Searches Beyond the Standard Model

Experimental Summary (Draft 0)

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Experiment: search for new symmetries

- even if particle content of the SM was complete, we'd know that there is something beyond
- $M_P >>$ EWK scale, VV unitarity at TeV scale, dark matter in the Universe
- for a long time our understanding of the particle interactions has been based on unrderstanding their symmetries
- symmetries beyond SU(3)xSU(2)xU(1)
- carriers of interactions defined by the new symmetries are the new particles sought for experimentally

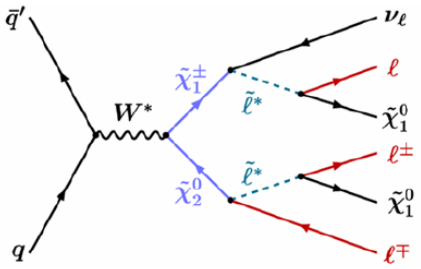
SUSY

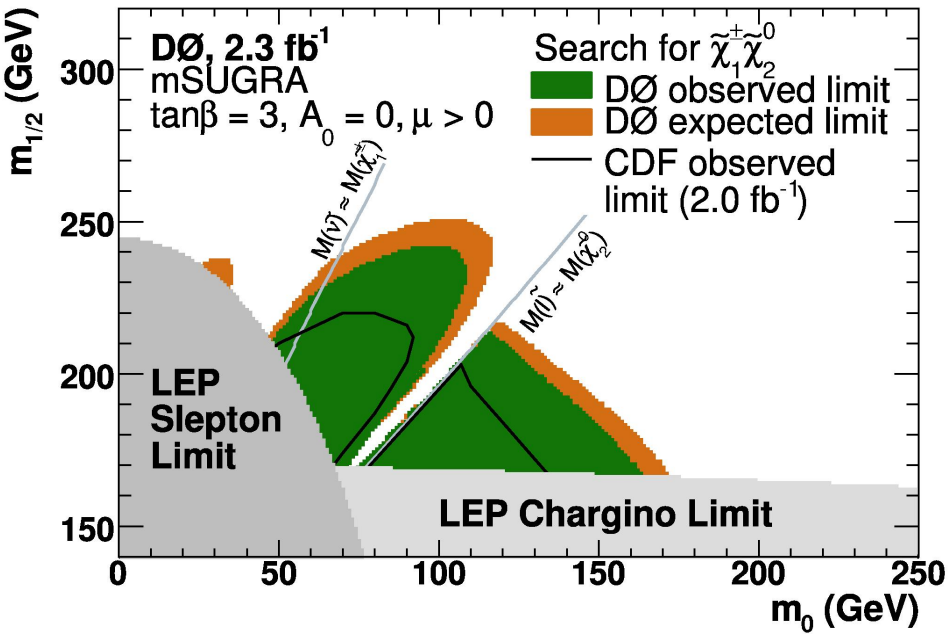
- a symmetry between fermions and bosons
- one of the most motivated symmetries
- introduces framework for multiple models
- more than 100 free parameters
- number of free parameters is reduced by the model-dependent assumptions about the symmetry breaking mechanisms down to 5 or 6
- rich new particle contents and many choices
- sought for very extensively

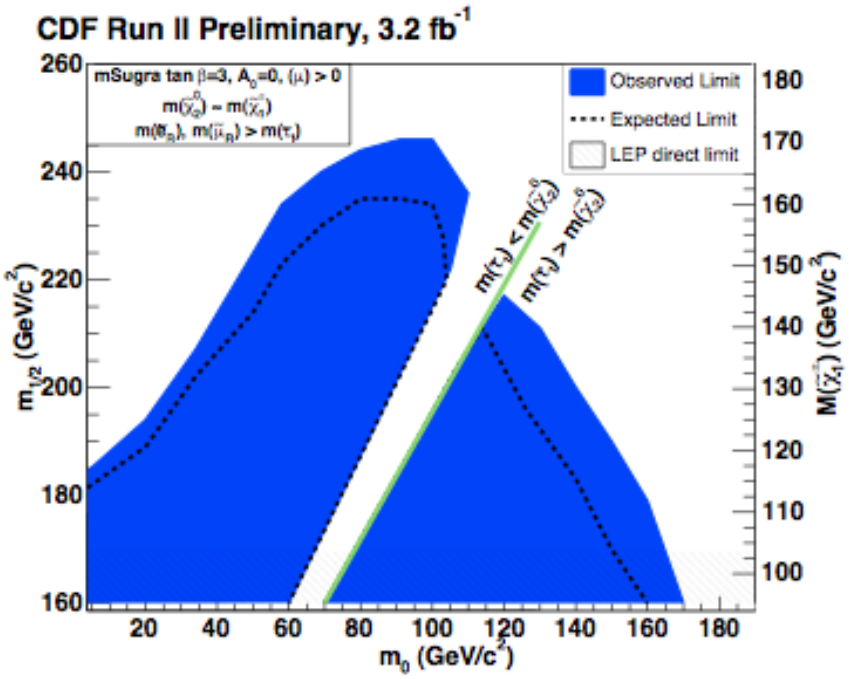
Search for the SUSY Gauginos

- most of the latest results on SUSY searches come from the Tevatron
- "trademark": $p\bar{p} \rightarrow \tilde{\chi}^0\tilde{\chi}^{\pm} \rightarrow 3\ leptons + \not{E}_T$

