Status of Tevatron Searches Beyond the Standard Model

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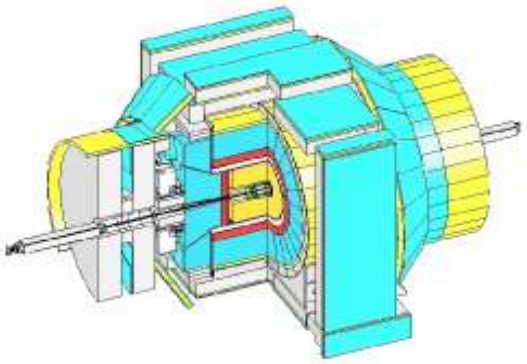
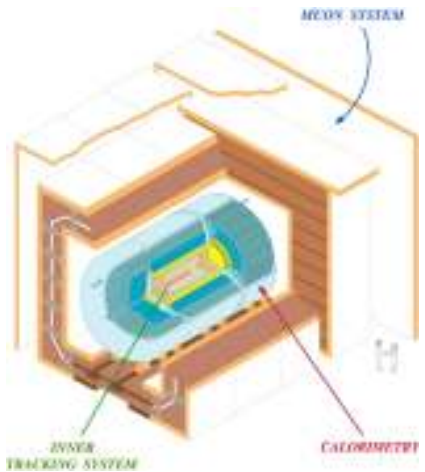
APS May 4, 2009

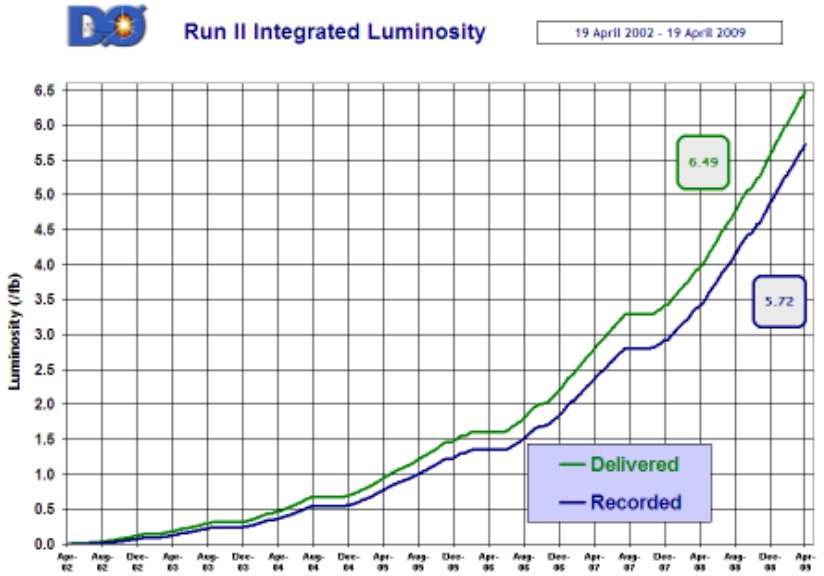




Introduction

- multi-fb^{-1} data samples and well-understood CDF/D0 analyses allow searches for New Phenomena beyond the Standard Model

- Multipurpose detectors: e, μ, τ and photon ID, vertexing (for b,c ID), missing E_T and jets
  - excellent tracking systems
  - excellent calorimetry, muon system. good lepton acceptance



>6.5 fb^{-1} delivered; >5.7 fb^{-1} recorded (data collection efficiency is almost 90%).
For today, analyses use 1-4 fb^{-1}

Introduction

- In 2008 and 2009, 27 published, 3 submitted and 16 preliminary results from CDF and D0 on NP searches
  - Not including rare B states or BSM Higgs searches
- This talk will cover only searches for
  - Extra Dimensions
  - High Mass ee,$\mu\mu$ Resonances
  - Chargino and Neutralino
  - Charged Massive Stable Particles
  - Sneutrino
  - Model Independent Searches
- Uncovered topics include
  - Technicolor
  - Leptoquarks
  - New or Excited Fermions
  - Other SUSY (squark/gluino, stop, sbottom)
  - Other High Mass Resonances (e.g. X→ZZ)

Large Extra Dimensions (LED)

- Possible solution to the Hierarchy Problem
  M_H ~ 100 GeV $M_{GUT/Planck}$ ~ 10^{16}-10^{19} GeV
- model of Arkani-Hamed, Dimopoulos and Dvali (ADD)
  → gravity propagates to n extra spatial dimensions
  → gives massive stable Kaluza-Klein gravitons G_{KK}
  → effective Plank scale M_{Pl} related to fundamental Plank scale in (n+4) dim M_D

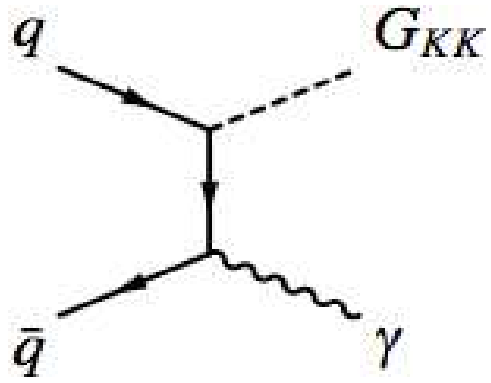
$$M_{Pl}^2 \sim R^n M_D^{n+2}$$

SIGNAL (real graviton)

- high E_T single photon + missing E_T
- monojet + missing E_T

SIGNAL (virtual graviton)

- high mass pair resonance: ee,μμ,γγ

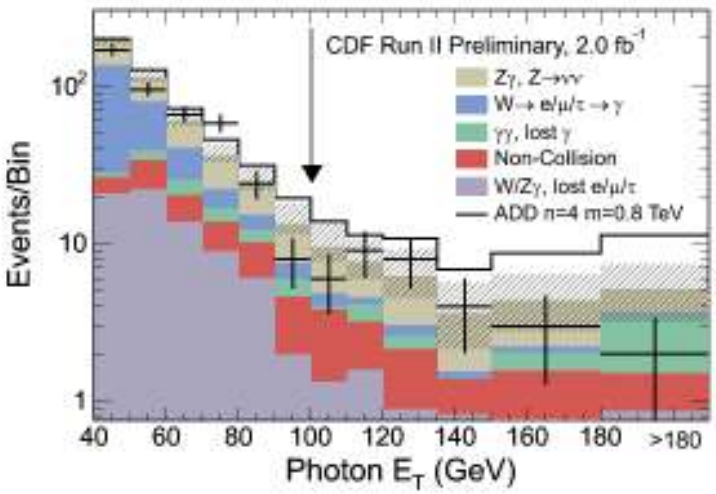


LED $\gamma + \text{MET}$

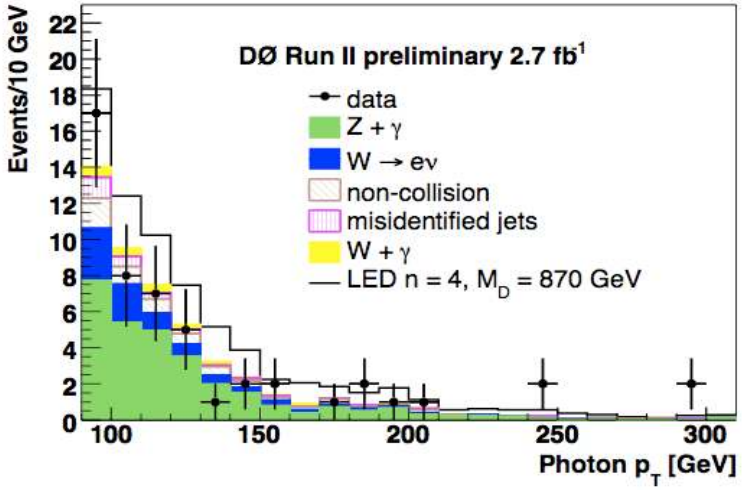
- CDF: PRL 101:181602 (2008)
- Overview
  - $E_T^{\gamma} > 90$ GeV; MET > 50 GeV
  - No jet with $E_T > 15$ GeV
  - No tracks with $P_T > 10$ GeV

- D0 preliminary
- Overview
  - $E_T^{\gamma} > 90$ GeV; MET > 70 GeV
  - No jet with $E_T > 15$ GeV
  - No tracks with $P_T > 6.5$ GeV

