Search for New Phenomena at the Tevatron

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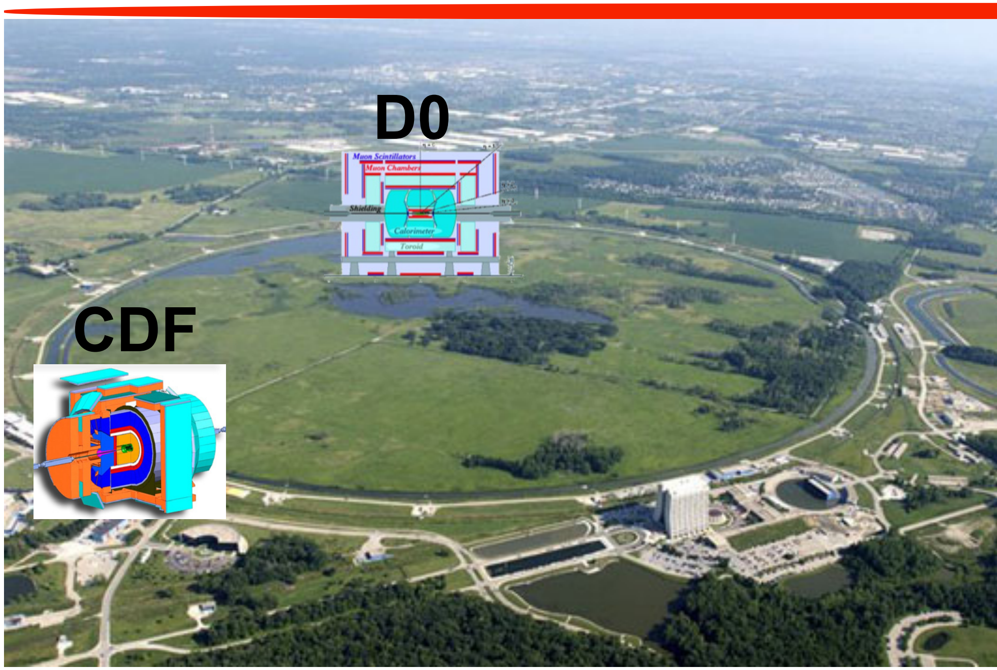
For the CDF and D0 Collaborations

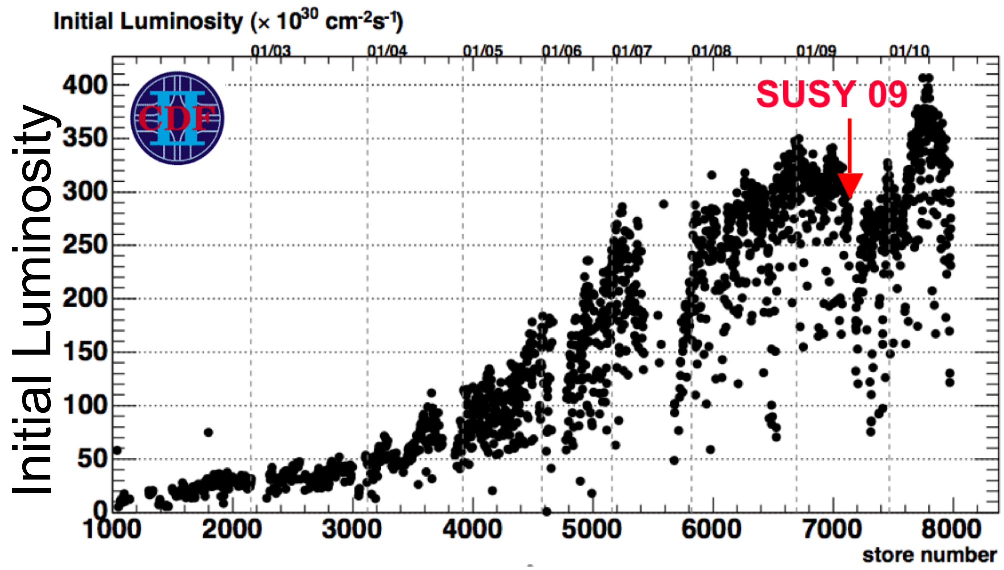
Why Physics Beyond the Standard Model?

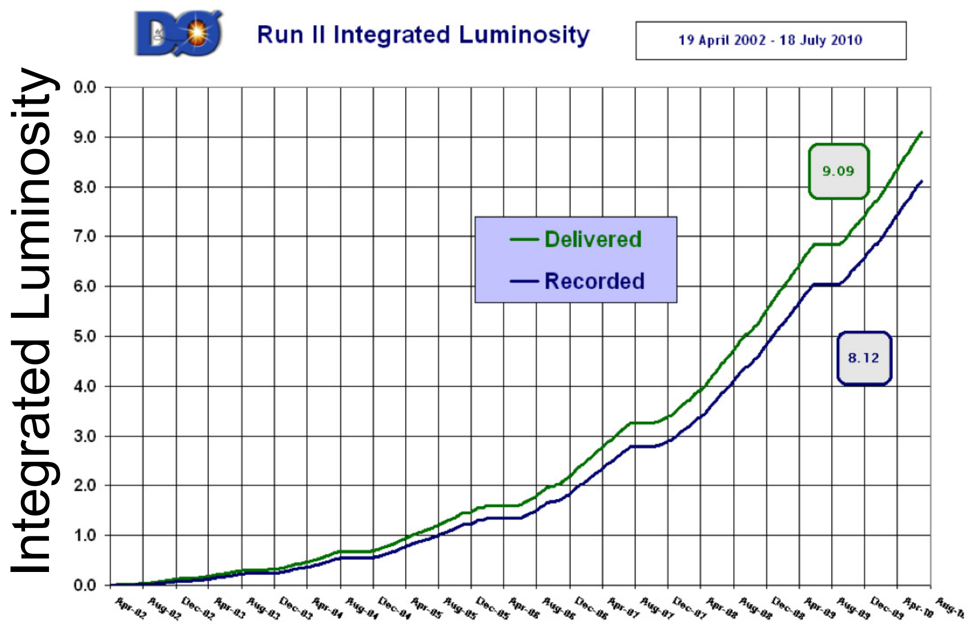
- Although extremely successful, the Standard Model does not answer all our basic questions about nature
  - Why are the Planck scale and the electroweak scale 17 orders of magnitude apart (and how can we avoid the "fine-tuning")
  - How is gravity incorporated?
  - What is the origin of mass?
  - What is the source of dark matter and dark energy?
  - Why is there a boson/fermion asymmetry?
  - Why is there a particle/antiparticle asymmetry?
  - Why do we have several interactions instead of one unified one?
  - ....

- Our job as experimentalists is
  - to perform experiments to discover new-physics effects that could give answers to the above questions
  - to perform experiments to test current theories that offer answers to the above questions

The Tevatron



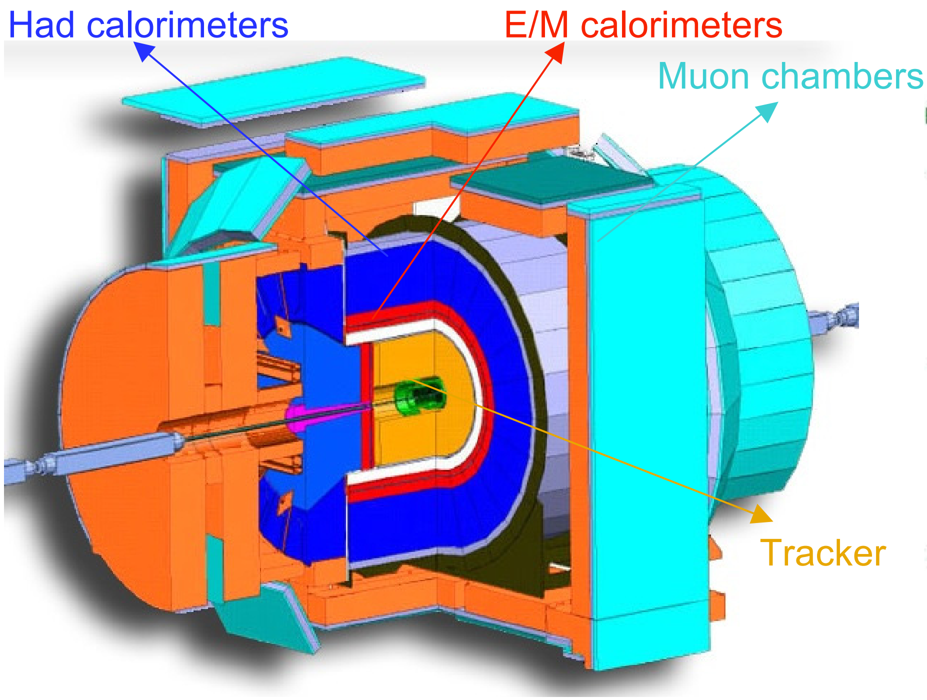




- Tevatron collides protons with antiprotons at 1.96 TeV center-of-mass energy
- Instantenous luminosity exceeded 400×10^{30} cm^{-2} s^{-1} !!
- Delivered luminosity ~ 9 fb^{-1}
- Recorded luminosity: ~ 8 fb^{-1} per experiment
- **Presented in this talk up to 6.3 fb^{-1}**

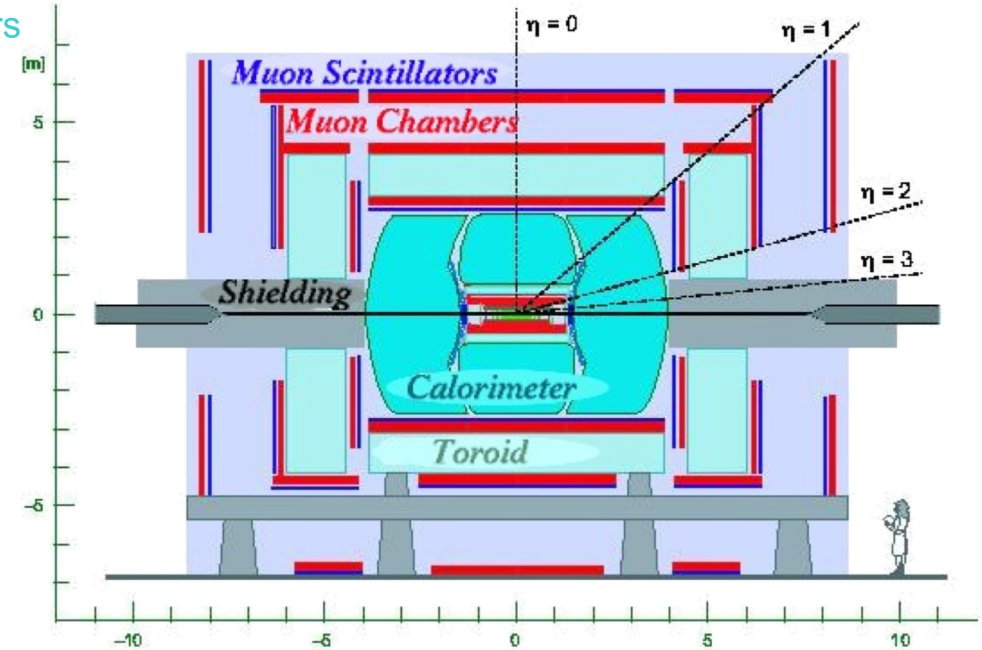
The CDF and D0 detectors

CDF



- Central silicon and drift tracking
- Lead/Steel+scintillator calorimeter
- Outer muon chambers
- Magnetic field of 1.4 Tesla

D0



- Central silicon and drift tracking
- Uranium/Steel+Liquid-argon calorimeter
- Outer muon chambers
- Magnetic field of 1.8 Tesla

Searches for new Phenomena

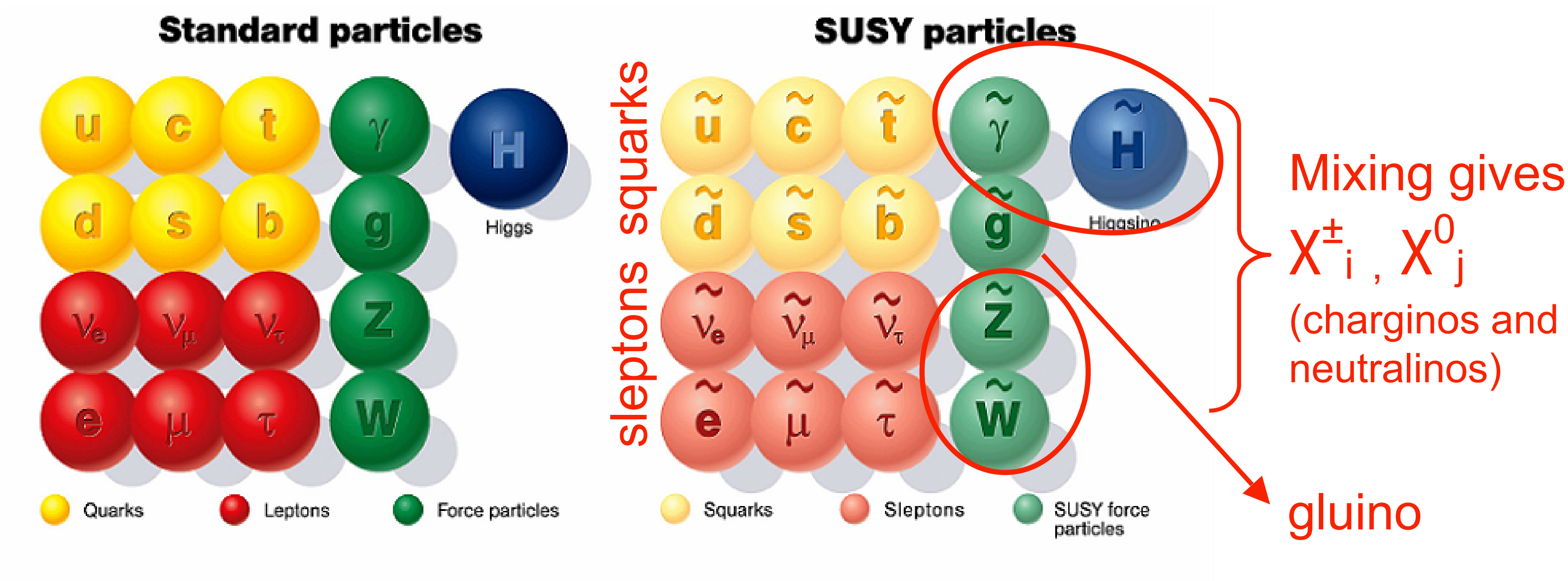
- Searches for phenomena predicted by specific current theories
  - SUSY
  - RS-gravitons
  - 4th generation
  - New gauge bosons
  - Universal Extra dimensions
  - Technicolor

- Searches for signatures inconsistent with the Standard Model
  - Mass resonances
  - Rare events
  - Not necessarily predicted by current theories

- Even searches that look for particles predicted by current theories can be generic enough to discover the unpredictable

Introducing Supersymmetry (SUSY)

- Create an extension of the SM, where for each boson we have a fermion and vice versa (superpartners differ only in their spin)

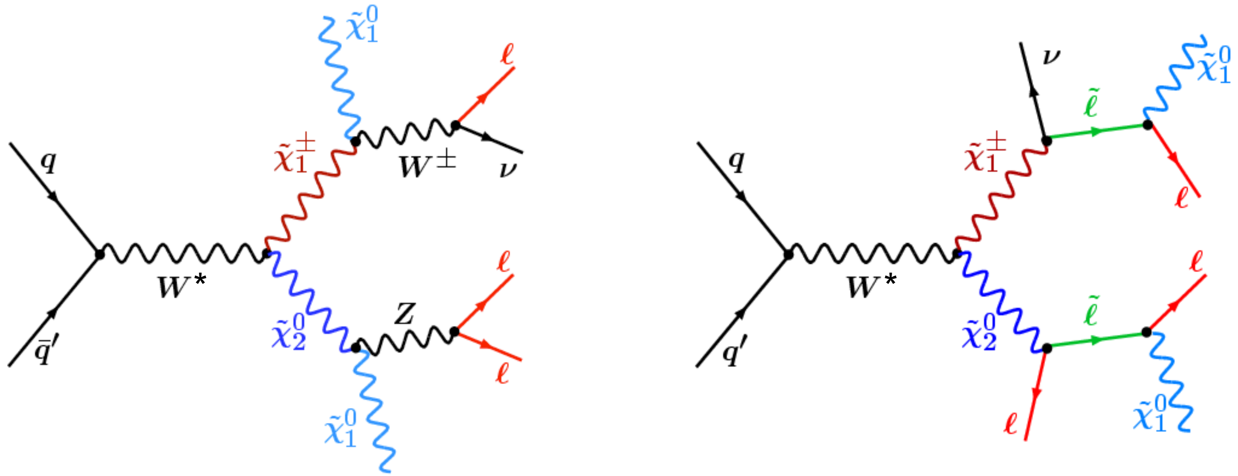


Supersymmetry

- SUSY is obviously broken, which leads to a new mass-spectrum for sparticles. We study "soft" SUSY breaking
  - mSUGRA (LSP=neutralino), GMSB (LSP=gravitino)
- Removes fine tuning and offers ultra-violet completeness
  - Large radiative corrections of superpartners cancel each-other
- Offers possibility of force unification
  - Not exactly possible with SM
- Offers a cold dark matter candidate
  - If the lightest supersymmetric particle (LSP) is stable. This is the case if R-parity = $(-1)^{3(B-L)+2S}$ is conserved
- Possibility of radiative Electroweak symmetry breaking
  - As an alternative to spontaneous breaking
- Today I present searches for sbottom and stop quarks, R-parity violating sneutrinos, R-parity violating gluinos, GMSB models
  - Will also remind current limits for mSUGRA charginos/neutralinos and squark/gluinos

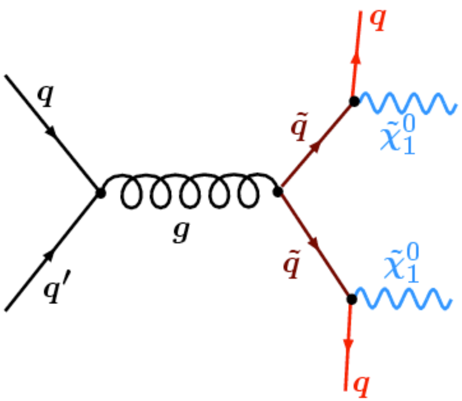
Charginos and neutralinos at the Tevatron

- **Golden chargino-neutralino signature: trileptons + MET**

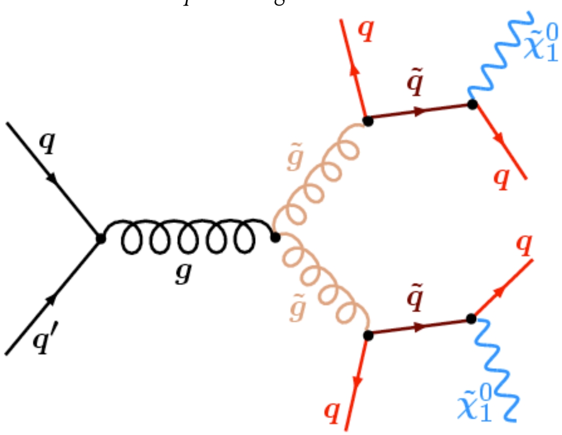


- **Squark and gluinos are strongly produced and give jets + MET**

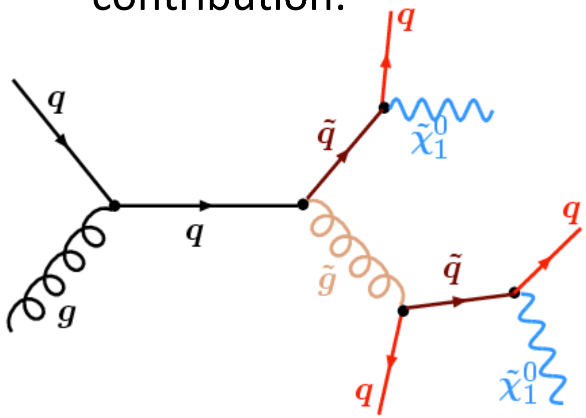
If $M_{\tilde{q}} < M_{\tilde{g}}$



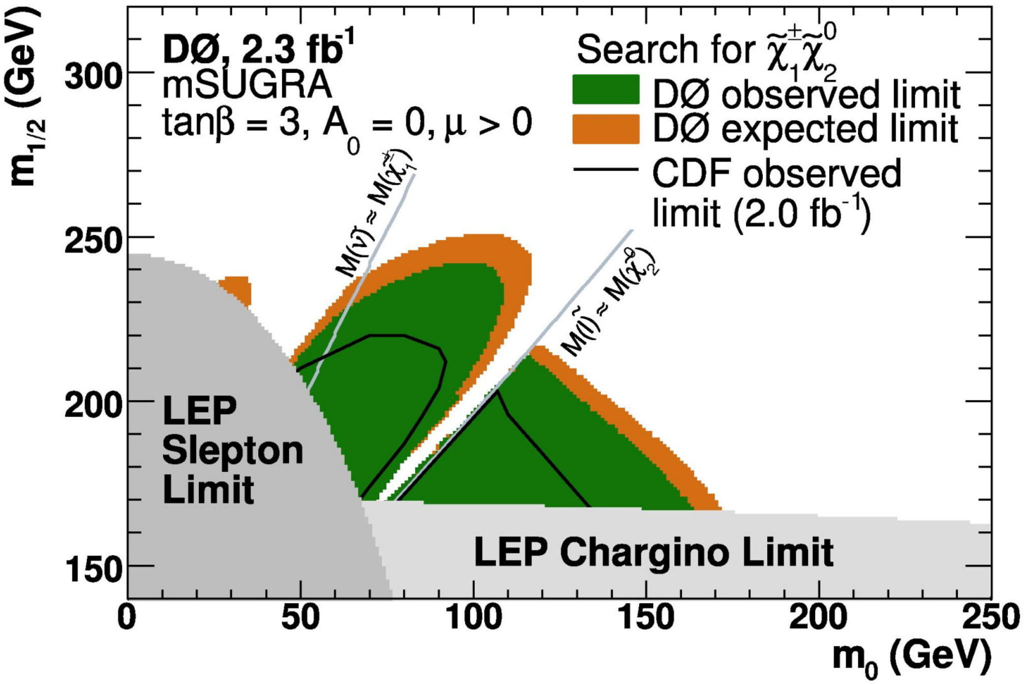
If $M_{\tilde{q}} > M_{\tilde{g}}$

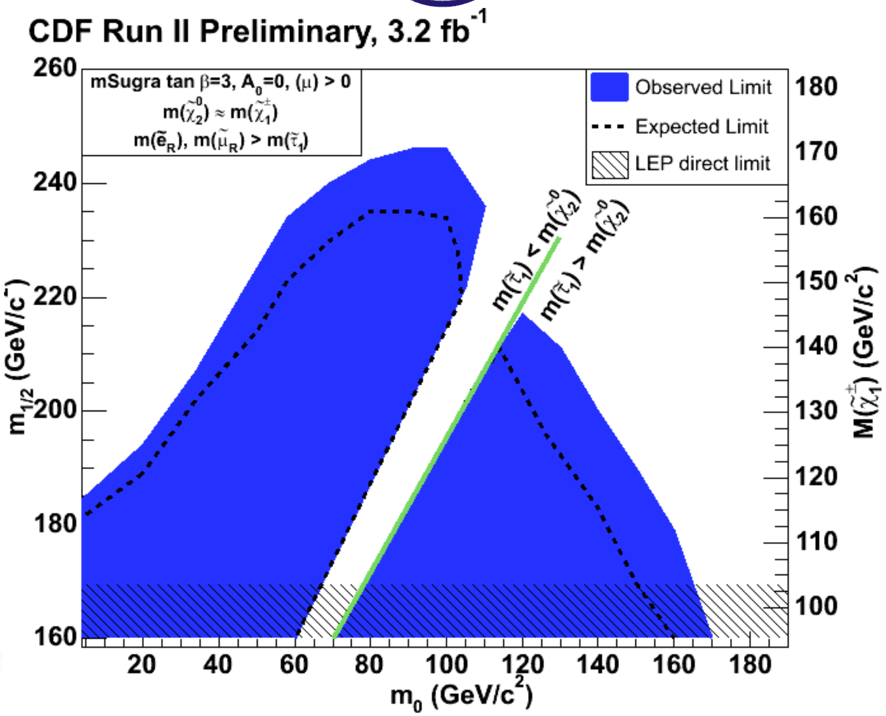


If $M_{\tilde{q}} \approx M_{\tilde{g}}$ then additional contribution:



Current chargino-neutralino limits





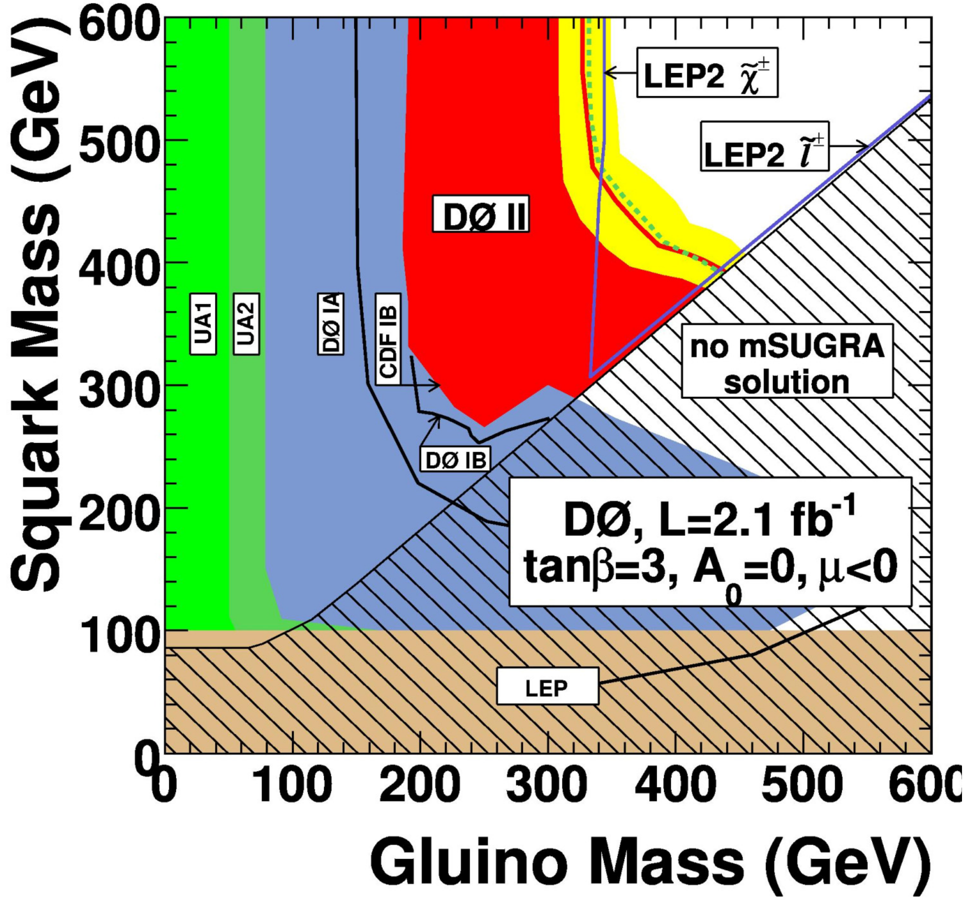
Phys. Lett. B 680, 34 (2009)

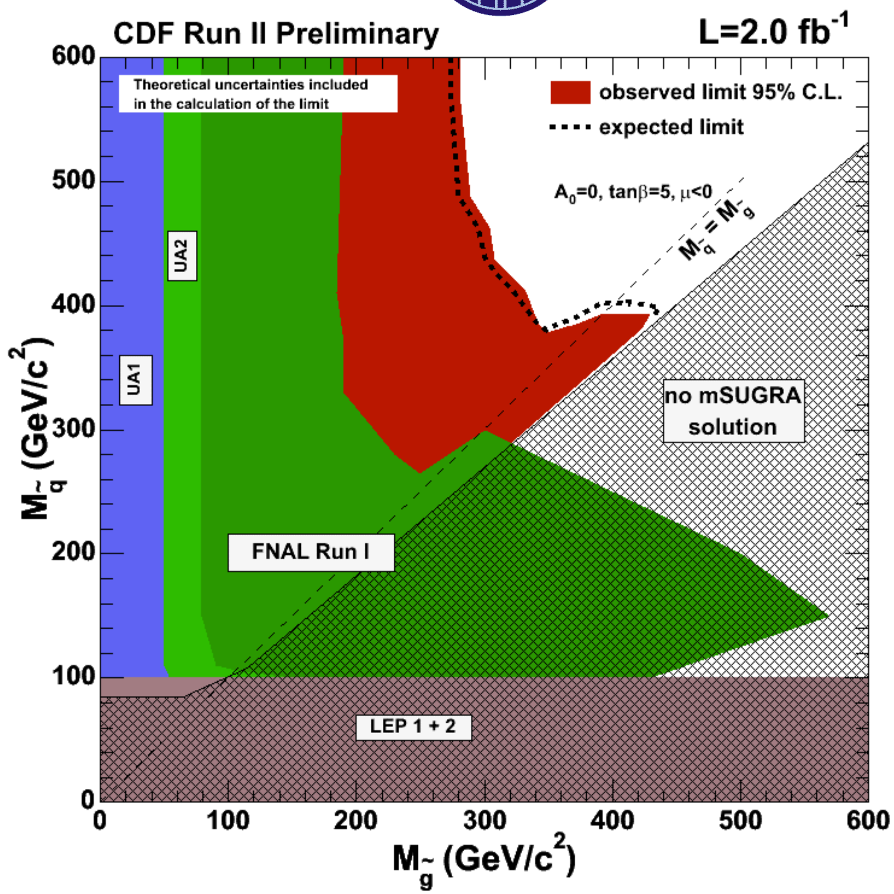
CDF public note 9817 (2009)

- mSUGRA limit: Chargino mass > 165 GeV/c^2 @ 95% CL (for m_0=60 GeV/c^2)

  -- expected limit 155 GeV/c^2

Current squark-gluino limits





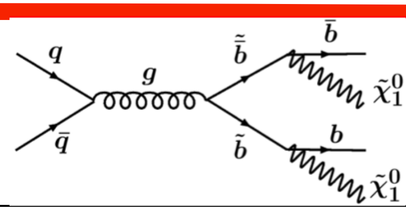
Phys. Lett. B 660, 449 (2008)

Phys. Rev. Lett. 102, 121801 (2009)

M_{gluino}> 382-390 GeV/c^2 (D0-CDF) if M_{squark}= M_{gluino}

Search for sbottom at the Tevatron

- Investigate $\tilde{b} \rightarrow b + \tilde{\chi}_1^0$ (assume BR=1), signature from pair production: 2 b-jets and MET



- L = 5.2 fb^{-1}
- 2 or 3 jets, E_T>20 GeV, at least 2 b-tagged (NN), leptons vetoed
- MET>40 GeV, MET away from jets
- E_T^{jet1}>20,50 GeV, MET>40,850 GeV H_T>60,220
  - cuts optimized per mSUGRA point, based on ΔM(sbottom-LSP)=240 and 45 GeV/c^2
- Point1: N_{obs} = 901, N_{SM} = 971± 152

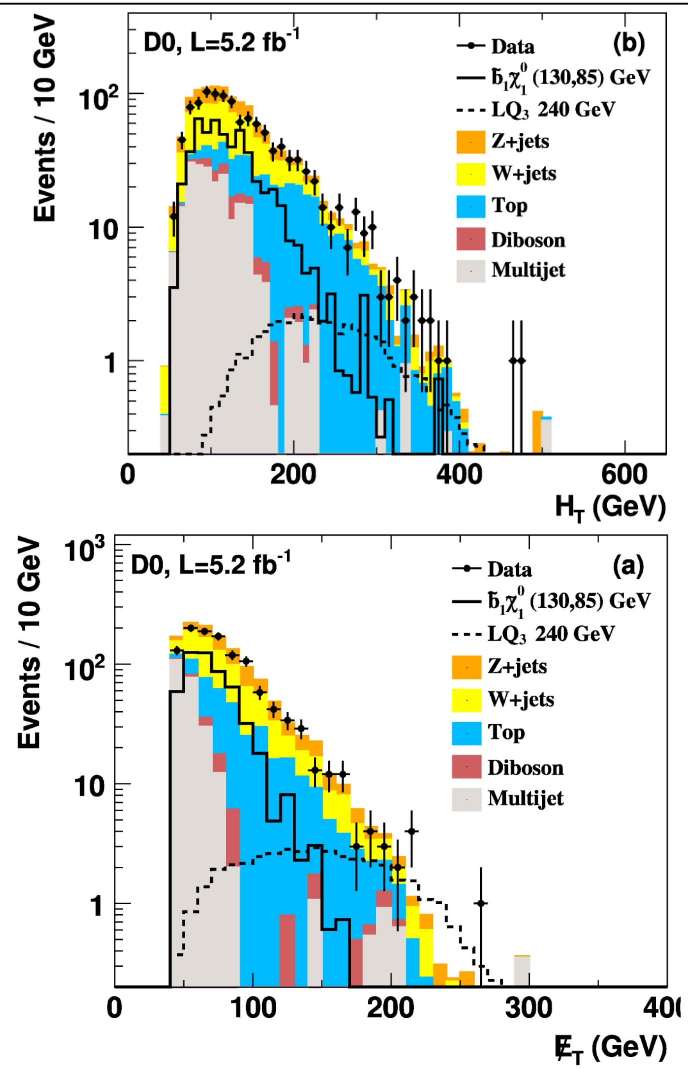
  Point2: N_{obs} = 7, N_{SM} = 7 ± 2
- Main backgrounds: W/Z+jets, multi-jet with fake MET

- L = 2.65 fb^{-1}
- 2 jets, at least one b-tagged, $\Delta\phi(\text{MET-jet}_{1,2})$>0.4,0.7
- E_T^{jet1}>80,90 GeV, E_T^{jet2}>25,40 GeV, MET>60,80 GeV H_T>165,300
  - cuts optimized per mSUGRA point, based on ΔM(sbottom-LSP)< or >90 GeV/c^2
- ΔM<90 : N_{obs} = 139, N_{SM} = 134 ± 25