- cascade decays
- use low p_T , down to 5 GeV/c, leptons

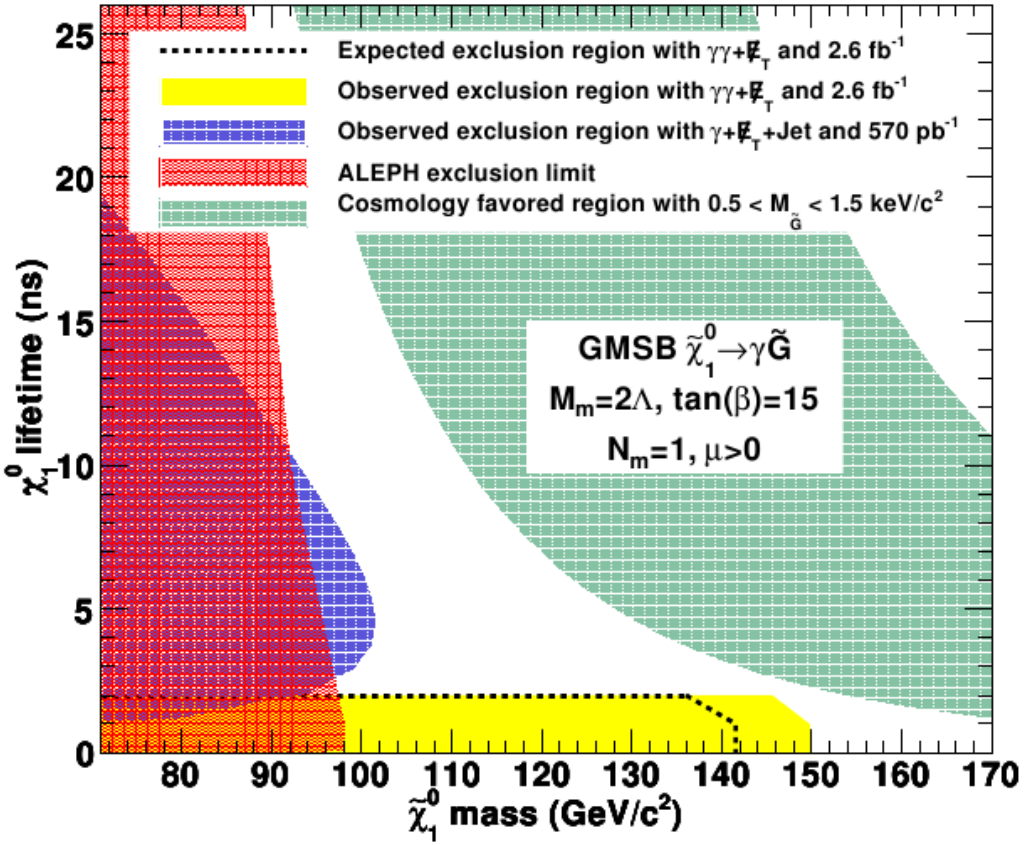


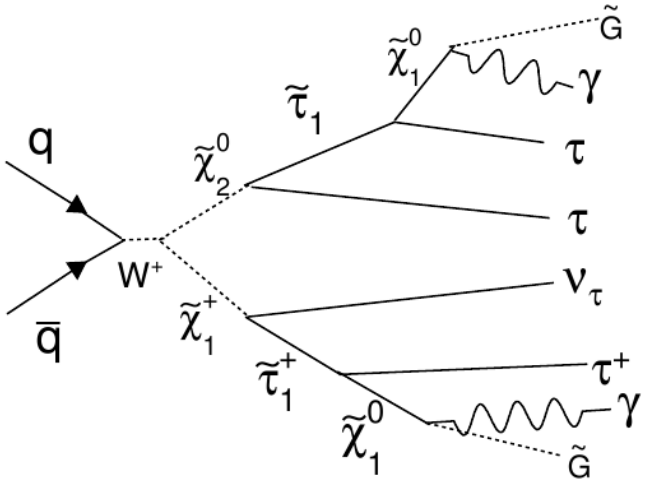




GMSB SUSY: $\gamma\gamma + \not{E}_T$

- in GMSB, the LSP is the gravitino $\tilde{G}$, $M_{\tilde{G}}$ in a $\sim$KeV range.
- If NLSP is $\tilde{\chi}_1^0$, gaugino / stau pair production can cascade to $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \gamma\gamma\tilde{G}\tilde{G}$
- SM background ($W/Z + \gamma\gamma$) very low





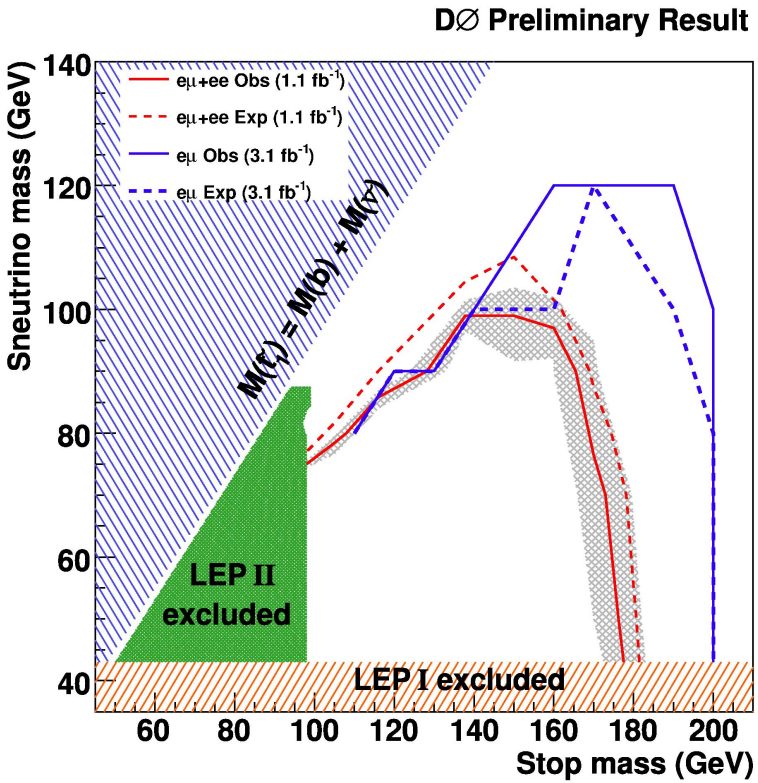
- $M(\tilde{\chi}_1{}^0) > 149 GeV$ at 95% CL (CDF 2.6fb^{-1}, PRL 104(2010)011801)

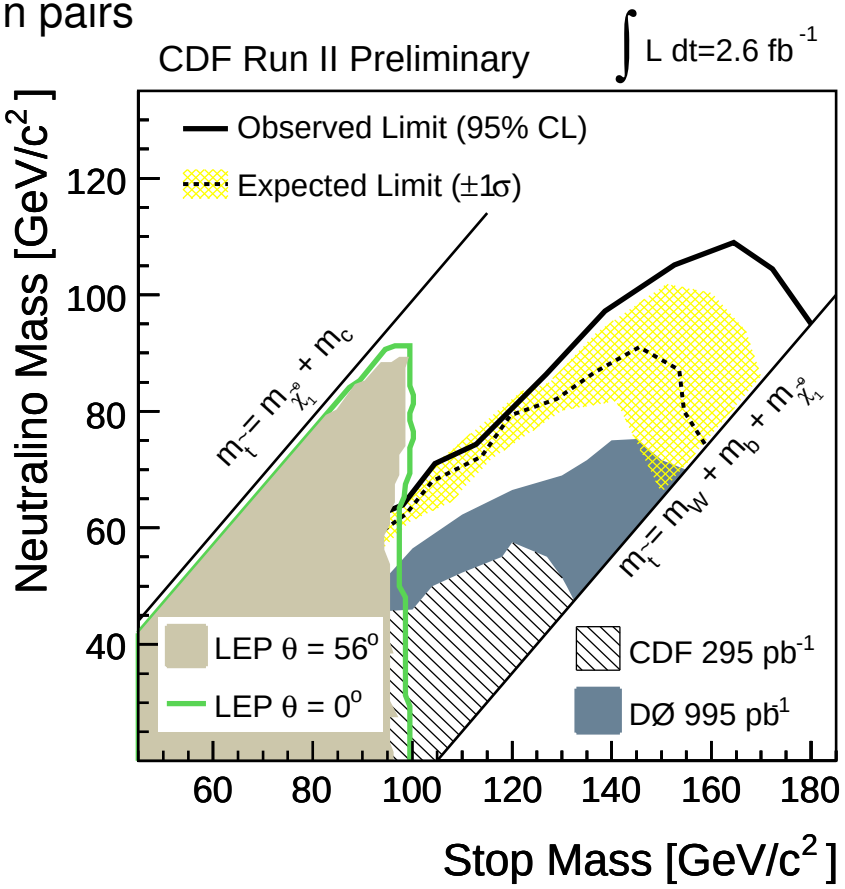
UPDATED GMSB SUSY: $\gamma\gamma + \not{E}_T$

- replace previous slide with D0 result if approved by D0

Searches for $\tilde{t}$ quark

- mixing in the 3rd generation: $\tilde{t}_1$ can be light
- R-parity conservation: $\tilde{t}$ quarks produced in pairs