2 fb^{-1}



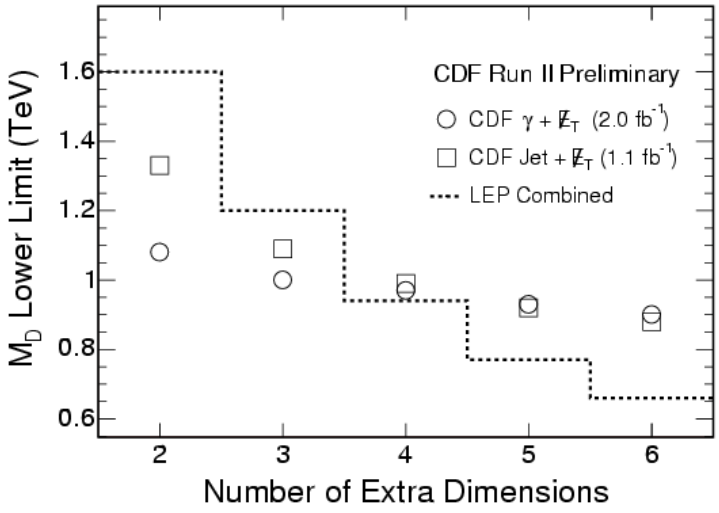
2.7 fb^{-1}



http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/NP/N63/

LED $\gamma + \not{E}_T$

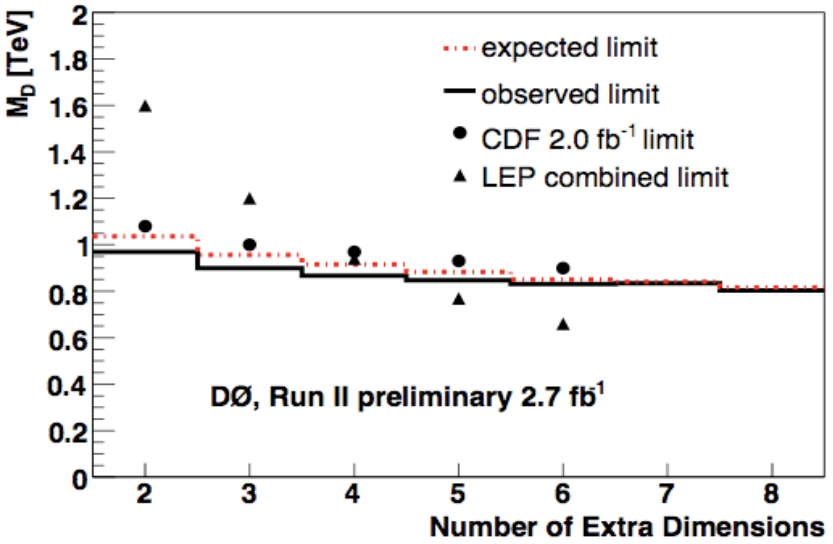
2 fb^{-1}



CDF: Combined with Mono-jet analysis

→ M_D > 1040 GeV at n=4

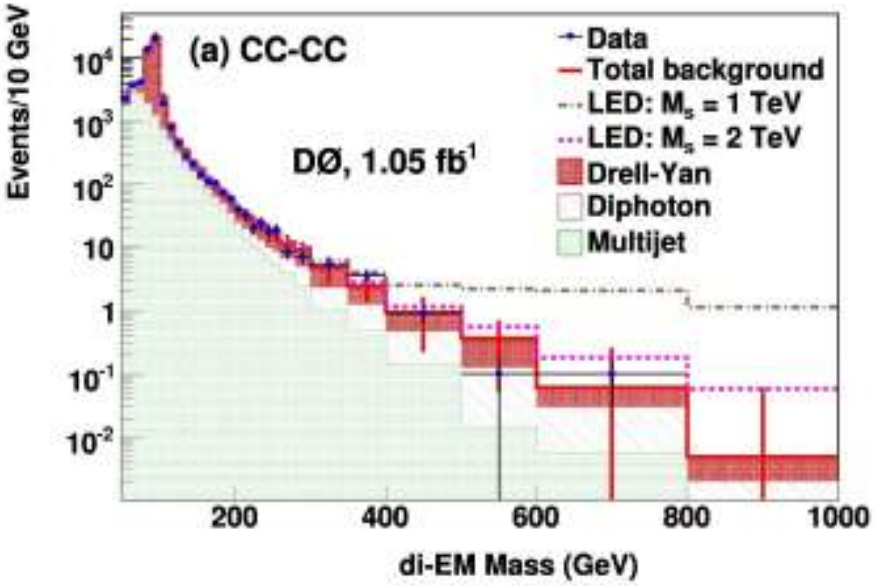
2.7 fb^{-1}

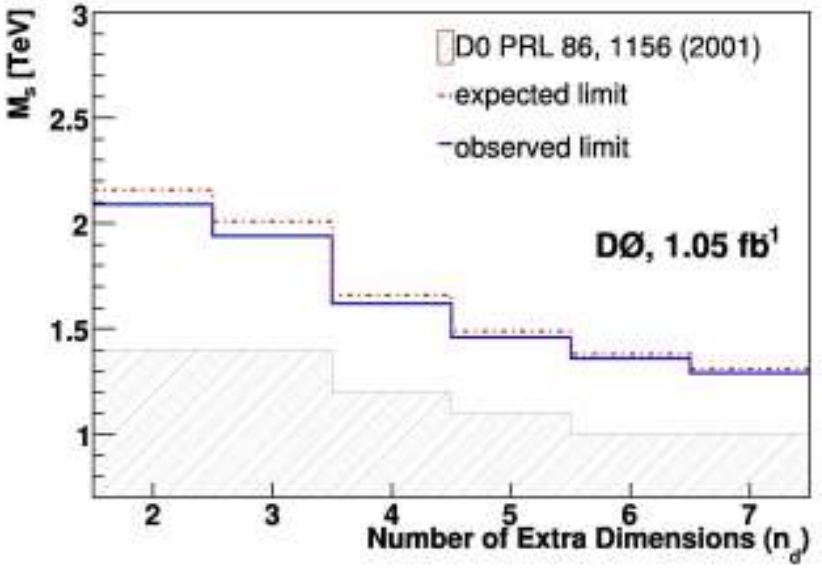


LED $\gamma\gamma$ or ee

- PRL 102:051601 (2009)
- Analysis overview
  - 2 isolated EM showers $E_T(e,\gamma) > 25$ GeV
  - require 1 in $|\eta| < 1.1$ (CC) other either CC or EC ($1.5 < |\eta| < 2.4$)
  - assume $BR(G_{KK} \rightarrow \gamma\gamma)/BR(G_{KK} \rightarrow ee) = 2$

1.05 fb^{-1}





M_S (~M_D) > 2.09 TeV for n=2, > 1.29 TeV for n=7

Other High Mass Resonances

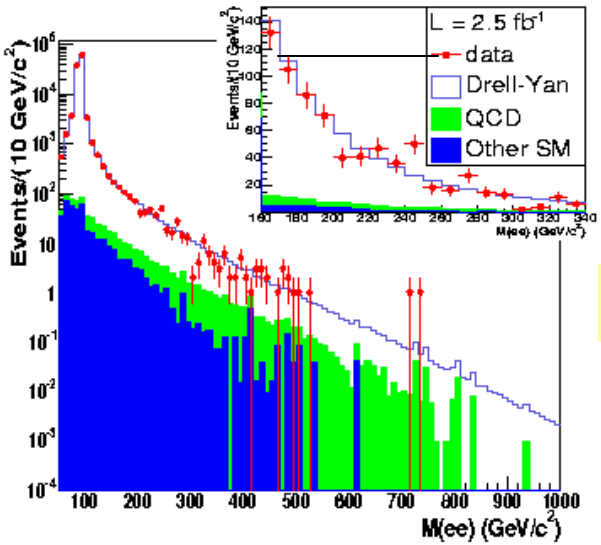
- high mass resonances are sensitive to new physics, e.g.
  - Z' in SM or extended gauge models like E_6
  - Randall-Sundrum model of Extra Dimensions
    → 1 extra dimension plus curvature k
    → variables are graviton mass M_G and k/M_{Pl} which is related to the coupling
- CDF ee/μμ analyses with 2.5 fb^{-1} and 2.3 fb^{-1}
  - 1 central e plus 1 central or plug e. $E_T > 25$ GeV, $|\eta| < 2$
    - 2 central muons with $p_T > 30$ GeV

- ee: Phys. Rev. Lett. 102, 031801 (2009)
  μμ: Phys. Rev. Lett. 102, 091805 (2009)

