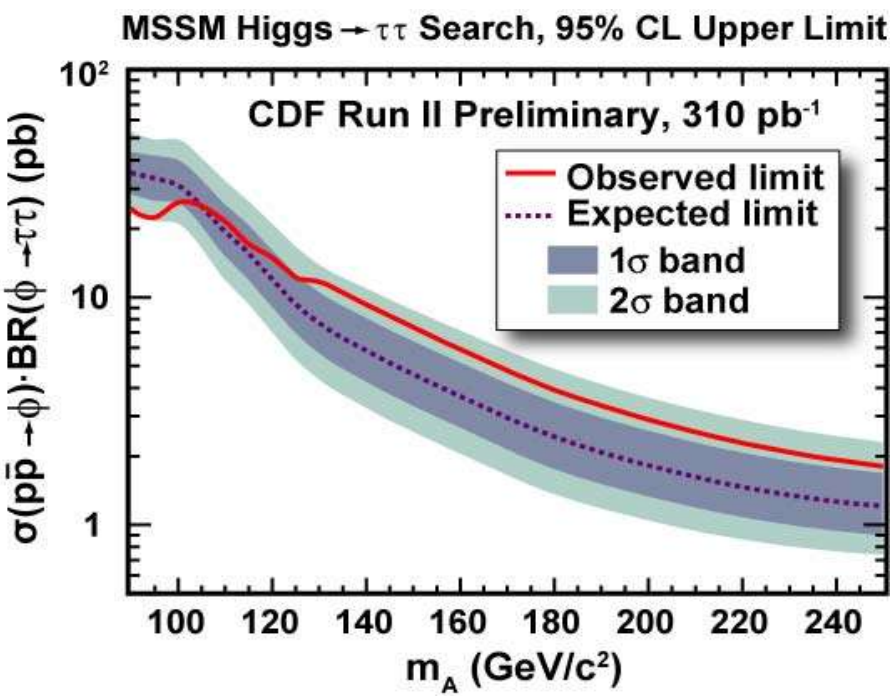
$$H_T = p_T^{\tau} + p_T^{l} + \not{E}_T > 50 \text{ GeV}$$

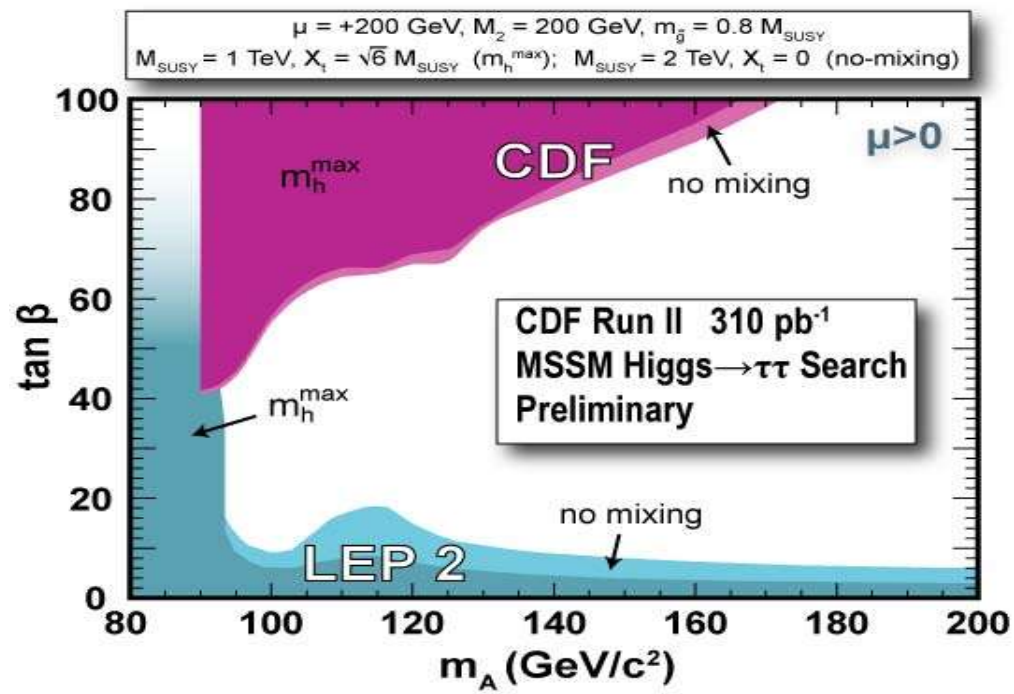
496 ± 5 (stat) ± 28 (sys) ± 25 (lum) events expected; ***487*** *observed*