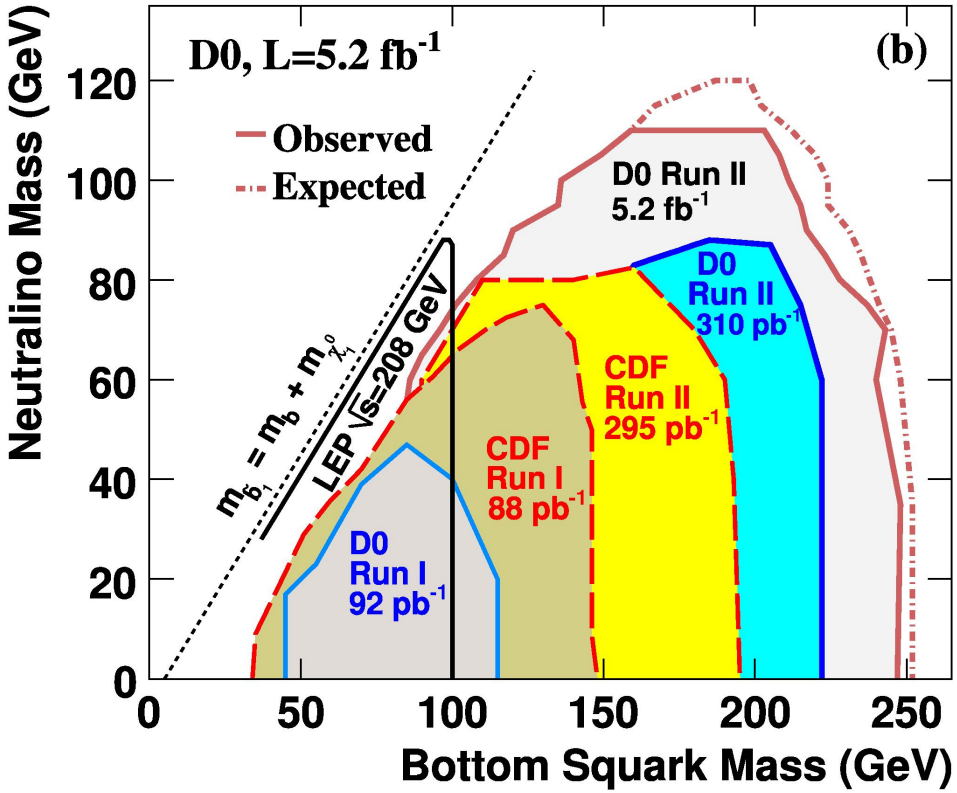


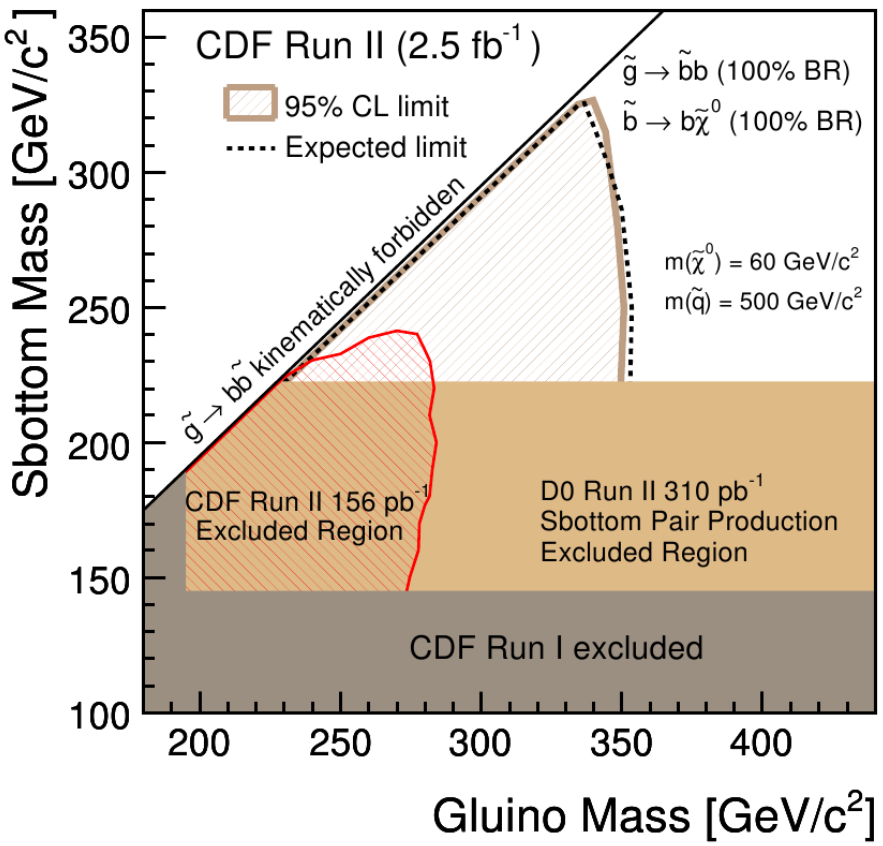


- D0: $\tilde{t} \rightarrow bl\tilde{\nu}$, $e\mu$ channel, 3.1fb^{-1}
- CDF: $\tilde{t} \rightarrow c\tilde{\chi}_1^0$, 2.6$fb^{-1}$, charm tagger

Searches for the $\tilde{b}$ quarks

- due to mixing, 3rd generation squark, $\tilde{b}_1$, can be light



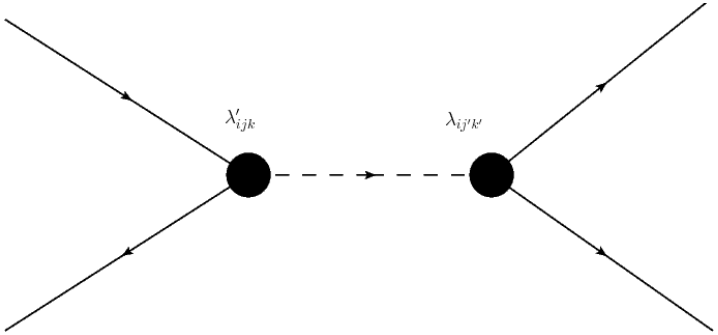


- direct $\tilde{b}\bar{\tilde{b}}$ pair production: $p\bar{p} \to \tilde{b}\bar{\tilde{b}}$
- B($\tilde{b} \to b\tilde{\chi}_1{}^0$)=100% : 2 b-jets and $\not{E}_T$
- M($\tilde{b}$) $>$ 247 GeV for $M_{\tilde{\chi}_1{}^0} = 0$