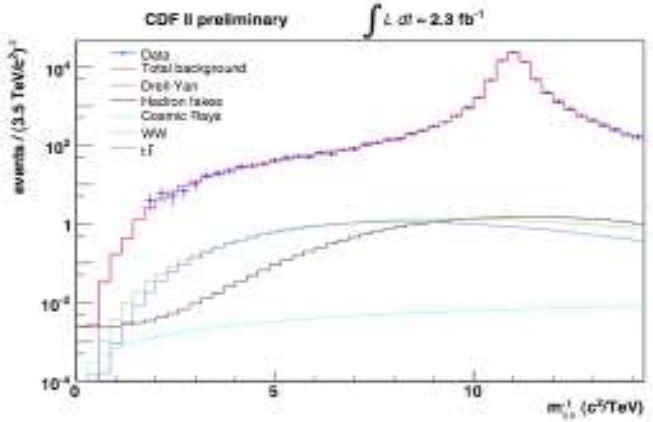
Z' → ee,μμ

CDF Run II

2.3-2.5 fb^{-1}

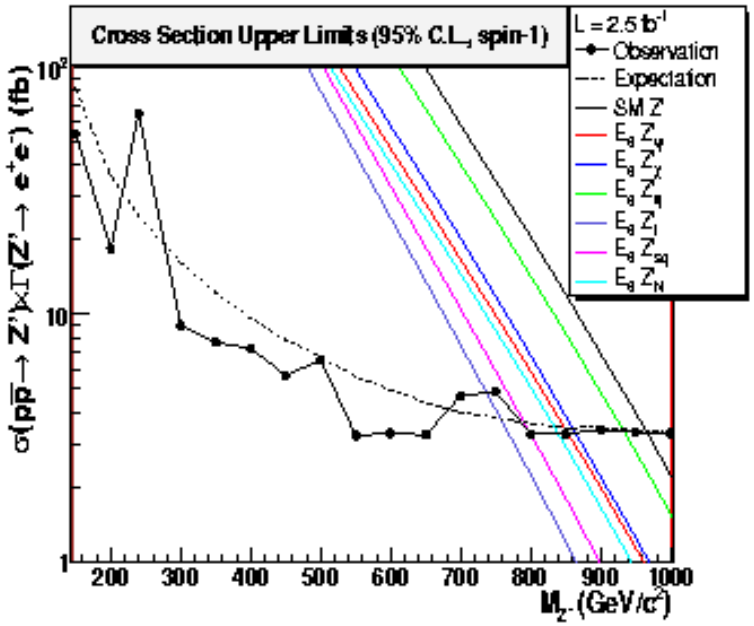


ee mass



μμ mass^{-1}

CDF Run II



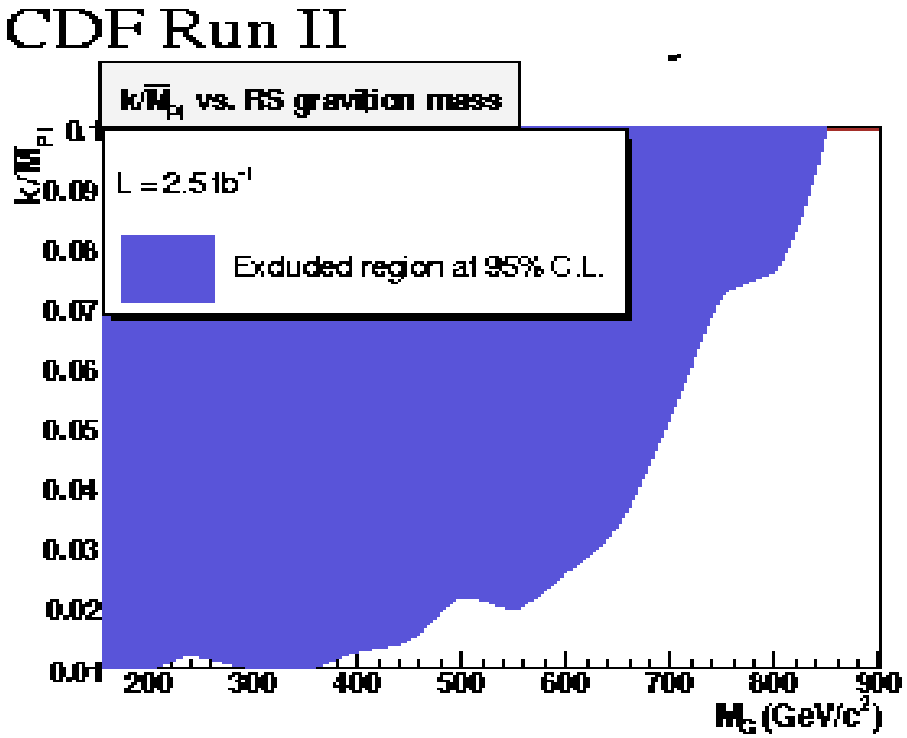
Spin 1: SM Z' < 966 GeV excluded (ee) and < 1030 GeV (μμ)
E_6 Z' < 737-933 GeV (ee) and < 789-904 (μμ) depending on mixing angles

RS Graviton → ee,μμ

2.3-2.5 fb^{-1}

Randall-Sundrum Gravitons

- Spin 2
- k = negative curvature
- M_{Pl} = effective Planck mass



M_G > 850 GeV (ee) and
> 921 GeV (μμ): k/M_{pl}=0.1

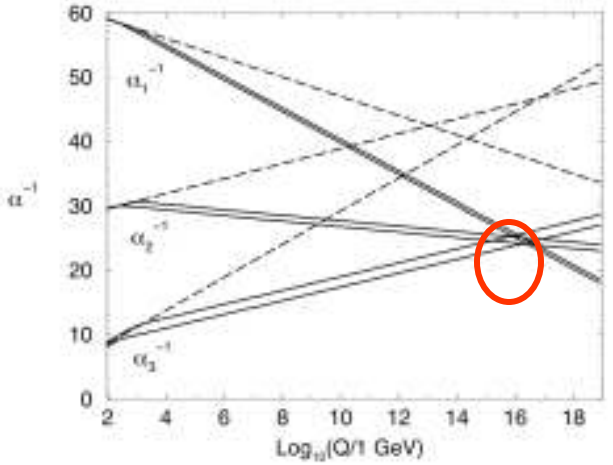
Supersymmetry

- add superpartner to quarks, leptons, and bosons
- Solves the Hierarchy Problem

$$\Delta M_H^2 - \frac{|\lambda_f|^2}{8\pi^2} \times (m_f^2 - m_S^2) log\left(\frac{\Lambda}{m_S}\right) + ...$$

- lightest supersymmetric particle (LSP) candidate for dark matter
- Unification of the gauge couplings

Names	spin	R_P	Gauge eigenstates	Mass eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	-1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ $\tilde{c}_L\ \tilde{c}_R\ \tilde{s}_L\ \tilde{s}_R$ $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	same same $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	-1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	same same $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	-1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\chi_1^0\ \chi_2^0\ \chi_3^0\ \chi_4^0$
charginos	1/2	-1	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\chi_1^\pm\ \chi_2^\pm$
gluino	1/2	-1	$\tilde{g}$	same
goldstino	1/2	-1	$\tilde{G}$	same



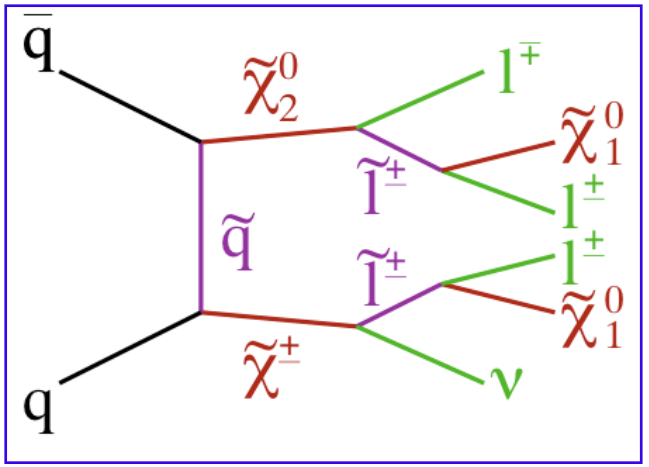
R-Parity:

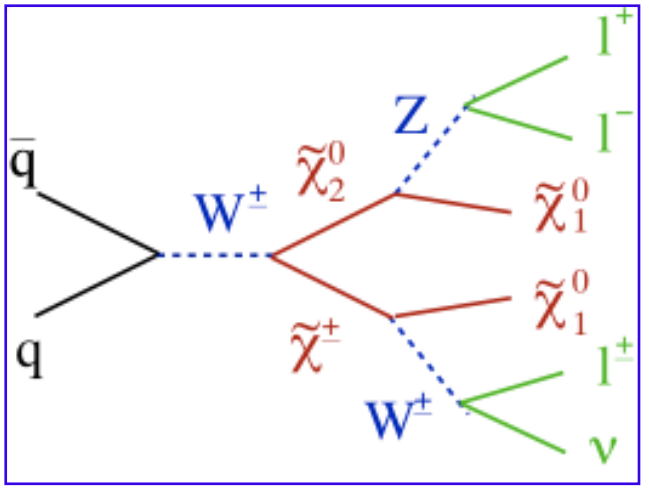
if conserved: LSP is stable, SUSY particles produced in pairs

not conserved: may generate ν masses/mixing

SUSY: $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ →Trileptons

- number of possible decay chains
- Very clean mode
  - 3 isolated leptons
  - MET from ν or χ^0
- low σ*BF (< 0.5 pb)
- leptons can be soft and depend on Δm





$$\tilde{\chi}_1^0 \Rightarrow LSP$$

SUSY: $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ → Trileptons

- CDF 2 fb^{-1}
- PRL 101:251801 (2008)
- Three lepton (3l) selections
  - 3 (e,μ)
  or 2 (e,μ) plus 1 track
- five 3l channels based on p_{tl} thresholds (5-20 GeV)
- MET > 20 GeV

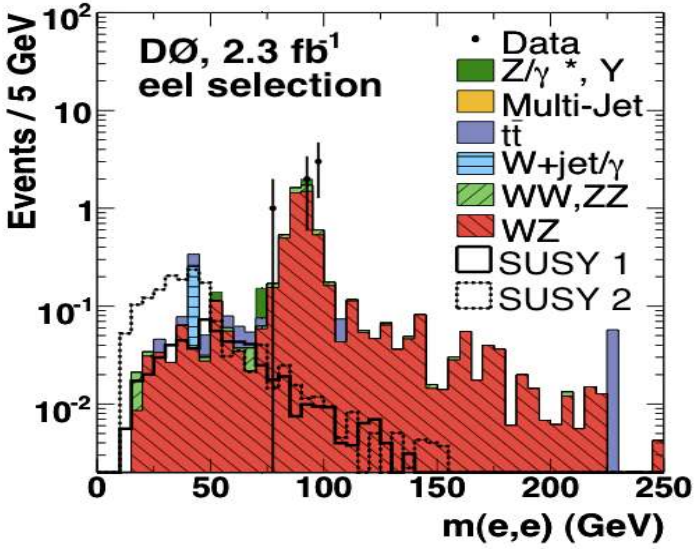
additional cuts on kinematic variables such as opening angles and dilepton masses

- D0 2.3 fb^{-1}
- arXiv:0901.0646 (2009) (sub. to PLB)
- Three lepton (3l) selections
  - 2 (e,μ) plus 1 track
  or (μ,τ) plus τ or 1 track
- eight 3l channels divided into low-p_t (>8-12 GeV) and high-p_T (>10-20 GeV)
- MET > 20 GeV

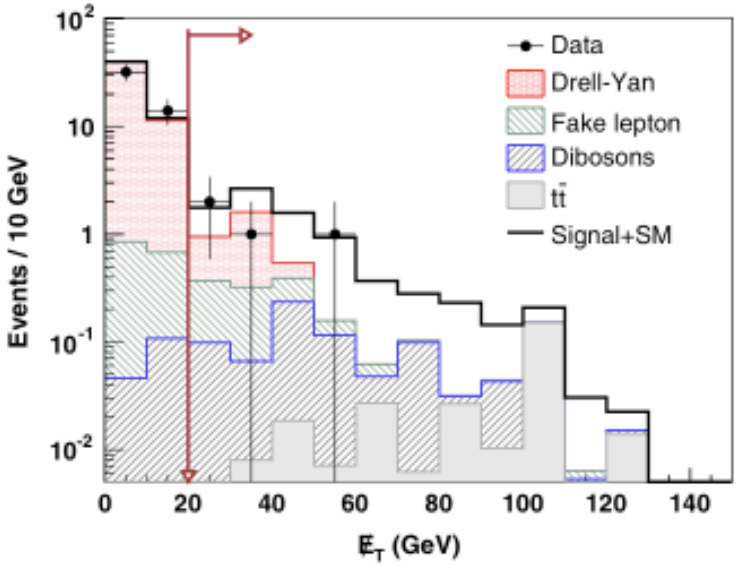
SUSY: $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ → Trileptons

- Data consistent with SM backgrounds (mostly WW,WZ)

DØ $\int \mathcal{L}dt = 2.3\ \mathrm{fb}^{-1}$			CDF $\int \mathcal{L}dt = 2.0\ \mathrm{fb}^{-1}$		
	Background	Data		Background	Data
low p_T	5.4±0.6	9	Trilepton	0.88±0.14	1
high p_T	3.3±0.4	4	Lepton+track	5.5±1.1	6

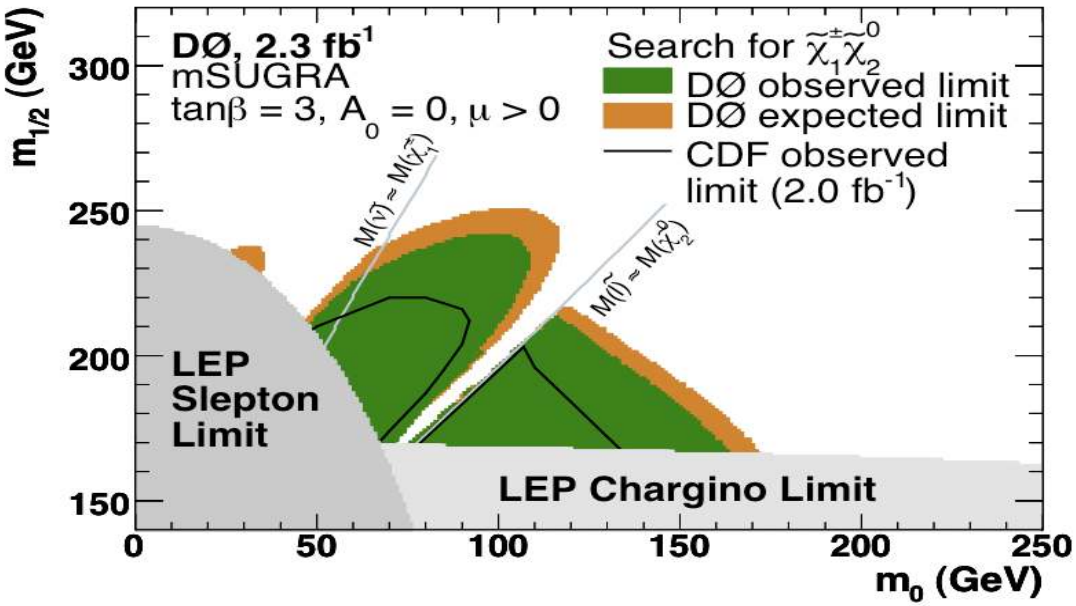


CDF



SUSY: $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ → Trileptons

- Set limits in mSUGRA model: parameters
  - m_0, $m_{1/2}$, tanβ, A0, sign(μ)
  - scenario: A_0 =0, tanβ=3, μ > 0, set limits in m_0, $m_{1/2}$ plane
- signal efficiencies vary from 1% - 5%