Higgs → ττ Search

Data consistent with background expectation

* Set cross section and mass limits on $H \rightarrow \tau\tau$





Small excess of events at high mass

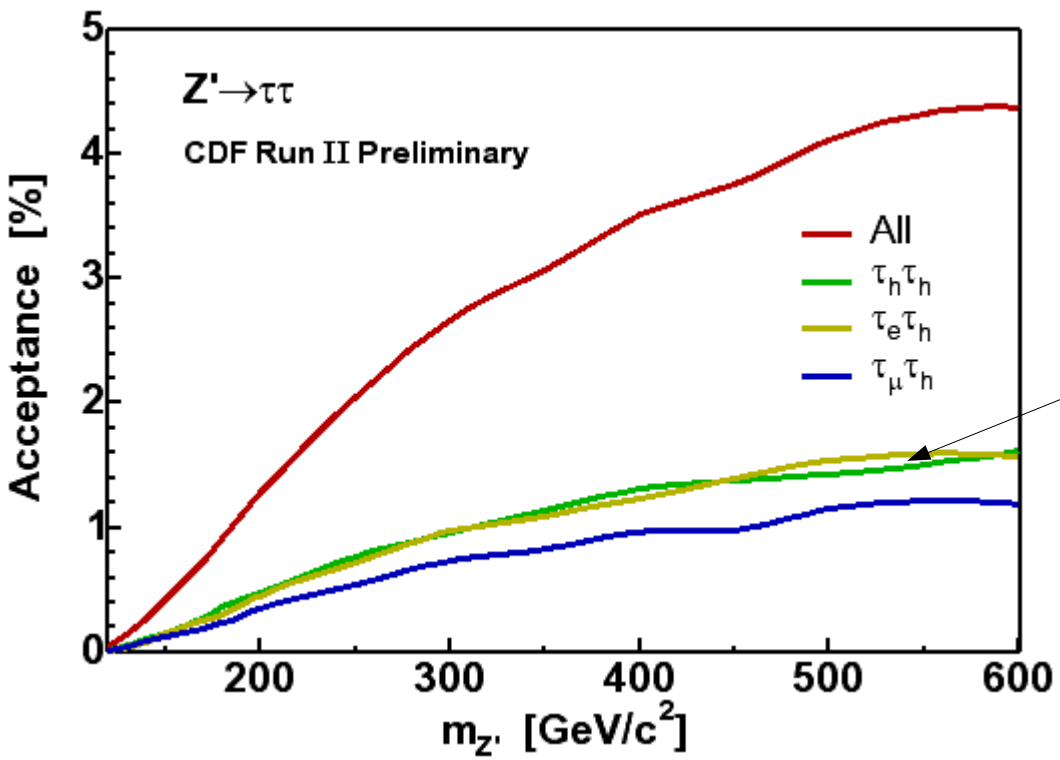
Significant region of SUSY parameter space excluded