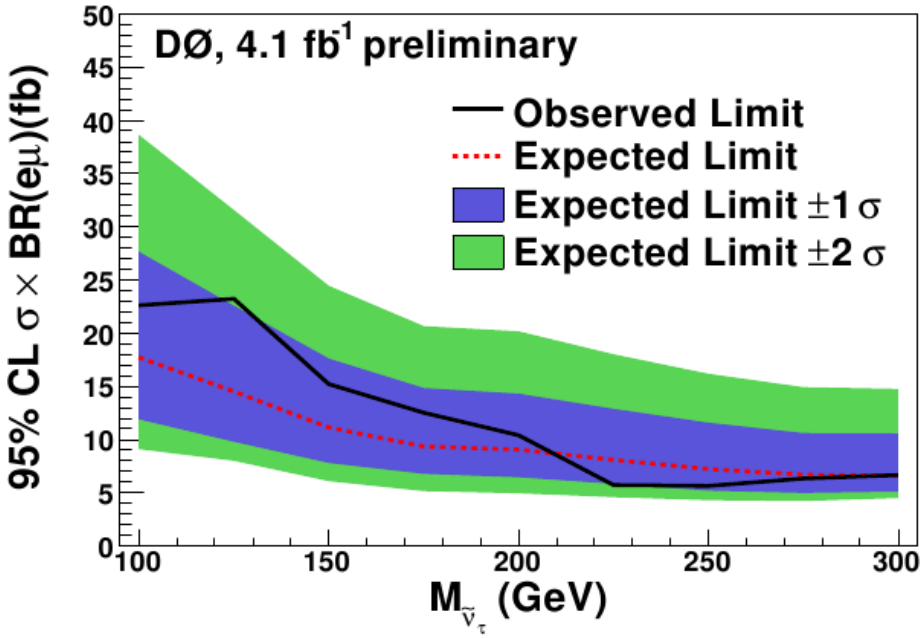
- gluino mediated pair production
- $p\bar{p} \to \tilde{g}\tilde{g}$, $\tilde{g} \to b\tilde{b}$, $\tilde{b} \to b\tilde{\chi}_1{}^0$
- $>=$ 2 B-jets + $\not{E}_T$

Search for Broken Symmetries: R-parity violation

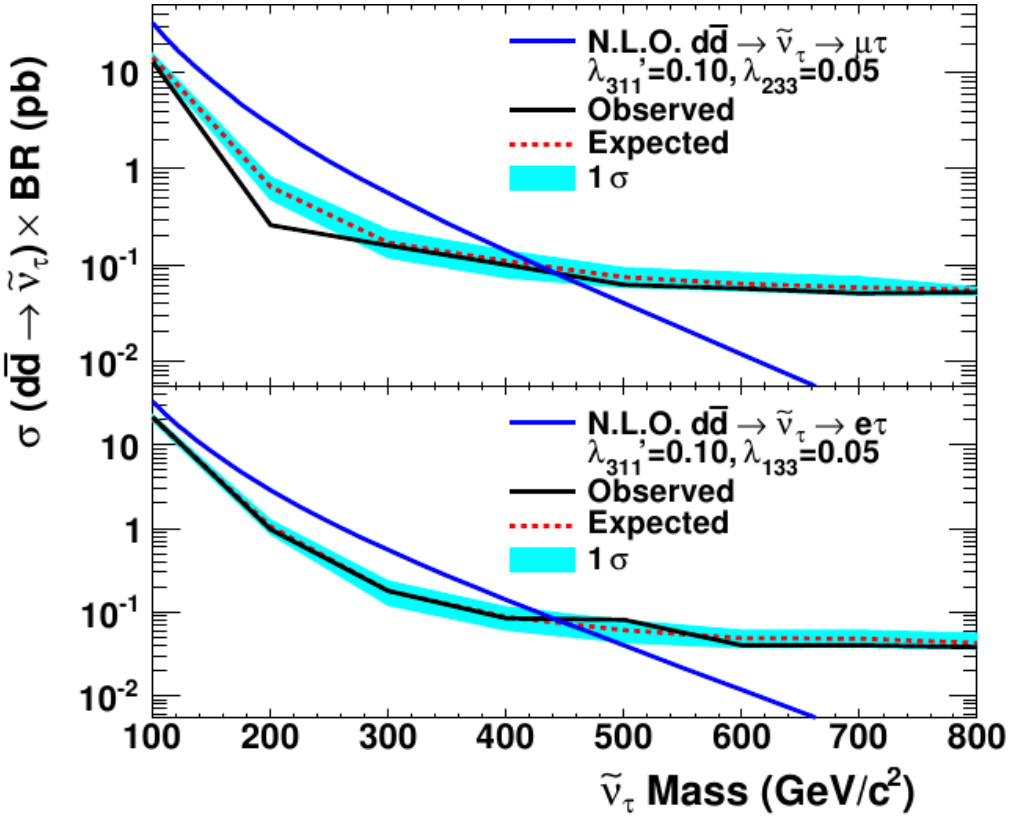
- R-parity, $R = (-1)^{2S+3(B-L)}$
- in most scenarios R-parity is assumed to be conserved
- RPV models: single resonant production of sparticles



searches for RPV decays of $\tilde{\nu}$:



CDF, $1 fb^{-1}$

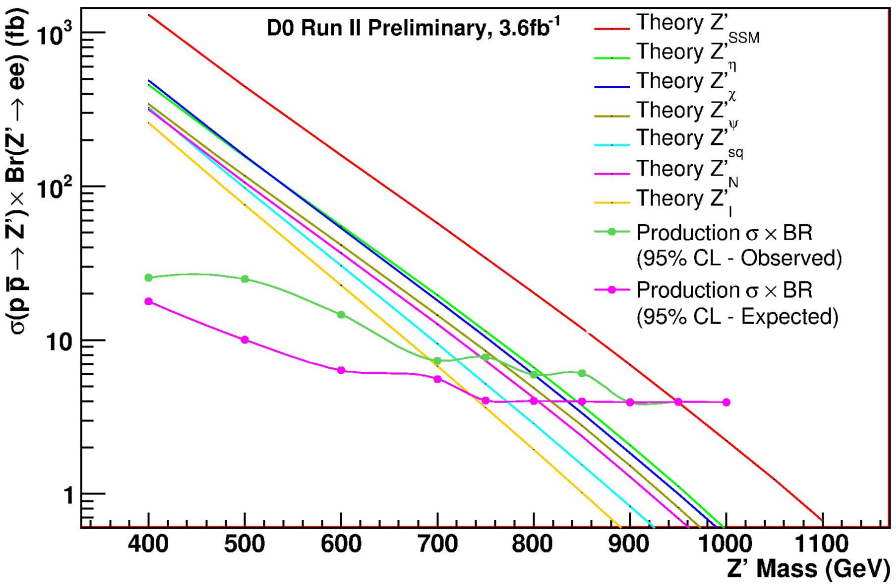


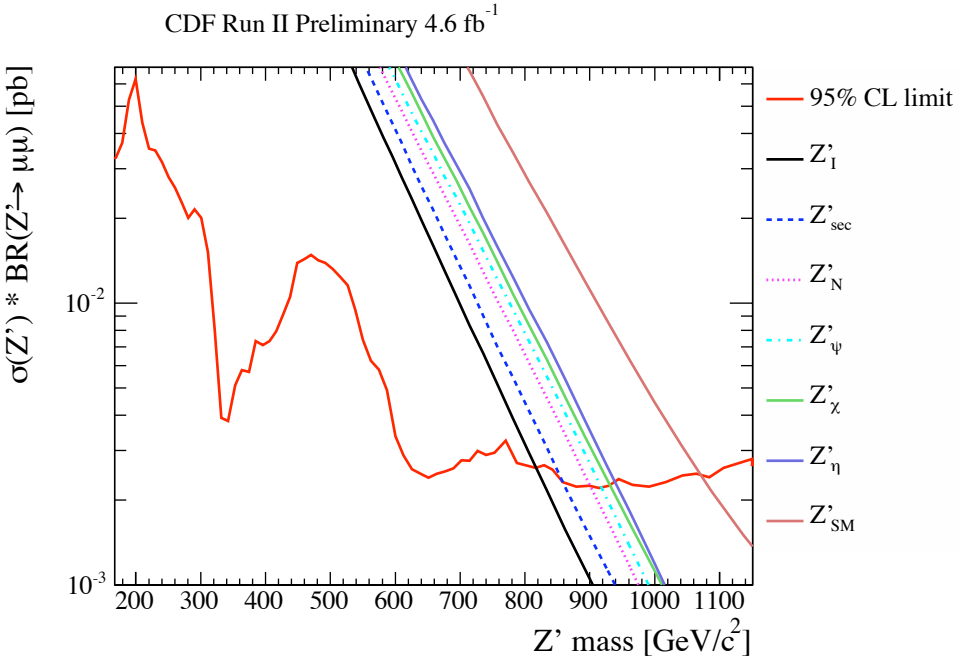
Search for Broken Symmetries: R-parity violation