Some examples of excluded charginos

CDF: m_0 = 60 GeV

$$m_{\tilde{\chi}_1^\pm} > 145.4\ GeV$$

CDF: m_0 = 100 GeV

$$m_{\tilde{\chi}_1^\pm} > 127.0\ GeV$$

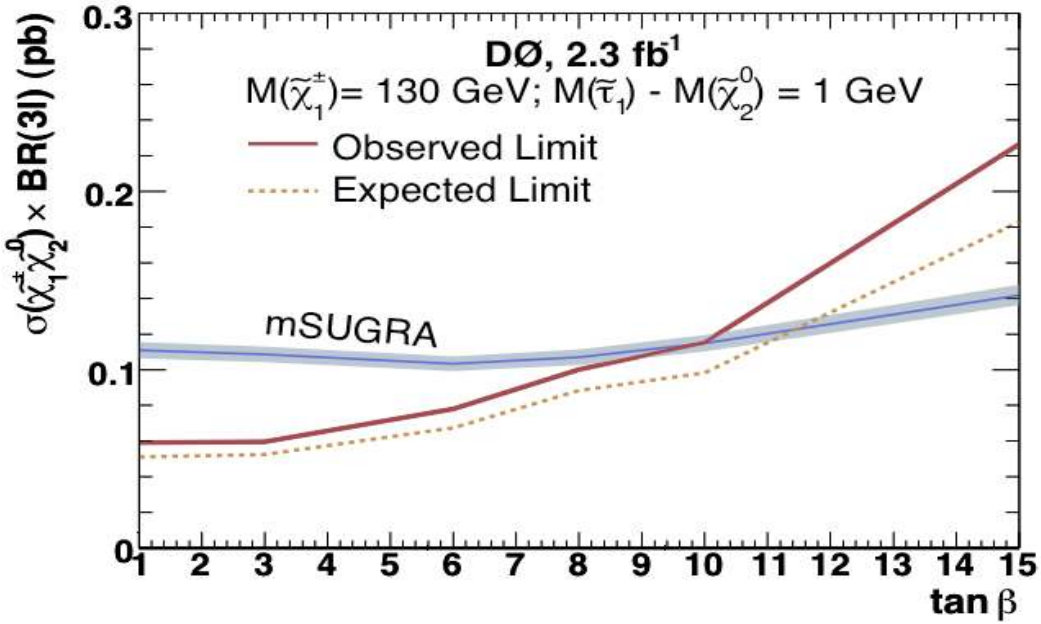
D0 : m_0 = 138 GeV

$$m_{\tilde{\chi}_1^\pm} > 138\ GeV$$

SUSY: $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ → Trileptons

- variation with tanβ

D0: Exclude chargino of 130 GeV up to tanβ=9.6



Charged Massive Stable Particles

• Charge massive stable particles (CMSPs or CHAMPS)

"stable" → lifetimes > ~10^{-8} sec

• extensions of the SM

→ stop, stau, or the chargino in some SUSY models

→ possibly long-lived if small mass difference to decay product

e.g. chargino → neutralino + X and neutralino is LSP

CMSPs may appear as "slow" moving muons.

Striking signature:

- isolated high pT muons
- use timing in muon system (D0) or central track TOF (CDF) to measure the speed
- the di-muon mass can also provide discrimination

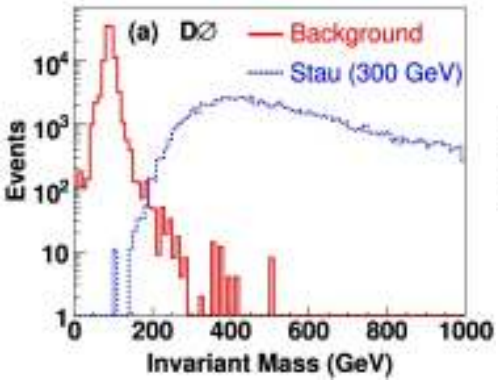
D0: PRL 102, 161802 (2009)
CDF: arXiv:0902.1266 (sub. to PRL)

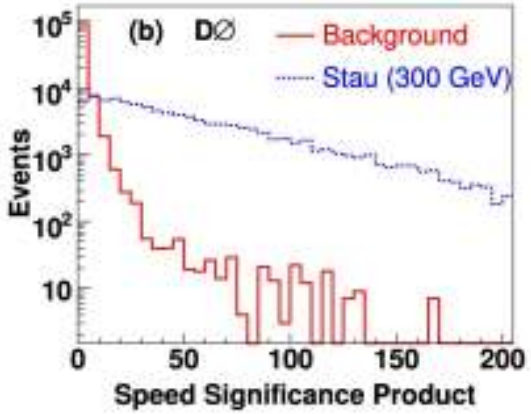
Charged Massive Stable Particles

D0: 2 isolated μ p_T>20 GeV

- $|\Delta\phi_{\mu\mu}+\Delta\theta_{\mu\mu}-2\pi| > 0.05$ plus timing cuts to reject cosmic ray muons
- backgrounds determined from data

1.1 fb^{-1}



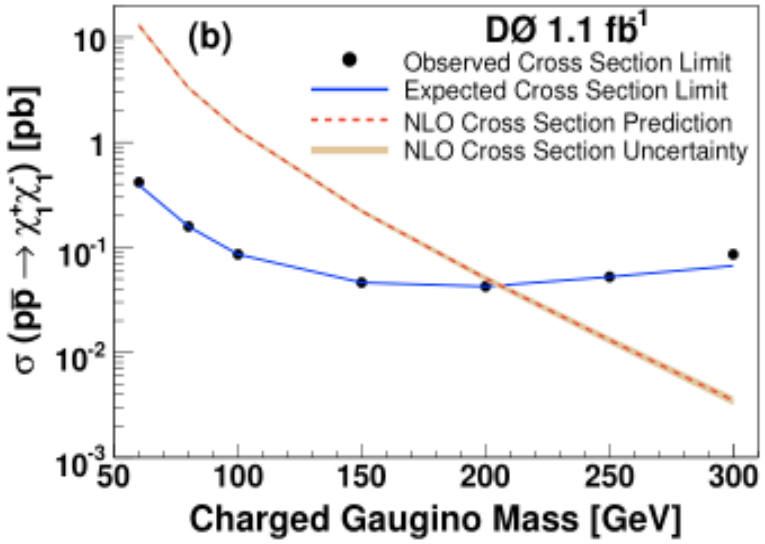


- pair-production limits:
σ~ 40 fb for M~ 200 GeV
- SUSY limits model dependent

no stau limit

$m_{\tilde{\chi}_1^+} > 171\ GeV$ higgsino-like

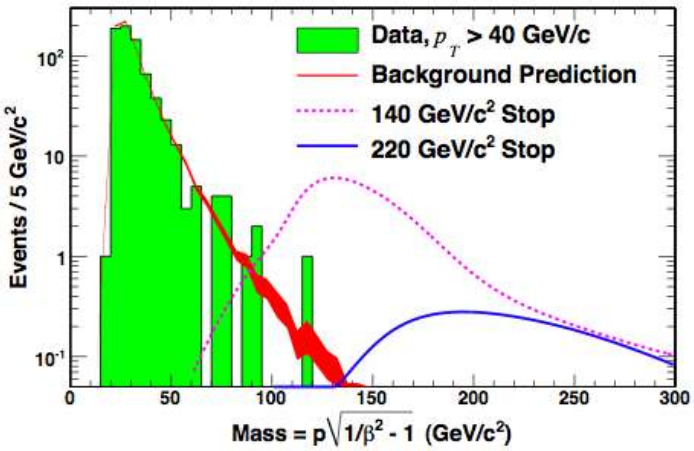
$m_{\tilde{\chi}_1^+} > 206\ GeV$ gaugino-like



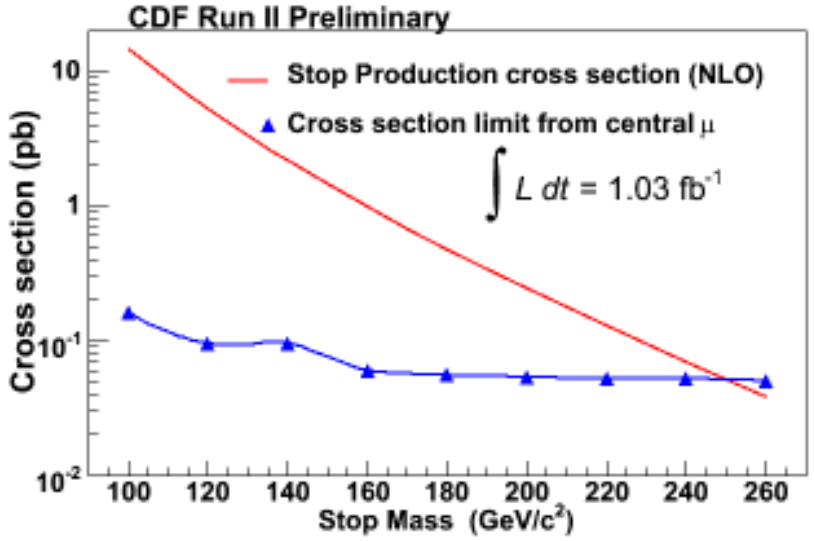
Charged Massive Stable Particles

CDF: 1 isolated μ p_T>40 GeV (for signal region)

- Determine mass from p and velocity
- use control region 20 < p_T < 40 GeV for bkgd est.