hep-ex/0508051

High-Mass ττ Search

Search for new particles at very high masses

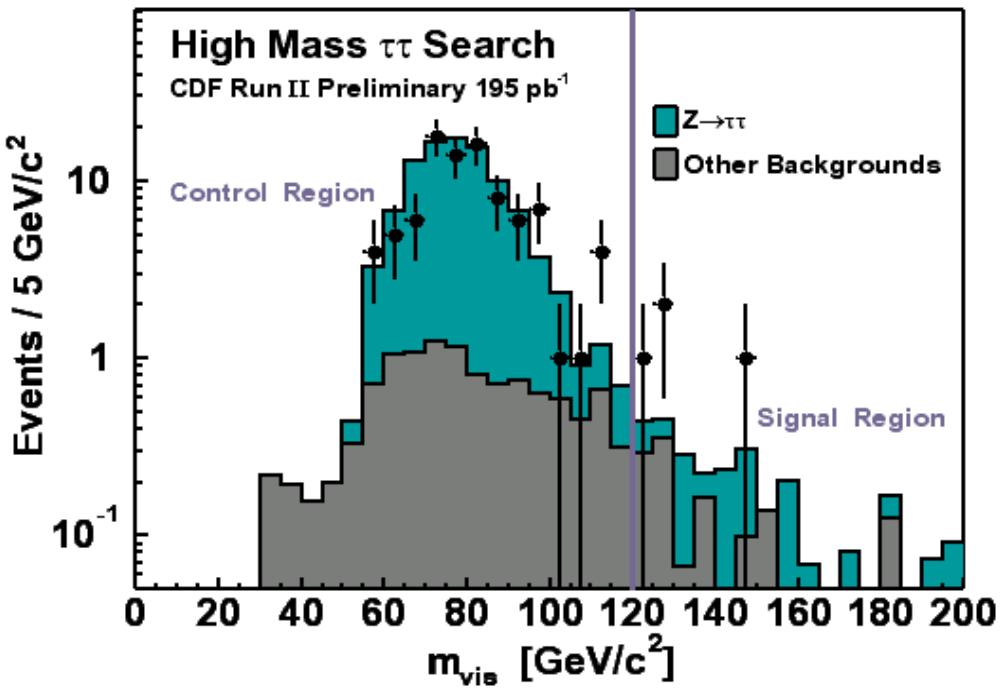
* Sensitive to, e.g., sneutrinos from $\not{R}$ SUSY, and sequential Z'
* High τ energies allow $\not{E}_T$ threshold to reduce background
* Include $\tau_h\tau_h$ mode using tau (> 20 GeV) + $\not{E}_T$ (> 25 GeV) trigger

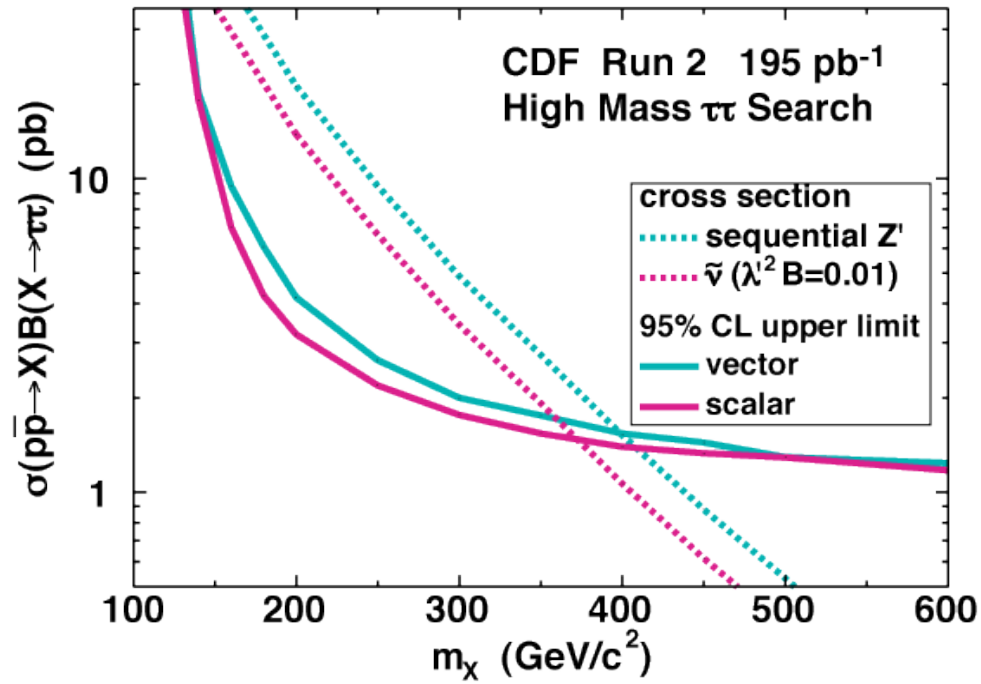


Large gain in acceptance from $\tau_h\tau_h$ mode

High-Mass ττ Search

Data consistent with background expectation





***Control** region (m_{vis} < 120 GeV):*

*99 ± 13 events expected, **90** observed*

***Signal** region (m_{vis} > 120 GeV):*

*2.8 ± 0.5 events expected, **4** observed*

Excludes scalar and vector particles with masses below ~350-400 GeV in particular models