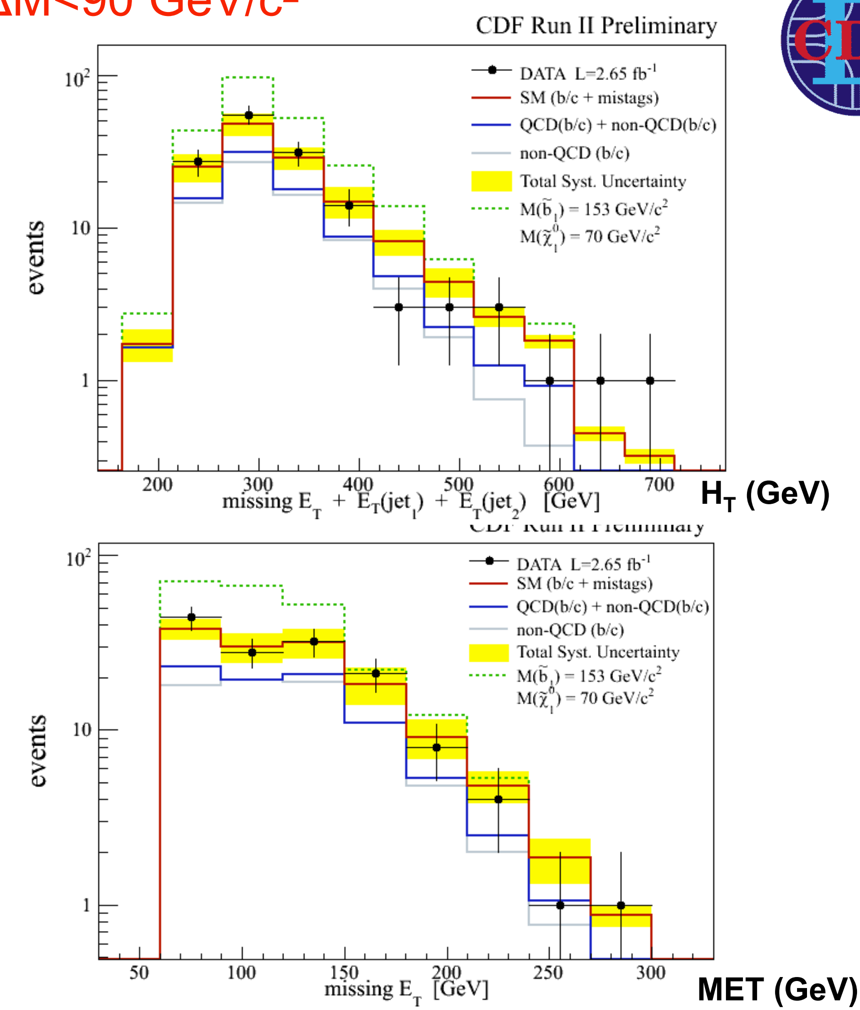
  ΔM>90 : N_{obs} = 38; N_{SM} = 48 ± 8
- Main backgrounds: light-flavor QCD with mistags and heavy-flavor QCD with high MET, W/Z+jets

Search for sbottom at the Tevatron (2)

- Kinematic distributions of MET and H_T are consistent with SM background



ΔM<90 GeV/c²

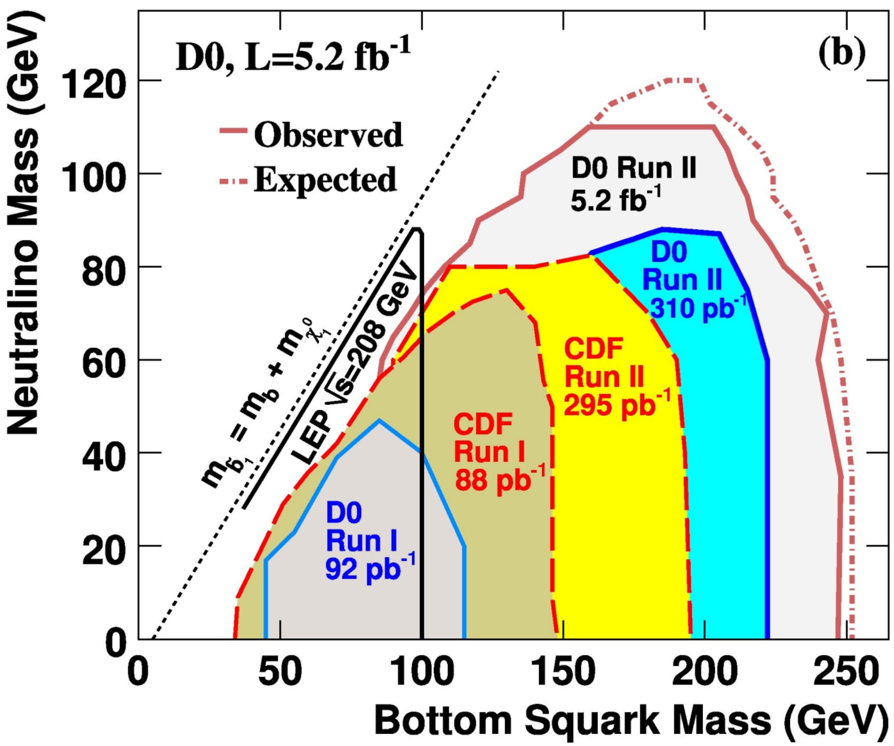


Search for sbottom at the Tevatron (3)

- Limits on the Neutralino-mass vs Sbottom-mass are set

arXiv:1005.2222 [hep-ex] (2010)

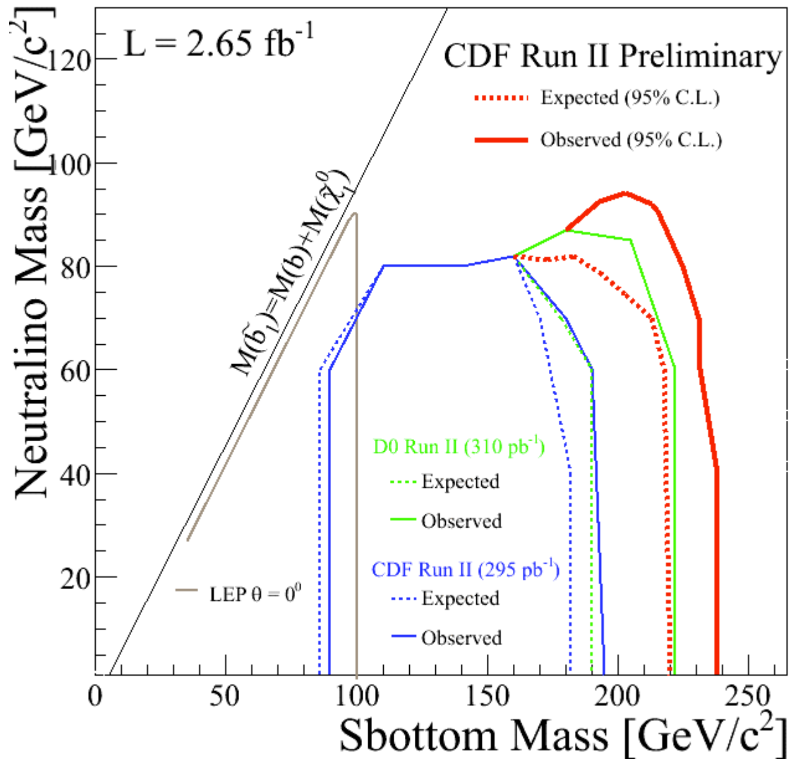
(accepted for publication by Phys. Lett. B)



- For neutralino mass < 70 GeV/c^2 observed sbottom mass limit is ~250 GeV/c^2

Phys. Rev. Lett 105, 081802 (2010)

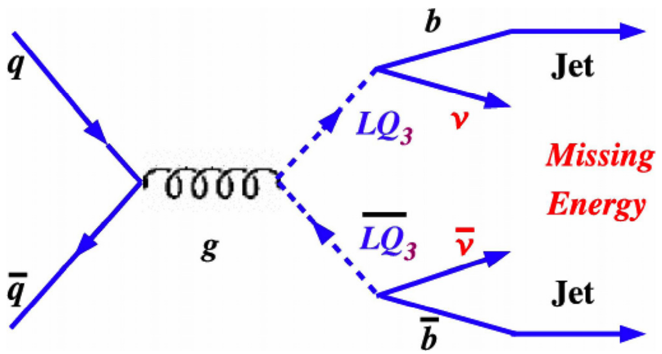
Published August 19, 2010

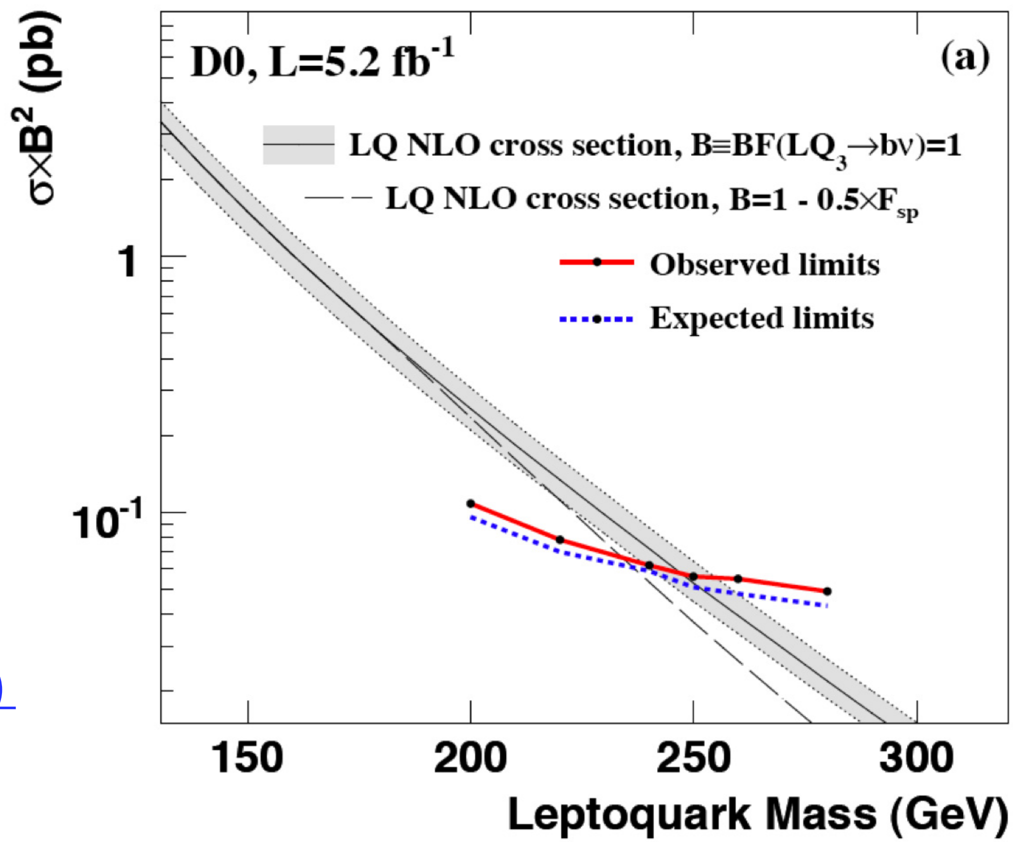


- For neutralino mass < 70 GeV/c^2 observed sbottom mass limit is ~240 GeV/c^2

Bonus: D0 leptoquark limit

- The jet+MET D0 analysis can be interpreted as a third-generation leptoquark limit





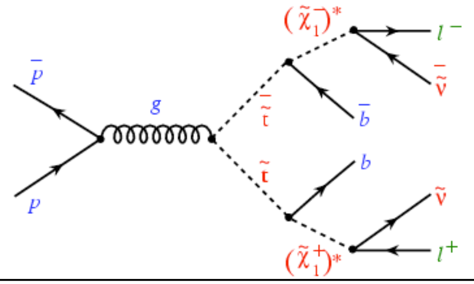
[arXiv:1005.2222 [hep-ex] (2010)]

M_{LQ3}>247 GeV/c^2 at 95% CL

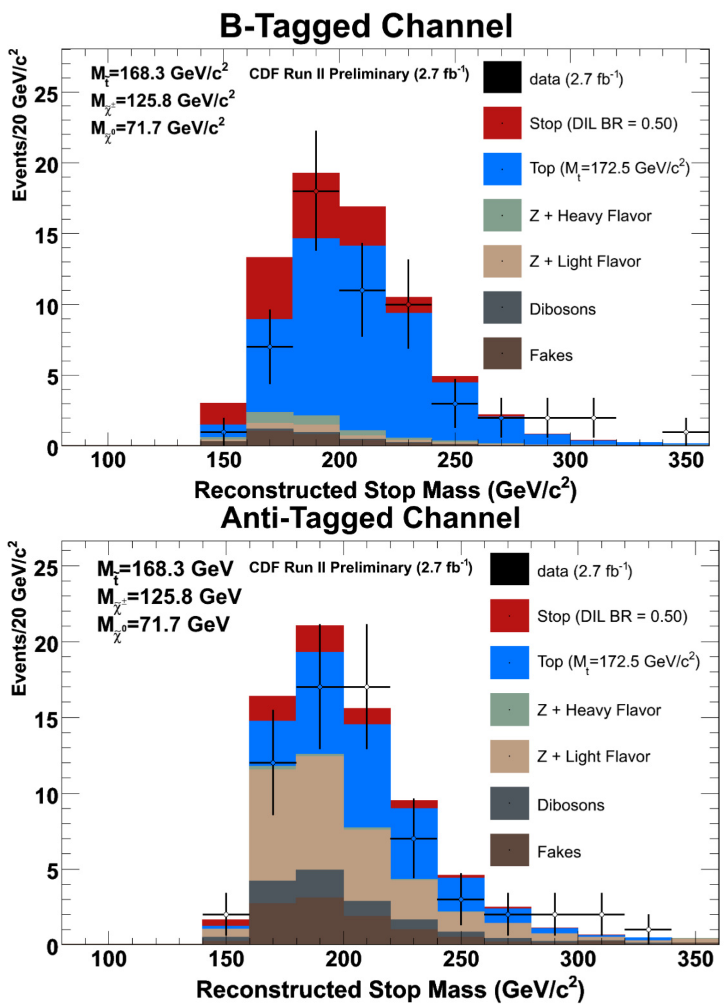
Search for stop at the Tevatron

- Search for $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm} \to b\tilde{\chi}_1^0 l\nu$ assuming :

$\tilde{\chi}_1^0$ is the LSP, and $\tilde{q}, \tilde{\ell}, \tilde{\nu}$ are heavy
$m_{\tilde{t}_1} \lesssim m_t$
$m_{\tilde{\chi}_1^+} < m_{\tilde{t}_1} - m_b$

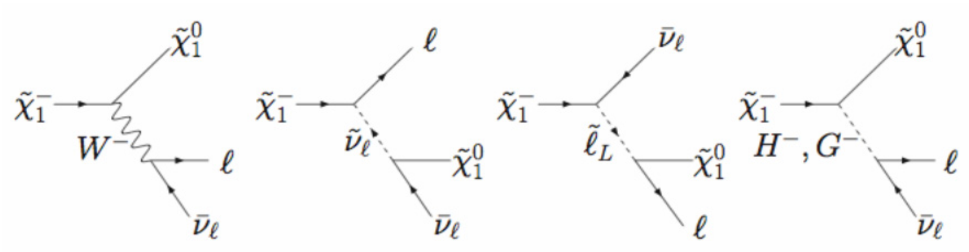


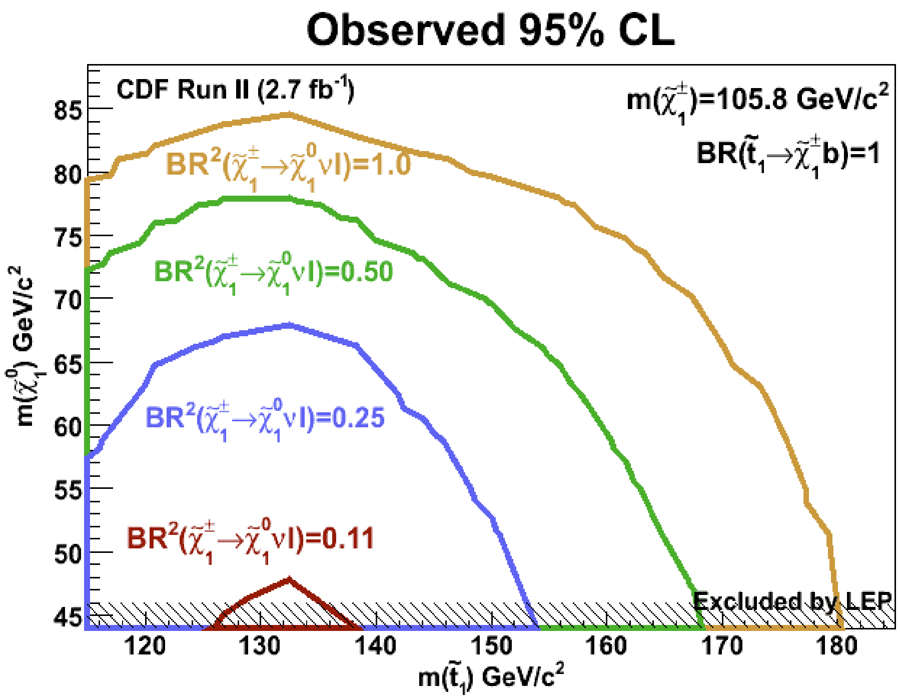
- L = 2.7 fb^{-1}
- 2 leptons (e or μ) >20 GeV and 2 jets >12-20 GeV
- MET>20 GeV
- Perform analysis with and without b-tag
- Genetic algorithm optimization
- Main background: top pairs, Z+jets (latter dies with b-tagging)
- Observation consistent with SM



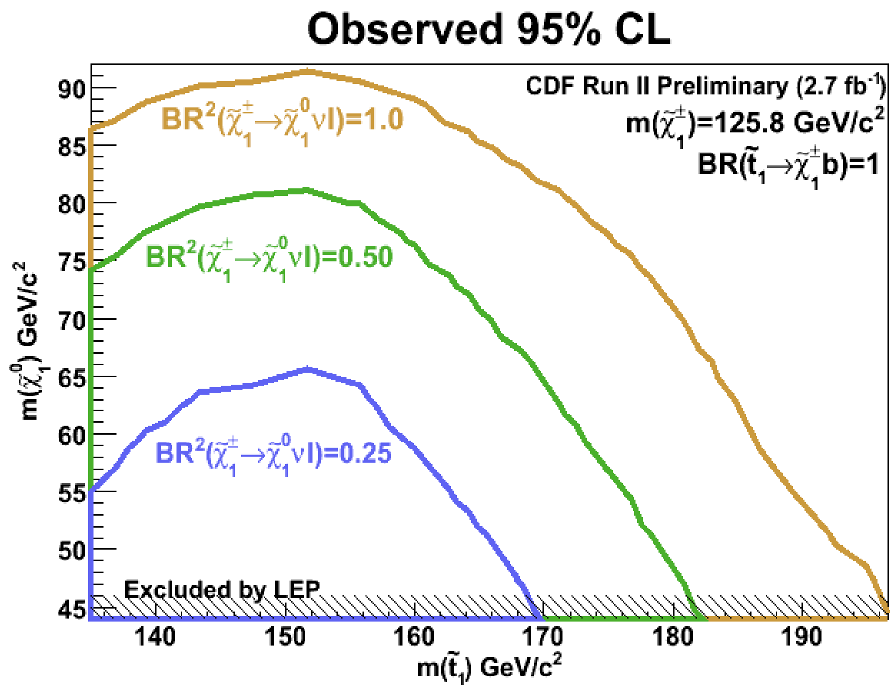
Search for stop at the Tevatron (2)

- Stop limits depend on the Branching Ratio of chargino





Chargino Mass of 105.8 GeV



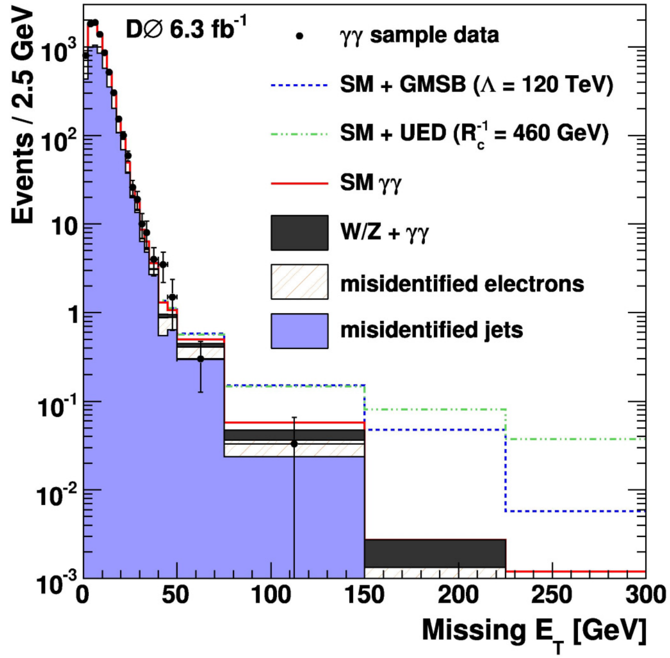
Chargino Mass of 125.8 GeV

PRL 104, 251801 (2010)

Searches for GMSB at the Tevatron

- Under GMSB the lightest neutralino could decay to photon and gravitino. Signature of neutralino pair production will be **two photons and MET**

- L = 6.3 fb^{-1}
- 2 photons > 25 GeV, MET>50 GeV
- ΔΦ separation between MET and γ or jets
- Background:
  - Fake MET: SM diphotons, γ+jets (estimate using dielectron/diphoton MET shape, fitted at MET<10,20 GeV)
  - Real MET: W+γ, W+jet, W/Z+γ
- Observation consistent with SM

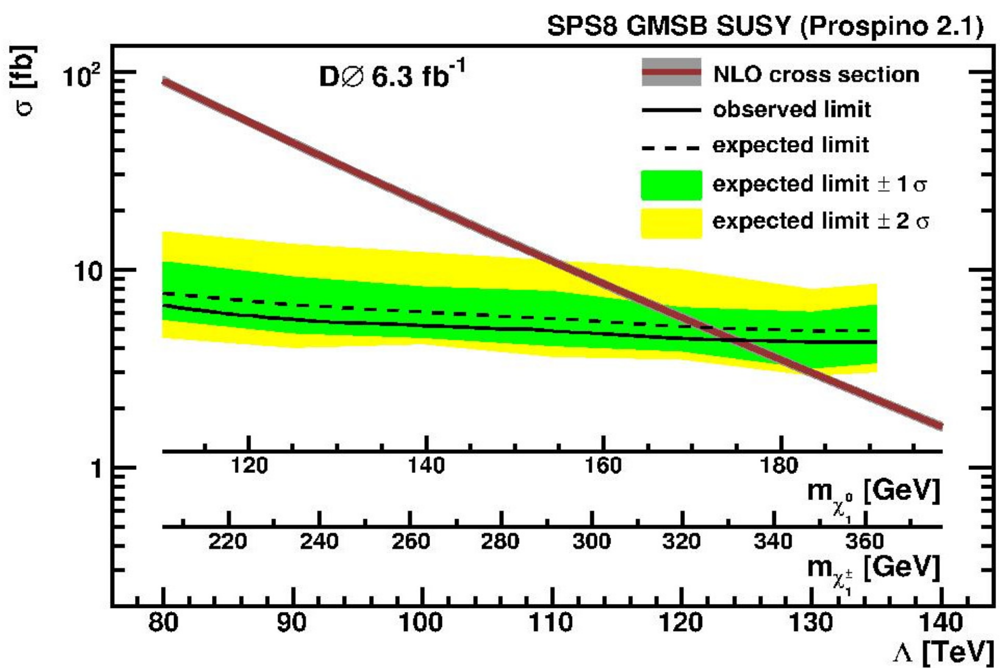


MET (GeV)	Expected	Observed
35-50	20 ± 2	18
50-70	5 ± 1	3
>70	0.9 ± 0.4	1

Searches for GMSB at the Tevatron (2)

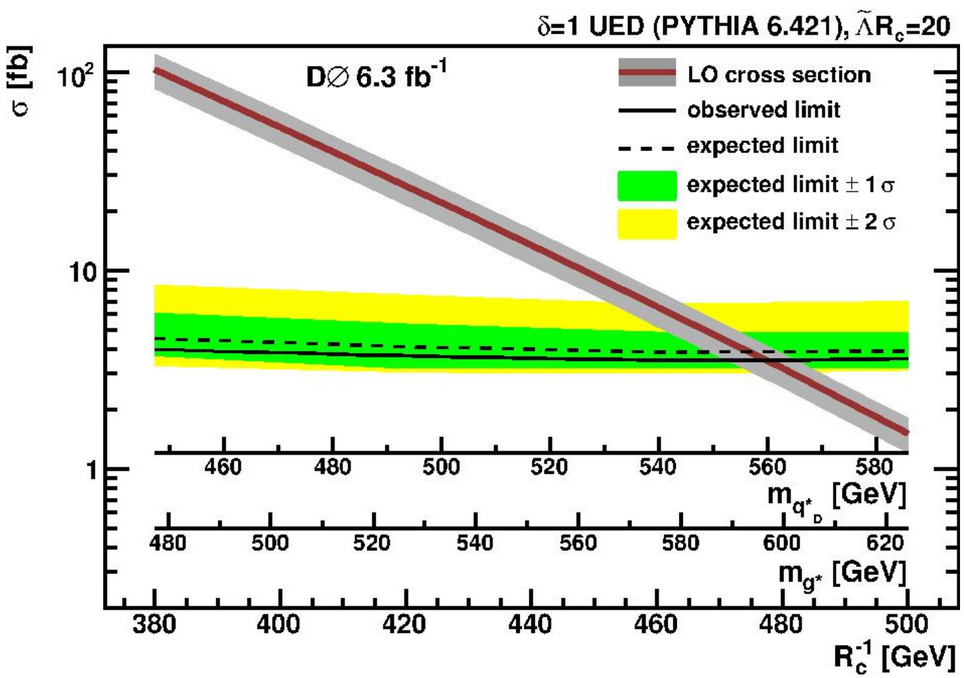
- D0 result also interpreted in the universal-extra-dimensions model, setting limits on the compactification radius

GMSB limit



$M_{\tilde{\chi}^0}$>170 GeV/c^2 at 95% CL

Universal extra dimensions limit



R_c^{-1} >477 GeV/c^2 at 95% CL

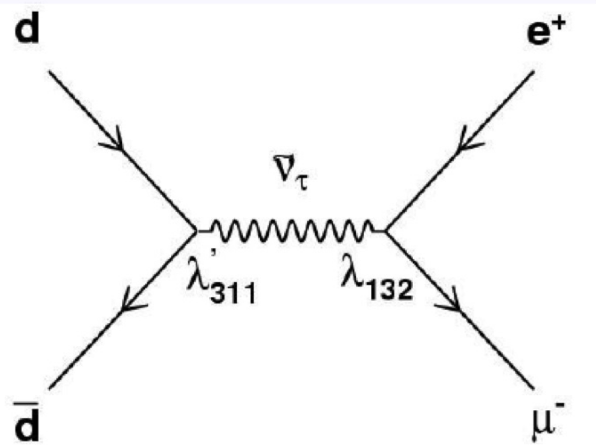
arXiv:1008.2133 [hep-ex]
Submitted August 12, 2010

R-parity violating (RPV) signals

- If R-parity is conserved, SUSY particles are produced in association
- If R-parity is violated, we can have singly-produced SUSY particles decaying to SM-only particles and also lepton-number or/and baryon number violation

$$L_{RPV} = \frac{1}{2}\varepsilon_{\alpha\beta}\lambda_{ijk}L_i^{\alpha}L_j^{b}E_k + \varepsilon_{\alpha\beta}\lambda'_{ijk}L_i^{\alpha}Q_j^{b}D_k +$$
$$\frac{1}{2}\varepsilon_{\alpha\beta\gamma}\lambda''_{ijk}U_i^{\alpha}D_j^{b}D_k^{\gamma} + \varepsilon_{\alpha\beta}\mu_i L_i^{\alpha}H_u^{b}$$

- We present sneutrino production with lepton-number violating decay

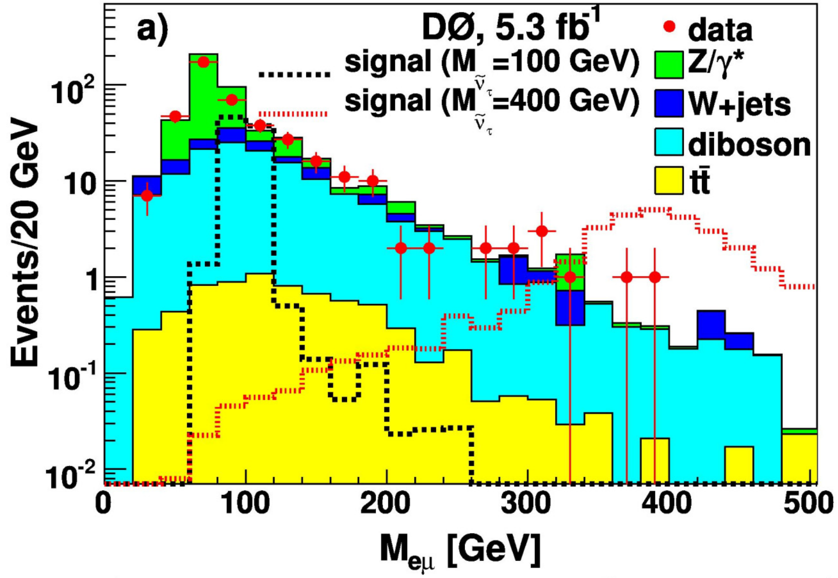


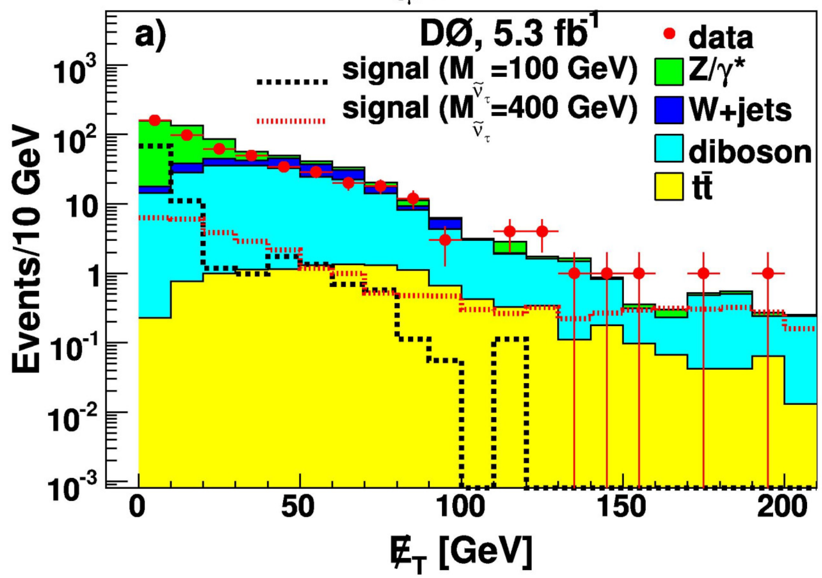
- We also present a multijet search that sets a limit on RPV gluino production

Search for RPV sneutrino at the Tevatron

- Look for electron+muon production (lepton-number violation)

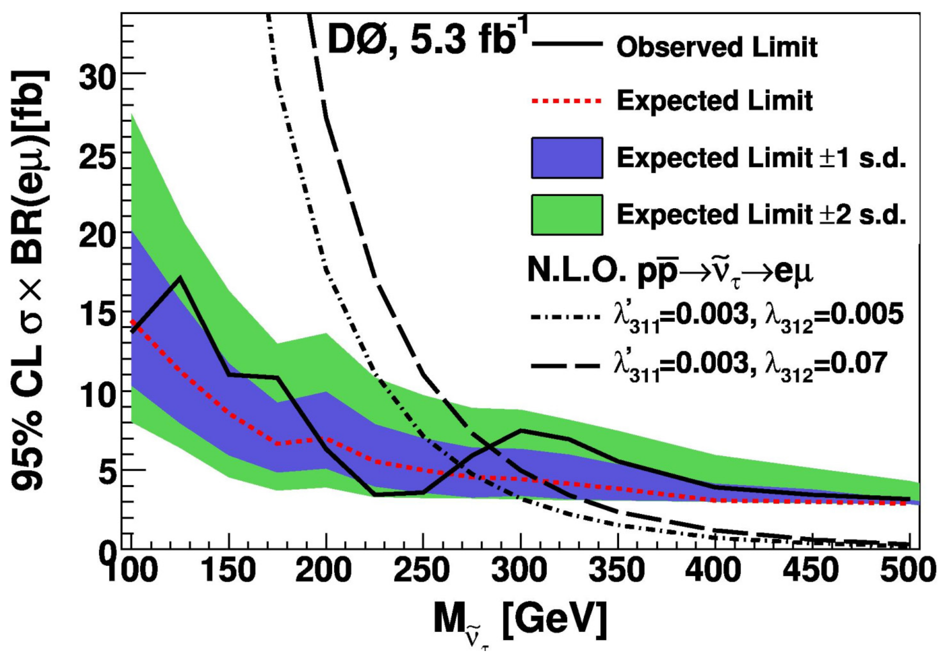
- L = 5.3 fb^{-1}
- 1 electron > 35 GeV,
  1 muon > 25 GeV/c, jet veto
- Neural-network based electron ID
- Main Background: $Z \rightarrow \tau\tau$, diboson
- Main systematics: Cross-sections and luminosity
- Expect 410 ± 38 from SM and observe 414

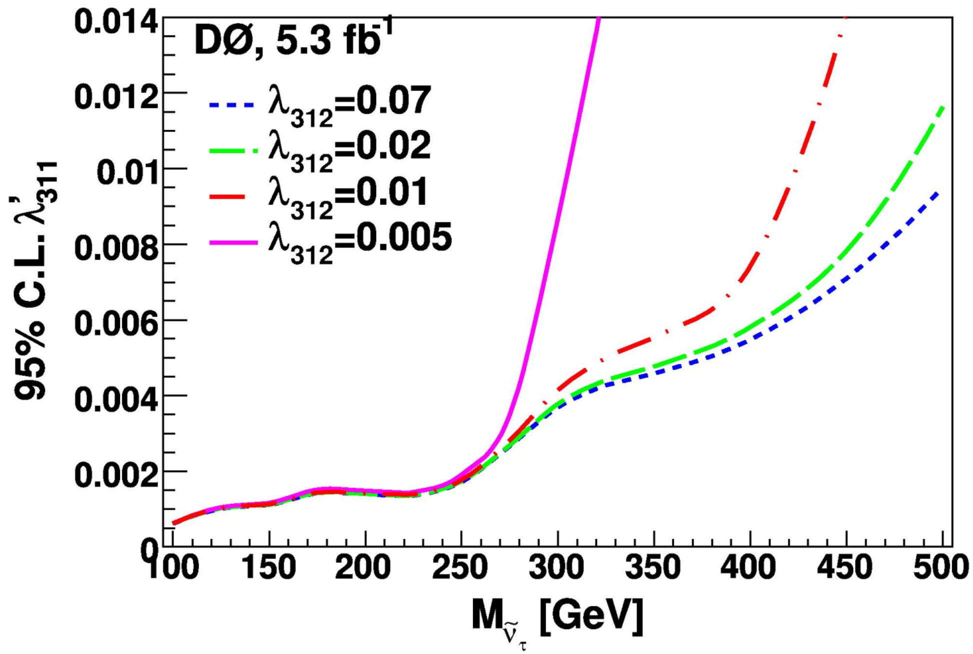




Search for RPV sneutrino at the Tevatron (2)