1.0 fb^{-1}



- set limits. For stop production include eff~0.23 due to hadronic effects (hadronizes to charged particle and interactions in calorimeter)

- production limits: $\sigma < 10$ fb (weak)

$\sigma < 48$ fb (strong)

- gives limit $m_{stop} > 249$ GeV

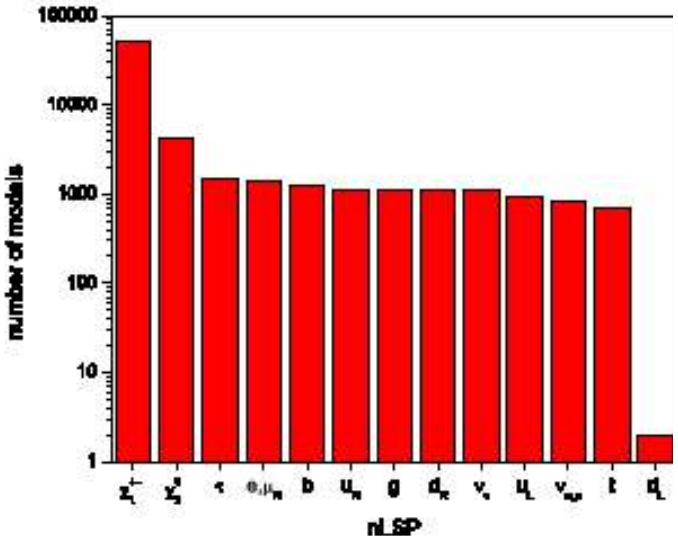
Charged Massive Stable Particles

Extend CMSP limits to other SUSY models

C.F. Berger, J.S Gainer, J.L. Hewett, T.G. Rizzo

JHEP 0902:023 (2009); arXiv:0812.0980

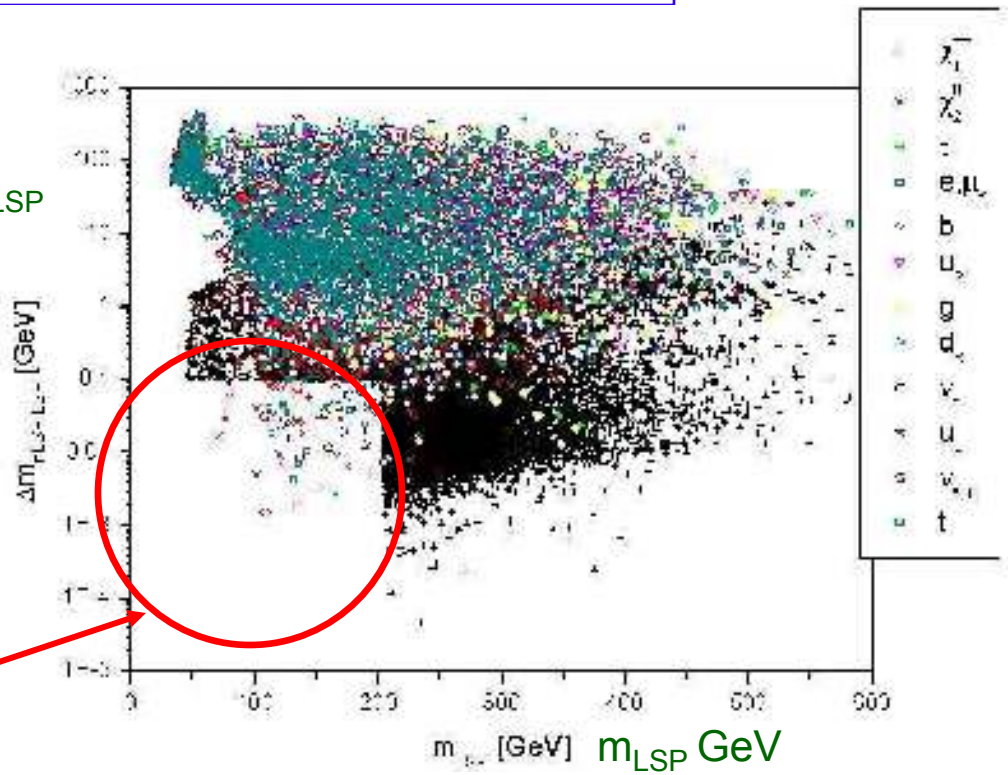
Most have chargino as nLSP; rule out low $\Delta m_{LSP\text{-}nLSP}$



$\Delta m_{nLSP\text{-}LSP}$ GeV

1

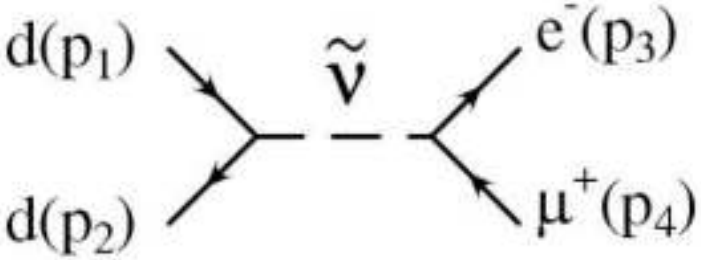
0.1

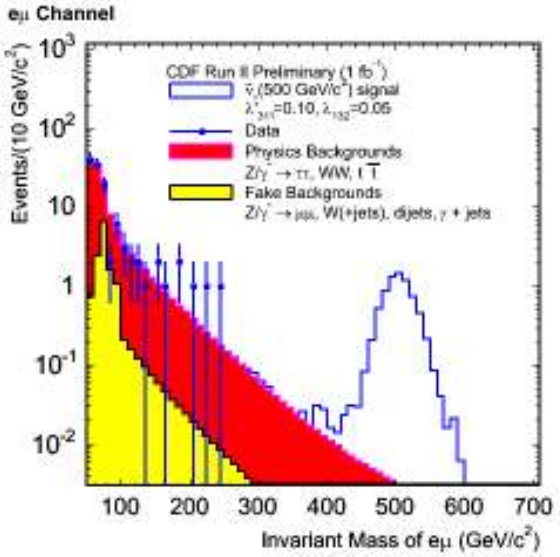


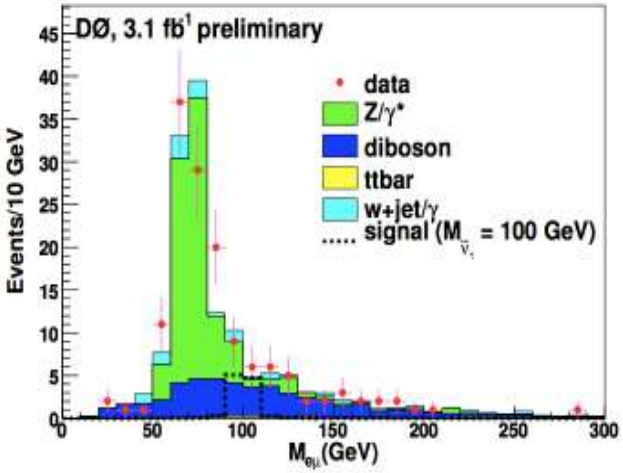
ruled out by D0 CMSP limits

RPV: $\tilde{\nu}_\tau$ Search

- Look for isolated high-p_T (> 25-30 GeV) lepton pairs
  - CDF: eμ, μτ, eτ 1.0 fb^{-1}
  - D0: eμ (1.0 + 3.1) fb^{-1}
- interpret as decays of tau-type sneutrino produced/decays through RPV terms







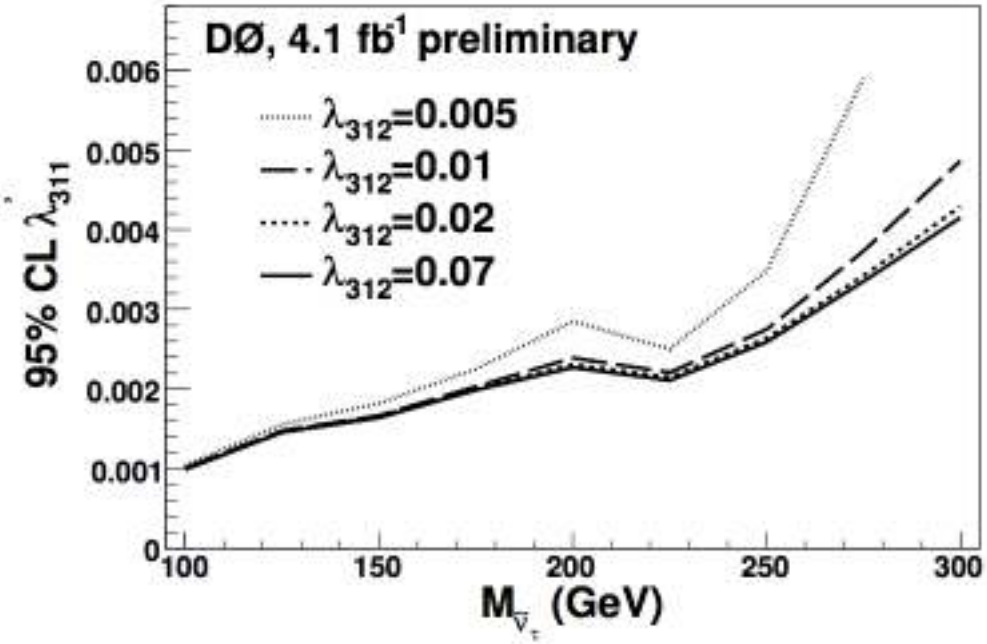
http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/NP/N64/