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Doubly-Charged Higgs Search

Extend tau searches to topologies with three or more leptons

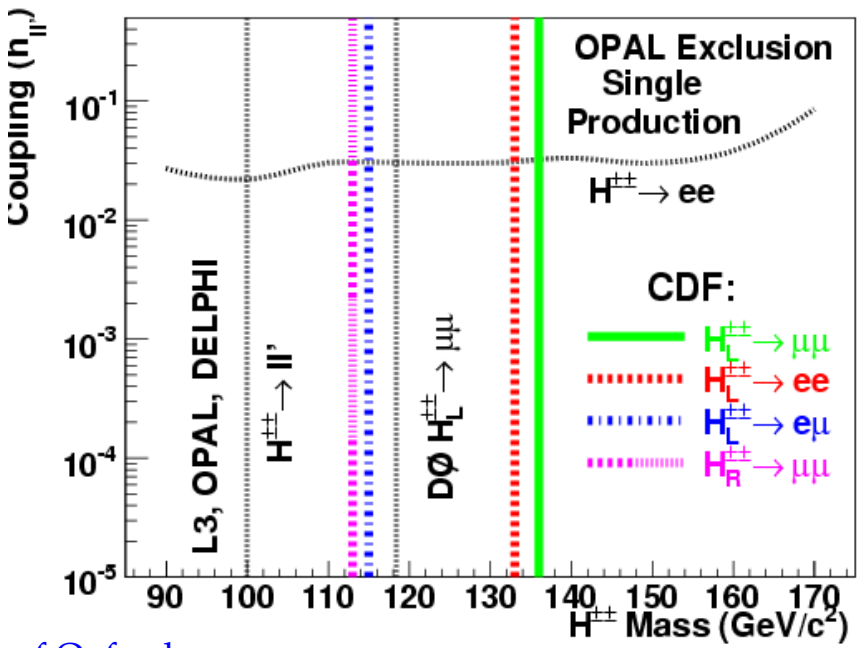
* Low background: loosen tau identification to increase efficiency

***$H^{\pm\pm}$*: predicted by L-R symmetric theories ($SU(2)_L$ x $SU(2)_R$ x $U(1)_{B-L}$)**

* Provides see-saw mechanism for neutrino masses
* Pair-produced via $p\bar{p} \rightarrow Z^* \rightarrow H^{++}H^{--}$
* Couplings not determined by fermion masses: lepton decays dominate

CDF: *World's strongest limits for $H^{\pm\pm} \rightarrow ee, e\mu, \mu\mu$*

New: *Search for $H^{\pm\pm} \rightarrow e\tau, \mu\tau$*



Doubly-Charged Higgs Search

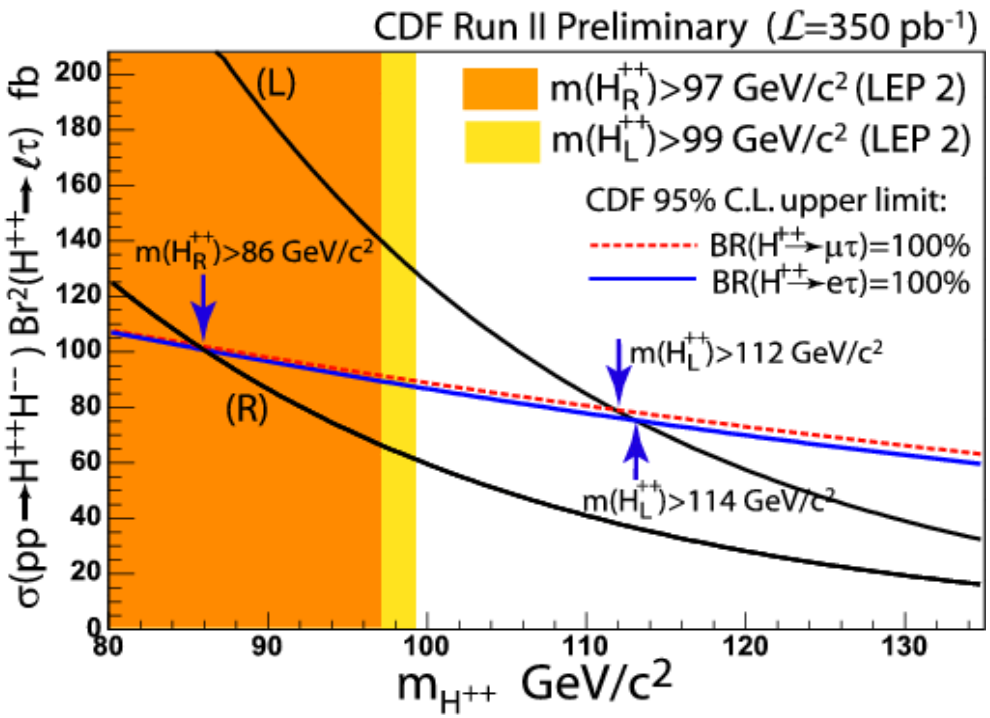
Final States $e^+\tau^+e^-\tau^-$ and $\mu^+\tau^+\mu^-\tau^-$