- update D0 result , if approved by D0

Extending the SM symmetries

- the simpliest way to extend SM gauge structure : include the 2nd U(1)
- Z' - gauge boson, associated with the new group



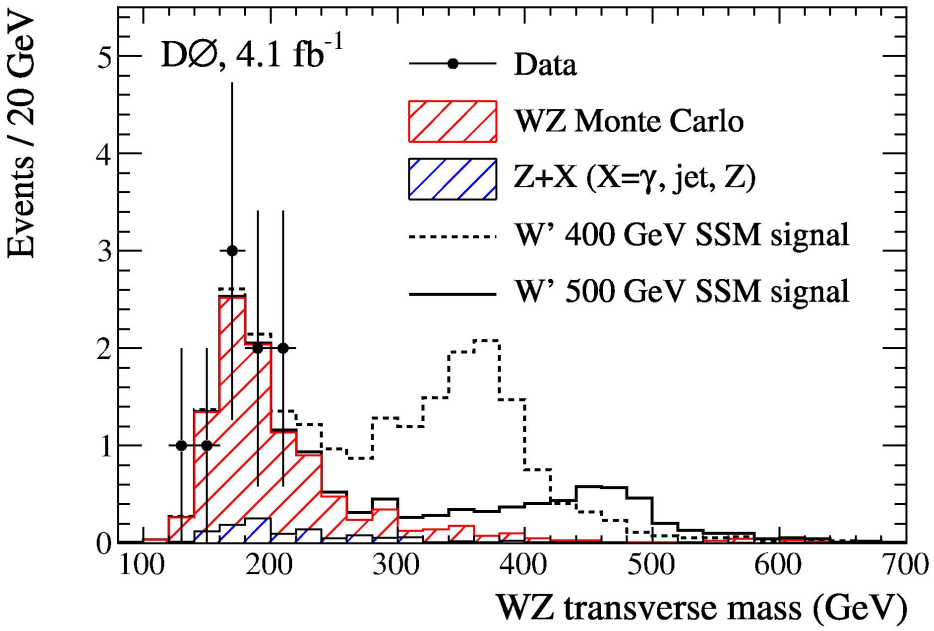


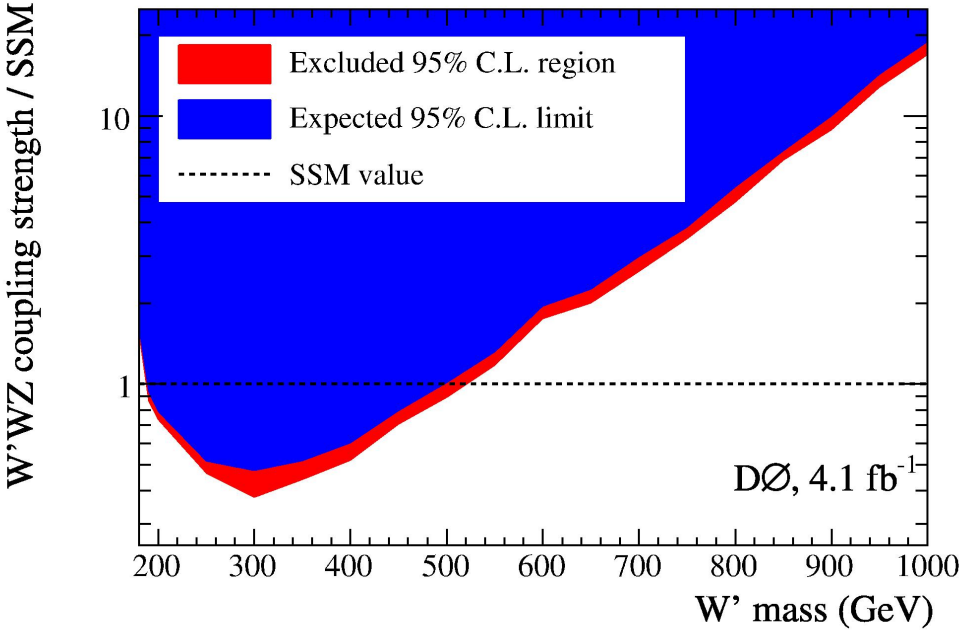
- $Z' \to ee$: M(Z'_{SM}) >950 GeV @ 95% CL (D0, 2009)
- $Z' \to \mu\mu$: M(Z'_{SM}) >1071 GeV @ 95% CL (CDF, 2010)

Update Extending the SM symmetries

- updated D0 result , if approved by D0

Heavy Bosons: W'





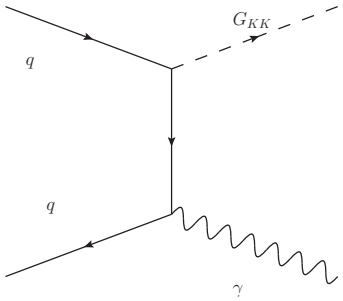
- D0'2010 $W' \rightarrow WZ$, 4.1fb^{-1}[lepton p_T>20 GeV, $\not{E}_T$>30 GeV]
- SSM: exclude W' mass range [188,520] @ 95% CL

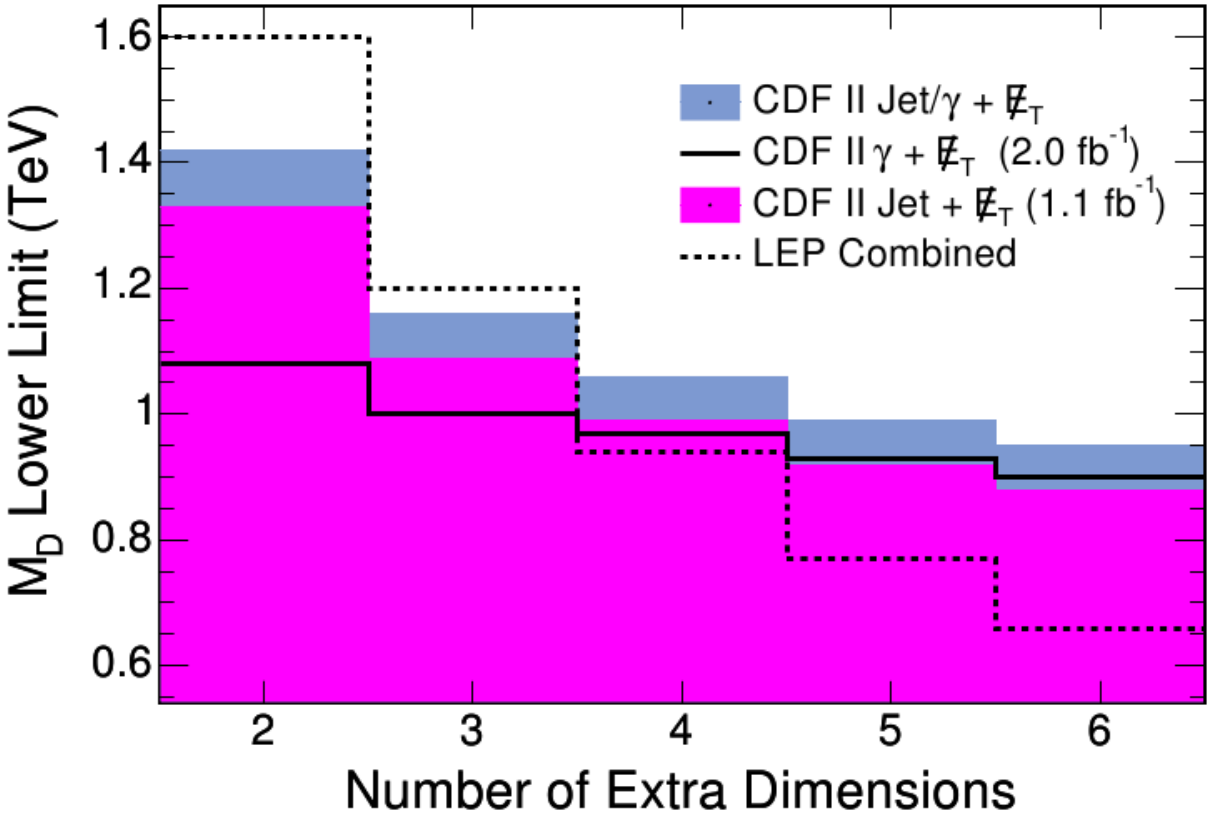
*** UPDATE *** Heavy Bosons: $W' \to tb$