- Look for electron+muon production (lepton-number violation)

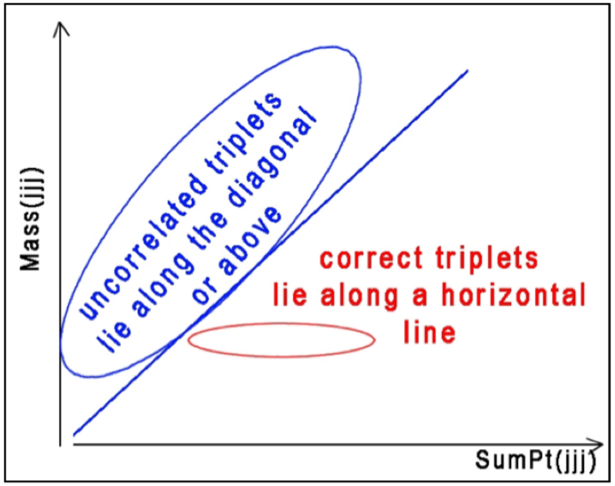




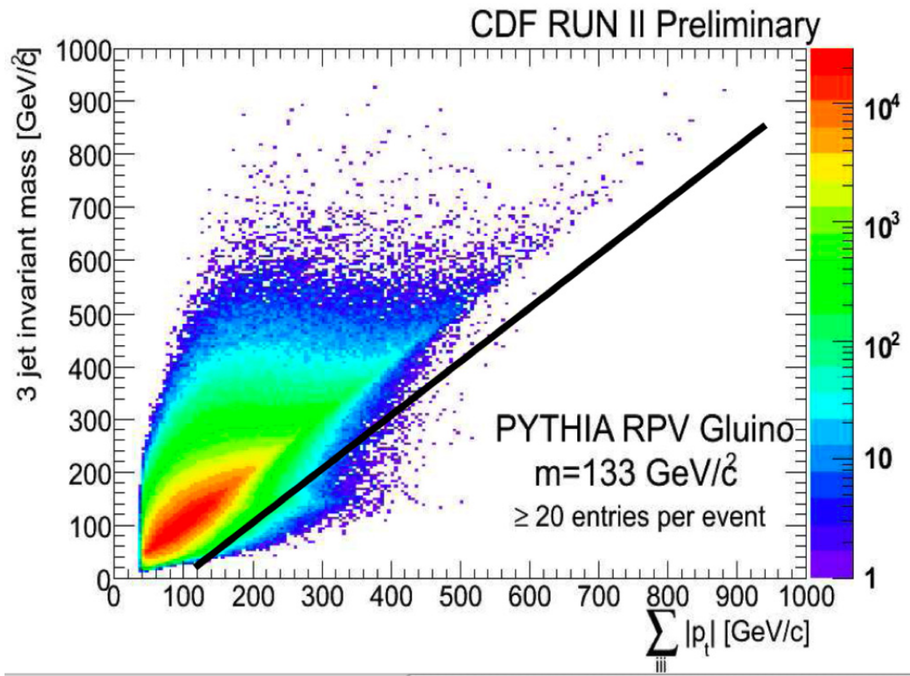
arXiv:1007.4835 [hep-ex]
Submitted July 27, 2010

Search for RPV gluino at the Tevatron

- R-Parity violating pair of gluinos decays to 6 outgoing partons

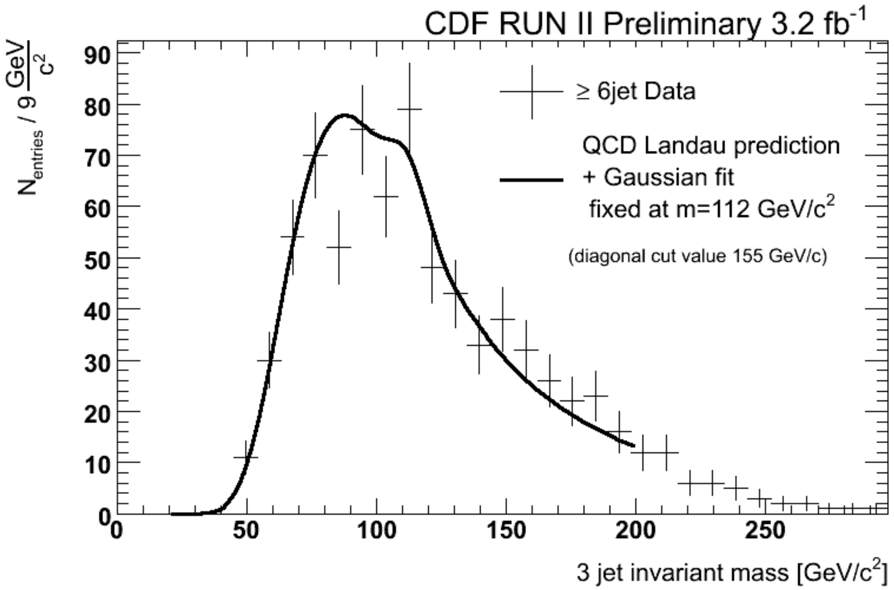


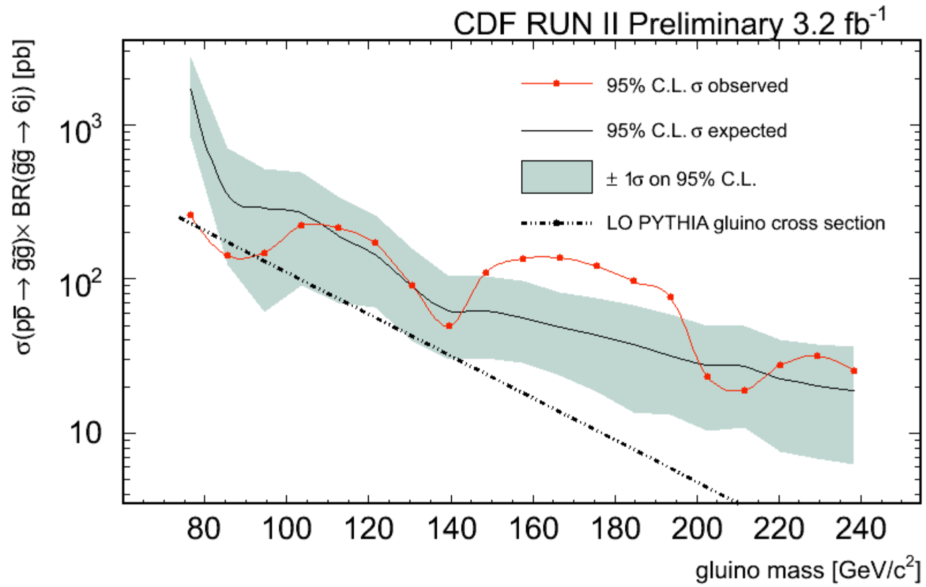
- $L = 3.2\ fb^{-1}$
- 6 jets >15 GeV, ΣE_T>250 GeV, jets coming from the same z-position
- MET<50 GeV
- Use all triplets of jets for each event
- Diagonal cut optimized for different gluino masses
- Main Background: multijets (use 5-jet bin to model the background)



Search for RPV gluino at the Tevatron (2)

- Data consistent with SM (a 2 σ effect around the top mass)

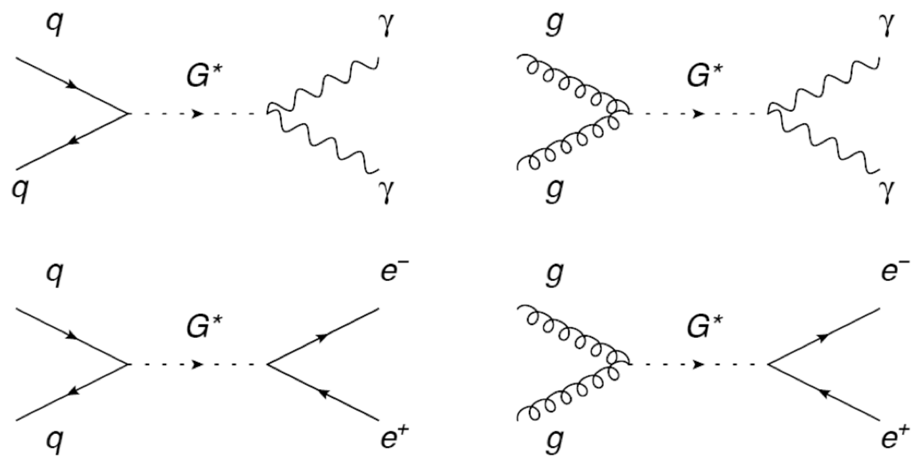




CDF public note 10256 (2010)

Introduction to RS-gravitons

- In the Randall-Sundrum (RS) model the hierarchy is generated by introducing an extra dimension
- 5-dimensional space-time -> 2 4-dimensional subspaces (branes)
- The SM particles are confined in the "TeV" brane, whereas gravity is localized on the "Planck" brane but can propagate in the bulk
- The extra dimension is compactified with a radius R_c
- Scale of physical phenomena is given by the warp factor $\Lambda = M_{PL} \exp(-kR_c\pi)$, where k is the curvature scale of the extra dimension
- The compactification of the extra dimension gives rise to a tower of Kaluza-Klein graviton states with masses $m_n = x_n (k/\overline{M}_{PL})\Lambda$
- 2 parameters determine the graviton couplings and widths: m_1 and $k/\overline{M}_{PL}$



Search for RS-gravitons at the Tevatron

- Investigate the decays of RS-gravitons to pairs of electrons or photons ($BR(\gamma\gamma) \sim 2BR(ee)$)

D0

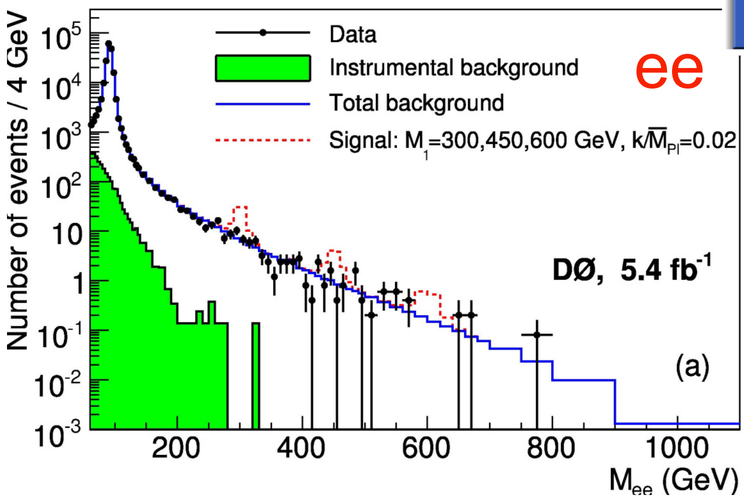
- $L = 5.4\ fb^{-1}$
- 2 central, isolated electrons or photons with $E_T > 25$ GeV
- For γγ Primary vertex selected with EM shower pointing
- Main backgrounds: DY->ee / SM γγ
- Background estimation is fitted to $60 < M_{ee}(M_{\gamma\gamma}) < 200\ GeV/c^2$
- Main systematics from cross sections (9-17%), EM energy resolution (6%), ISR and K-factors (5% each)
- Data consistent with SM

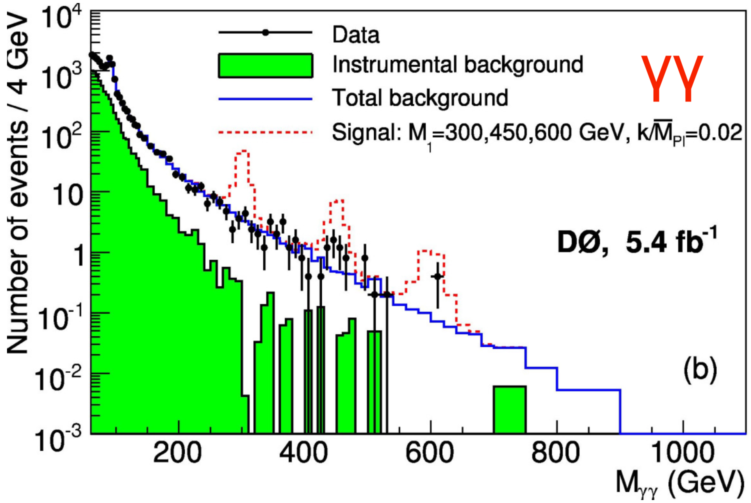
CDF

- $L = 5.4\ fb^{-1}$
- 2 central, isolated photons with $E_T > 15$ GeV
- Main backgrounds: SM γγ and dijets (misidentification of a jet as a photon)
- Get a MC diphoton mass shape and fit it above $100\ GeV/c^2$
  - The goodness of the fit is the actual result
- Main background systematics are ISR/FSR (4-8%) and luminosity (6%)
- Data consistent with SM

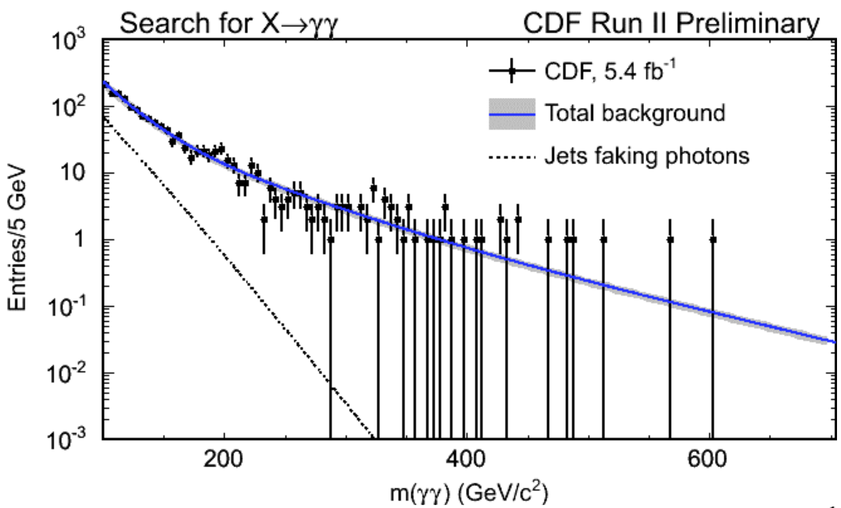
Search for RS-gravitons at the Tevatron (2)

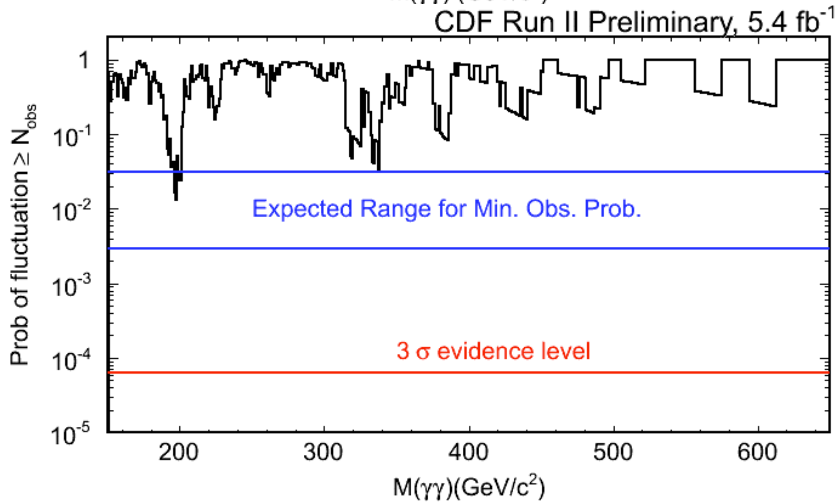
- Dilepton and diphoton high masses are consistent with the SM





Probability of the γγ excess ~450 GeV/c^2: 1.1% (2.3 σ)

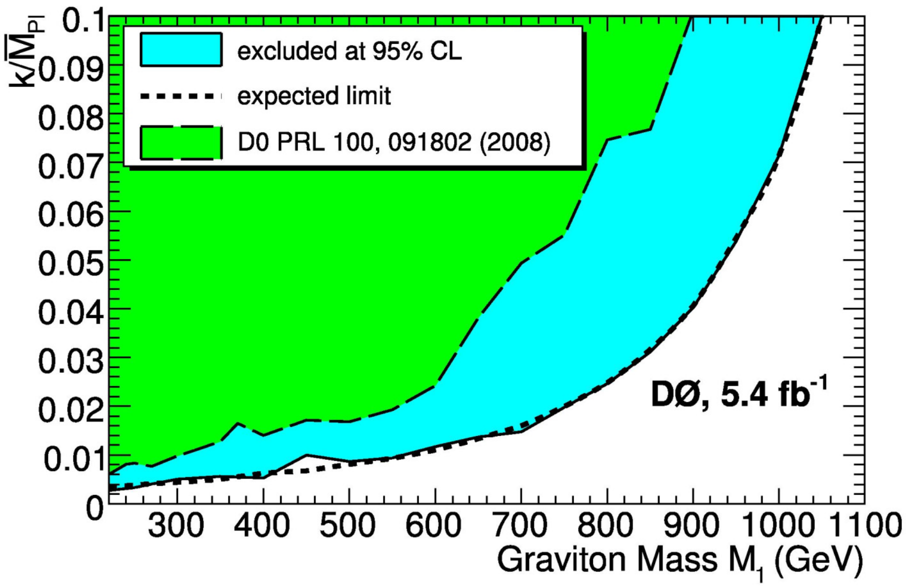




Probability of the excess ~200 GeV/c^2: 1.3% (2.2 σ)

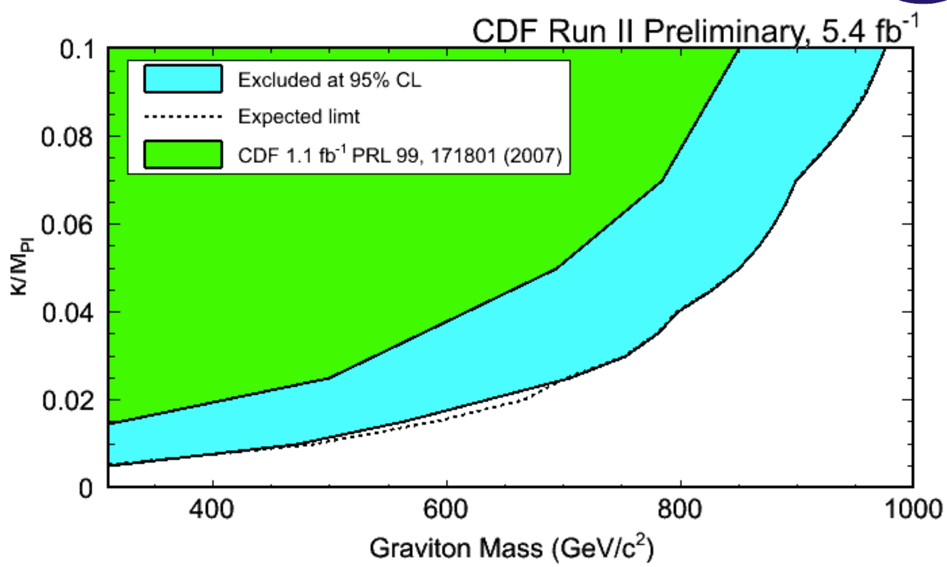
Search for RS-gravitons at the Tevatron (3)

- Limits are set on the coupling vs. Graviton mass plane



M_G>560 (1050) GeV/c^2
for k/M_{PL} =0.01 (0.1)

Phys. Rev. Lett. **104**, 241802 (2010)



M_G>472 (976) GeV/c^2
for k/M_{PL} =0.01 (0.1)

CDF public note 10207 (2010)

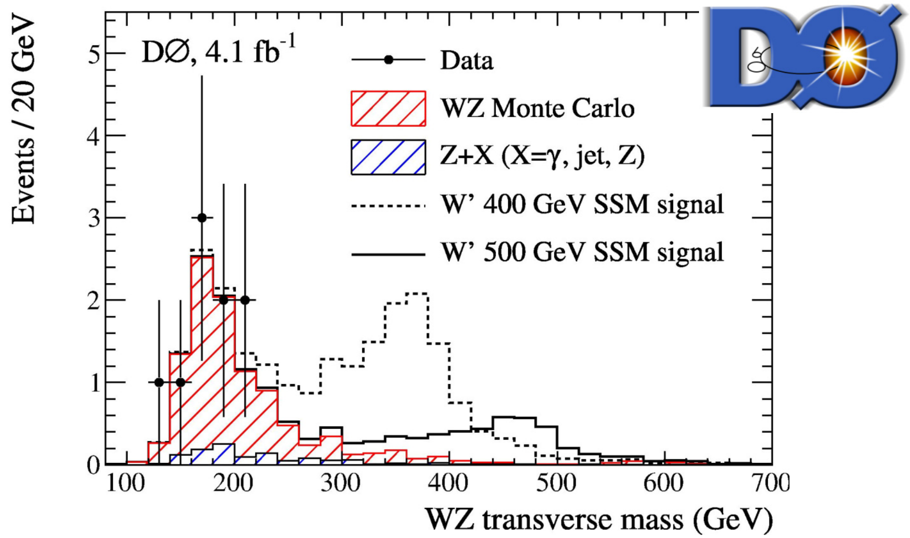
Search for diboson resonances at the Tevatron

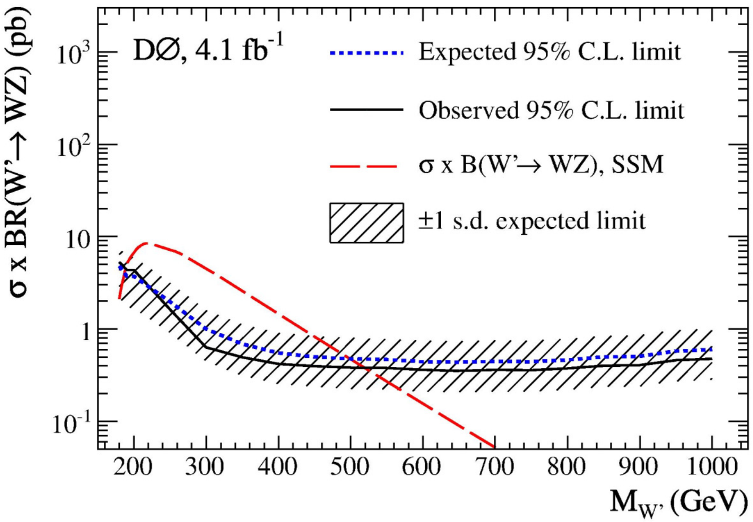
- Heavy W' and Z' or technicolor particles can decay to diboson pairs

• $L = 4.1\ fb^{-1}$ • Search for WZ to leptons • At least 3 isolated charged leptons (e/μ) with p_T>20 GeV/c • MET>30 GeV • Main backgrounds: SM dibosons, Z+jets, Z+γ (latter 2 estimated with data) • Main systematics from fake-rates, accepances/efficiencies • Expect 10.2 ± 1.6 SM events and see 9 (expect 4 from a 400 GeV/c^2 W')	• $L = 2.9\ fb^{-1}$ • Search for WW and WZ decaying to electron+neutrino+2 jets • E_T(electron)>30 GeV, MET> 30 GeV • 2 or 3 jets with E_T>30 GeV • Total H_T>150 GeV • Main backgrounds: W+jets, multijets • Main systematics from jet energy-scale and theoretical cross-sections • Data consistent with SM • Limits set by additional optimization (higher E_T cuts for higher masses)

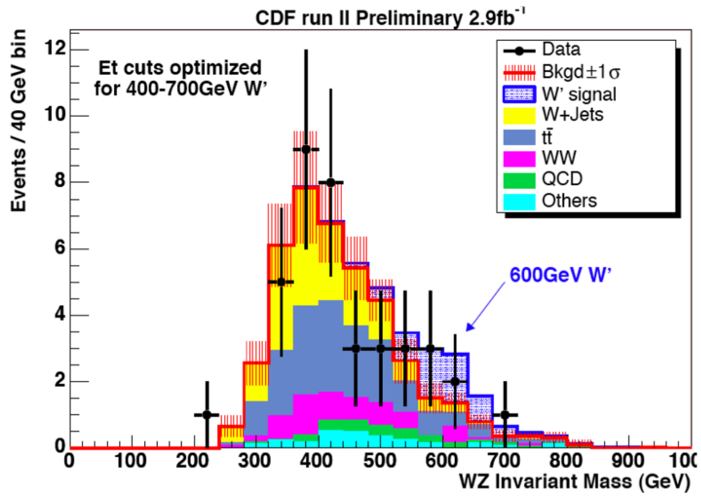
Search for diboson resonances at the Tevatron (2)

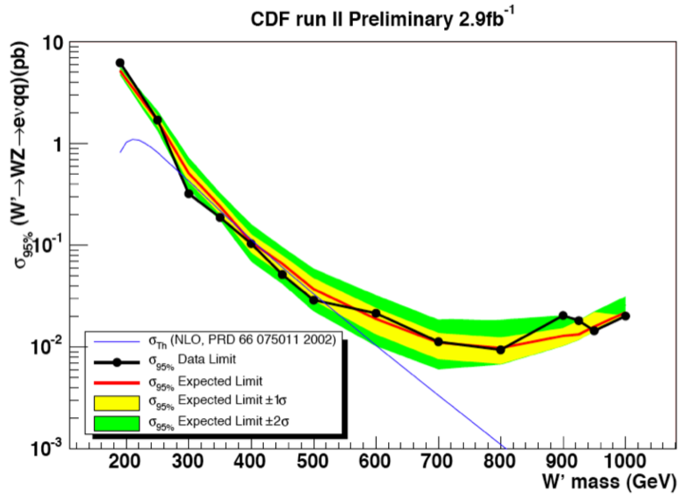
- Dibosons consistent with the Standard Model, **W' limits** set





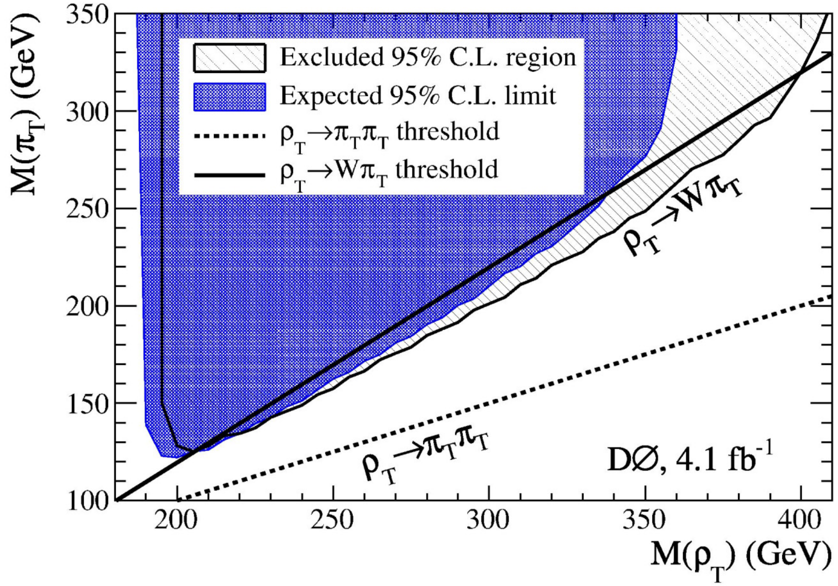
Exclude 188 $< M_{W'} <$ 520 GeV/c^2





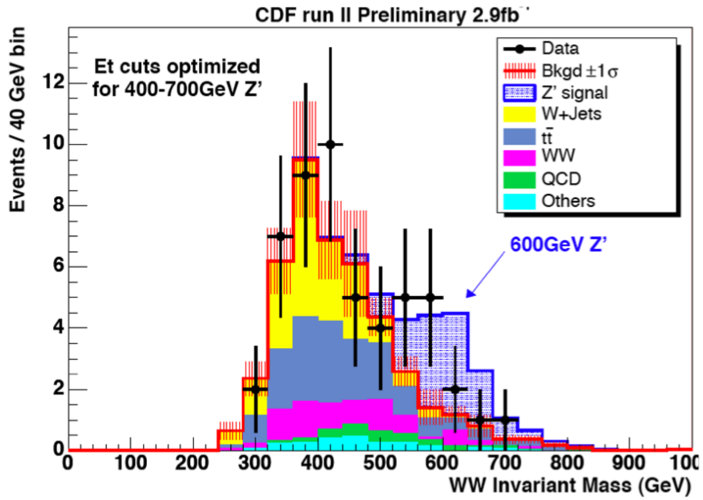
Exclude 285 $< M_{W'} <$ 516 GeV/c^2

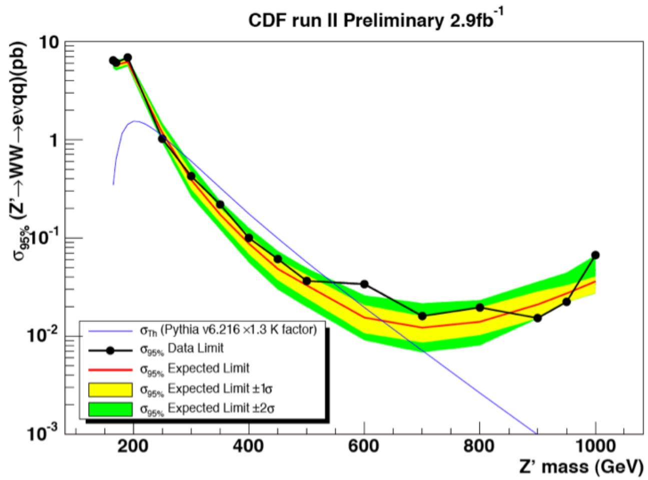
- Using the diboson analyses we can set limits on **technicolor and Z’**



Exclude 208 <$M_{\rho T}$< 408 GeV/c^2

PRL 104, 061801 (2010)





Exclude 247 <$M_{Z’}$< 544 GeV/c^2

PRL 104, 241801 (2010)

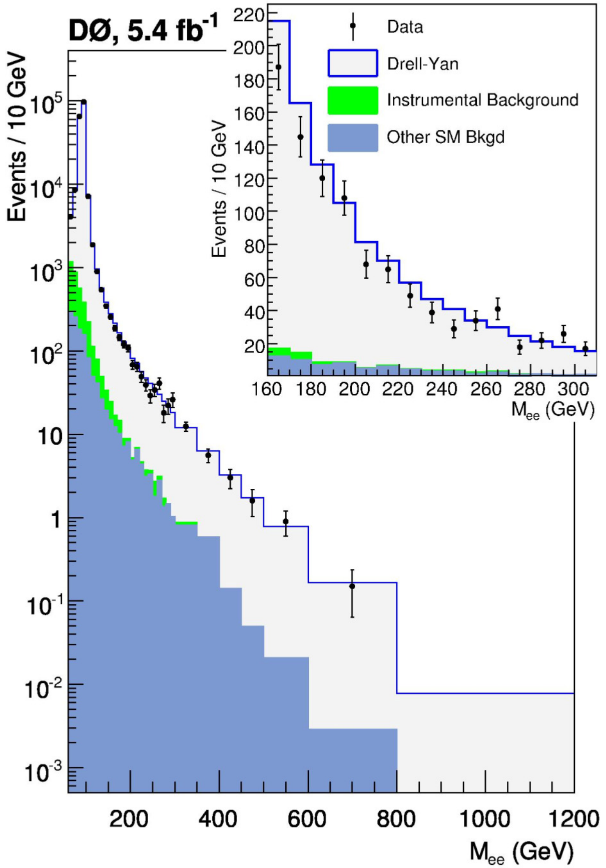
Dileptonic searches for Z' at the Tevatron

- Mainstream searches of Z' to dileptons

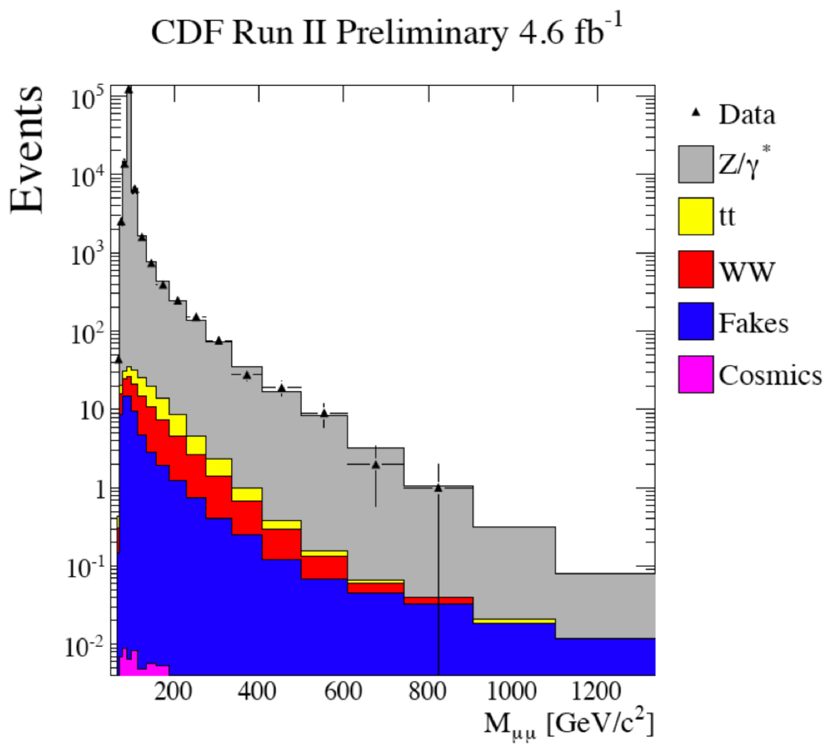
DØ	CDF
• $L=5.4\ fb^{-1}$ • Use of the dielectron analysis already presented	• $L = 4.6\ fb^{-1}$ • Two central muons > 30 GeV/c • Main background:Drell-Yan • Main systematics from PDF, K-factor • Data consistent with SM

Dileptonic searches for Z’ at the Tevatron (2)

- Mainstream searches of Z’ to dileptons



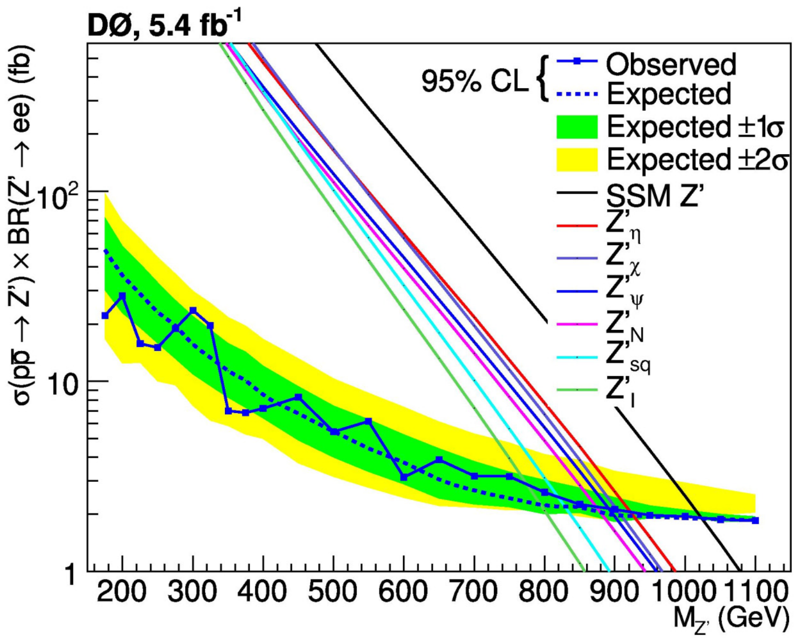
- Dielectron mass spectrum consistent with SM