* Separate into 3-lepton and 4-lepton categories
* For $H^{\pm\pm} \rightarrow \mu^\pm\tau^\pm$, select $\mu\tau$+isolated tracks to increase efficiency

Isolated track: no hadronic energy requirement, loose track isolation

Results

3-Lepton Signal and Backgrounds			
$e\tau$	Data	Bkg	$H^{++} \rightarrow e\,\tau$
Lepton ID	34	37.8 ± 1.3	2.9
M_{LS}, M_{OS}	29	35.4 ± 1.2	2.9
Z-Veto	8	9.7 ± 0.7	2.4
H_T	0	$0.24^{+0.27}_{-0.24}$	2.0
$\mu\,\tau$	Data	Bkg	$H^{++} \rightarrow \mu\,\tau$
Lepton ID	28	30.0 ± 1.4	3.1
M_{LS}, M_{OS}	20	24.6 ± 1.3	3.0
Z-Veto	7	6.6 ± 0.9	2.4
H_T	0	0.27 ± 0.13	1.8



4-lepton: *0.18 expected,* ***0*** *observed (combined)*

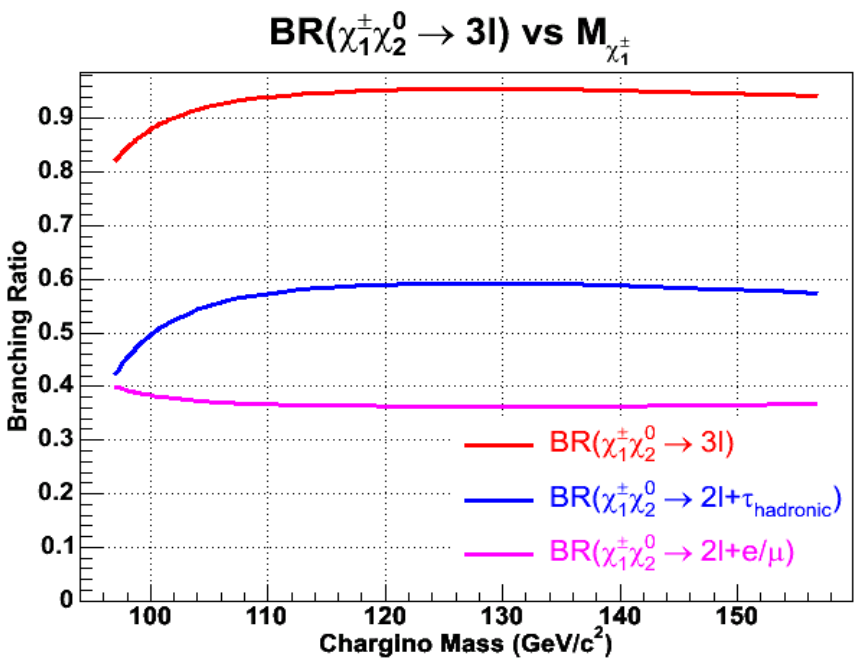
Chargino + Neutralino Search

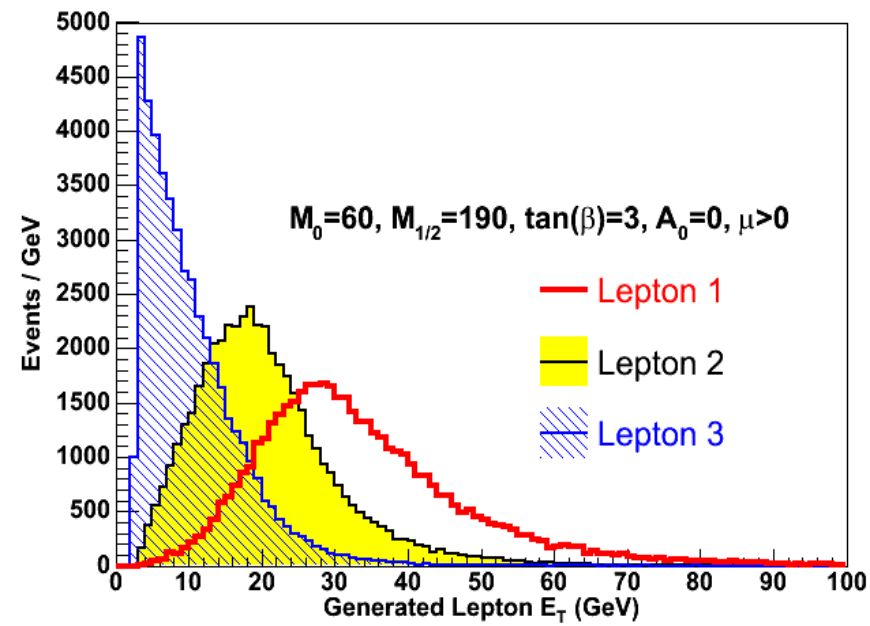