- add, if approved by D0

Search for Large Extra Dimensions

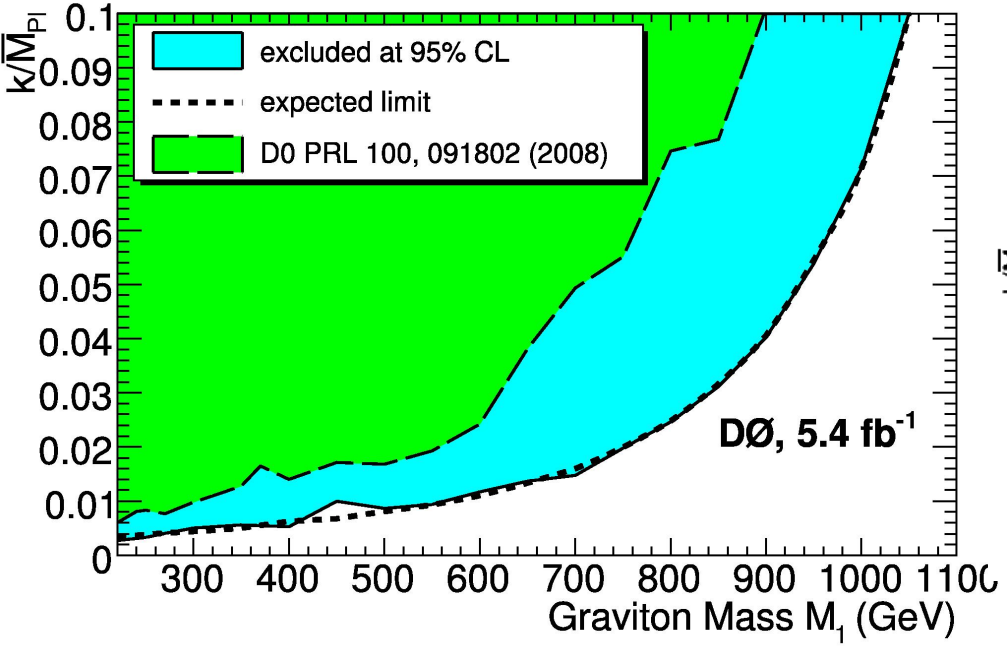
- in LED-type models: $q\bar{q} \rightarrow G + \gamma$, $q\bar{q} \rightarrow G + g$
- explored final states: $\gamma/jet + \not{E}_T$ (CDF'2008) and $\gamma/jet + \not{E}_T$ (D0'2008)