Phys. Rev. Lett. 100, 241803 (2008)

www-cdf.fnal.gov/physics/exotic/exotic.html

RPV: $\tilde{\nu}_\tau$ Search

- assume $\tilde{\nu}_\tau$ is the LSP
- assume all RPV couplings are zero except λ'_{311} , $\lambda_{321} = \lambda_{312}$
- limits on σ*BR give limits on λ for different values of the mass of the $\tilde{\nu}_\tau$ (or vice-versa)



example

$\lambda_{311} < 0.0022$ for

$\lambda_{312} = 0.07$ and m_{stau} = 200 GeV

Model Independent Searches

- Look for discrepancies between data and expectations (SM processes plus detector effects).

- Event counts in many final states
- Shapes of (many) kinematic variables

USE VISTA

- Mass peaks

USE BUMPHUNTER

- Event p_T and Σp_T distributions

USE SLEUTH

MIS with Vista

- Use p_T > 15-20 GeV (e,μ,τ,γ,jets,MET) to define exclusive states
- compare #data to expected and note discrepancies
- compare shapes using Kolmogorov-Smirnov probabilities and report significant discrepancies

CDF – 2.0 fb^{-1}

- use only MC (mostly PYTHIA and MadEvent) for SM simulation
- constrained fit for 43 correction factors
- **Phys Rev D 79 0111101 (2009)**

D0 – 1.1 fb^{-1}

- MC (PYTHIA and ALPGEN) plus data (multijets) for SM simulation
- collaboration-wide scale factors plus fit for additional factors (e.g. trigger efficiencies)
- preliminary

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/NP/N65/

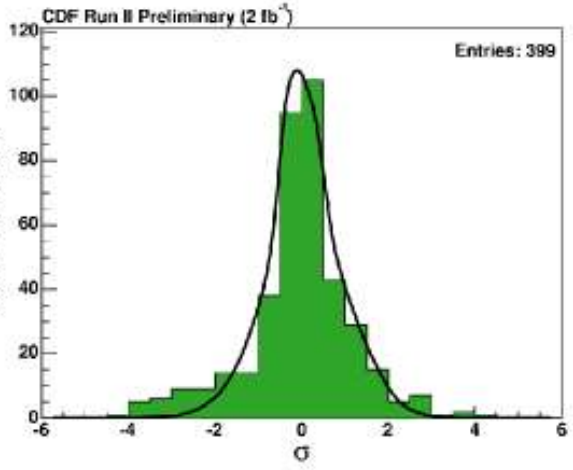
MIS with Vista - Channels

- CDF 0/399 exclusive channels have disagreements in the number of observed events.
  - 3 most positive:

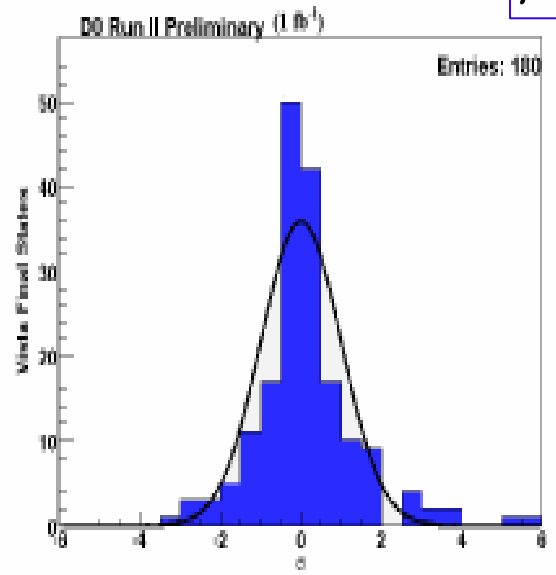
$\gamma\tau^{\pm}$	2.2σ
$\mu^{\pm}\tau^{\pm}\,(SS)$	1.7σ
$e^{\pm}\tau^{\pm}\not{p}_T\,(SS)$	1.4σ

- D0 requires high p_T isolated lepton and has 4/180 channels with disagreements.
  - 4 most positive

$\mu^{\pm}\not{E}_T + 2\,jet$	9.3σ
$\mu^{\pm}\gamma\not{E}_T + 1\,jet$	6.6σ
$\mu^{+}\mu^{-}\not{E}_T\,(OS)$	4.4σ
$\mu^{+}\mu^{-}\gamma\ (OS)$	4.4σ



CDF Curve: pseudoexperiments

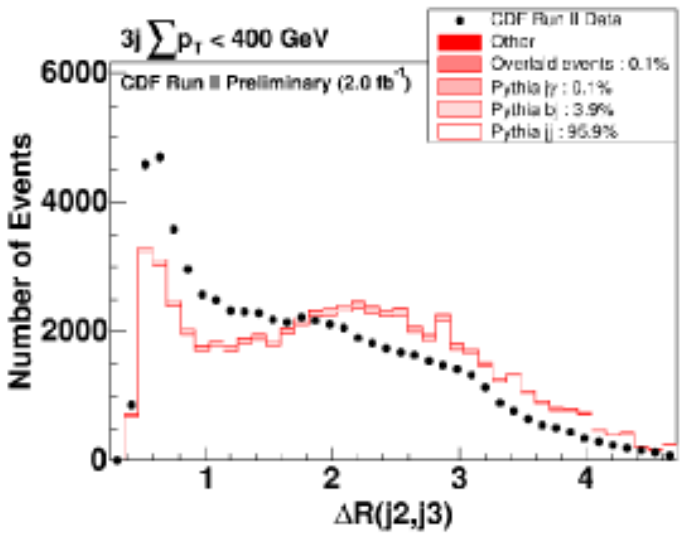


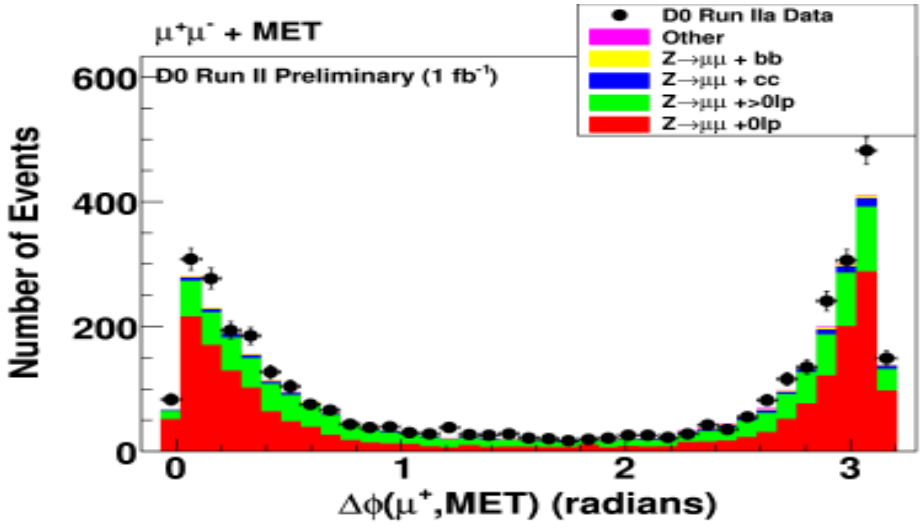
D0 Curve: Gaussian

MIS with Vista - Distributions

- CDF: 555 of 19650 kinematic distributions have KS disagreements in their shapes → most QCD-related: ΔR(jets), mass(jets), etc

- D0: 24 of 9335 kinematic distributions have KS disagreements in their shapes → most muon-related. e.g. muon resolution giving larger value of missing E_T