- Dimuon mass spectrum consistent with SM

Dileptonic searches for Z’ at the Tevatron (3)

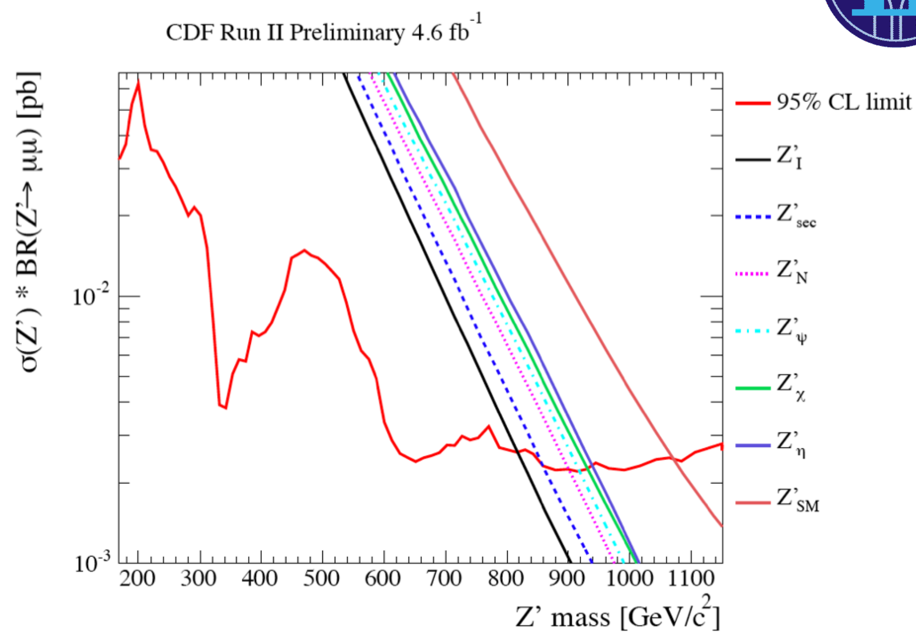
- Mainstream searches of Z’ to dileptons



- $M_{Z'}$ > 772 - 1023 GeV/c^2

  arXiv:1008.2023 [hep-ex]

  Submitted on August 11, 2010

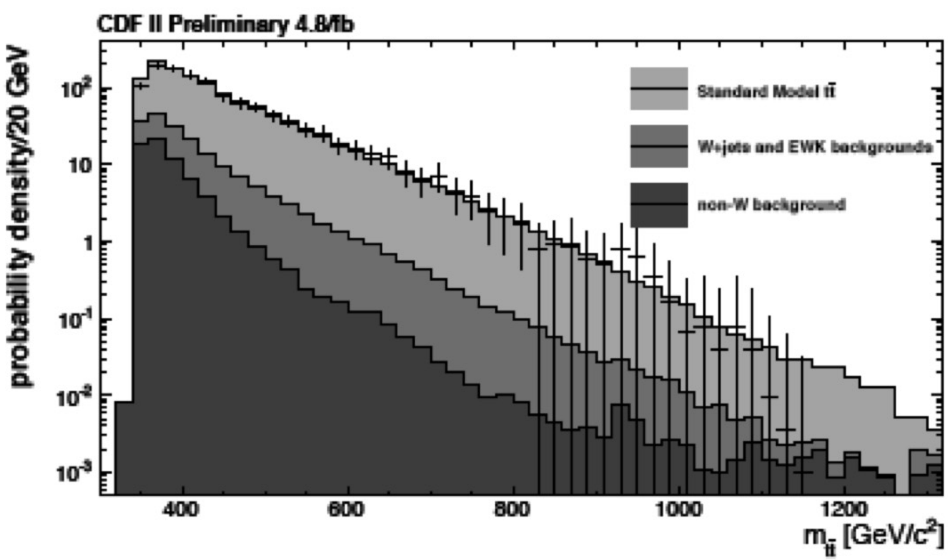


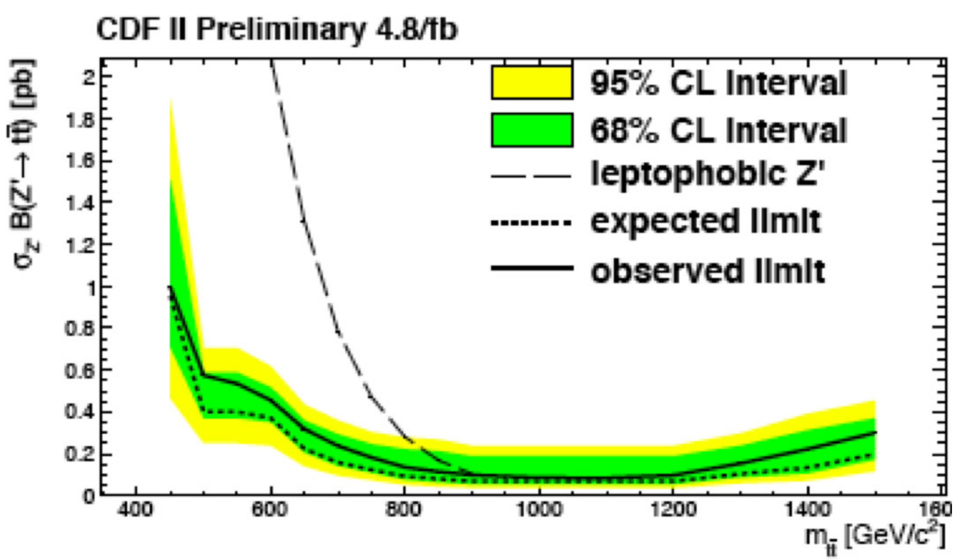
- $M_{Z'}$ > 817 to 1071 GeV/c^2

  CDF Public note 10165 (2010)

t-tbar-enhanced technicolor Z’

- 4.8 fb^{-1}
- 1 e/μ > 20 GeV, MET> 20 GeV, ≥4 15-GeV jets, 1 b-tagged
- Matrix-element reconstruction
- For each event observe a PDF of top-anti-top mass





95% CL exclusion of top-color-assisted technicolor Z' with
$m_{Z'} < 900$ GeV for $\Gamma_{Z'} = 0.012 M_{Z'}$

Searches for t' and b' at the Tevatron

- 4th generation is not excluded by electroweak precision measurements and could explain some forward-backward asymmetry in b-decays

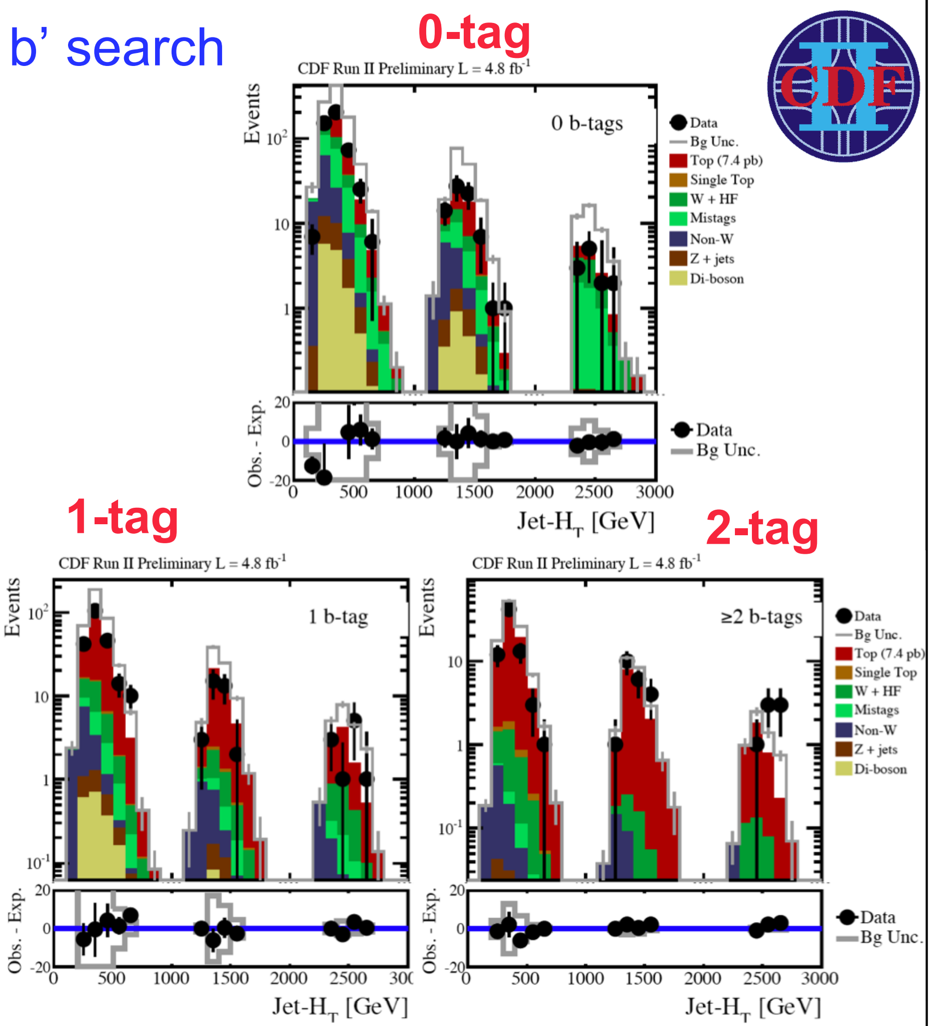
- **Search for b' → Wt → WWb** pair production
- $L = 4.8\ fb^{-1}$
- 1 e/μ > 20 GeV, MET>20 GeV, ≥5 jets >20 GeV (≥1 b tagged)
- Main background: top pairs
- Main systematics from Jet-energy scale
- Analysis performed for N_{jet}=5,6, ≥7 and for $N_{b\text{-}tags}$ =0,1 ≥2
- Some descrepancy compared to the SM for N_{jet} ≥7 and ≥1 b-tags could be due to parton showering

- **Search for t' → Wq (not b')** pair production
- $L = 4.6\ fb^{-1}$
- 1 e/μ > 25 GeV, MET>20 GeV, ≥4 jets >20 GeV (no b-tagging)
- Main background:W+jets, top pairs
- Fit the M_{reco} vs H_T distribution
- Main systematics from jet-energy scale
- Data consistent with SM

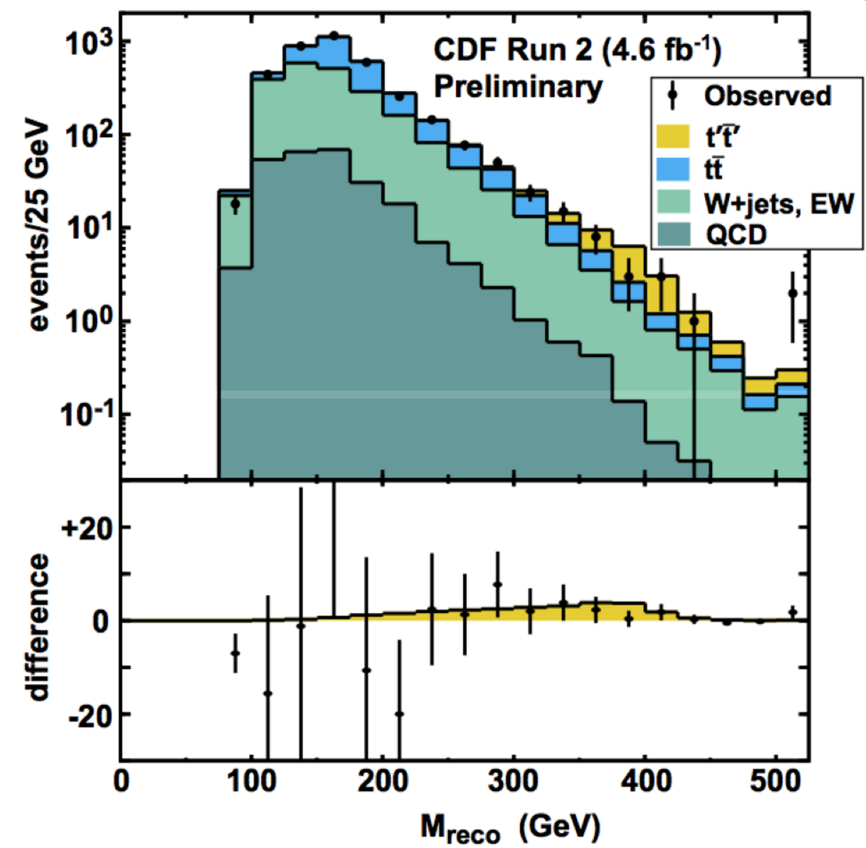
Searches for t’ and b’ at the Tevatron (2)

- 4th generation is not excluded by electroweak precision measurements

b’ search



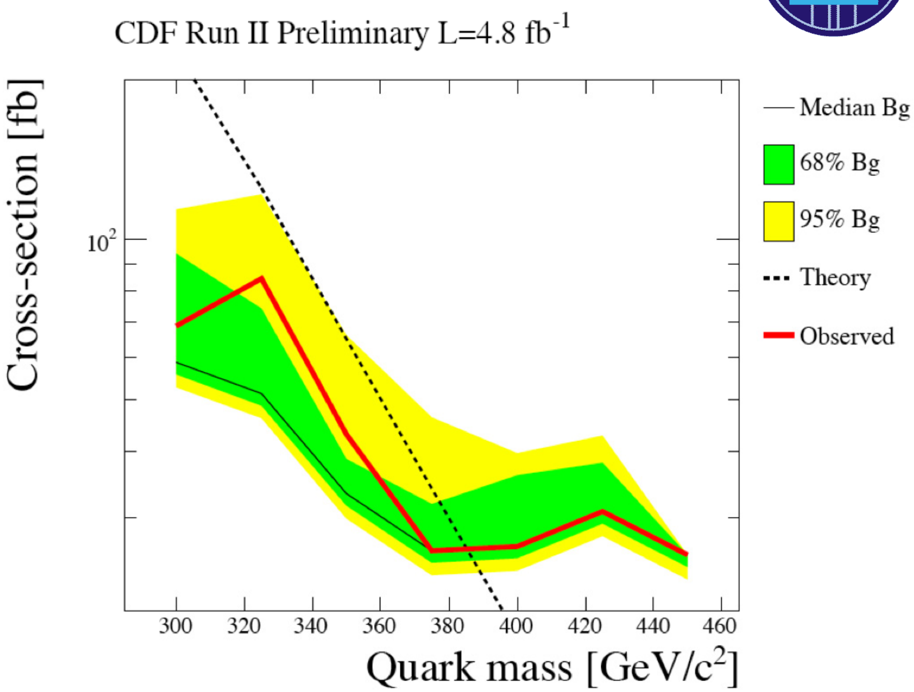
t’ search



Searches for t' and b' at the Tevatron

- 4th generation is not excluded by electroweak precision measurements

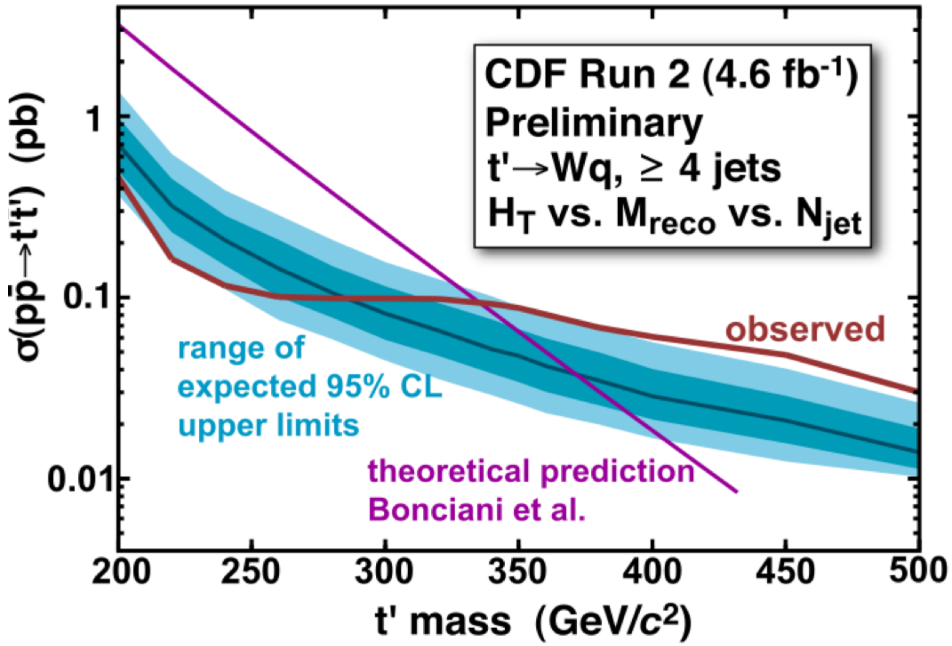
b' search



b' > 385 GeV/c^2

CDF Public Note 10243 (2010)

t' search



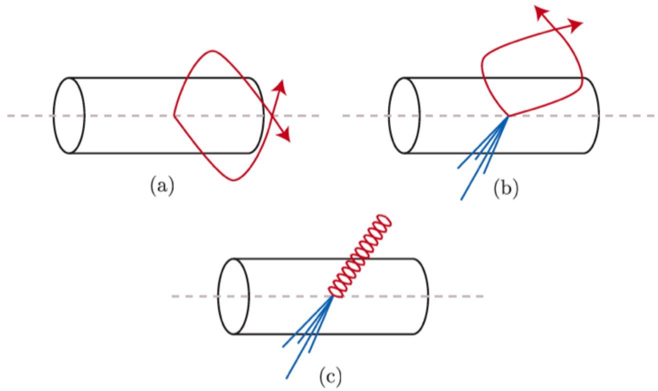
t' > 335 GeV/c^2

CDF Internal Note 9846 (2010)

Quirks and Hidden Valleys

- Extra QCD-like SU(N) theories predict new kind of quarks. Parameters are the scale Λ where "infracolor" becomes strong and the mass M_Q of the "quirks"

Kang and Luty (2008)
arXiv:0805.4642v3 [hep-ph]

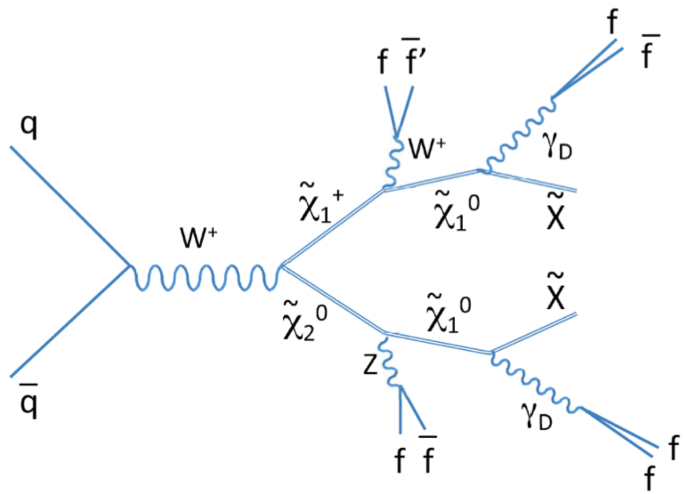


→ Detect either strange tracks

→ Or detect highly-ionizing slow heavy particle

- SUSY hidden sector γ_D could give rise to "lepton jets" that are detectible at the Tevatron

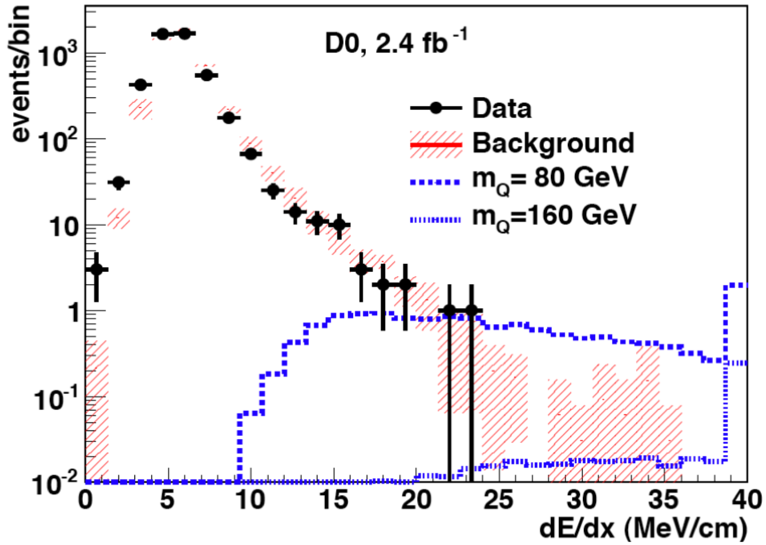
Han *et al.* ,
J. High Energy Phys. **07**, 008 (2008)
Strassler and Zurek,
Phys. Lett. B **651**, 374 (2007)

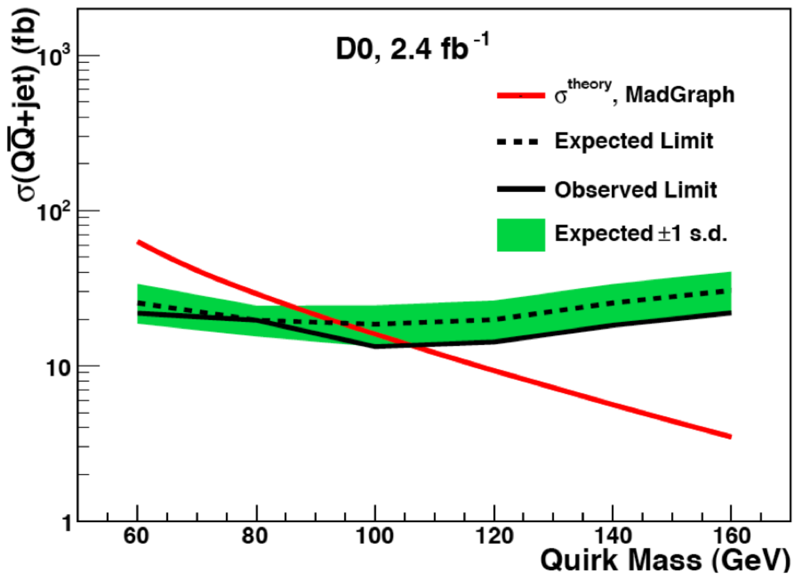


Search for the … Quirks

- Investigate $10 < \Lambda < 1$ MeV/c² (mesoscopic range) and $60 < M_Q < 160$ GeV/c²

- L = 2.4 fb^{-1}
- Look for slow, high-ionizing track
- Select an isolated track > 40 GeV/c, a jet > 75 GeV and MET > 50 GeV
- MET alinged with the track, jet opposite direction
- Expect large dE/dx , ~ 15 MeV/cm
- Main background: W+jets and multijets
- Discriminating variable: dE/dx, measured with the tracking system

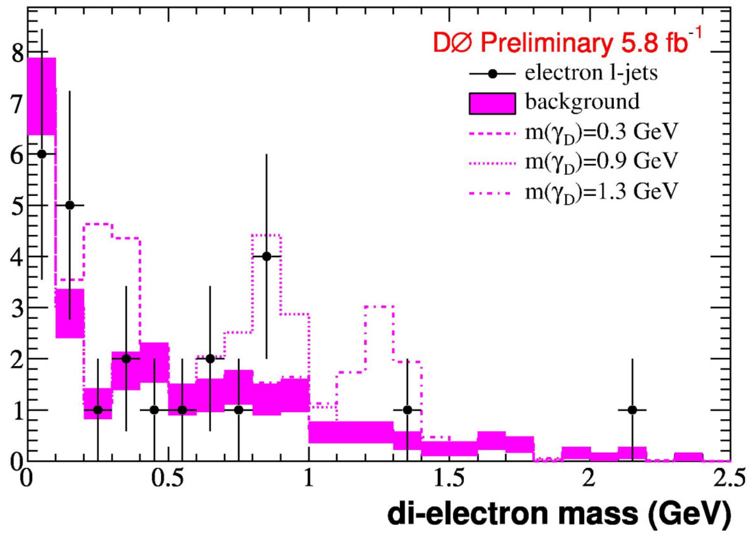


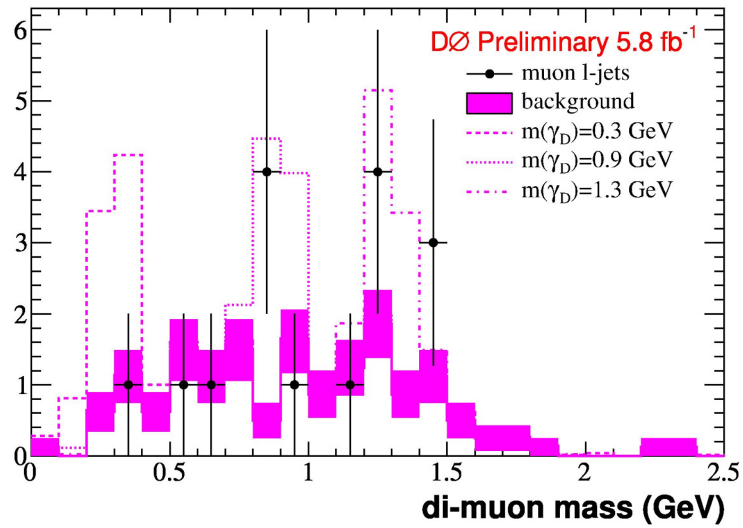


Search for hidden valleys

- Hidden sector's force carrier (dark photon γ_D) will decay to leptons
- Signal is many "lepton jets"

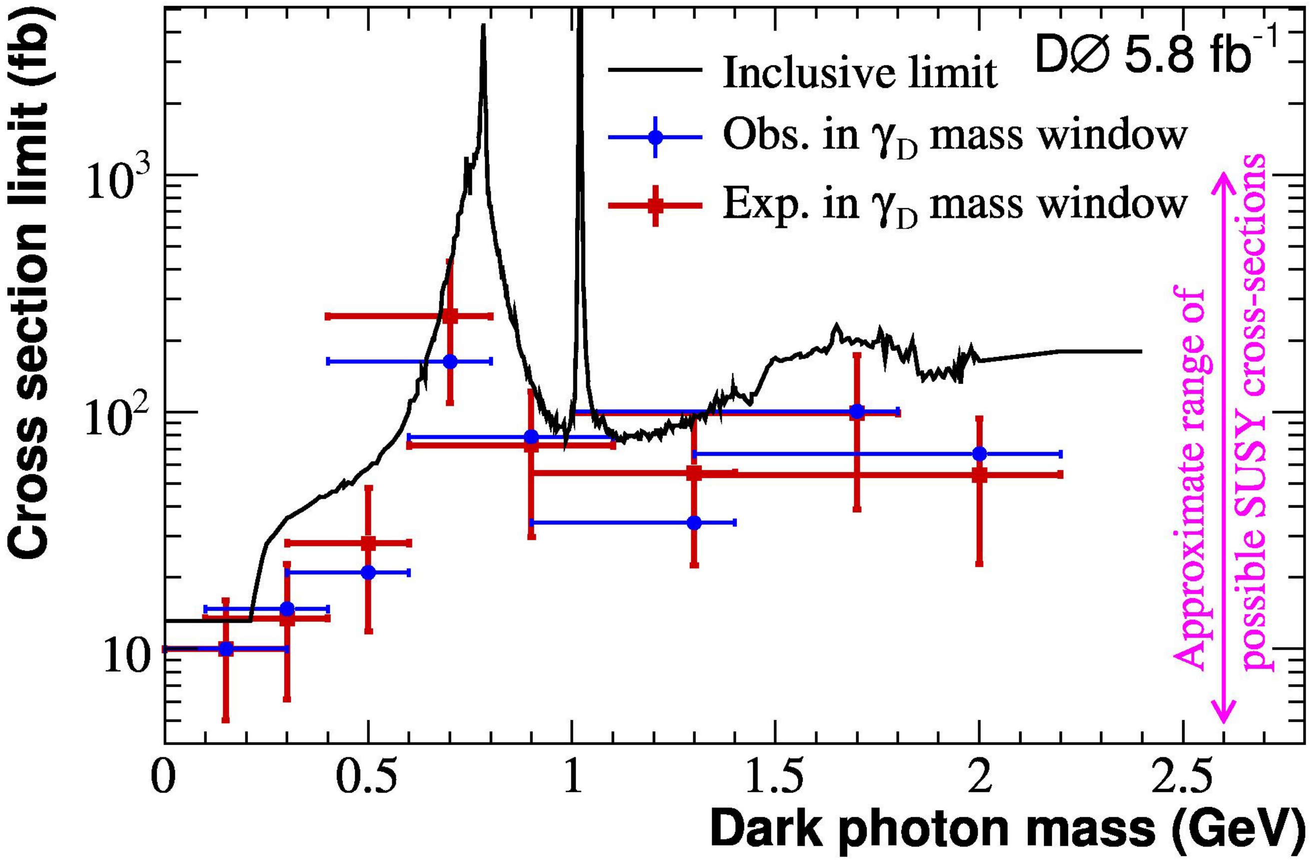
- L = 5.8 fb^{-1}
- Select a seed electron or muon track >10 GeV/c with a companion track of opposite charge of >5 GeV/c
- MET > 30 GeV
- Both track and calorimeter isolation
- At least 2 such "lepton jets"
- Main background: multijet events and (for "electron jets") conversions
- Results for ee, eμ,μμ and combined
- Form invariant mass of dark photon from seed and companion track





Search for hidden valleys (2)

- Limit on the cross-section vs dark-photon mass is set



arXiv:1008.3356[hep-ex] Submitted August 19, 2010

Evidence for an anomalous like-sign dimuon charge asymmetry

- Dimuon charge asymmetry due to B-mixing:

$$a_{sl}^{b} \equiv \frac{\Gamma(\overline{B} \to \mu^{+}X) - \Gamma(B \to \mu^{-}X)}{\Gamma(\overline{B} \to \mu^{+}X) + \Gamma(B \to \mu^{-}X)} = A_{sl}^{b}$$

- The SM-expected asymmetry for the B_s and B_d produced at the Tevatron comes from CP-violating phase of the B mass matrix

$$a_{sl}^{q} = \frac{\Delta\Gamma_q}{\Delta M_q}\tan(\phi_q)$$

PRL 105, 081801 (2010)
PRD 82, 032001 (2010)

- SM-expected asymmetry

$$A_{sl}^{b}(SM) = (-0.023^{+0.005}_{-0.006})\%$$

- Measured by D0 is 3.2 σ higher:

$$A_{sl}^{b} = (-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst}))\%$$

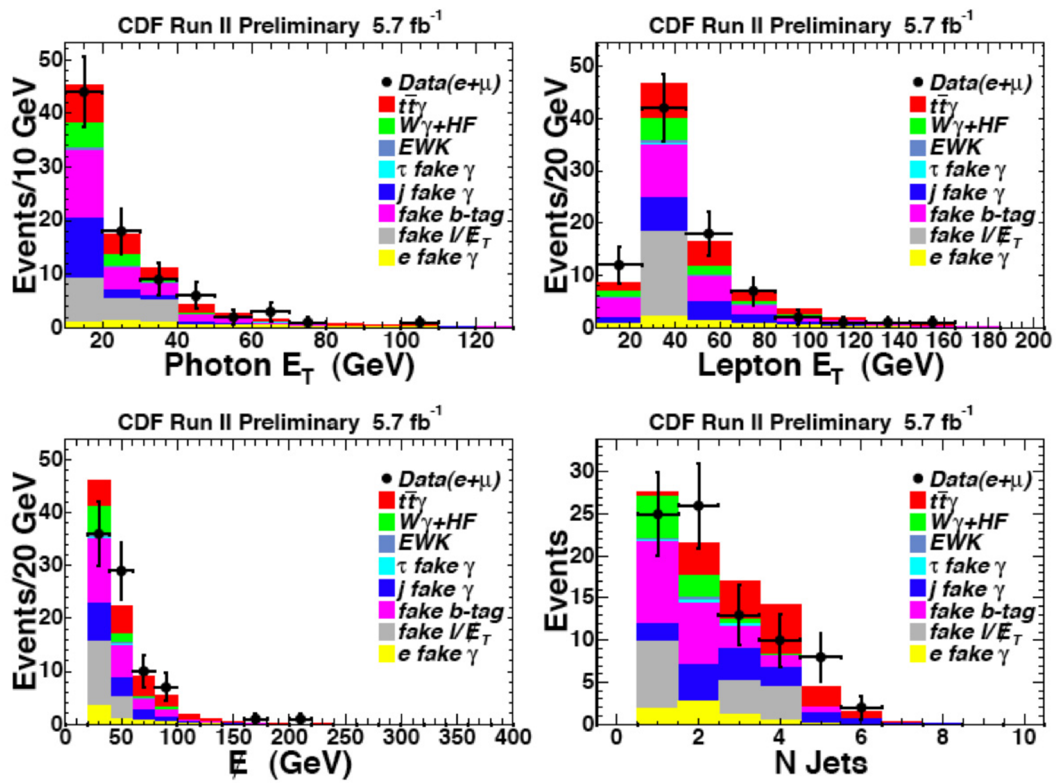
Just blessed: lepton+gamma+MET+b-quark

- Signal could be due to t-ttbar+photon with semileptonic decay or due to some new physics

- L = 5.7 fb^{-1}
- Select an electron or muon with E_T>20 GeV, MET>20 GeV, photon with E_T >12 GeV
- b-tagged jet with E_T>20 GeV
- Main background: t-tbar+γ and Wγ+jets
- Results consistent with the EM

CDF Run II Preliminary, $5.74 fb^{-1}$

Lepton + Photon + $\not\!\!E_T$ + b Events, Isolated Leptons			
Total SM Prediction	56.5 ± 7.9	29.8 ± 2.1	86.4 ± 8.5
Observed in Data	51	33	84



More details about some of the analyses at the parallel sessions

Tevatron new-phenomena non-BSM-higgs parallel talks at SUSY 10

- D0

Sudeshna Banerjee:

Searches for physics beyond the standard mode in final states with two leptons and jets with the D0 detector

Sudeshna Banerjee:

Searches for physics beyond the standard model in final states with long lived particles.