Promising SUSY discovery channel at the Tevatron

* $p\bar{p} \rightarrow \chi^{\pm}\chi^{0} \rightarrow l^{\pm}\chi^{0}_{LSP} l^{+}l^{-}\chi^{0}_{LSP}$
* Small mass difference between $\chi^{\pm}$ or χ^{0} and χ^{0}_{LSP} results in low-p_T $l^{\pm}$
* High tanβ enhances decays to taus

e, μ, τ

1 fb^{-1} data set: ee + isolated track (p_T > 4 GeV) + $\not{E}_T$:





Results: *1.0 ± 0.3 events expected,* ***3*** *observed (2.1 expected SUSY events)*

Search for t Decays to $\tau\nu q$

Goal:

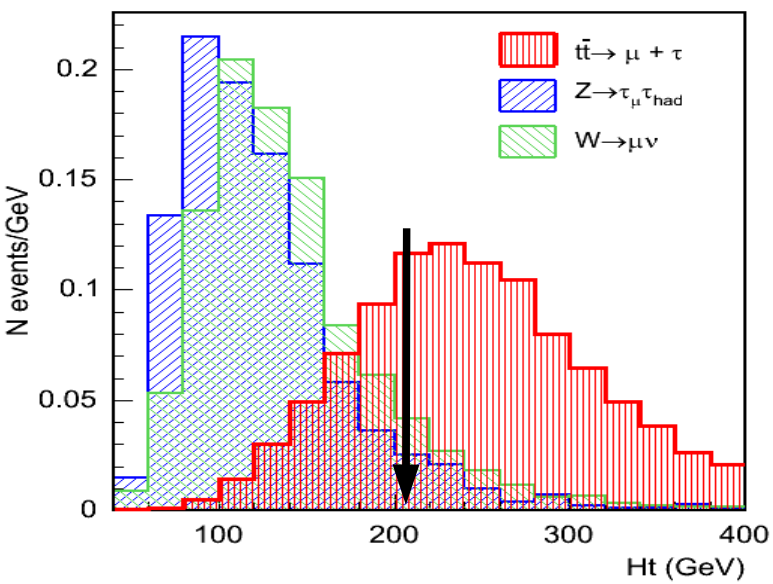
* Observe rare SM process in tau decay channel

Strategy:

* Use inclusive high-p_T lepton trigger to search for $t\bar{t} \rightarrow l\nu q\tau\nu q$ (l=e,μ)

Reduce W + *jets* (*jet* $\rightarrow \tau$), Z + *jets* backgrounds:

* Tighten π^0 isolation, add calorimeter isolation & H_T threshold



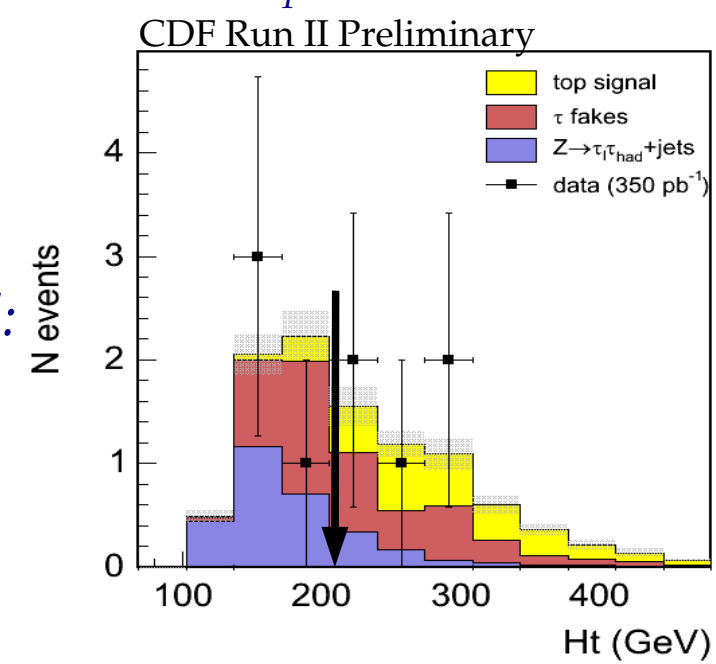
Results

5 observed events,

2.7 ± 0.4 background:

>1σ excess

(2.2 expected $t\bar{t}$)