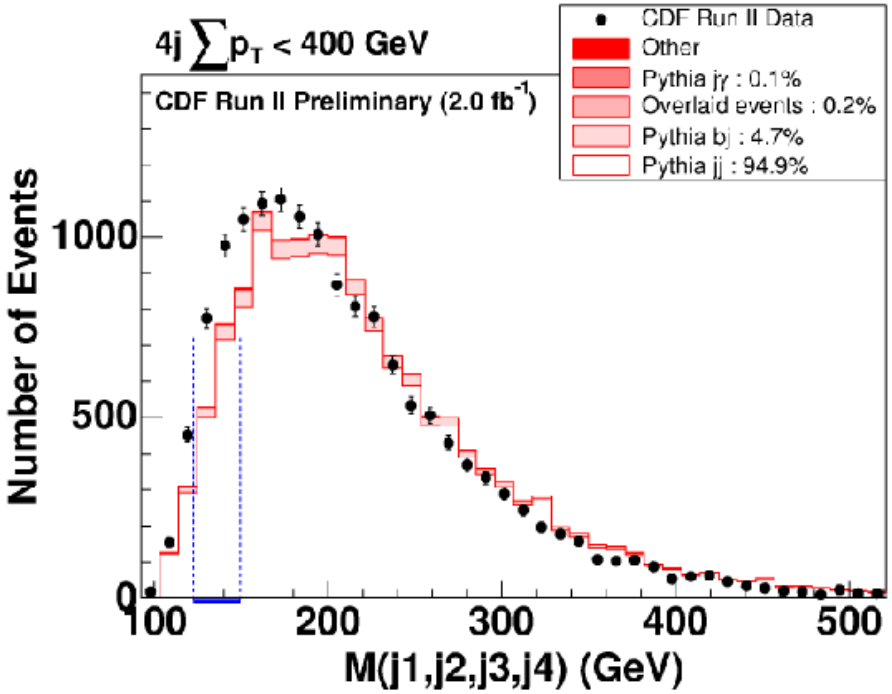


CDF Bump Hunter

2.0 fb^{-1}

- Search for narrow resonances in invariant masses
- for mass resolution ΔM use search window: $2\Delta M$
- estimate excess significance using psuedoexperiments

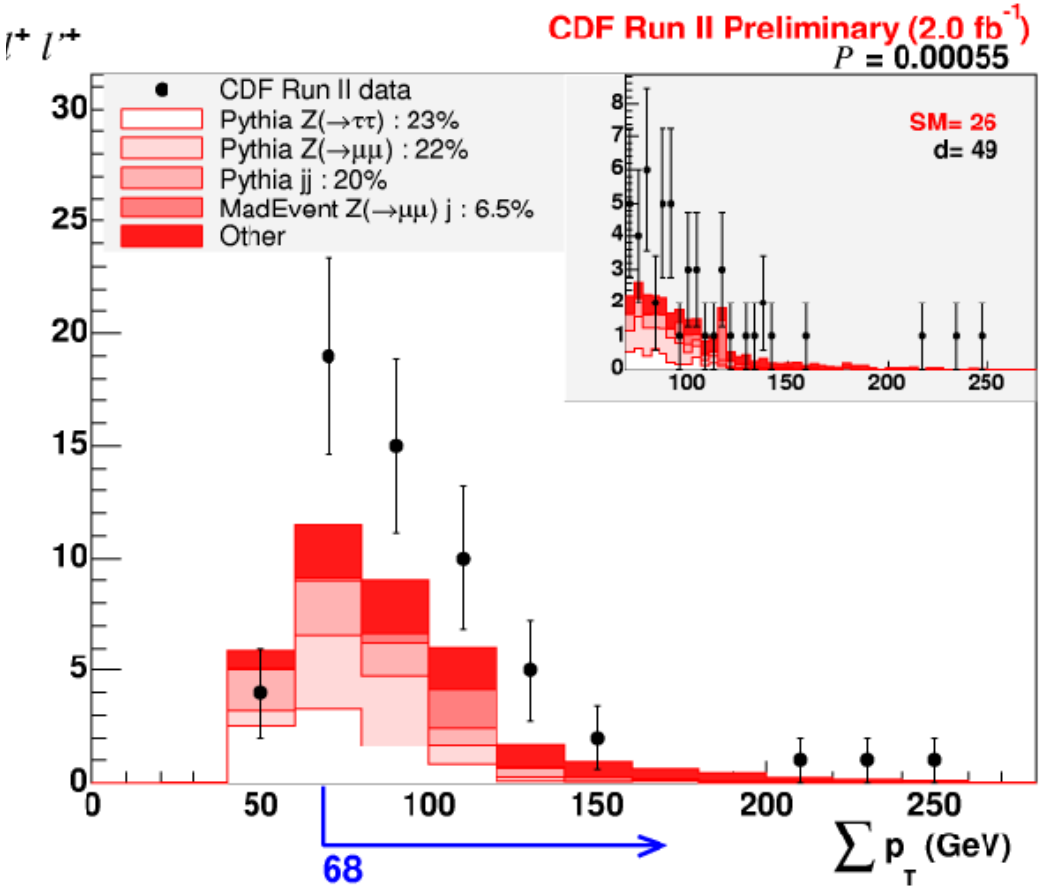
→ of 5036 mass distributions find 1 excess, in 4-jet mass attribute to problems in low-E_T QCD modeling



Sleuth Searches

- look for excesses at the high end of the Σp_T distributions for Vista states using the Sleuth algorithm
- Sleuth combines similar Vista states
- find cut on Σp_T with most significant excess; estimate significance using pseudoexperiments

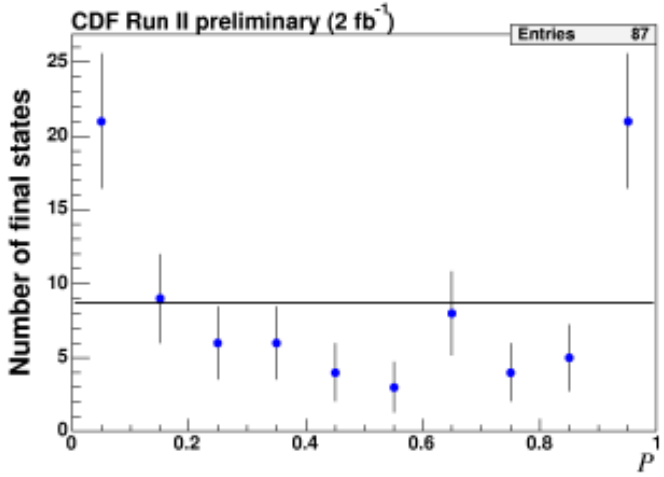
$e^{\pm}\mu^{\pm}$ (SS)

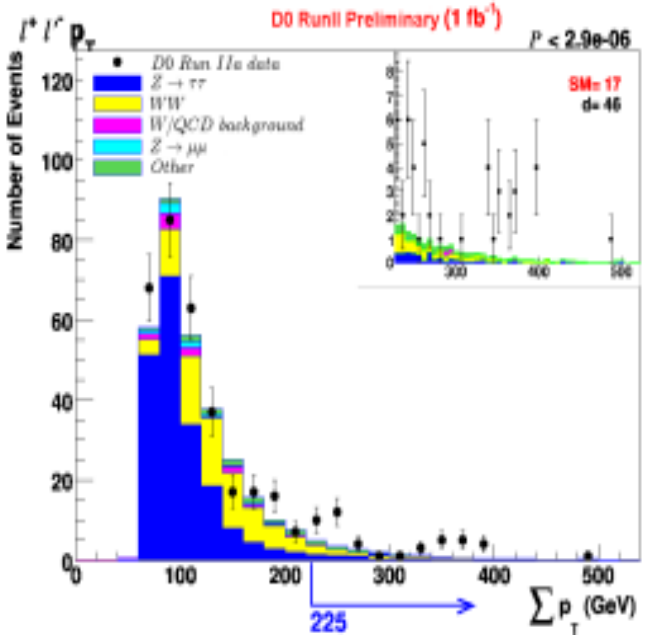


Sleuth Searches

CDF: 87 distributions, 4 channels with excesses (2 pb^{-1}), none significant and 8% probability to occur

D0:44 distributions, 5 channels with excesses (1.1 pb^{-1}) only one significant (μ resol.) Also checked CDF's 4 channels → no excess





$$e^{\pm}\mu^{\mp}\not{p}_T \quad (OS) \quad P < 0.001$$

Conclusions

- Searches for New Phenomena at the Tevatron have yet to see hints of new physics while ruling out regions of parameter space
  - data sets range from 1-4 fb^{-1}
  - using tools to search for model-independent excesses
- Data sets of over 5 fb^{-1} are available and are growing and these searches will continue. CDF/D0 combined limits in squark/gluino and trileptons in progress.
- Updates and channels not included in this talk can be found at:

http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

http://www-cdf.fnal.gov/physics/exotic/exotic.html