Mark Cooke:

Searches for supersymmetry in ppbar collisions at sqrt(s) =1.96 TeV with the D0 detector

- CDF

Maxwell Chertok:

Searches in Same-Charge Dilepton Events at CDF and Searches for Supersymmetry Using the Trilepton Signature at CDF

Gianluca de Lorenzo:

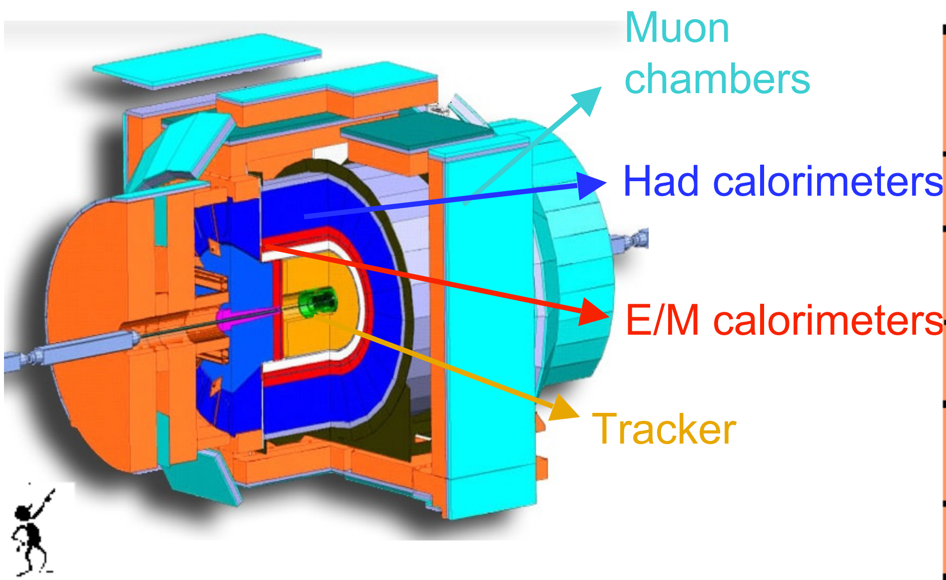
Searches for Squarks and Gluinos in Jets and Missing Energy Final States at CDF

Conclusions

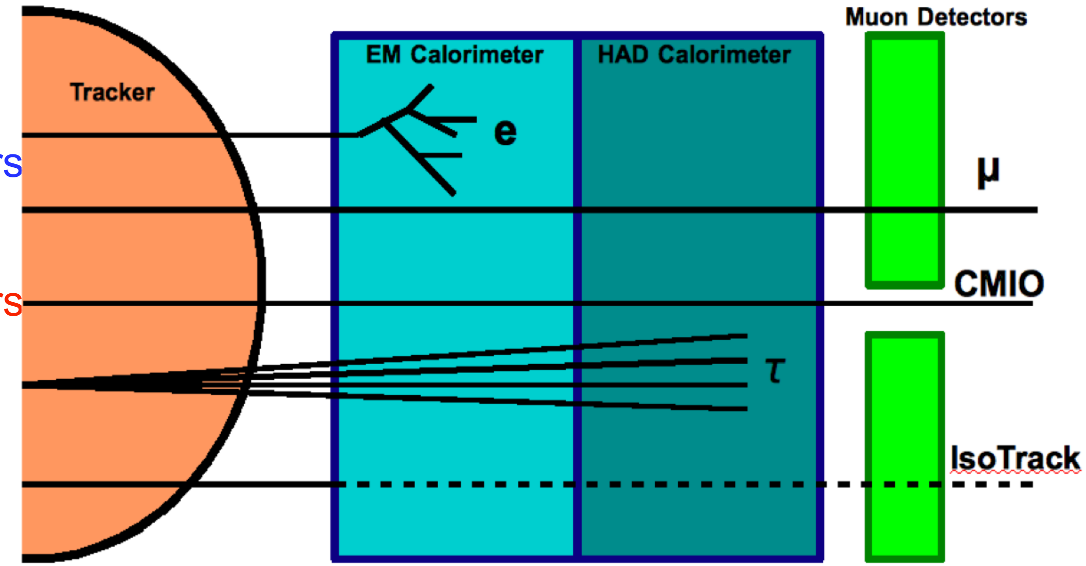
- The Tevatron experiments are extremely active in the search of new phenomena
- We try to test old and new theories without neglecting to perform model-independent searches
- We look at final states never investigated before
- We haven't discovered new physics yet, but we keep expanding our kinematic and parameter space reach and we keep searching
- Our analyses improve continuously and the Tevatron performs extraordinarily, so we will keep increasing our discovery potential and limits-setting / theory-testing power
- Don't forget to check the CDF and D0 public exotic pages: …
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm
  - http://www-cdf.fnal.gov/physics/exotic/exotic.html

BACKUP

The CDF II detector



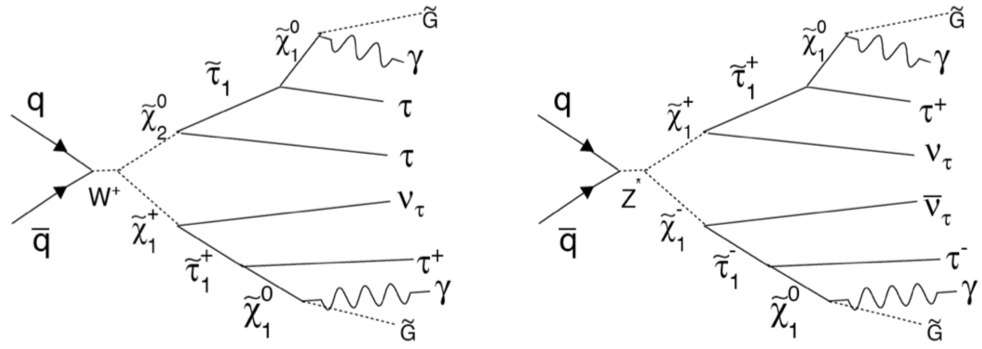
Lepton definitions

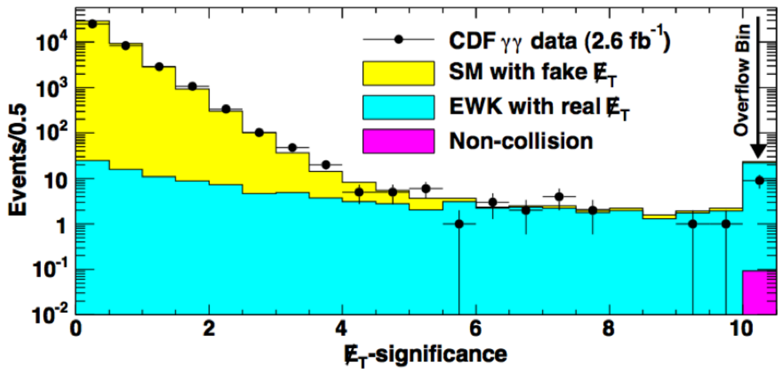


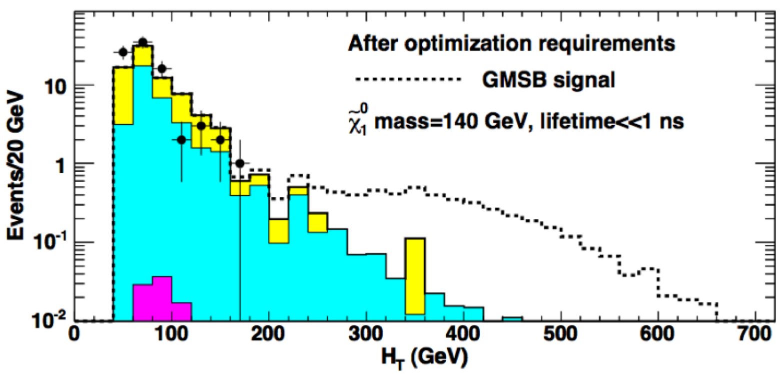
- Central tracker measures charged particle trajectories
- These trajectories are matched to calorimeter energy depositions and hits in muon chambers to reconstruct electrons and muons
- Hadronic Jets (from outgoing quarks and gluons) and imbalance in transverse momentum (MET) are also determined with the calorimeters
  - MET is indication of particles that do not interact with our detector

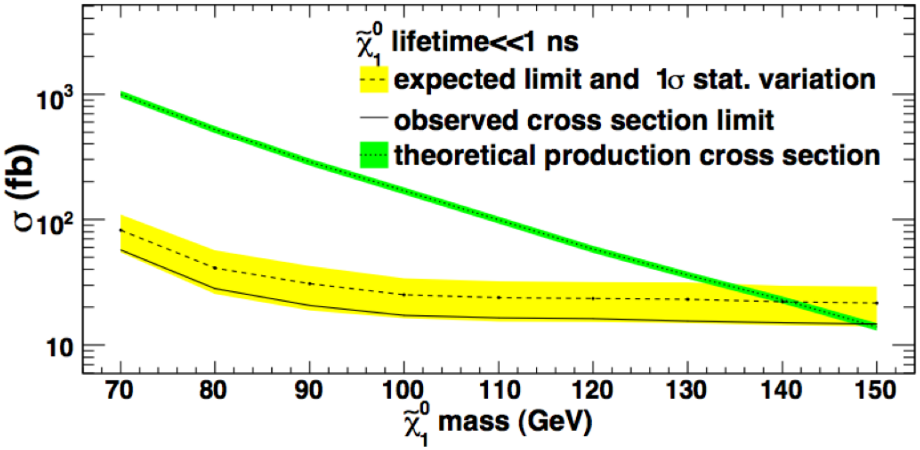
GMSB $\chi\chi \rightarrow \gamma\gamma$+MET

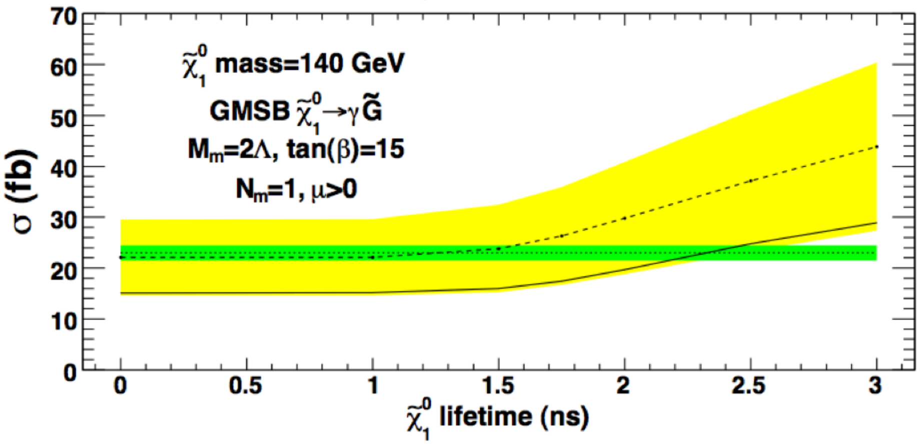
- L = 2.6 fb^{-1}
- Selection: 2γ (E_T>13 GeV)
  MET significance > 3
  H_T >200 GeV, Δϕ(γ,γ)<π-0.15
- SM backgrounds: electroweak with real MET (67%), QCD with fake MET(17%), non-collision
- Expect 1.2 ± 0.4 SM and observe none
- **Set limits on lightest neutralino and its lifetime**



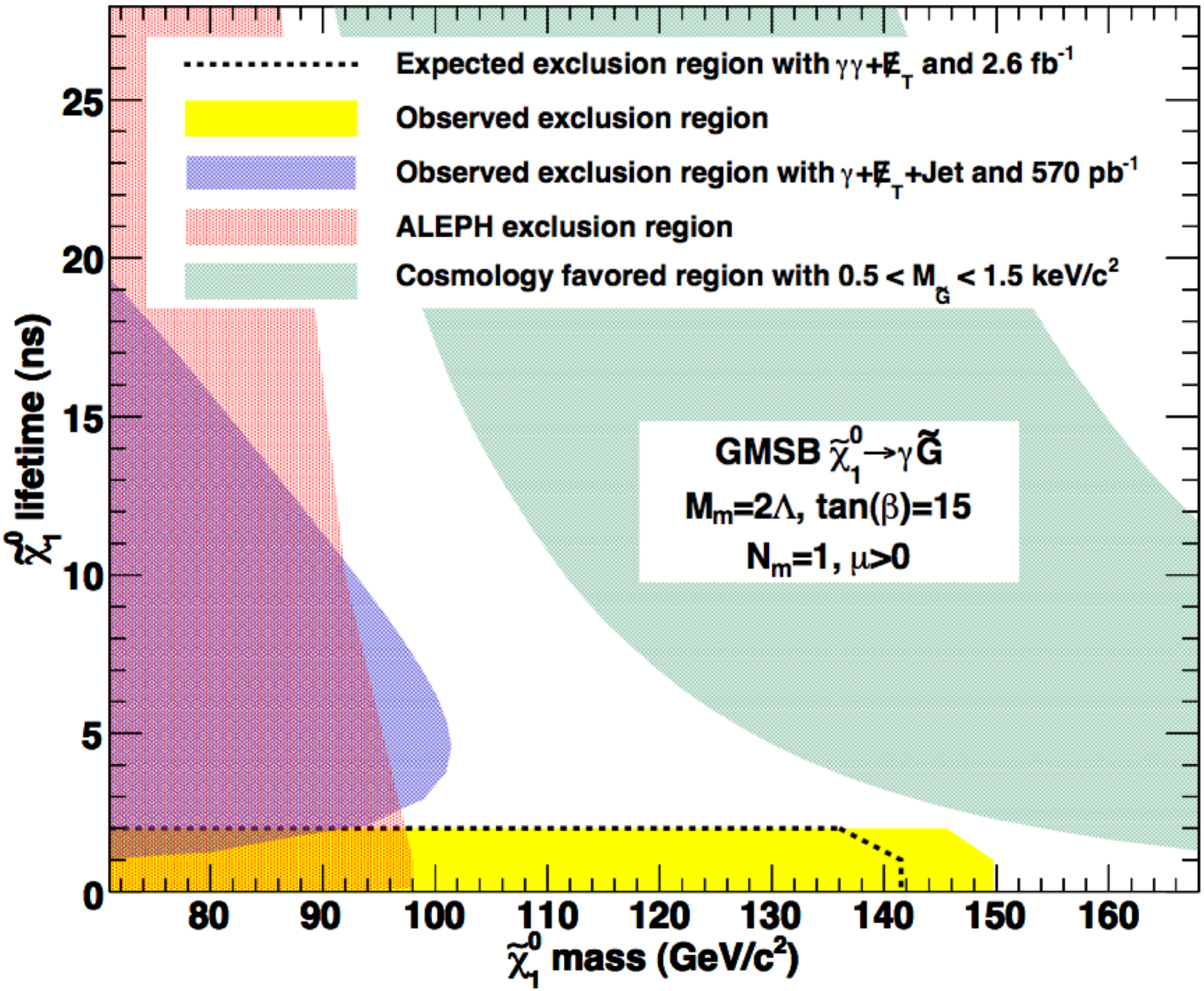








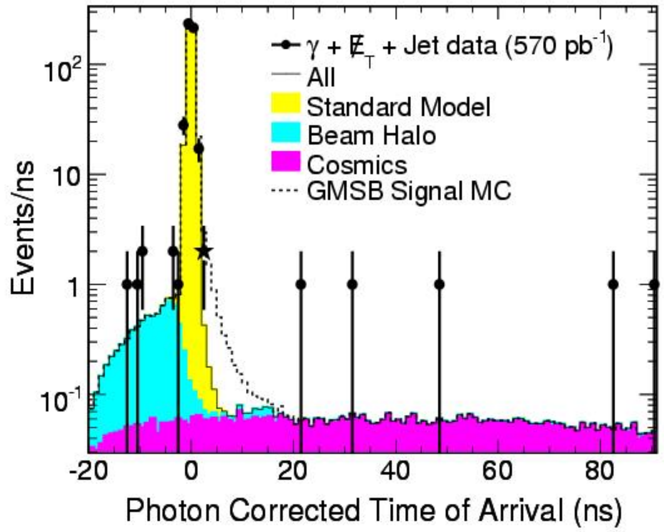
GMSB χχ→γγ+MET (2)

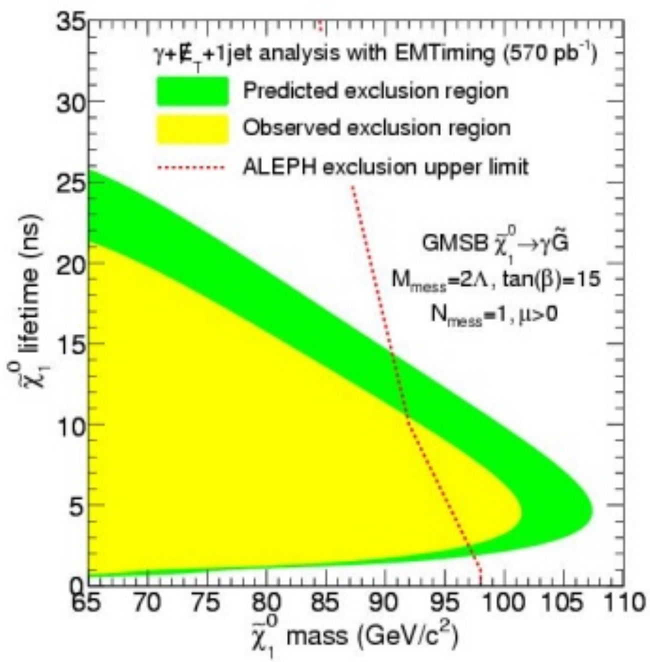


Long-lived neutralinos

- L = 570 pb^{-1}
- Looking fro neutralino to gamma+gravitino
- The photon is "delayed" since it is originated from the decay of the neutralino
- Signature: photon + jet + MET
- Investigated GMSB signal
  - M_mess = 2 Lambda, tanbeta=15, mu>0 N_mess = 1
- Backgrounds:
  - Collision: γ+jet+fake-MET, di-jet + fake-MET, W → e ν
  - Non-collision: cosmic rays and beam effects
- Preselection:
  - photon ET> 30 , met ET> 30, jet ET>30 GeV
  - Geometric separation of muon hits and gamma (cosmic reduction)
  - Delayed signal 2 ns – 10 ns
  - Selection optimized for neutralino mass of 100 GeV/c^2 and lifetime of 5 ns
- Optimization of final cuts
  - MET>40, JET_ET>35, Δϕ(Jet-met)>1 rad, 2 ns <t<10 ns.
- m(neutralino)>101 GeV for lifetime of 5 ns.

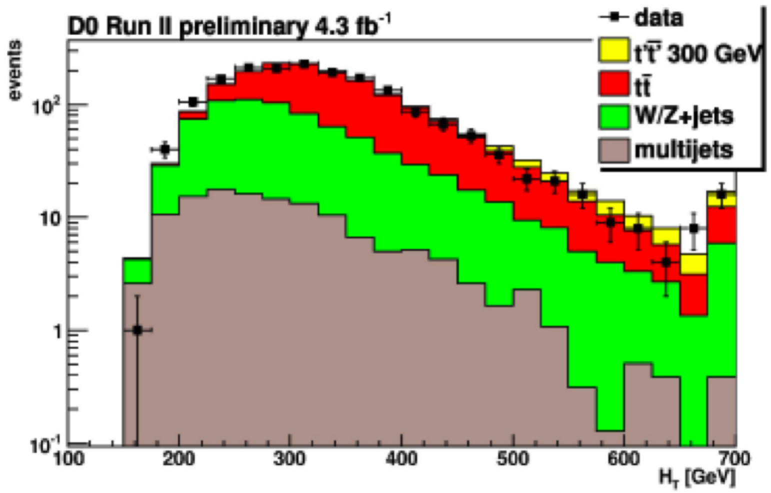
PRL 99, 121801 (2007)

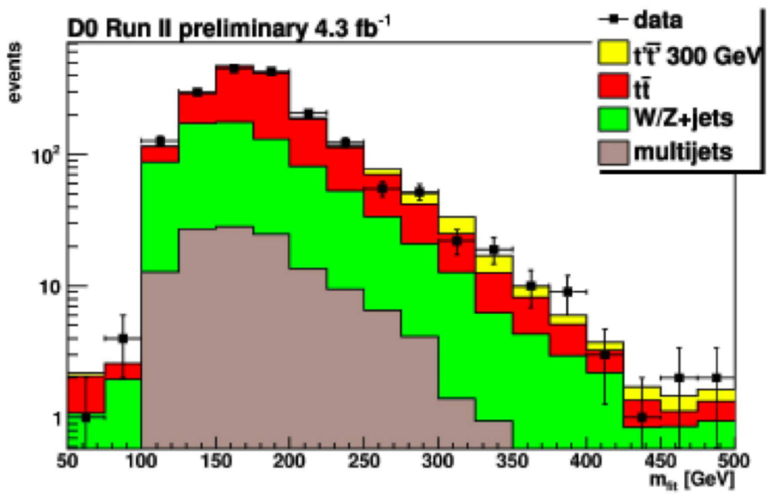




t' D0 result from Verzocchi's wine+cheese

t' Search (I)





Use 4.3 fb^{-1}

Similar selection to top cross section measurement

Use H_T and $m_{t'}$ to build 2D discriminant

Slight excess observed in data

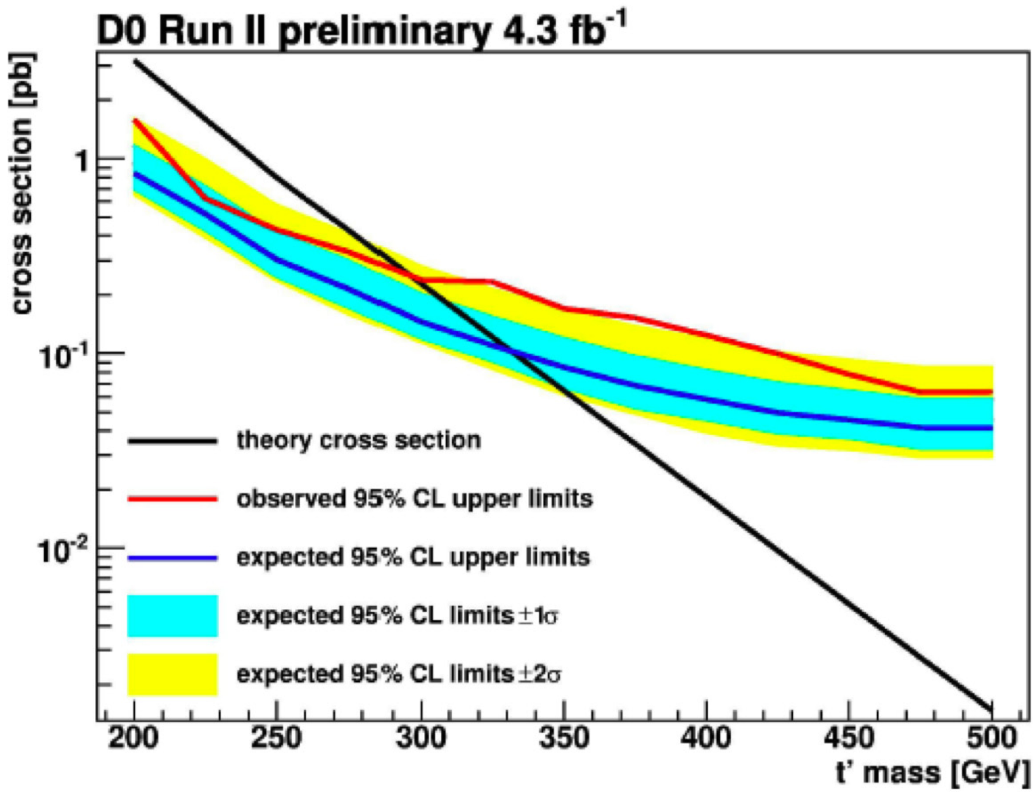
Set lower limit on t' mass

t’ D0 result from Verzocchi’s wine+cheese (2)

t' Search (II)

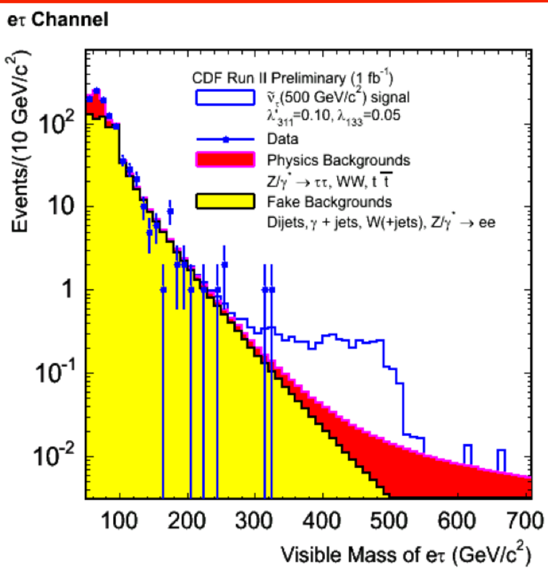
Expected limit $m_{t'}$ > 330 GeV

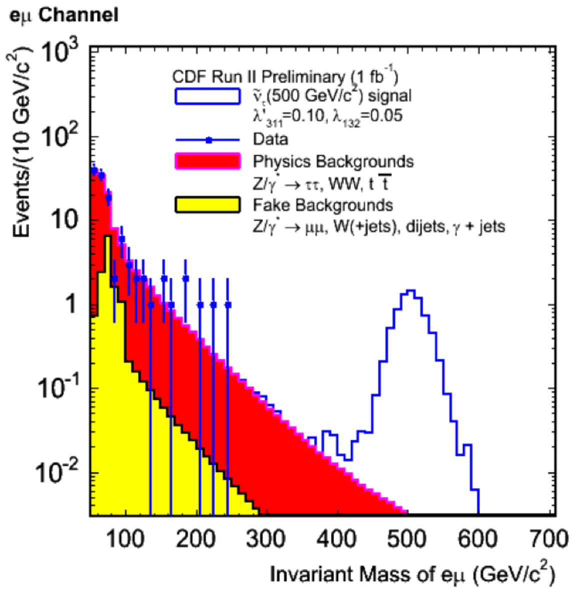
Observerd limit $m_{t'}$ > 296 GeV @ 95% C.L.



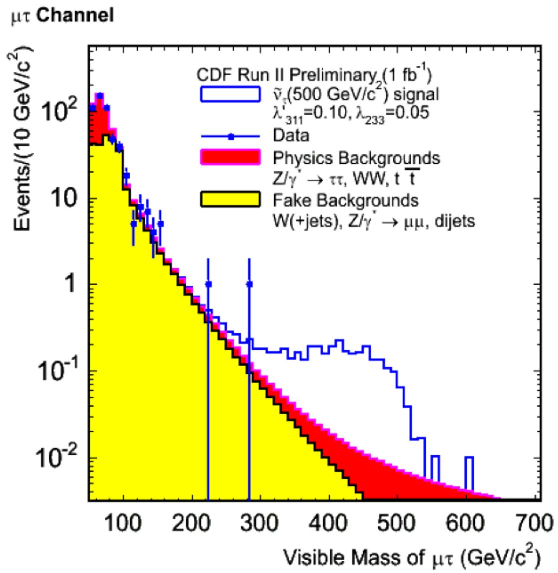
R-parity violating sneutrino→eμ or eτ or μτ

- $L = 1\ fb^{-1}$
- Selection: eμ, eτ, μτ
  (e,μ:pT>20, τ:pT>20 GeV/c)
- SM backgrounds: Z→ττ, diboson, tt, W/Z+ fakes
- Control regions: 50-110 GeV/c^2
- Benchmark Signal regions: $M_{e\mu}$>500, $M_{e\tau}$>310, $M_{\mu\tau}$>280 GeV/c^2
- Observation consistent with SM expectation
- **Set limits on RPV sneutrinos**





Channel	Mass cut (GeV/c^2)	N_{exp}	N_{obs}
eμ	500	0.1 ± 0.1	0
eτ	310	1.4 ± 0.3	2
μτ	280	1.0 ± 0.3	2

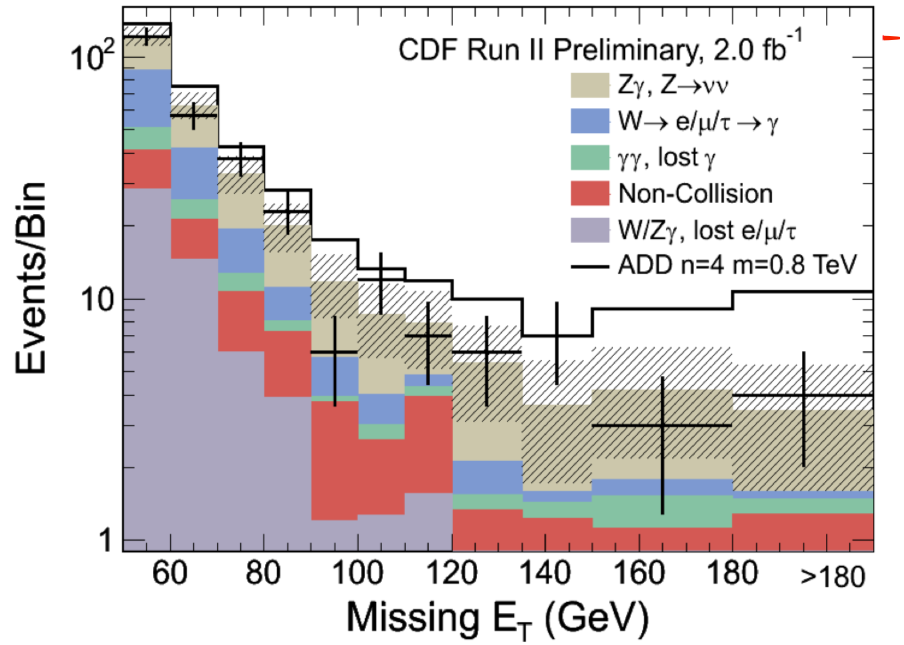


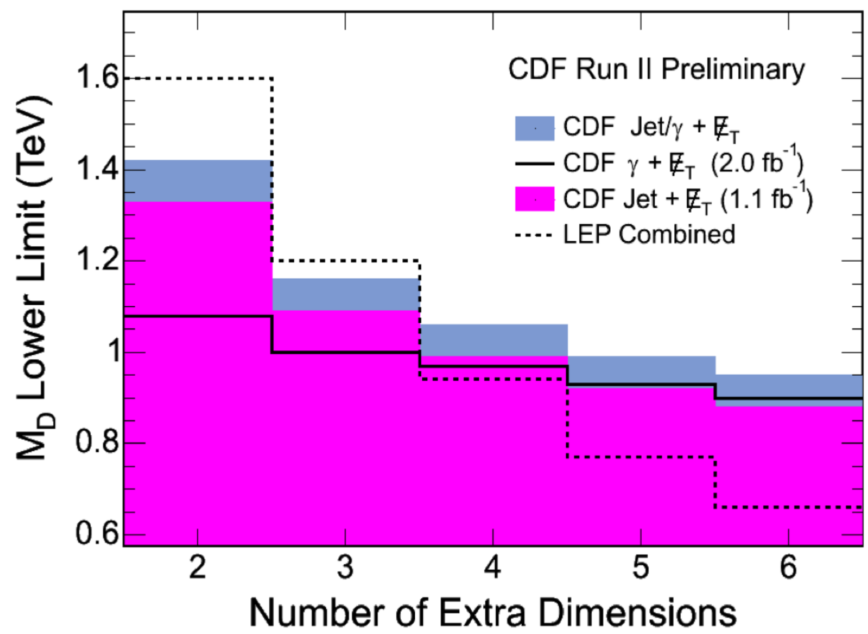
Large extra dimensions

Extra dimensions (γ+MET)

- $L = 2\ fb^{-1}$
- Signal: G+γ → MET + γ
- Selection: $E_\gamma > 90$ GeV
  MET > 50 GeV
  No jets(tracks) above 15(10) GeV
- SM backgrounds: Z+γ→ννγ(54%), cosmics (20%),W+γ (10%), W→fake γ (6%),γγ (5%)
- Expect 46.7 ± 3 SM and observe 40
- **Set limits on number and mass-scale of Large extra dimensions (combined with the jet+MET analysis)**

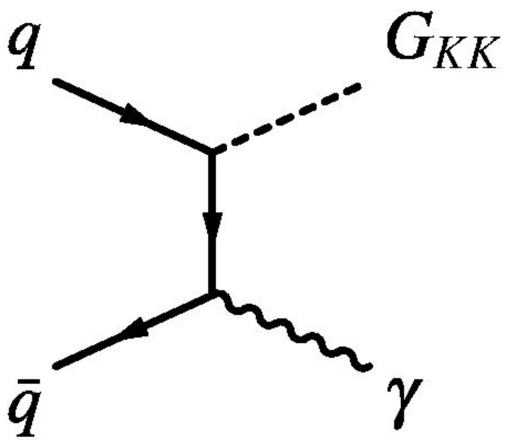
Phys. Rev. Lett **101**, 181602 (2008)