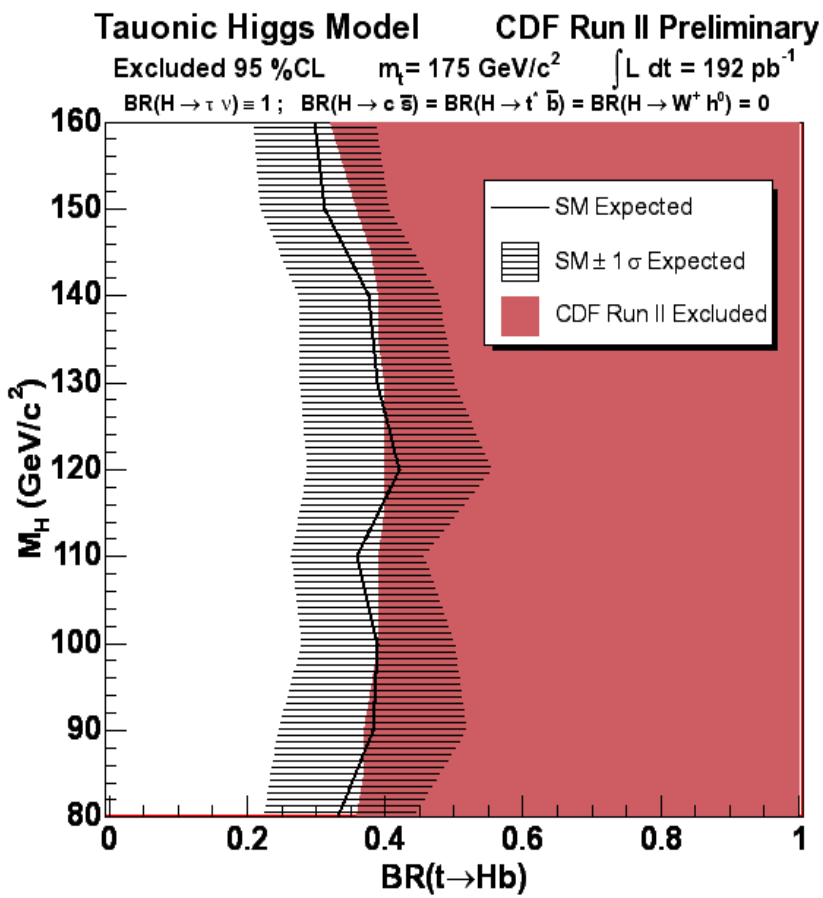


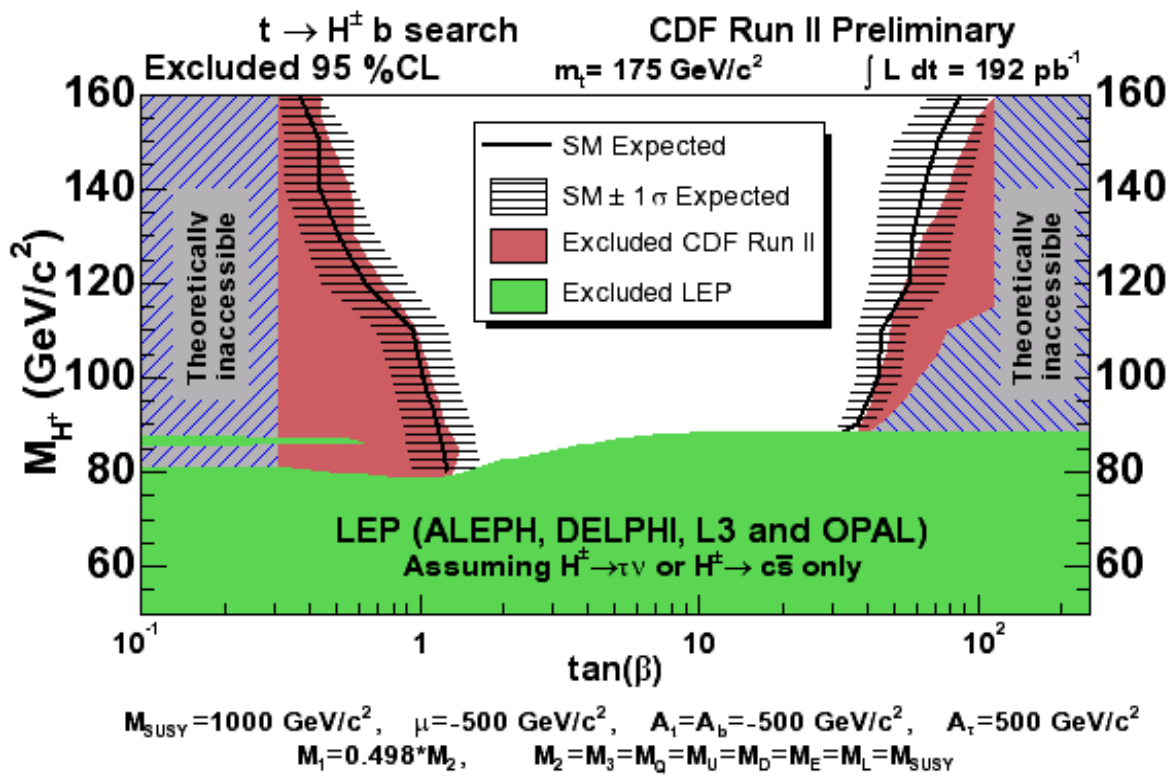
Search for t Decays to $H^{\pm}b$

In MSSM, charged Higgs can preferentially decay to τν

Combine $t \rightarrow \tau\nu q$ search with t cross section measurements

* Set limits on $t \rightarrow H^{\pm}b$, $M_{H\pm}$ vs tanβ in MSSM





Phys. Rev. Lett. 96 (2005), 042003

Summary

Rich tau physics program at the Tevatron

* SM: studying electroweak boson decays to taus, will observe $t \to \tau \nu q$
* MSSM: Promising Higgs, chargino & neutralino discovery modes
* LRSM: Doubly-charged Higgs sensitivity

Variety of τ identification methods

* Tailor to analysis -- high rejection vs high efficiency
* Acceptance over wide range of momenta

Expect x10 more data than shown here

* Significant improvements in measurements and sensitivities

Backup

Physics with Taus

Measurements:

* W/Z production and decay to taus

Searches:

* Low-p_T tau's: SUSY $\chi^{\pm}\chi^{0}$ production and decay
* Mid-p_T tau's: Neutral Higgs (MSSM), $H^{\pm}$ and $H^{\pm\pm}$, top to $\tau\nu$
* High-p_T tau's: High-mass particles (Z')