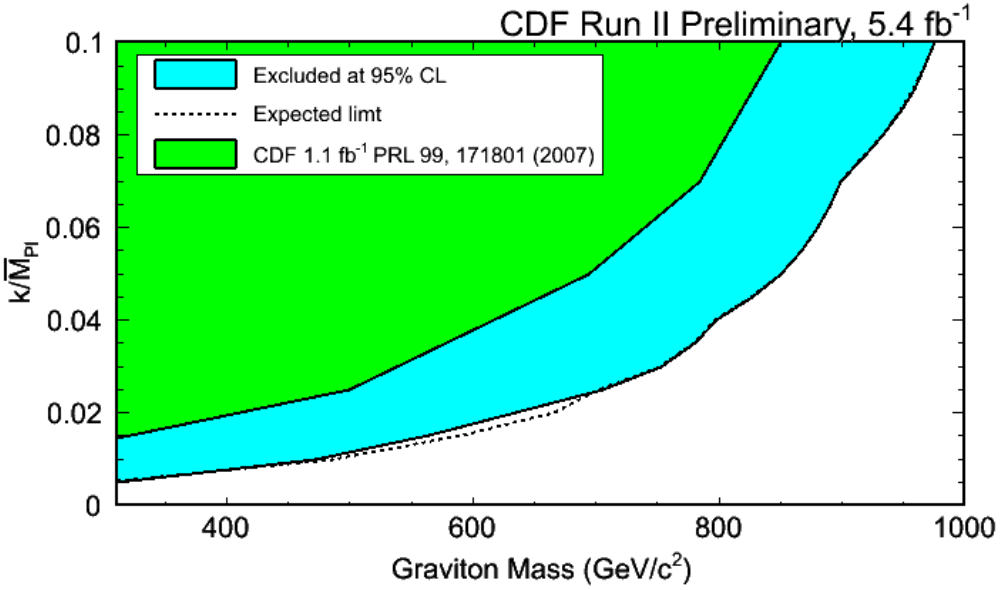




Warped Extra Dimensions

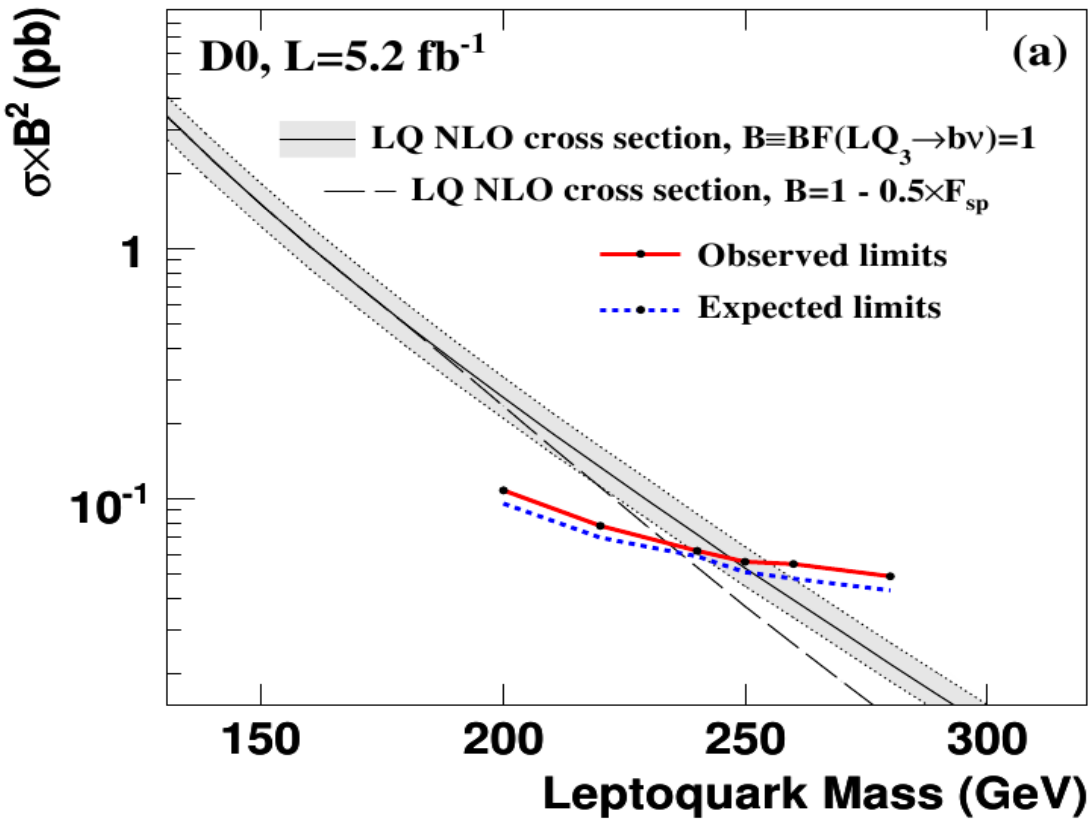
- probe models of warped extra dimensions (Randall, Sundrum'99)





- $G \to \gamma\gamma$, ee [D0, arXiv:XXXXXX]
  - D0: M(G) $>$ 1045 GeV @ 95% CL for $k/M_{Pl} = 0.1$ (**** check with D0)
- $G \to \gamma\gamma$ [CDF, arXiv:0910.5170]

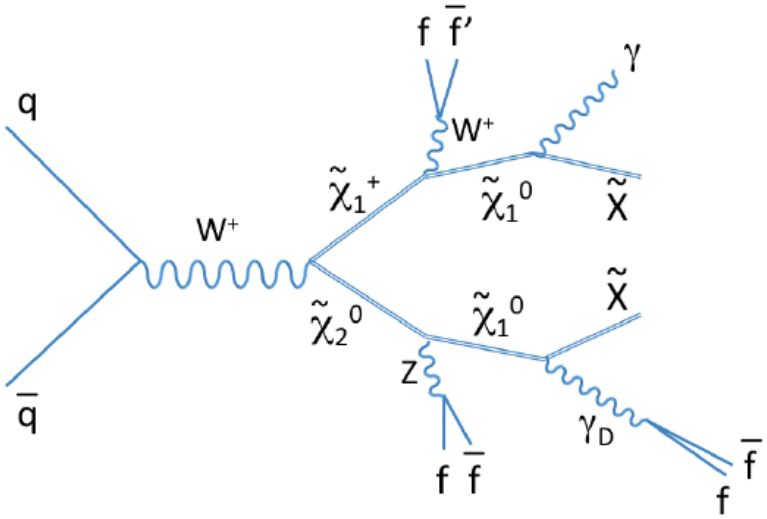
Search for symmetries between the leptons and quarks

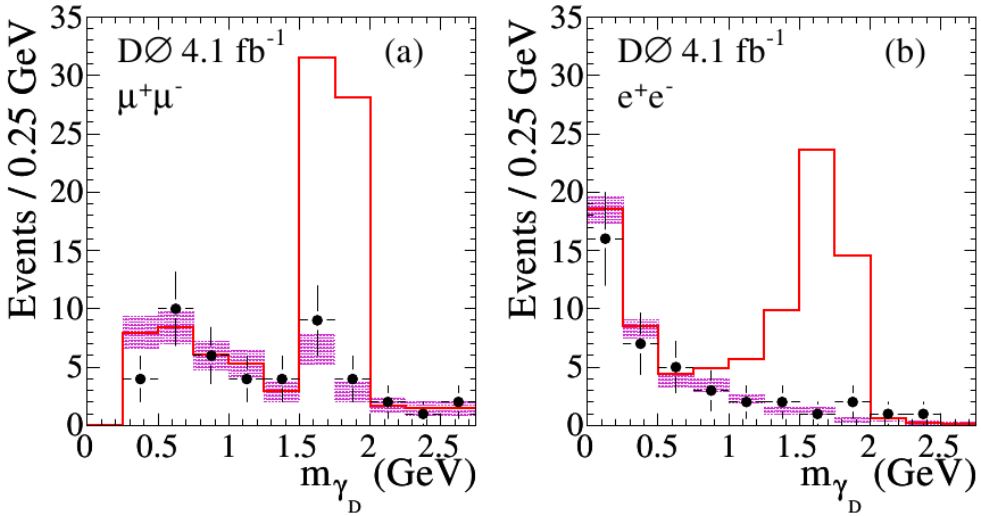


- N(lepton generations) = N(quark generations) - a consequence of an additional symmetry?
- additional interactions would be carried by leptoquarks
- D0 ($5.2 fb^{-1}$): scalar LQ_3: M(LQ_3) $>$ 247 GeV for $B(LQ_3 \rightarrow b\nu) = 1$

Search for Hidden Symmetries: “Hidden Valley” Models

- “hidden valley” models: weakly coupled sector with low mass particles
- γ_D, a force carrier, is light and decays predominantly into SM fermions
- $B(\tilde{\chi} \rightarrow \tilde{X}\gamma_D)$ is a free parameter