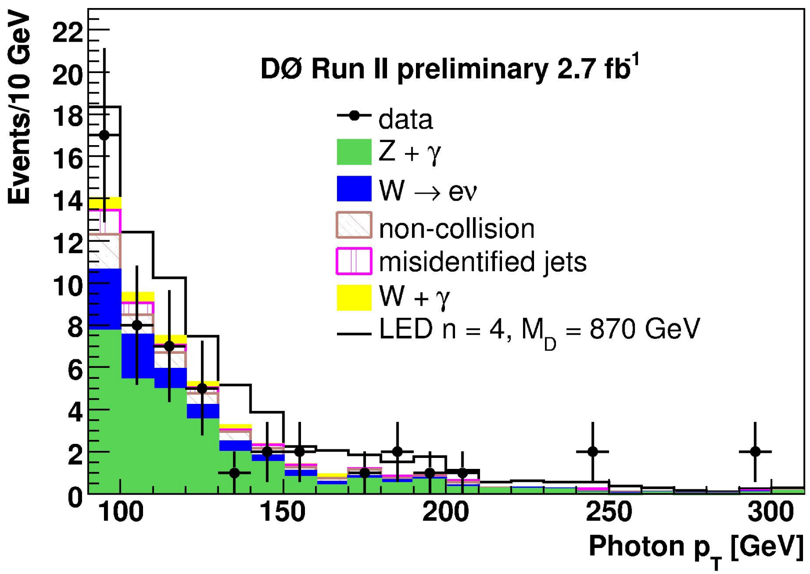


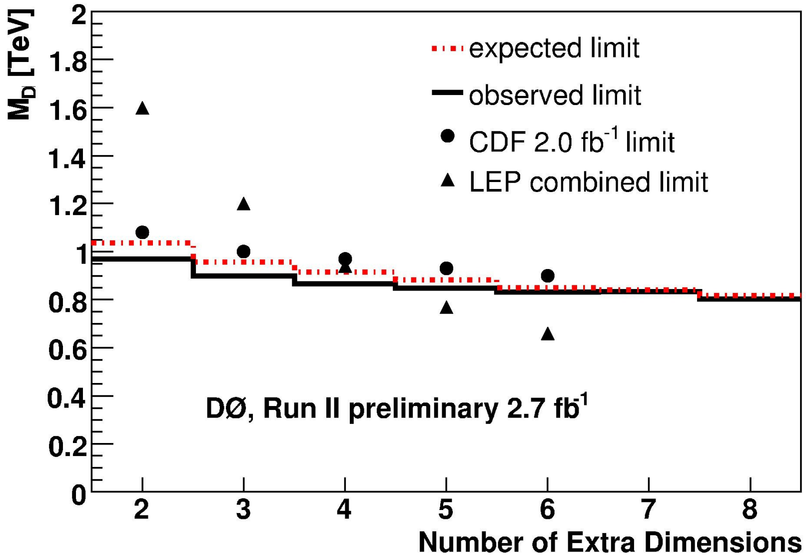


D0 Large extra dimensions

- 2.7 fb^{-1}
- Photon > 90 GeV
- MET > 70 GeV
- Jet veto







CDF chargino/neutralino and squark/gluino

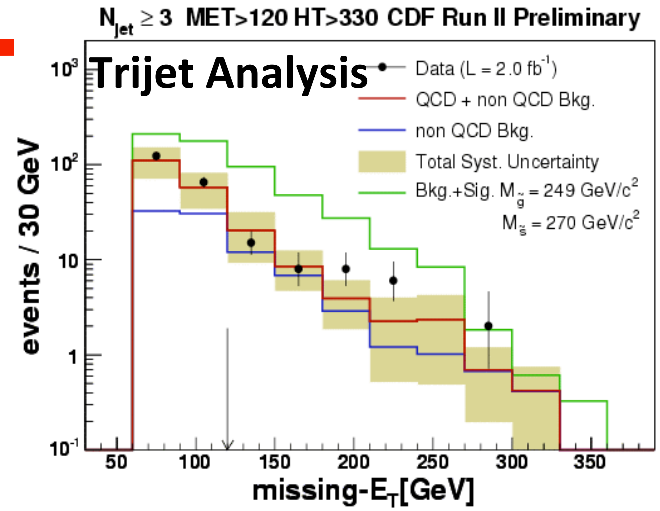
Gluino-Squark

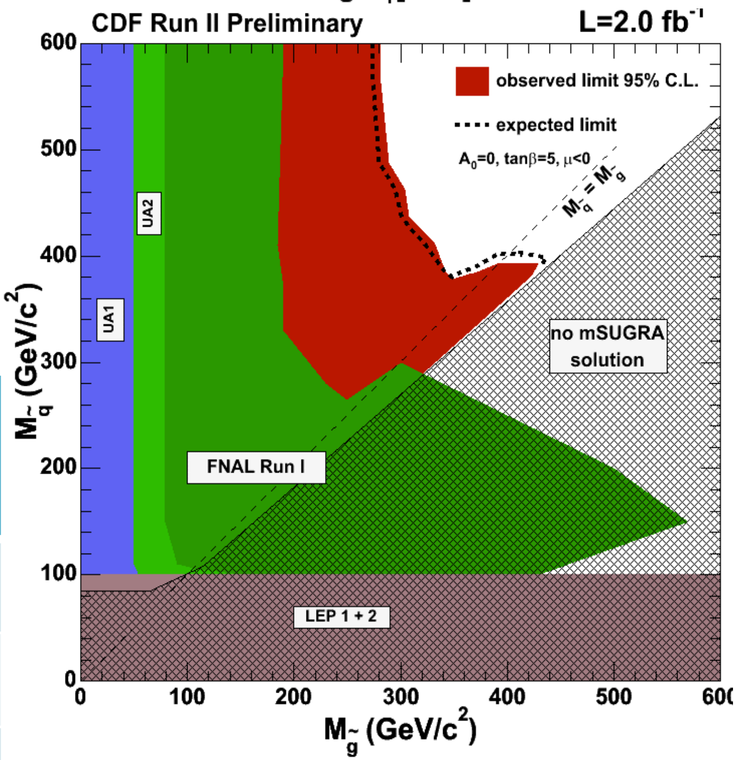
arXiv:0811.2512 [hep-ex]

- L = 2 fb^{-1}
- Signature: Jets + MET
- Selection:
  - High MET (for QCD reduction)
  - lepton-veto (for top and boson reduction)
  - small jet-met angle (for QCD reduction)
  - separate optimized cuts for 3 analyses
- Backgrounds: QCD multijets, Z+jets, W+jets, top, diboson
  - (all MC, for QCD it is normalized to data at low-met)

95% CL: Mass of gluino > 392 GeV/c^2

Analysis	HT cut (GeV)	MET cut (GeV)	Jet Et (GeV)	Bckg.	DATA
Dijet	330	180	165,100	16 ± 5	18
Trijet	330	120	140,100,25	37± 12	38
4-jet	280	90	95,55,55,25	48 ± 17	45





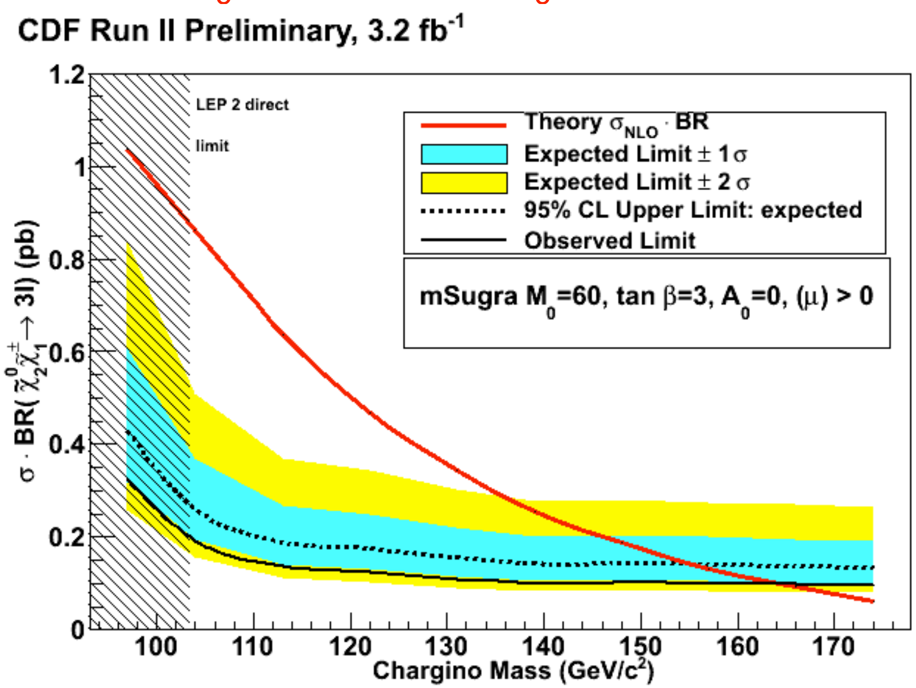
Result and limits

- Our counting result is consistent with the Standard Model

Analysis	Backg.	Signal	DATA
Trilepton	**1.5 ± 0.2**	7.4 ± 0.7	**1**
Dilepton+Track	**9.4 ± 1.4**	11.2 ± 1.1	**6**

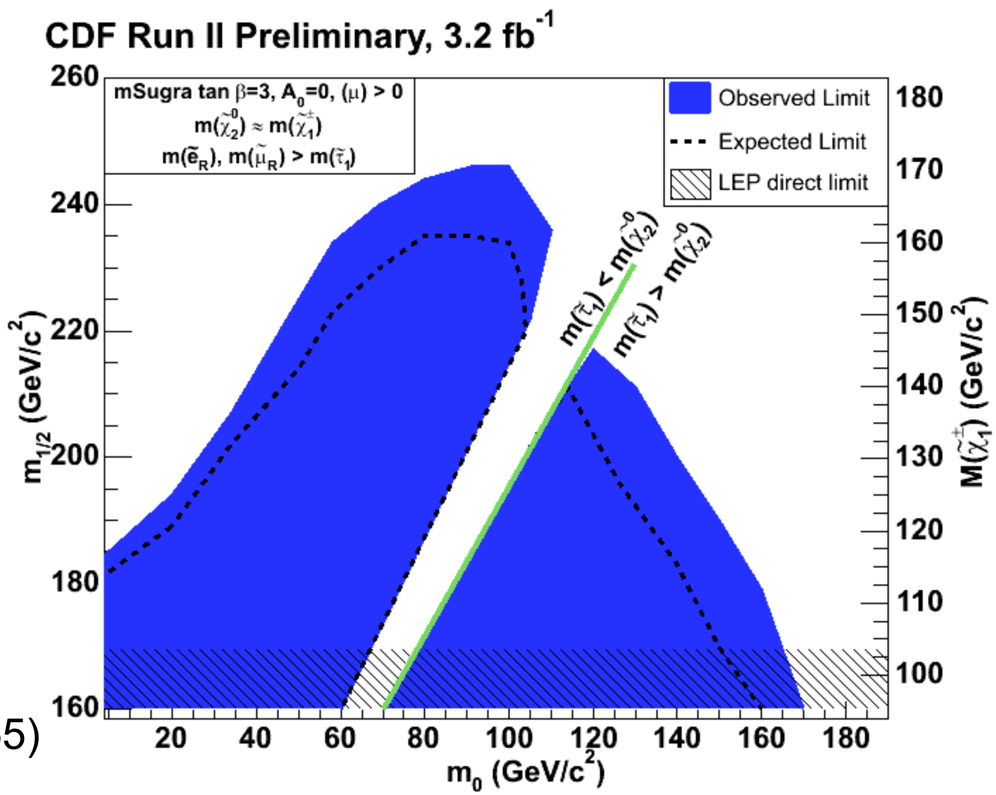
m_0=60 GeV,
$m_{1/2}$=190 GeV,
tanβ=3, A_0=0, μ>0

(m_0=60 ,tanβ=3, A_0=0, μ>0)



$M(\chi_1^{\pm})$ > 164 GeV/c² at 95% CL (expected 155)

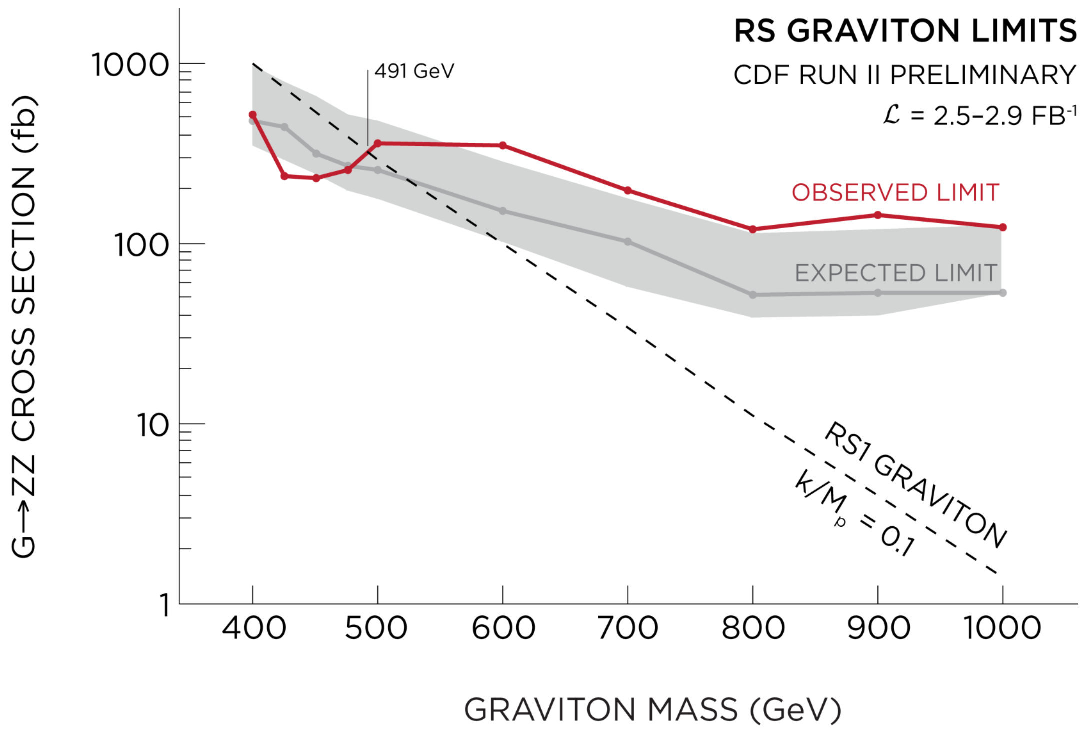
(tanβ=3, A_0=0, μ>0)

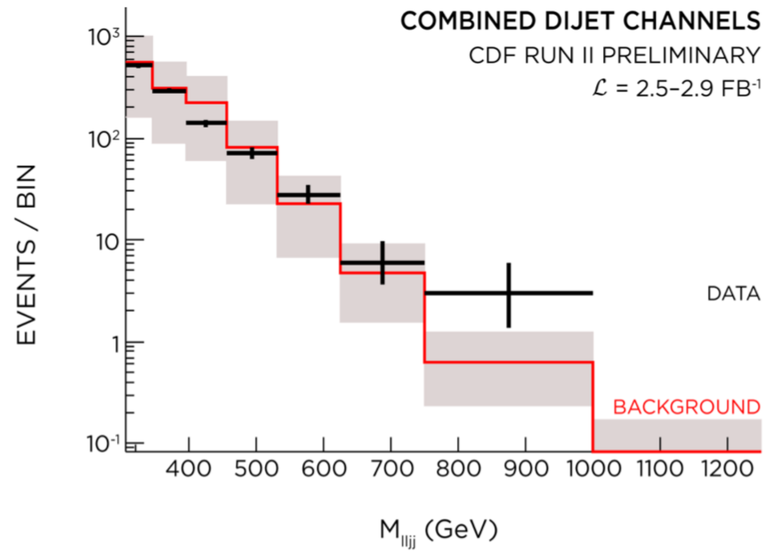


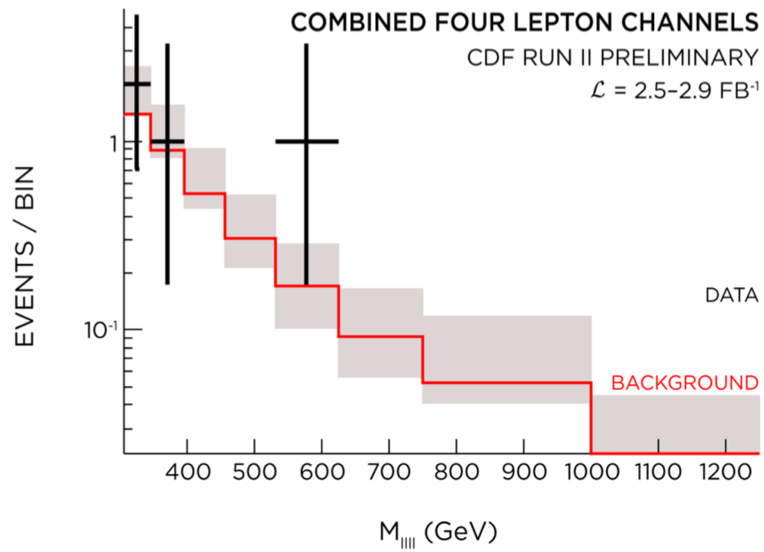
Older analyses

Search for high-mass $X \rightarrow ZZ$ resonance

- L = 2.5-2.9 fb^{-1}
- Signature: $X \rightarrow ZZ \rightarrow \ell\ell\ell\ell$ or $\ell\ell jj$, ℓ=e or μ
- Selection: ee(μμ) of 5,20 (2 or 10, 20) GeV/c
- SM backgrounds: W+jets, Z+jets, QCD, diboson
- Signal region: based on the recontructed Z-mass probability and M_X>300 GeV/c^2
- Observation consistent with expectation



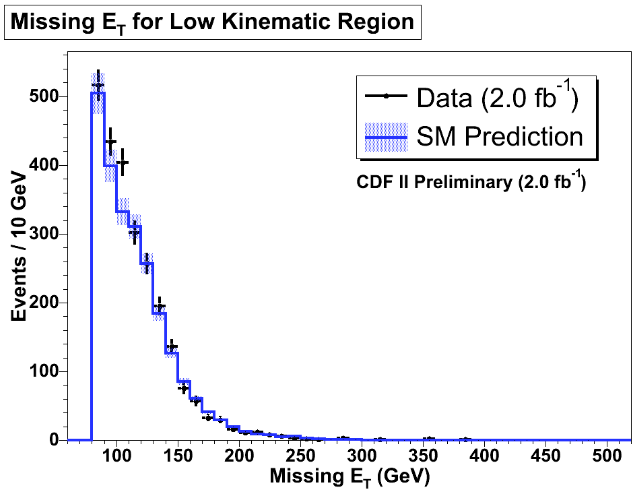


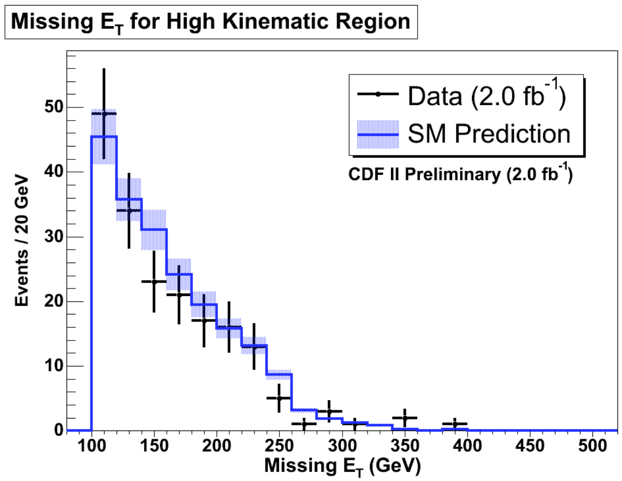


jet+jet+MET (CDF leptoquarks)

- # 2 Jets with ET > 30 GeV
- # No 3rd Jet with ET > 15 GeV
- # Scalar Jet HT > 125 GeV
- # Event Missing ET > 80 GeV
- Main backgrounds: Z→νν, W→lν

- # 2 Jets with ET > 30 GeV
- # No 3rd Jet with ET > 15 GeV
- # Scalar Jet HT > 225 GeV
- # Event Missing ET > 100 GeV
- Main backgrounds: Z→νν, W→lν



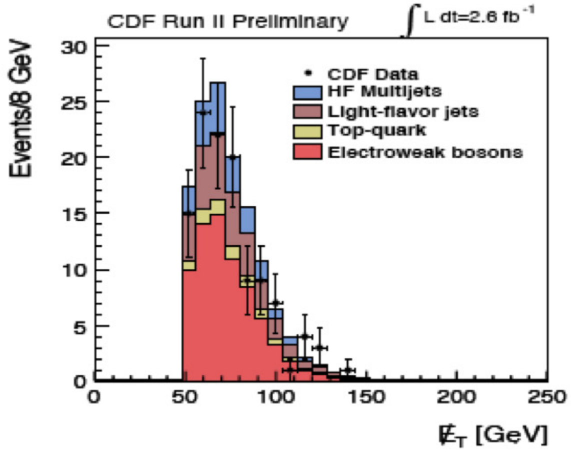


Leptoquark Generation	Lower mass limit (GeV/c^2)	Higher cross-section limit (pb)
1st and 2nd	190	0.29
3rd	178	0.442

Sbottom to c + neutralino

Search for Direct Stop Production

- MSSM scenario with conserved R_P with BR($\tilde{t}_1 \to c\,\tilde{\chi}_1^0$) = 100%.
- Final state with 2 c-jets and MET.
- NN-based flavor separator algorithm to enhance the c-tagging efficiency.
- QCD and mistags from DATA, other bkg from MC simulation.
- Sensitivity optimized with NN-based selection.
- No hint for SUSY, 95% CL limit:
  - $M_{\tilde{t}}$>180 GeV/c^2 (with $M_{\tilde{\chi}}$~90 GeV/c^2)



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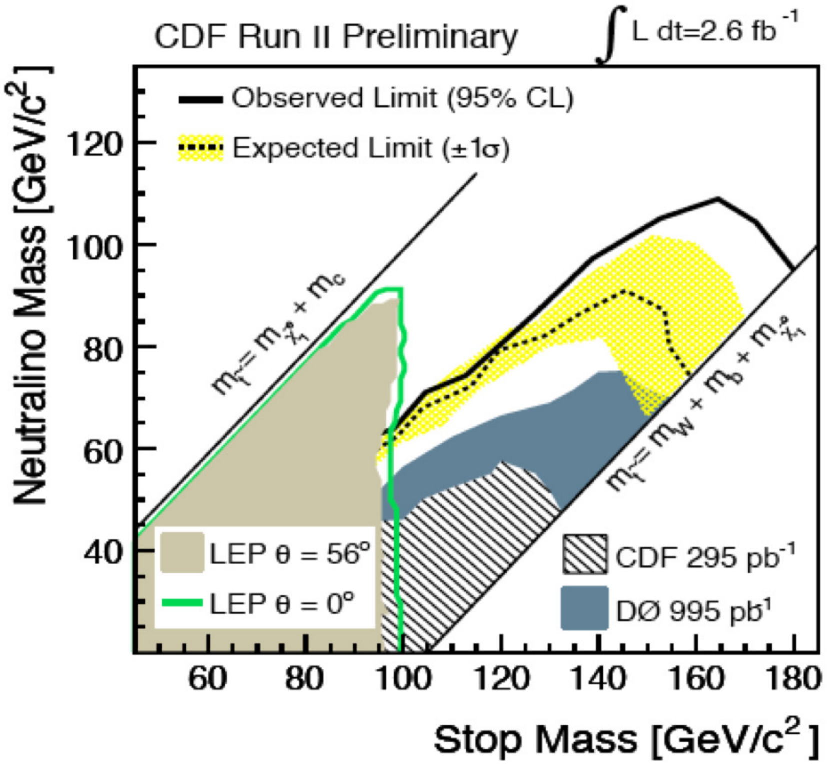


Systematic uncertainties:

- 20% on bkg and 25% on signal dominated by the uncertainty on mistag rate and flavor separator algorithm.

Gianluca De Lorenzo, IFAE Barcelona

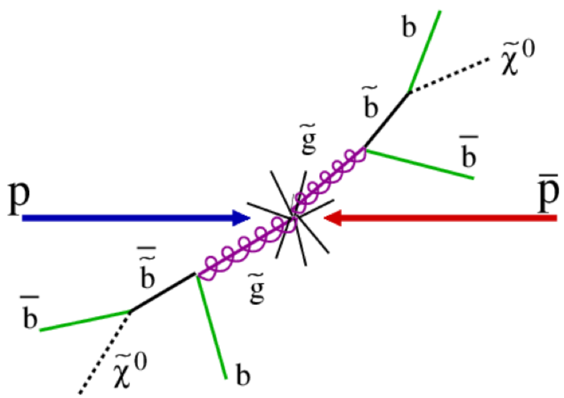
Gluino-mediated sbottom

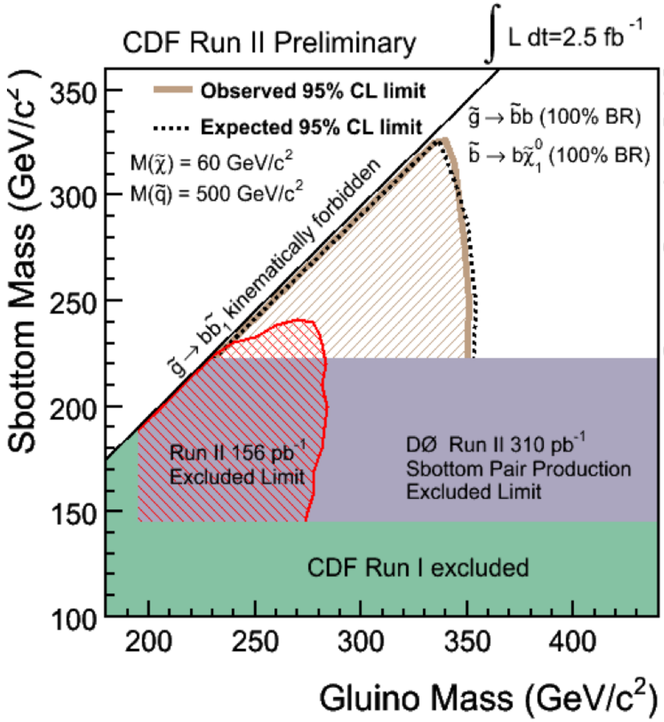
- L = 2.5 fb^{-1}
- Selection: ≥2 jets (25,35) GeV

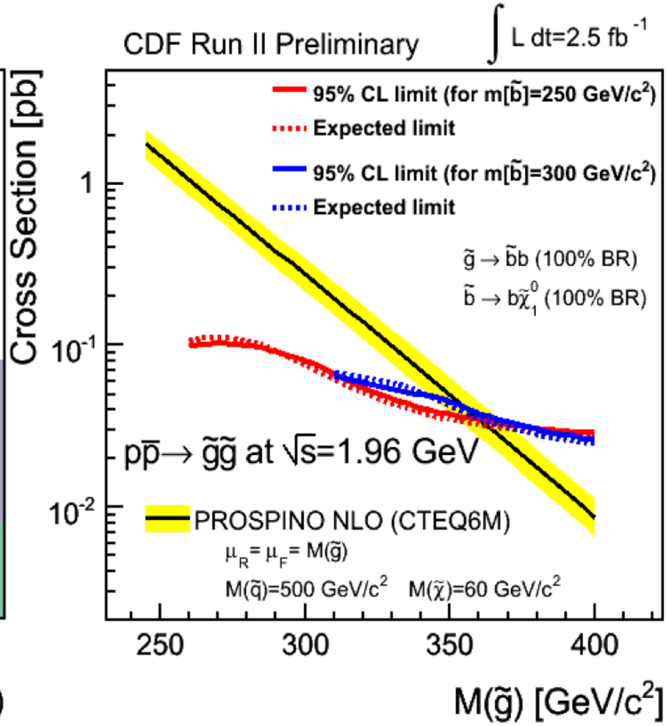
  MET > 70 GeV

  either 1 b-jet or ≥2 b-jets
- Study of QCD and EWK control regions
- Two signal hypotheses used for optimization:

  A: Large Δm: M(gluino) = 335 GeV/c^2, M(sbottom) = 260 GeV/c^2, M(neutralino) = 60 GeV/c^2
- **B: Small Δm: M(gluino) = 335 GeV/c^2, M(sbottom) = 315 GeV/c^2, M(neutralino) = 60 GeV/c^2**
- SM backgrounds: QCD (light and heavy flavor), top pair, W/Z+jets
- For two-b-jet analsis:For optimization A (B) Expect 4.5 ± 1.4 (2.3 ± 0.8) SM events and observe 5 (2)
- M(gluino)>350 GeV at 95% CL





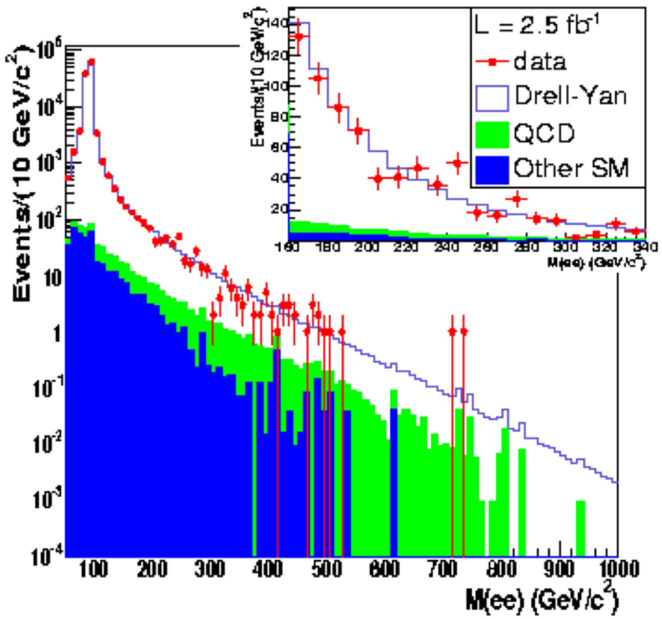


Search for high-mass X→ee or μμ resonance

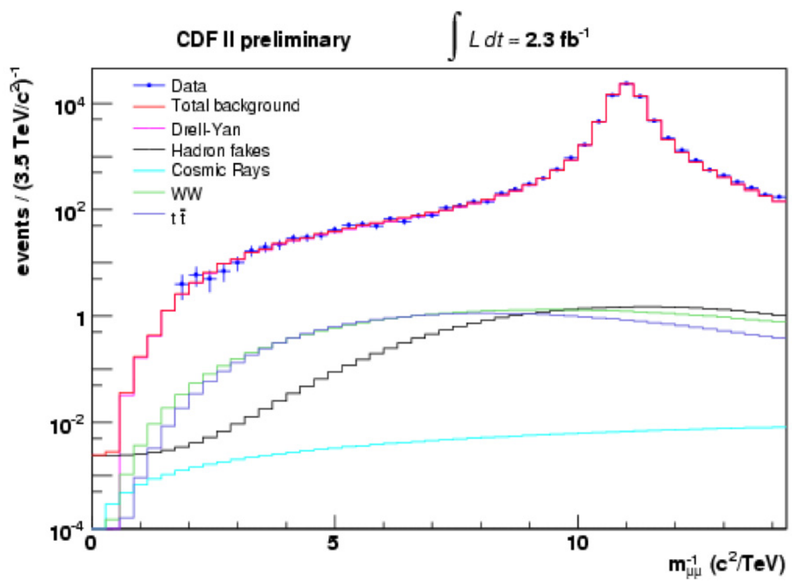
- L = 2.3-2.5 fb^{-1}
- Possible signal investigated
  - Spin 0 (RPV sneutrino)
  - Spin 1 (Z')
  - Spin 2 (Randall-Sundrum Graviton)
- Selection: 2 μ (2e), opposite charge,p_T>30 (25) GeV/c
- Backgrounds: **Drell-Yan**,diboson,tt,fakes

- ee →Observation consistent with expectation with the exception of the 241 GeV/c^2 window
  - "local" 3.8 σ
  - Probability to see that from 150 GeV - 1 TeV is 0.6% (2.5 σ)
- μμ→Observation consistent with expectation

- Set limits for different bosons:
  - **M(Z'$_{SM}$)>1030 (966) GeV/c^2** using μμ (ee)
  - **M(Graviton)>921 (850) GeV/c^2** for k=0.1M_{Pl} using μμ (ee)
  - **M(sneutrino)>866(397) GeV/c^2** for λBR=0.01(0.0001)



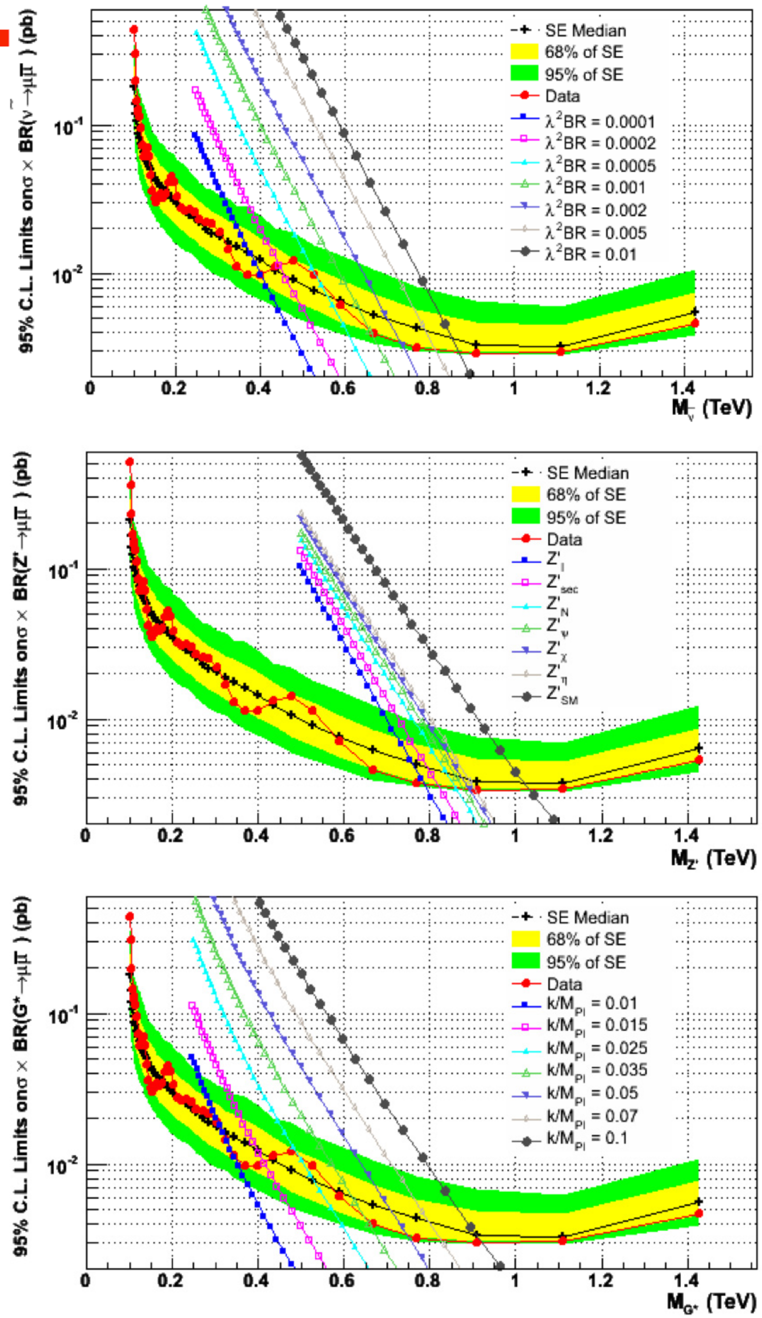
Phys. Rev. Lett. 102, 031801 (2009)



arXiv:0811.0053v1 [hep-ex]

Search for high-mass $X \to \mu\mu$ resonance

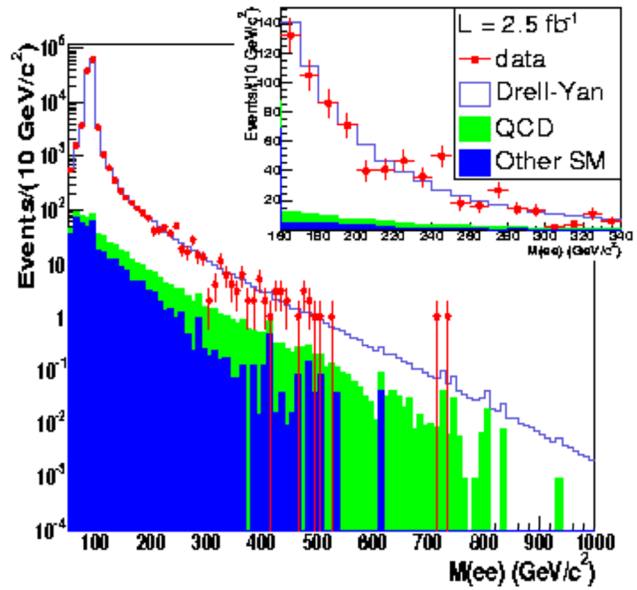
- $\underline{L = 2.3\ fb^{-1}}$
- Possible signal investigated
  - Spin 0 (RPV sneutrino)
  - Spin 1 (Z')
  - Spin 2 (Randall-Sundrum Graviton)
- Selection: 2 μ, opposite charge, $p_T > 30$ GeV/c
- Backgrounds: **Drell-Yan**, diboson, tt, fakes
- Strategy: Normalize dimuon background template to the data from 70-100 GeV/c^2 and look for resonance at the high mass tail (> 100 GeV/c^2)
- Observation consistent with expectation
- Set limits for different bosons:
  - **M(sneutrino)>866(397) GeV/c^2** for λBR=0.01(0.0001)
  - **M(Z')>1 TeV/c^2**
  - **M(Graviton)>921(293) GeV/c^2** for $k=0.1M_{Pl}(0.01M_{Pl})$

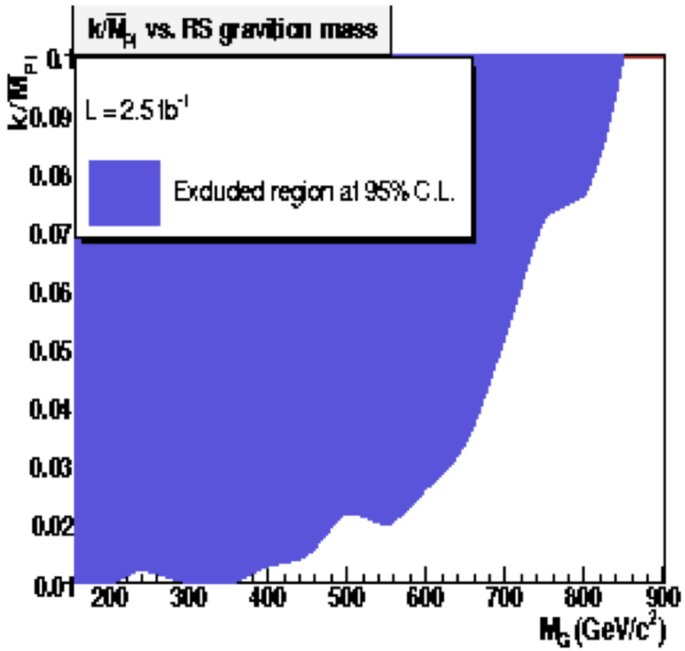


Search for high-mass X→ee resonance

- $\underline{L = 2\ fb^{-1}}$
- Possible signal investigated
  - Spin 1 (Z')
  - Spin 2 (Randall-Sundrum Graviton)
- Selection: 2 e, opposite charge, p_T>25 GeV/c
- Backgrounds: **Drell-Yan**, diboson, tt, fakes
- Scan procedure: Use likelihood ratio L_b/L_{s+b} and scan the dielectron mass spectrum from 150 GeV/c^2 to 1 TeV/c^2
- **Observation consistent with expectation with the exception of the 241 GeV/c^2 window**
  - "local" 3.8 σ
  - Probability to see that from 150 GeV - 1 TeV is 0.6% (2.5 σ)
- Set limits for different bosons:
  - **M(Z')>966 GeV/c^2**
  - **M(Graviton)>850GeV/c^2** for k=0.1M_{Pl}(0.01M_{Pl})

CDF Run II Preliminary





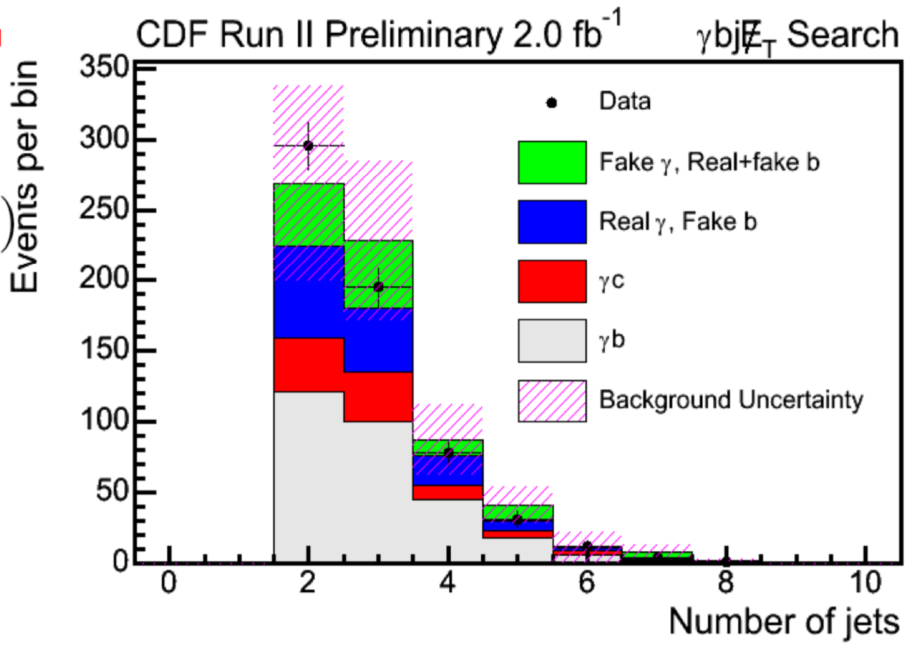
Photon+jet+MET+b-jet

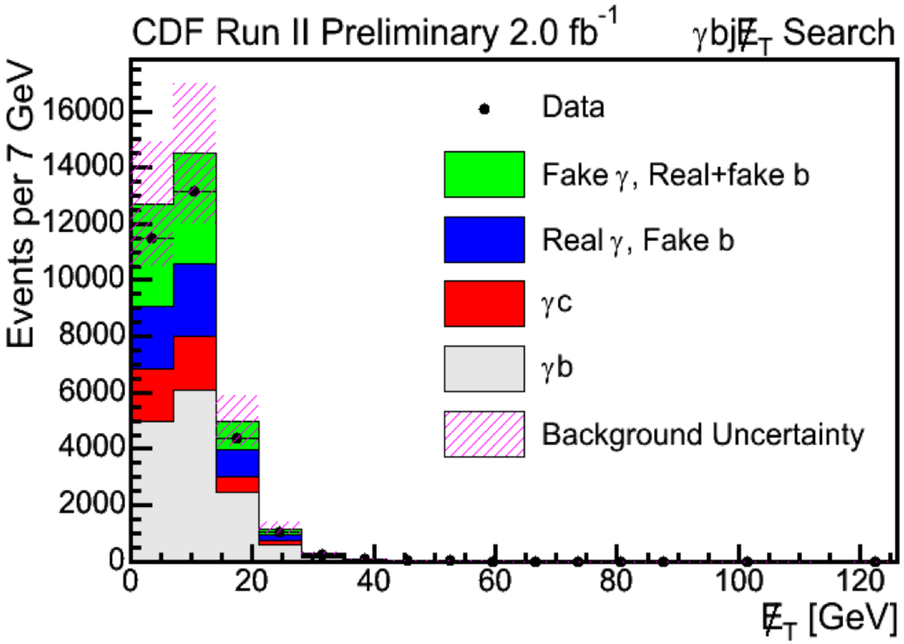
- L = 2 fb^{-1}

$$\tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow (\bar{b}\tilde{t})(\gamma\tilde{\chi}_1^0) \rightarrow (\bar{b}c\tilde{\chi}_1^0)(\gamma\tilde{\chi}_1^0) \rightarrow (\gamma\bar{b}c\not{E}_T)$$

- Selection: 2 jets > 15 GeV (at least one b-tagged), 1 photon > 25 GeV, jet-jet and jet-photon separation of ΔR>0.4
- Backgrounds: multijets+(real/fake) photon+fake MET
  - b-tag can be real or fake
- Estimate fake-γ from shower shapes
- Estimate real-γ/real-b from MC
- Estimate real-γ/fake-b with mistag matrix

- Observation consistent with expectation
  - Expect 637 ± 139 from SM and observe 617

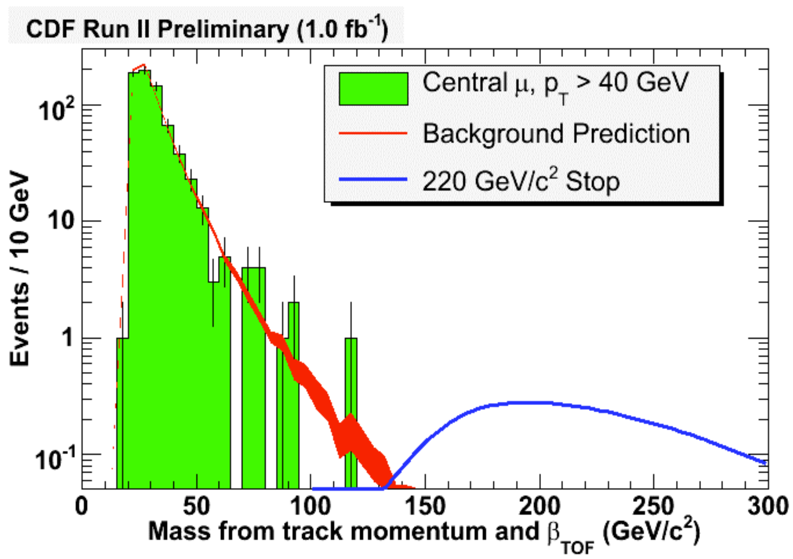


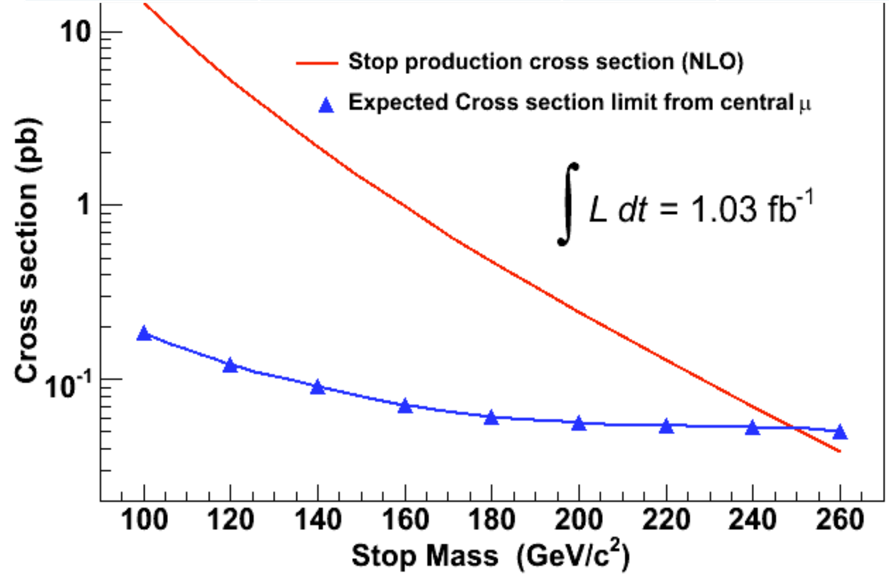


Long-lived top as CHAMP

- L = 1.0 fb^{-1}
- Slow particle signature : slowly-moving highly-ionizing highly-penetrating particle
  - Will look like muon with possible calorimetry energy deposition
- Goal: Measure Time of Flight mass of tracks
- Shape of TOF mass determined by beta-resolution, measured with W→eν
- Backgrounds: Cosmics, multiple interactions

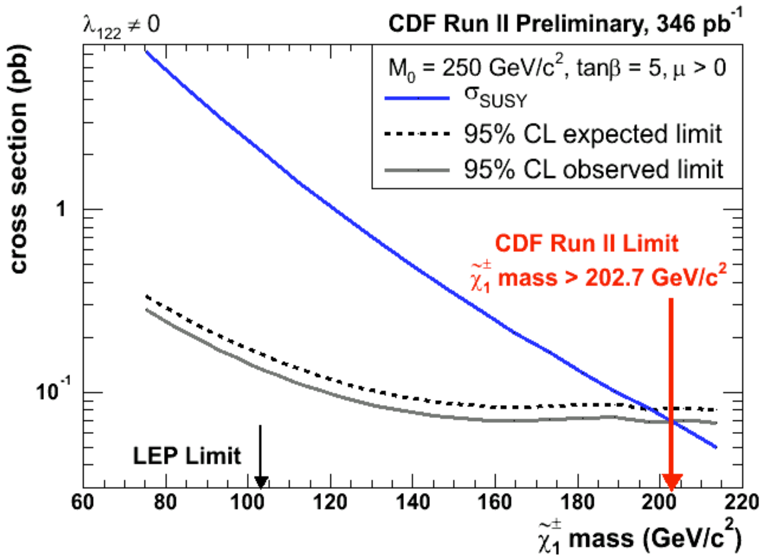
Stop Mass (GeV/c²)	Bckg.	DATA	$\sigma_{95\%}$ (fb)
100	4.7± 0.3	4	160
120	1.9± 0.2	1	90
260	(2.6 ± 0.5)10^{-2}	0	50

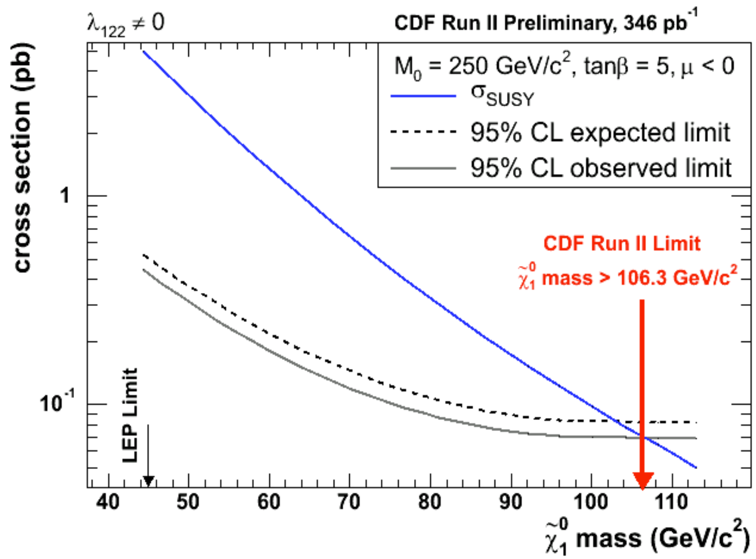




Stable stop mass > 250 GeV/c² at 95% CL

R parity violation with multileptons





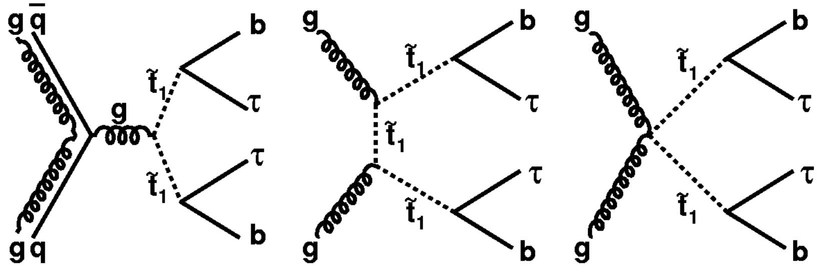
PRL 98, 131804 (2007)

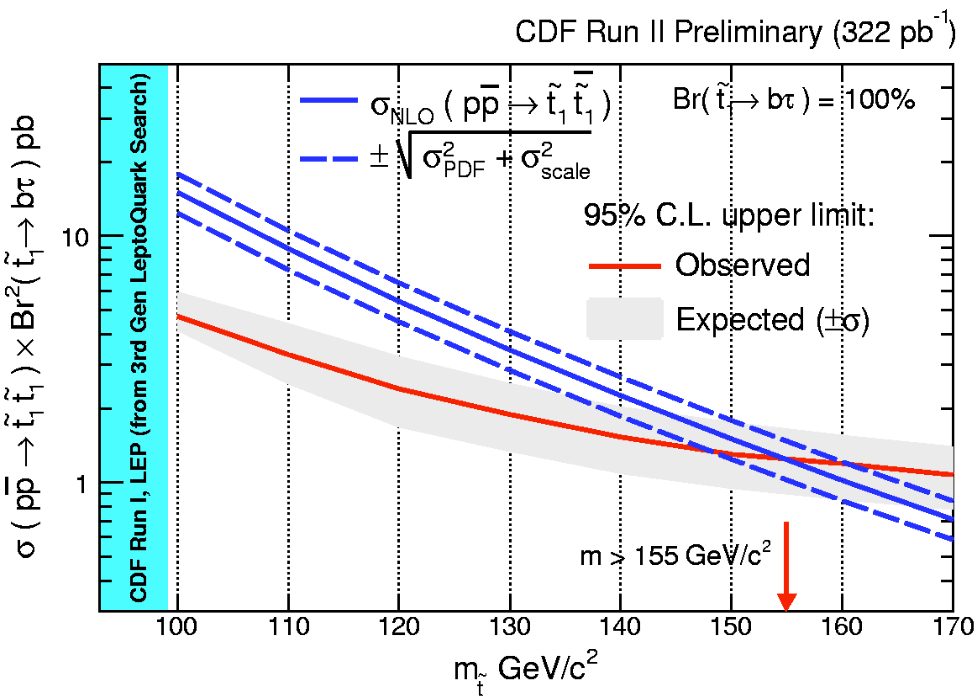
- L = 346 pb^{-1}
- Search for anomalous production of 3 or ≥ 4 leptons
- Both electrons and muons are used

Mass Limits				
	$M_{\tilde{\chi}^0_1}$ (GeV/c^2)		$M_{\tilde{\chi}^\pm_1}$ (GeV/c^2)	
SUSY Scenario	**Expected**	**Observed**	**Expected**	**Observed**
λ_{121} and μ > 0	105.0	101.5	191.9	185.3
λ_{121} and μ < 0	101.1	97.7	192.2	185.6
λ_{122} and μ > 0	107.7	110.4	197.5	202.7
λ_{122} and μ < 0	102.7	106.3	195.3	201.9

RPV stop to tau + b

- L = 322 pb^{-1}
- Process: two stops produced, each of which decay to tau + b with a BR~β
  - Selection for one hadronic and one leptonic tau
- Signature: lepton + narrow jet + 2 jets
- SM Backgrounds: QCD (bb, γ+jet) and W/Z+jets
- Selection:
  - Electron or muon with p_T > 10 GeV/c
  - Hadronic tau with p_T > 15 GeV/c
  - Conversion, cosmic removal and Z → τ τ vetos
  - Signal region (blind) N_{jets} >2 and $M_T(\ell$,MET)<35
- Expected ~2±0.5 e+τ_h and observed 1
- Expected ~1±0.5 μ+τ_h and observed 1
- For β=1, m_{stop} >151 GeV/c^2 at 95% CL





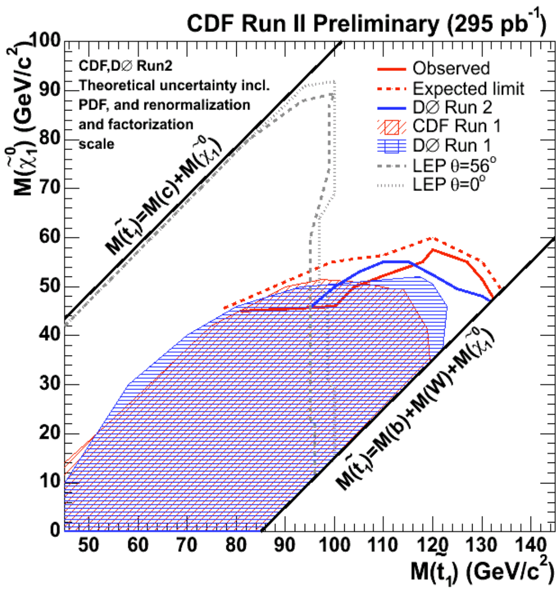
Phys.Rev.D **77**, 052002 (2008)

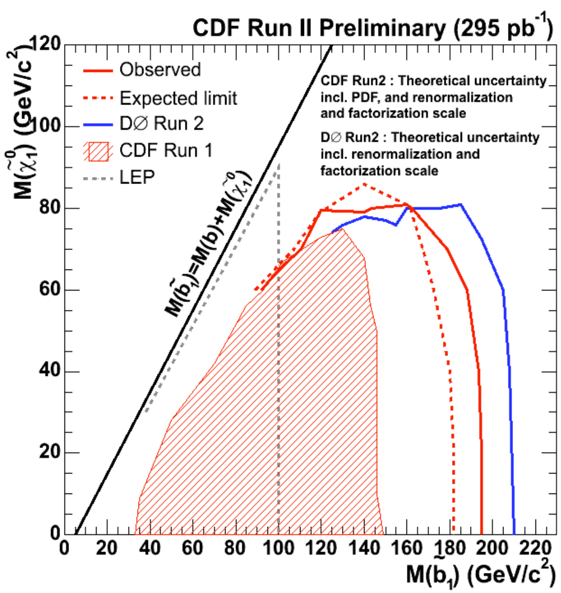
Stop-sbottom

- $L = 295\ pb^{-1}$
- Expected σ of 50 pb to 0.25 pb for stop and sbottom masses from 80 to 200 GeV/c^2
- Signature: c+cbar+MET and b+bbar+MET
- Three mass ranges for each of the sbottom and stop analyses
- Backgrounds:
  - QCD multijet (from data, normalized to low-MET and MET//jet regions)
  - W/Z+jet, single top, ttbar, diboson.
- Selection:
  - Charged particle and EM fraction cut (reduces cosmics, beam-hallo, fake jets, wrong PV selection)
  - MET>50 GeV, no additional jets, no collinear jet and met and jets not collinear or back-to-back (for QCD reduction)
  - Lepton veto and high jet track multiplicity (for W/Z+jets reduction)
  - HF tagger (efficiency 40% and 17% for b and c – 1% and 5% mistag)
- After cuts the highest source of background is Mistag and HF multi-jet
  - the latter goes to zero for the high mass region of search)

	M_{stop} <100	M_{stop} 100-120	M_{stop} >120
SM	137±1	95 ± 11	43 ± 5

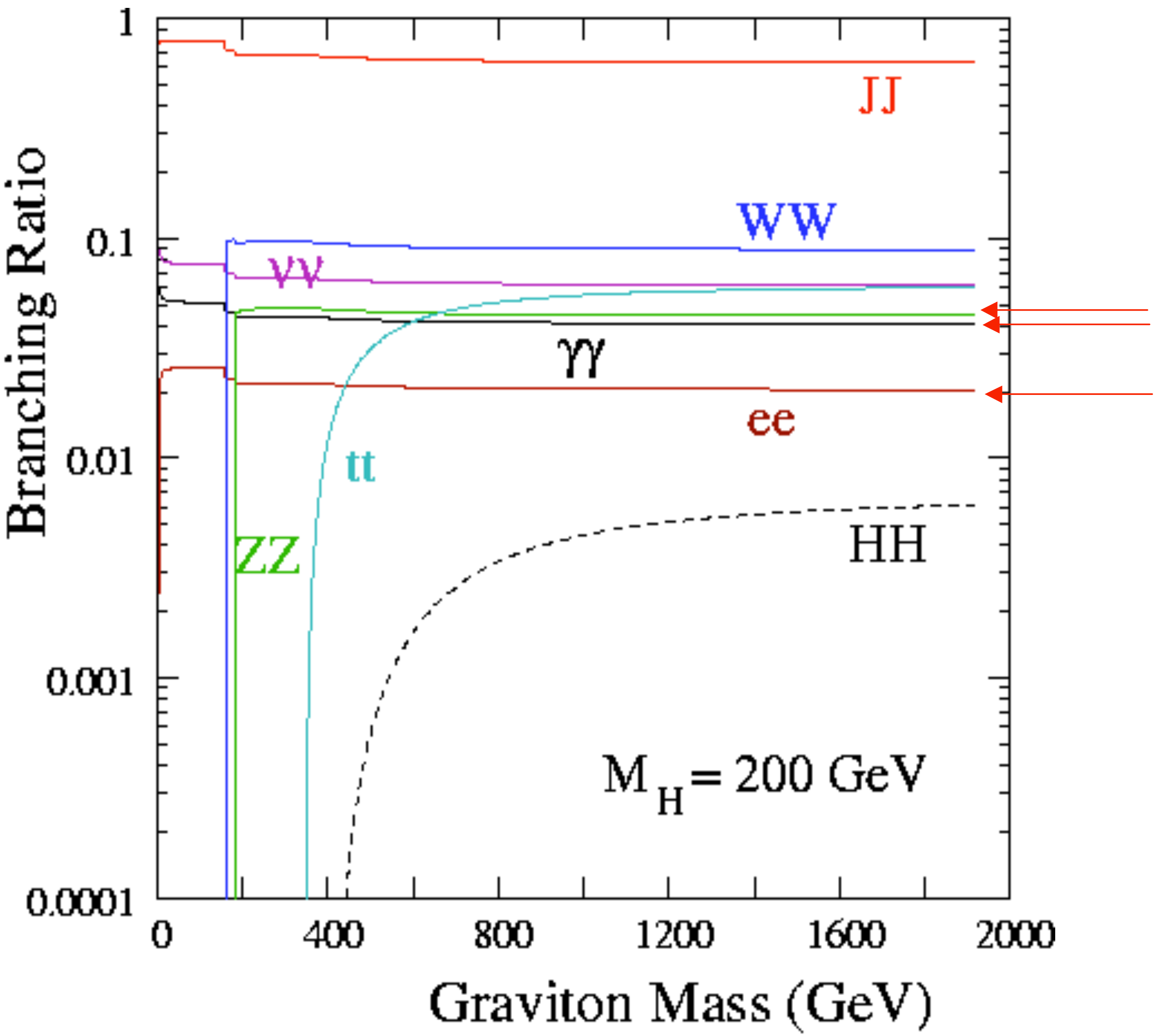
	$M_{sbottom}$ <140	$M_{sbottom}$ 140-180	$M_{sbottom}$ >180
SM	55 ± 7	18 ± 2	4.7 +2.2/-0.7
DATA	60	18	3





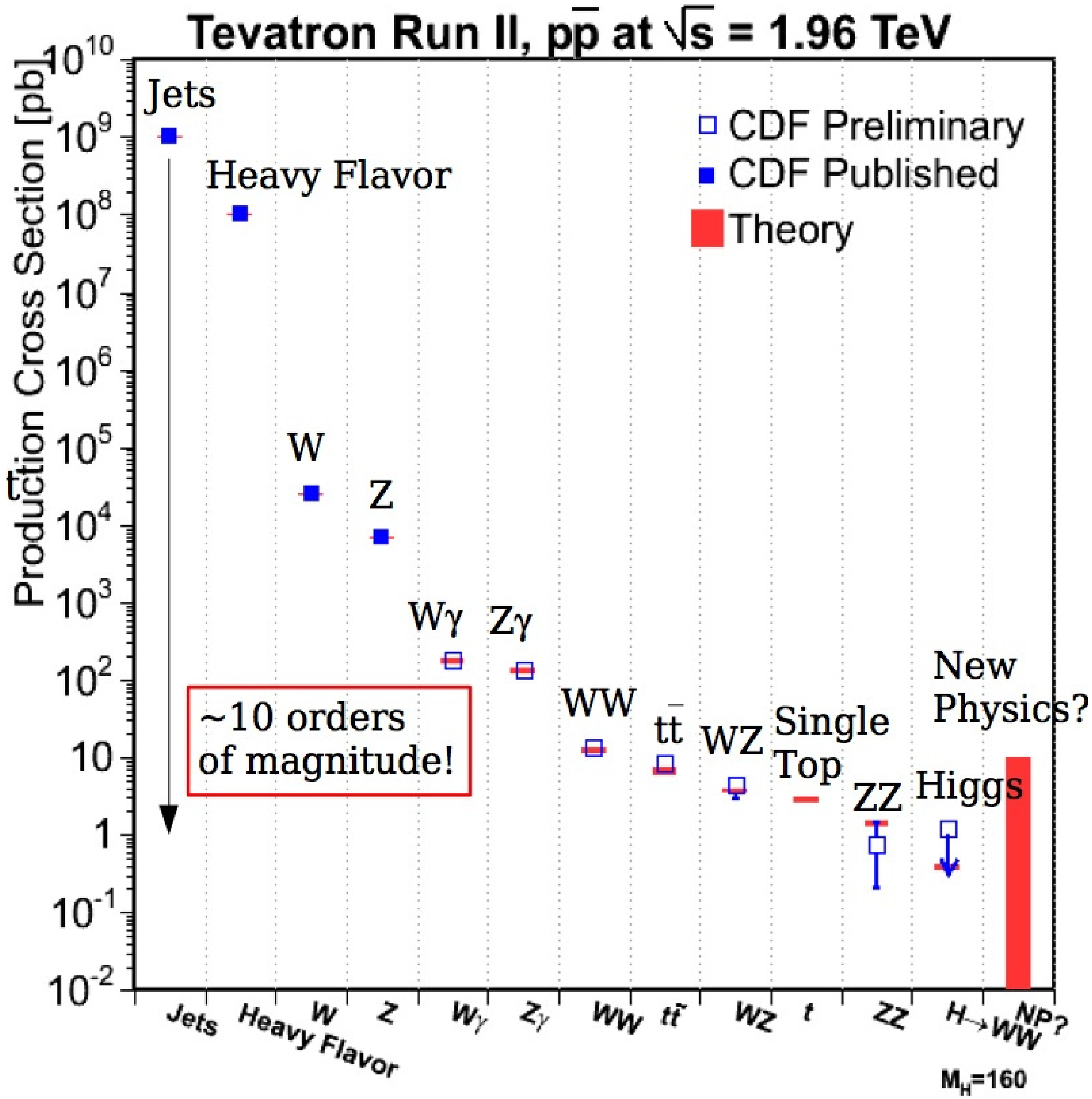
Extra material

Graviton Branching Ratios



Same for all KK modes

Feeling about the SM cross-sections

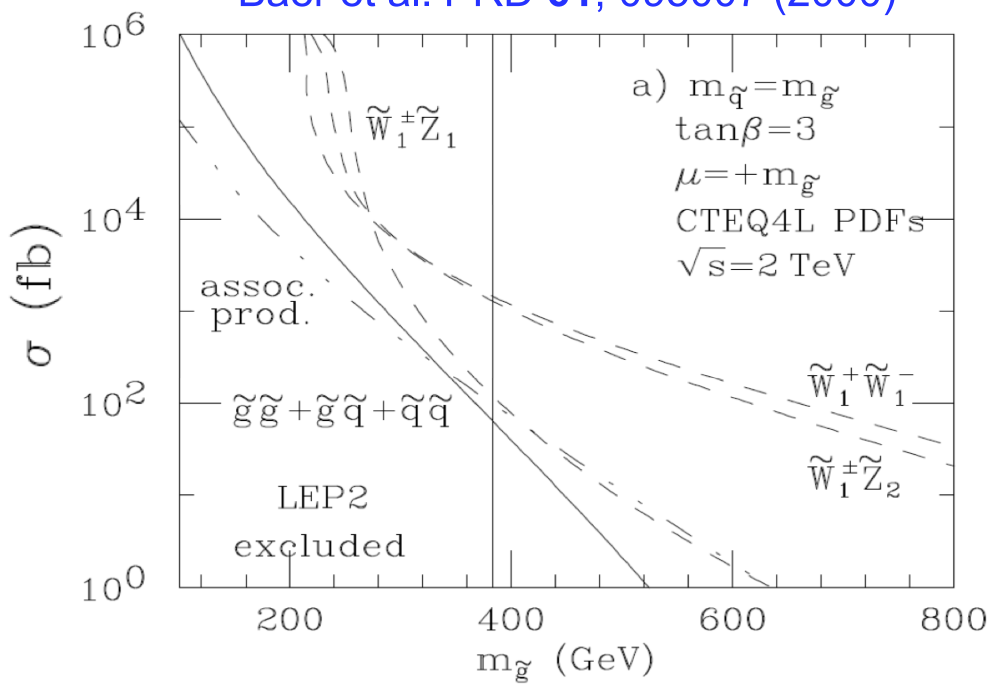


- But generic production is not enough:
- We care about the branching ratios to leptons
  - ~11%/flavor for W
  - ~3.5%/flavor for Z
- We care about the probability for jets to be mis-reconstructed as leptons
  - Depends on the jet and lepton identification requirements
  - 10^{-2} - 10^{-4}
- And we care about the trigger and reconstruction efficiency and detector acceptance

Why chargino-neutralino, why trileptons?

- The non-excluded chargino-neutralino production cross-section at the Tevatron is of the order of 0.1-1 pb, depending on the SUSY parameters

Baer et al. PRD **61**, 095007 (2000)



- The leptonic decays of the chargino and the next-to-lightest neutralino give ***3 leptons and MET***, a signature with low SM backgrounds.
- For these reasons, the trileptons are ***the golden channel for the discovery of SUSY at the Tevatron***

R-parity violation

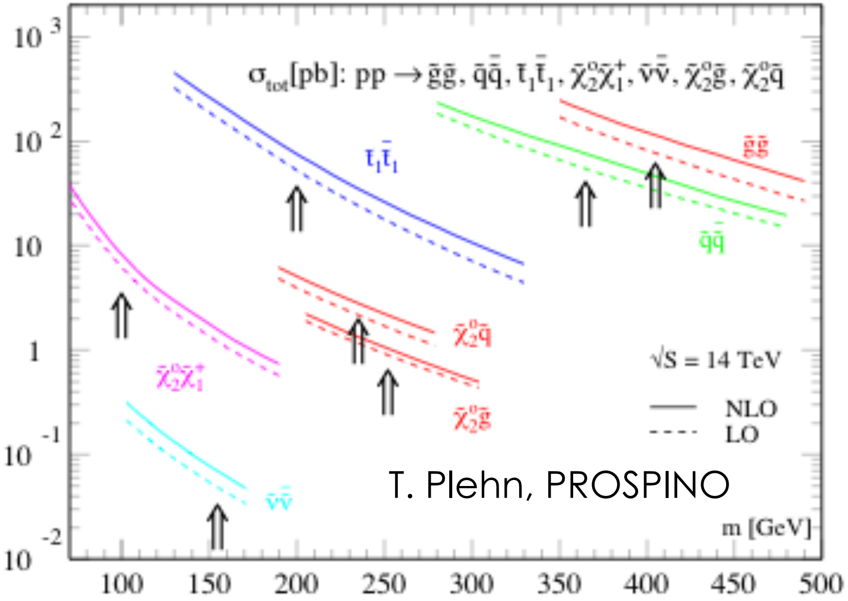
- R-parity violating part of Lagrangian

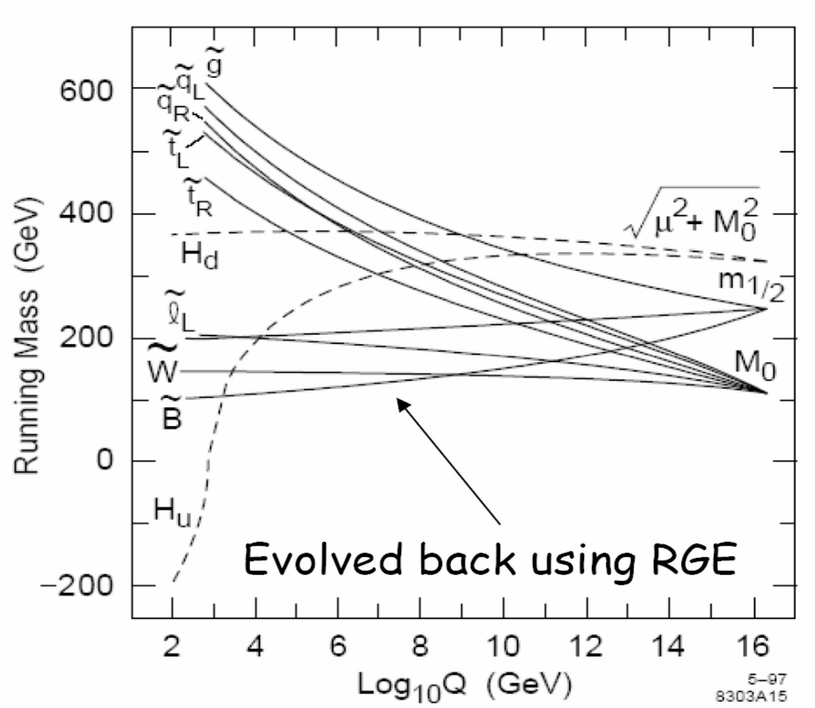
$$L_{RPV} = \boxed{\tfrac{1}{2}\varepsilon_{\alpha\beta}\lambda_{ijk}L_i^{\alpha}L_j^{b}E_k + \varepsilon_{\alpha\beta}\lambda'_{ijk}L_i^{\alpha}Q_j^{b}D_k} + \tfrac{1}{2}\varepsilon_{\alpha\beta\gamma}\lambda''_{ijk}U_i^{\alpha}D_j^{b}D_k^{\gamma} + \varepsilon_{\alpha\beta}\mu_i L_i^{\alpha}H_u^{b}$$

- μLH → neutrino masses
- LLE and LQD → lepton number violation
- UDD → baryon number violation
- We set limits on the couplings λ,λ'

mSUGRA

mSUGRA a LHC





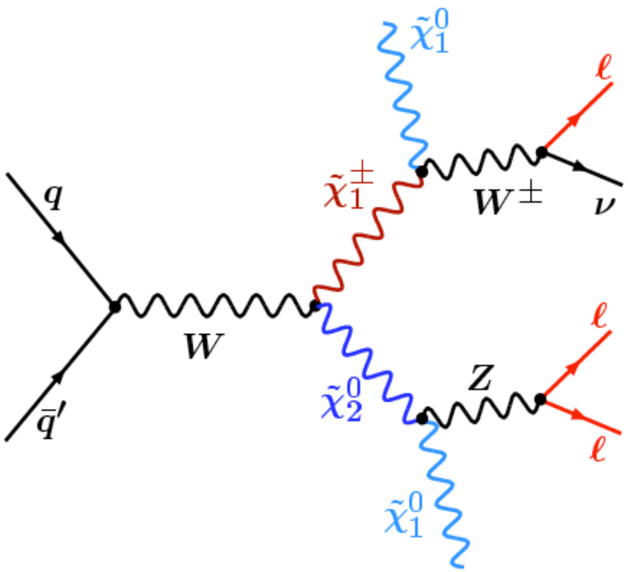
- The free parameters are
  - m_0, the common sfermion mass
  - $M_{1/2}$, the common gaugino mass
  - tanβ, the ration of higgs vacuum expecation values
  - A, the trilinear sfermion-sfermion-higgs coupling
  - Sign of μ, the higgs parameter scale

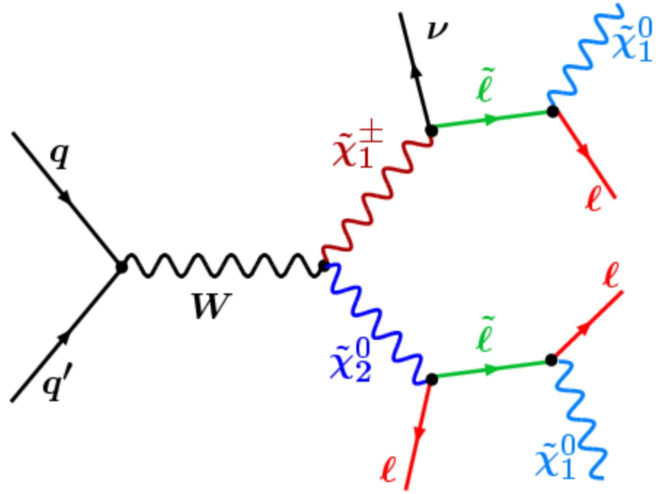
Checking one SUSY benchmark point

- This is point m_0=60 GeV/c^2, $m_{1/2}$=190 GeV/c^2, tanβ=3, A_0=0, μ>0
  - Benchmark used in CDF, Phys. Rev. Lett. 101, 251801 (2008)
- Spectrum created with Isajet 7.79
- The decay to leptons is really good and our acceptance even better
  - Neutralino goes 30% to selectron, 30% to smuon, 40% to stau
  - Chargino goes 2% to electron, 2% to muon, 2 % to tau, 92% to stau
- Cross section (prospino) equals to 0.47 pb.
- Masses:
  - Lightest chargino ~ 122 GeV/c^2
  - Next to-lightest chargino ~ 325 GeV/c^2
  - Lightest neutralino ~ 67 GeV/c^2
  - Next-to-lightest chargino ~ 125 GeV/c^2
  - Lightest higgsion ~ 100 GeV/c^2
  - Heavy higgsinos ~ 350 GeV/c^2

Chargino – Neutralino to Trileptons

- Chargino-Neutralino production and decay to trileptons is a golden SUSY signature
  - Very low SM backgrounds, cross sections of the order of 0.1-1 pb have not been excluded yet





Decays through W/Z favorable for heavy sleptons, but BR to leptons low

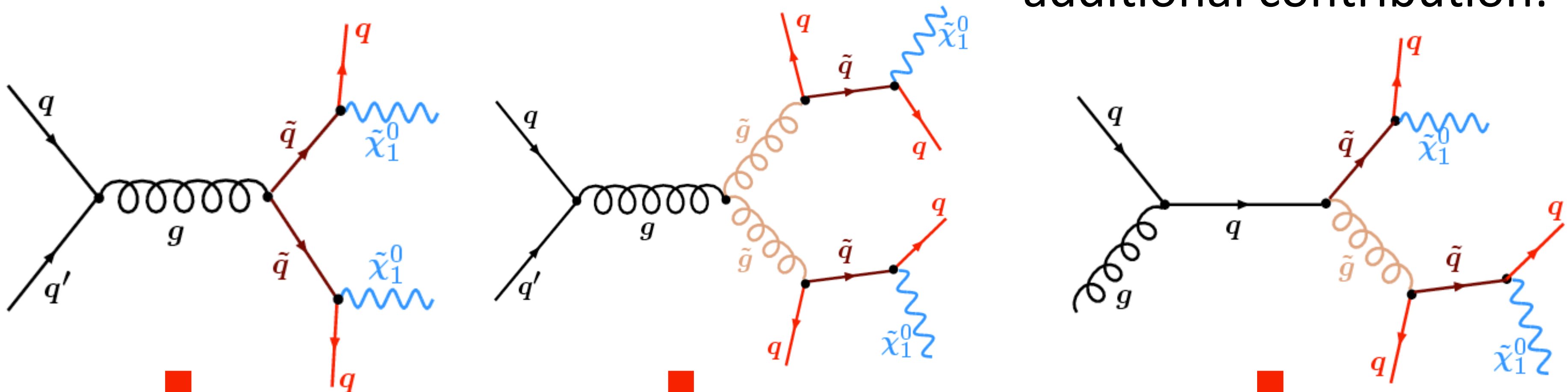
Decays through sleptons guarantee final leptons, but also preference to $\tilde{\tau} \rightarrow \tau$

- Signature of interest: ***Three leptons and Missing Transverse Energy*** (MET) due undetected neutralinos (LSP in mSUGRA with R-parity conservation) and neutrinos

Squark-Gluino production and decay

- The dominant squark-gluino production process depends on their mass (σ~0.1-0.2 pb for our sensitivity region)

If $M_{\tilde{q}} < M_{\tilde{g}}$ | If $M_{\tilde{q}} > M_{\tilde{g}}$ | If $M_{\tilde{q}} \approx M_{\tilde{g}}$ then additional contribution:



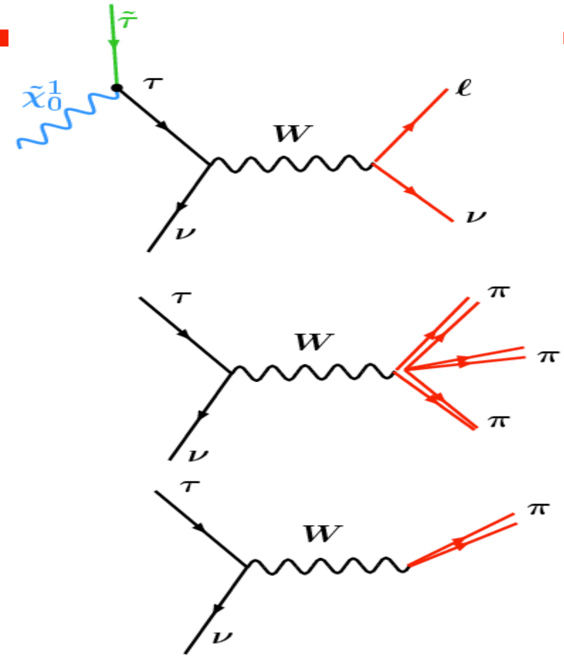
Result: <u>2 jets and MET</u> | Result: <u>4 jets and MET</u> | Result: <u>3 jets and MET</u>

- Although the production is strong, the analyses are challenging due to <u>QCD-multijet and W/Z+jet backgrounds</u>
  - <u>Solution</u>: break-down analyses in jet-multiplicity bins and optimize separately (using MET and HT Sum of jet E_T)

Supersymmetry breaking and spectrum

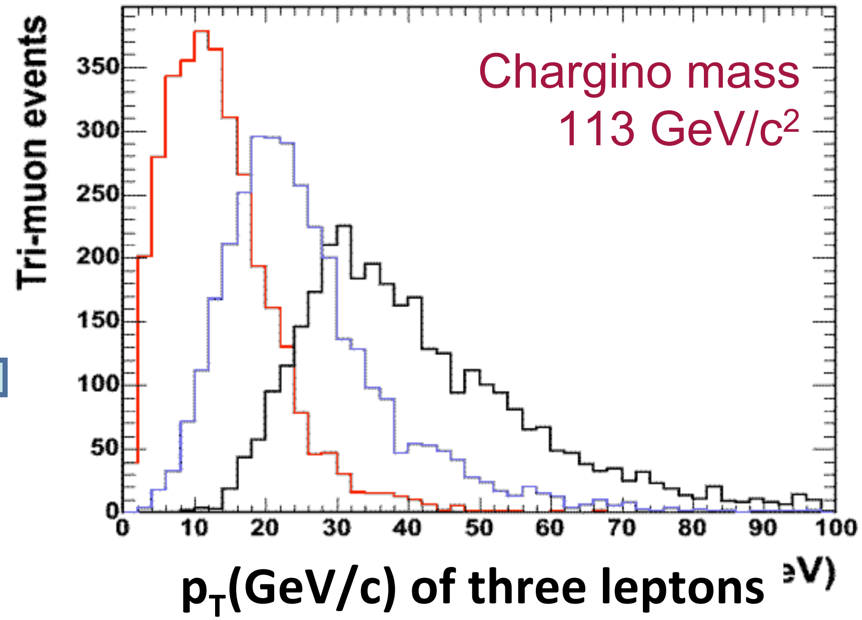
- "Minor detail": We haven't discovered new particles with same masses as our known SM particles and only a spin difference
- So if SUSY is a symmetry of nature, it has to be broken at a higher energy-scale and the effects are mediated to the electroweak scale.
- In Minimal SUSY (MSSM), supersymmetry is broken by introduction of extra Lagrangian terms
  - Soft SUSY Breaking
- Minimal Supergravity (mSUGRA) is MSSM with some extra boundary conditions and assumptions
  - SUSY breaking is mediated by gravity
  - LSP is the Neutralino
  - Only 4 parameters and a sign (m_0 , $m_{1/2,}$ tanβ, A, μ)
- Alternatively, in Gauge Mediated SUSY Breaking (GMSB), SUSY breaking is mediated by gauge fields
  - LSP is the Gravitino

Soft leptons and isolated tracks



- Staus are expected to be the lightest sleptons
  - They will decay to one or three charged hadrons resulting to one or three tracks
  - Or, they will decay to soft leptons
- For this reason, we include isolated tracks to reconstruct some of the "hadronic" taus

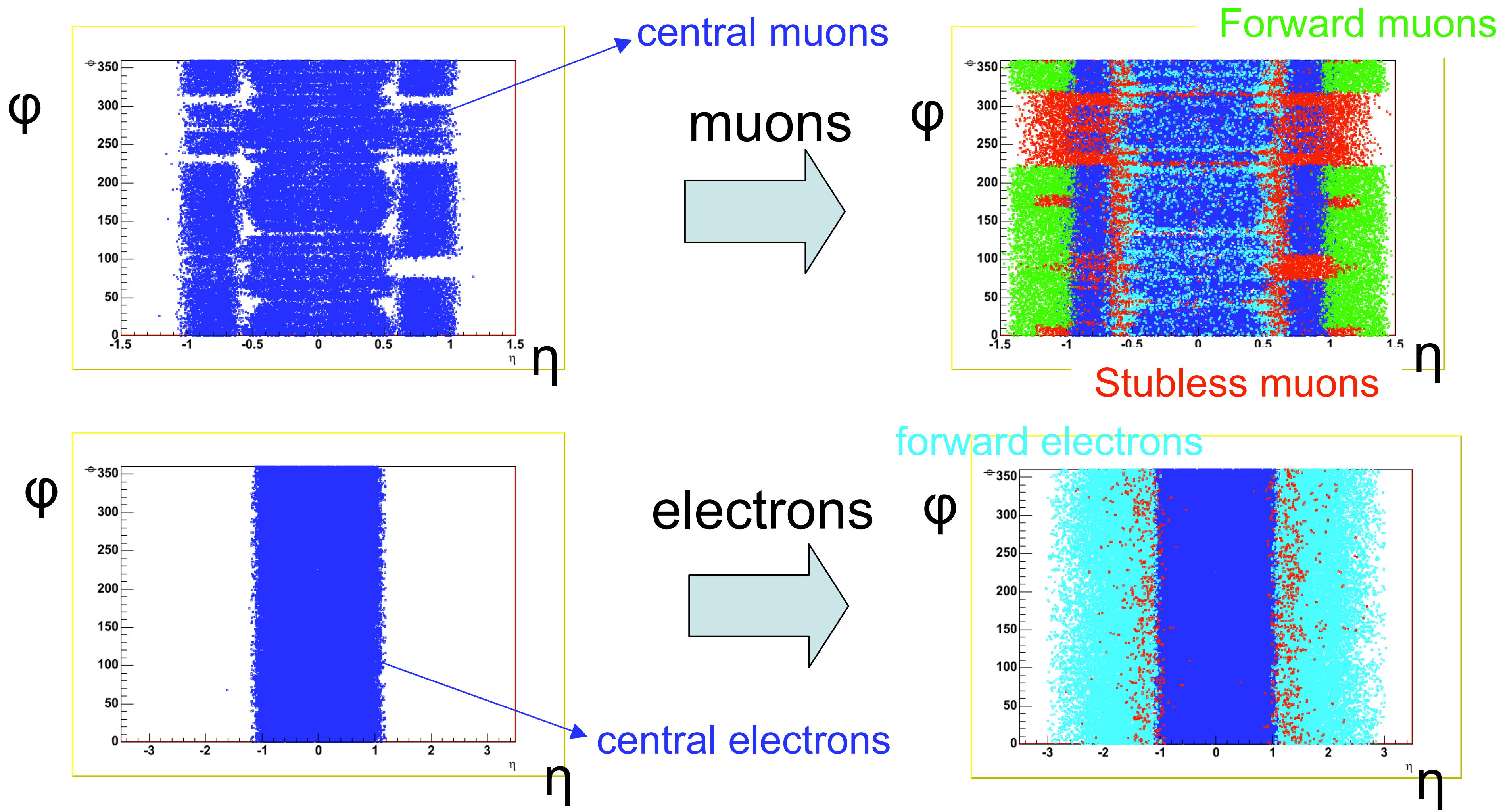
p_T of leptons can be really low
(we consider momenta > 5 GeV/c)



Current trilepton analysis improvements

- We are in the process of extending/improving the chargino-neutralino analysis (in addition to adding more data, currently 4 fb^{-1} in total, and new triggers)
- We expand geometrically
  - We include forward ($|\eta|>1$) regions of the detector
- We expand kinematically
  - Low-p_T and low-M_{ll}
- We include new objects
  - tau leptons
- Our goal is the completion of the most sensitive CDF analysis
  - For the greatest discovery potential
  - For the best limits settings
  - For setting benchmarks for the current LHC experiments

Increase coverage for muons and electrons

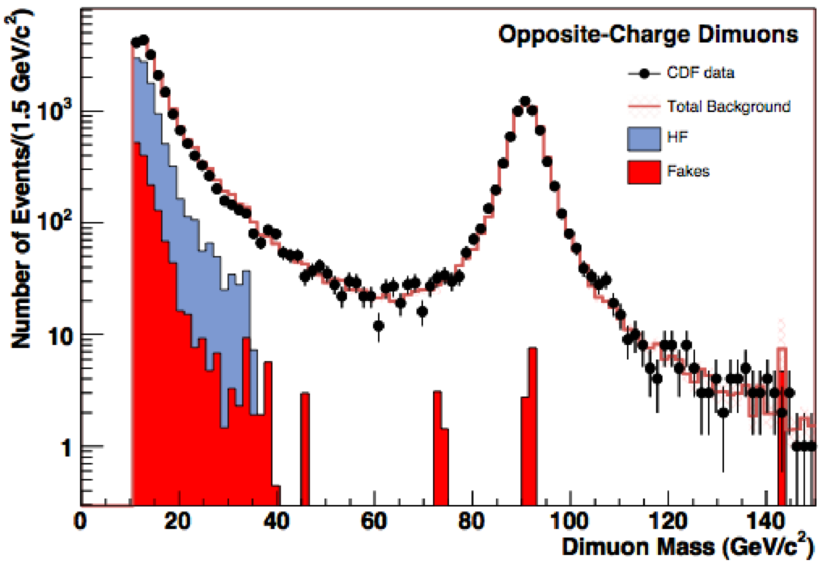


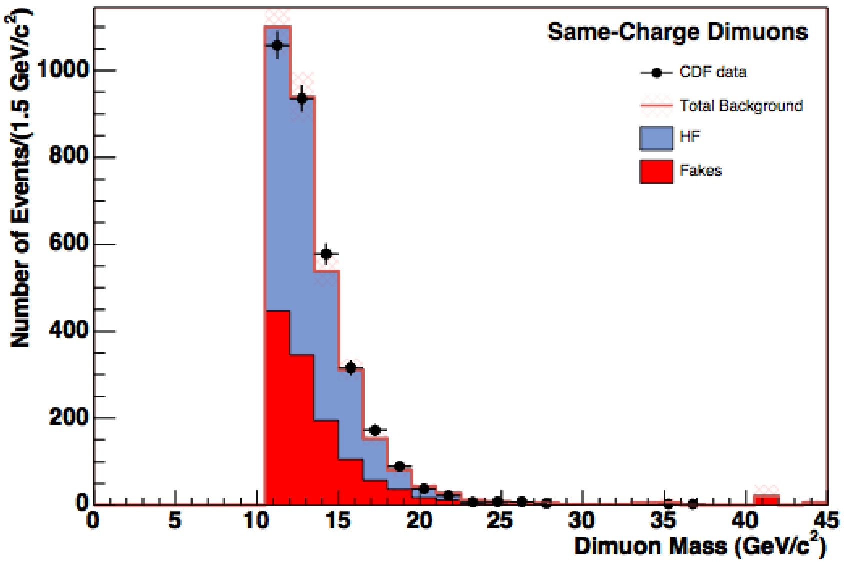
- We will use the full CDF detector, including the forward calorimeters and muon systems.
- The forward objects roughly double (triple) our dilepton (trilepton) acceptance

Lower lepton p_T and dilepton mass

- Lowest p_T value for most objects will be 5 GeV/c and lowest dilepton mass will be 10.5 GeV/c^2. Also looser cuts for low-p_T leptons will be used
- Motivation: the signal is most probably there !!
  - Due to cascade SUSY decays and the preferable production of staus that decay to taus that decay to soft leptons
- This way we fully utilize the low-p_T dilepton triggers
- **Extra backgrounds: Heavy-flavor**. We have developed and tested a method that estimates the HF with data

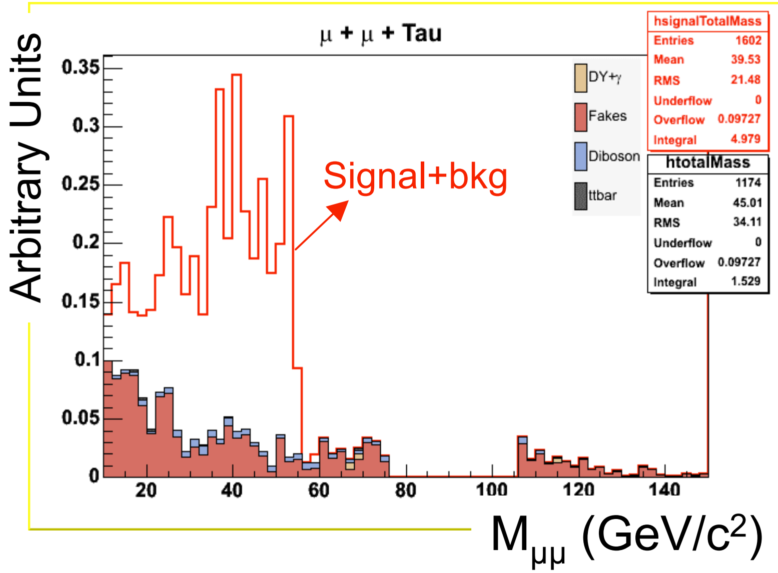
Example: 1 fb^{-1} dimuons Phys. Rev. D 79, 052004 (2009)

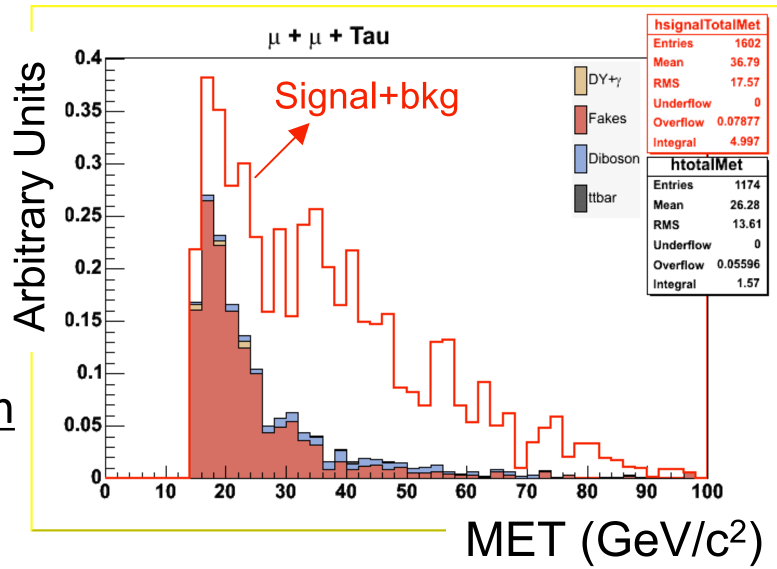




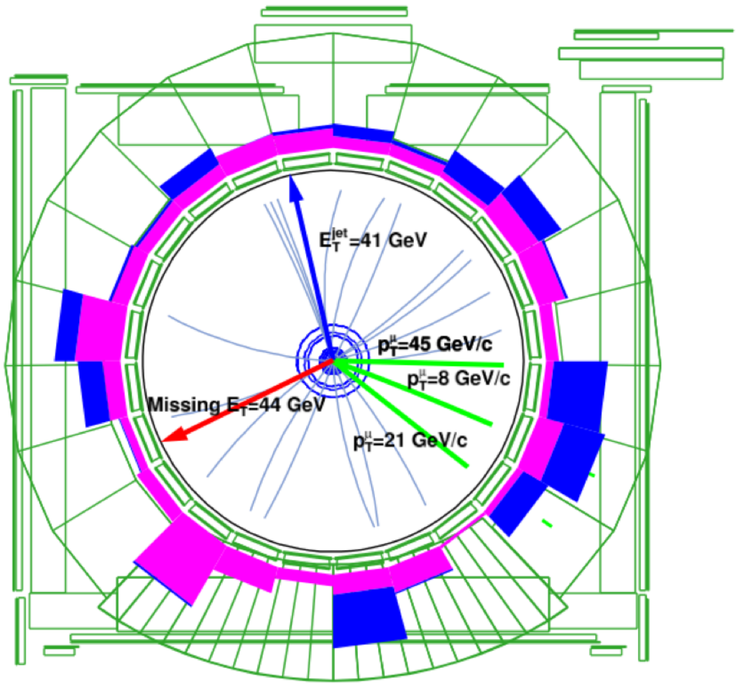
Inclusion of tau leptons

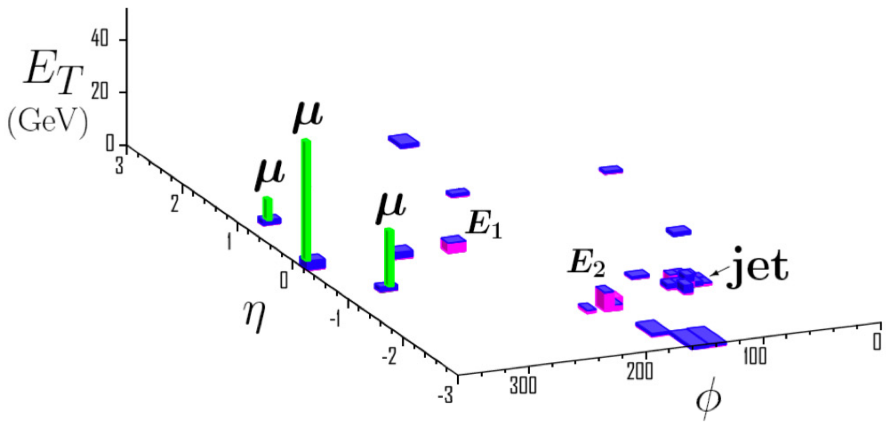
- For many SUSY scenarios and parameters the staus are the lightest sleptons
  - Especially for high tanβ
- <u>As a result, we expect many tau final states</u>
- We catch the leptonic decays of taus through the soft leptons (>5 GeV/c)
- We want to catch the hadronic decays of taus, by using tau objects
  - Initially for llτ, eventully for ττX decays
- We define a tau using 1 or 3 tracks (for 1 or 3 prong decays) isolated from extra hadronic activity
- For the [m_0=60 GeV, $m_{1/2}$=190 GeV, tanβ=3, A_0=0, μ>0] benchmark, <u>our sensitivity to third taus is better than that of third electrons!</u>

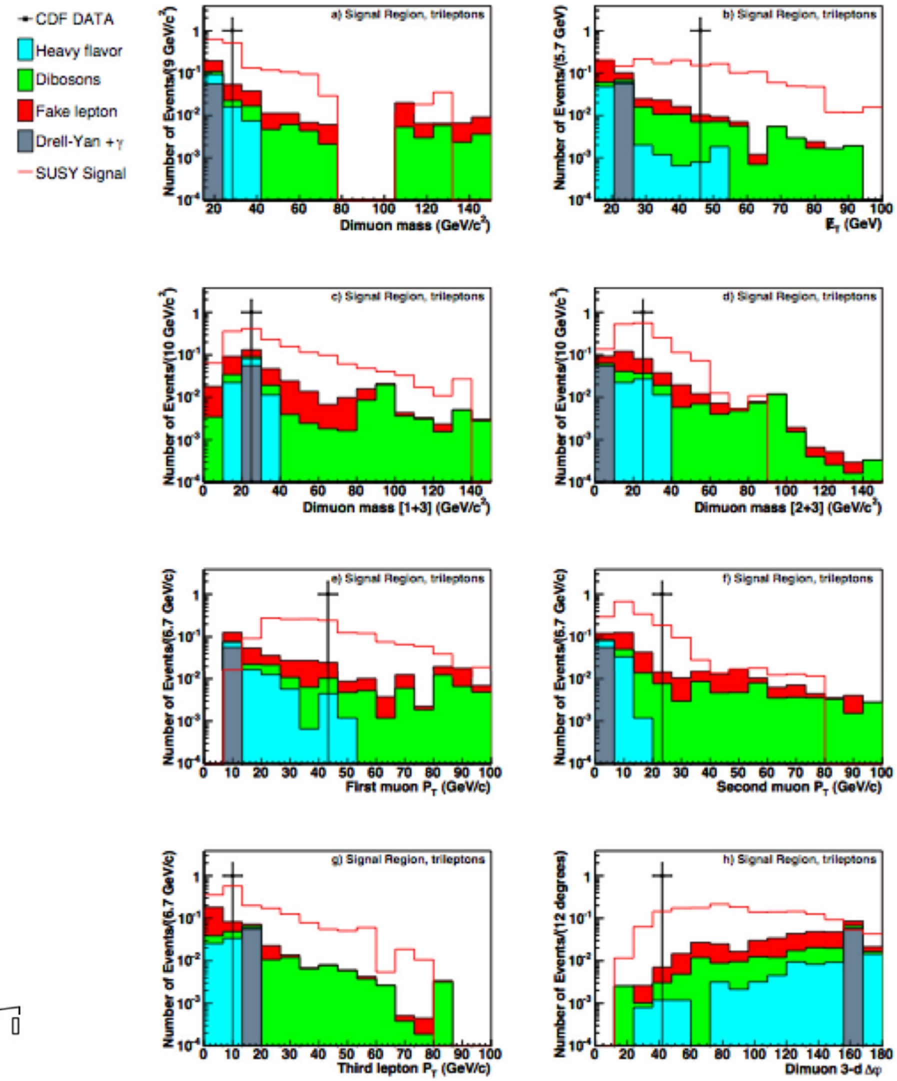




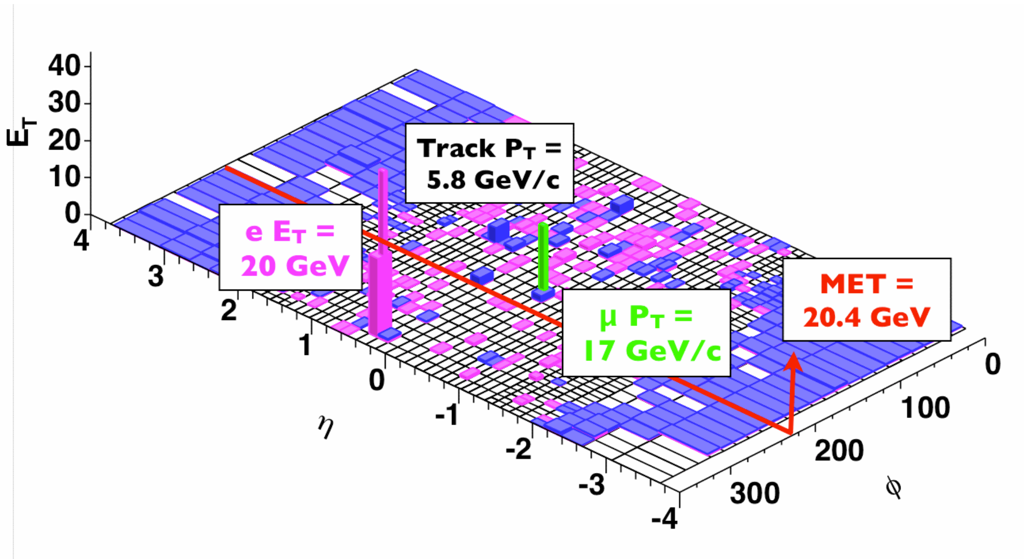
Event Display (1)

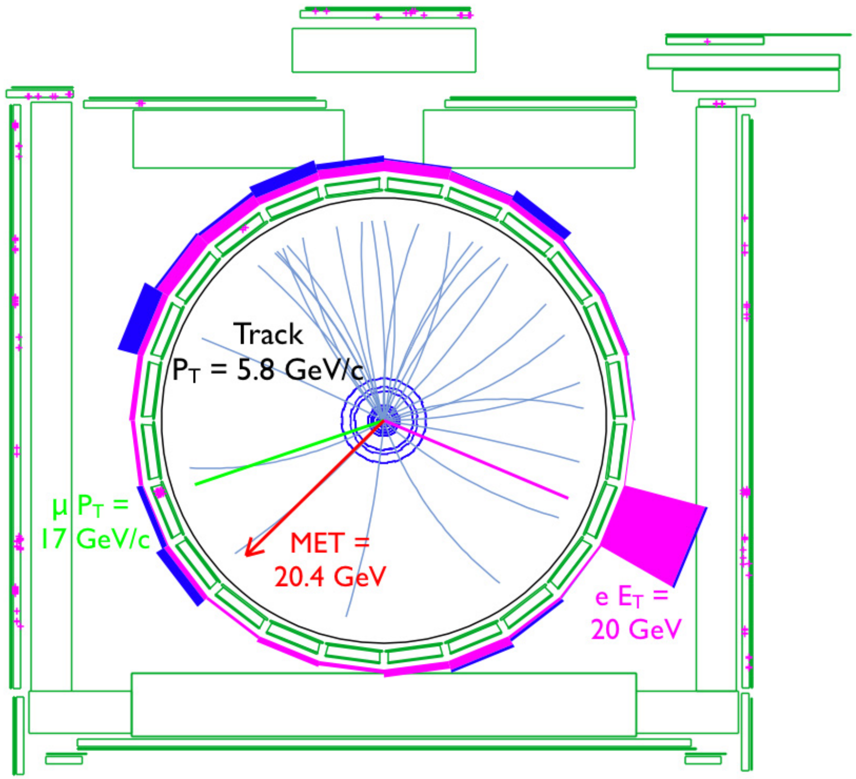






Event display (2)





Hadronic Tau reconstruction

- $|\eta|<1$
- E>20 GeV
- M<1.8 GeV/c^2
- N_{tracks} (inner cone)=1 or 3
- N_{tracks} (between inner and outer cone)=0
- $N_{towers} \leq 6$
- good tracking for seed track
- d0 cut on seed track
- track-EMcalorimeter matching with seed track