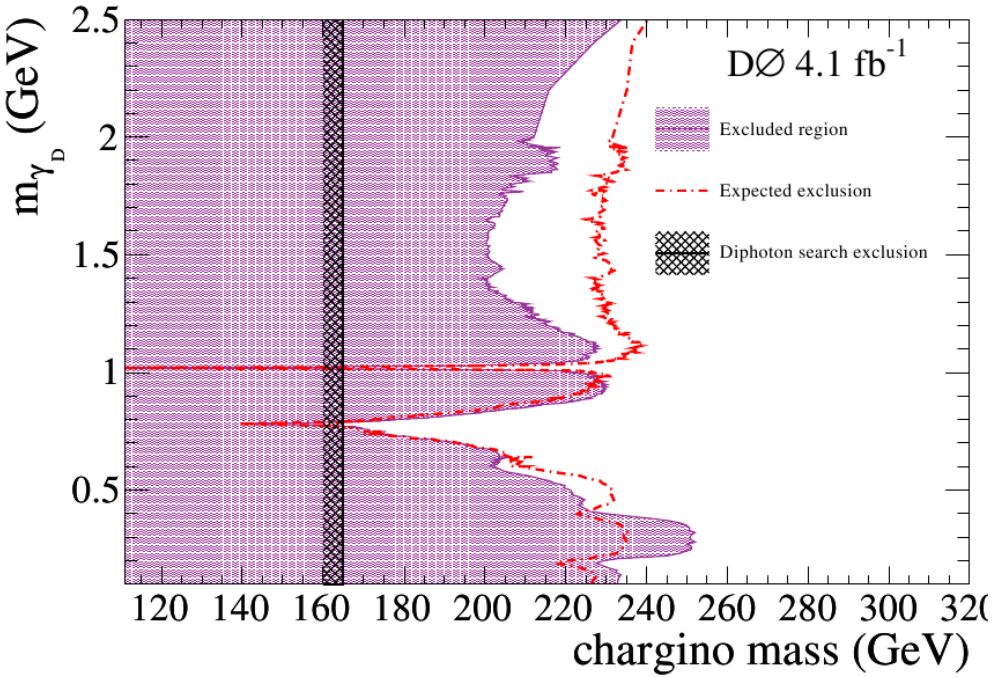


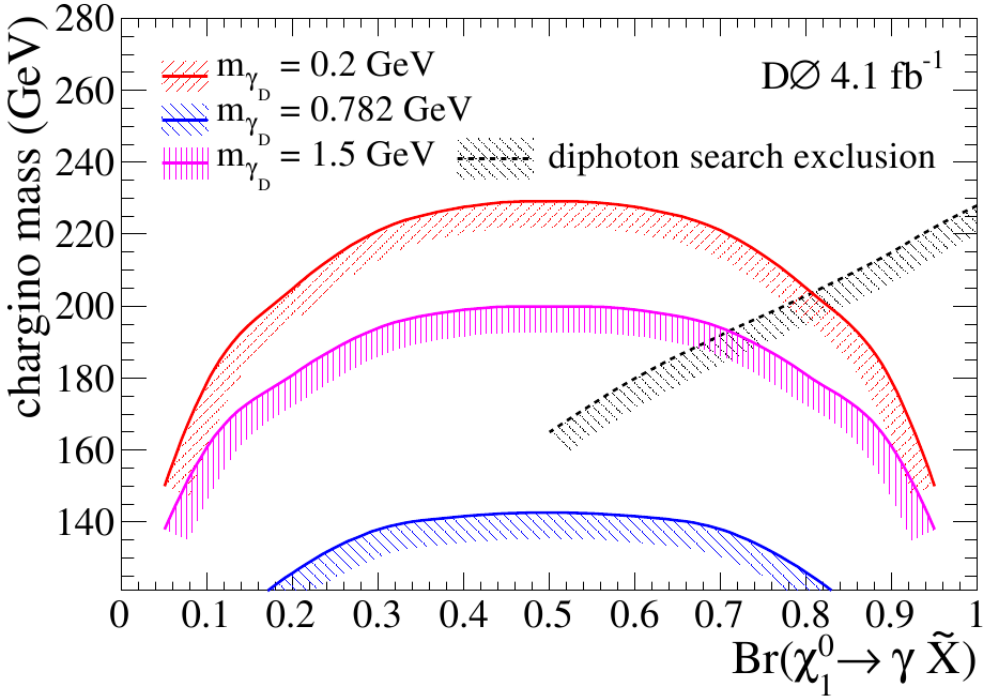


- Search for final states with a photon, 2 close leptons and $\not{E}_T$ (D0, 4.1fb^{-1}).

Constraining Hidden Symmetries

- "hidden valley" models: weakly coupled sector with low mass particles

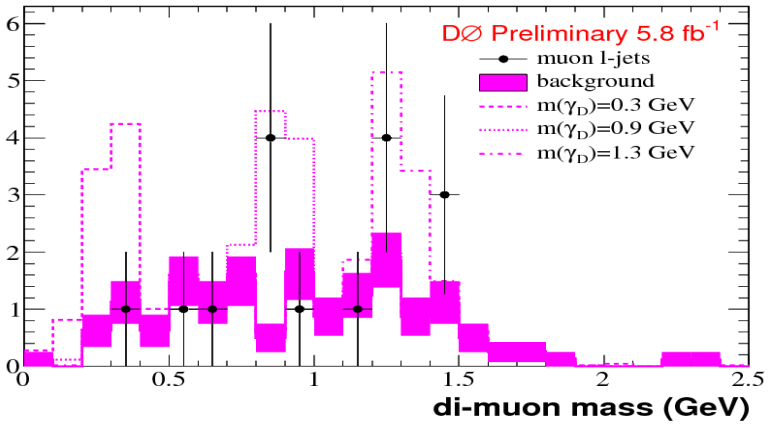


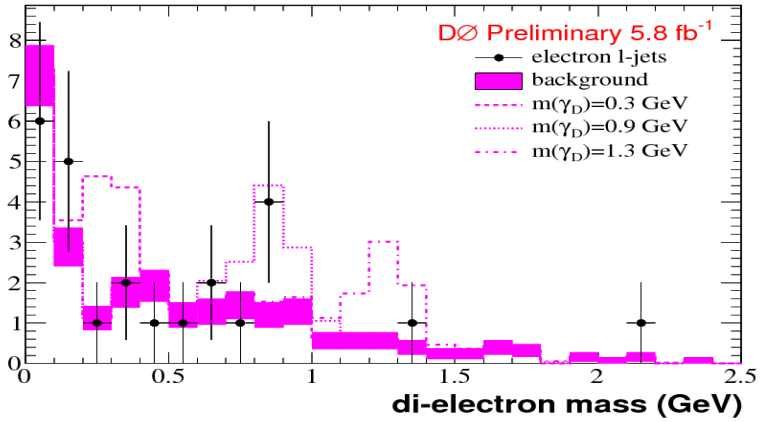


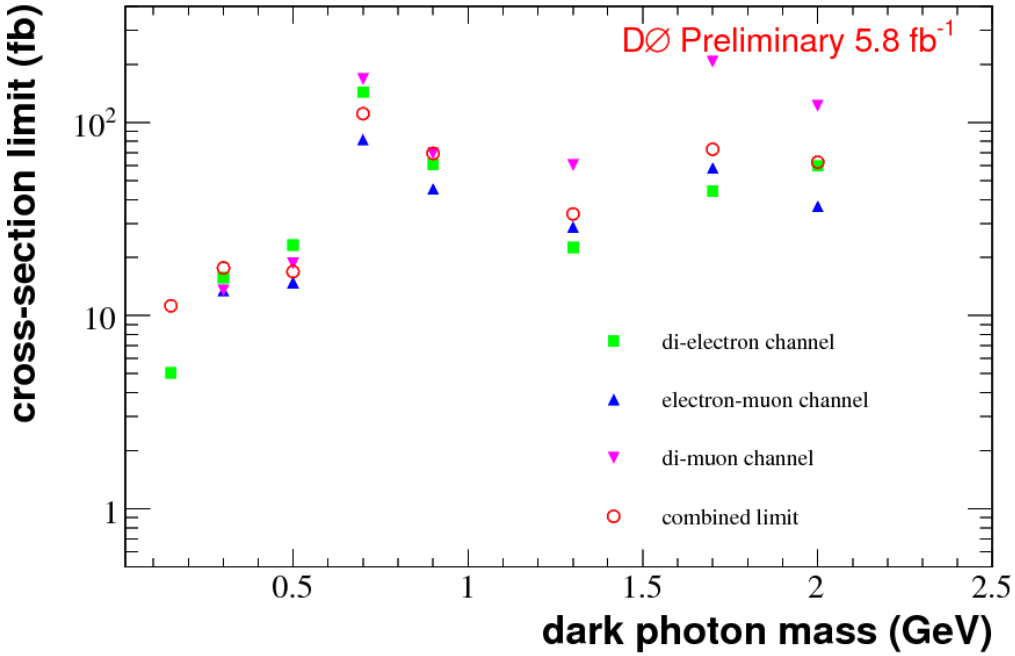
- Search for final states with a photon, 2 close leptons and $\not{E}_T$ (D0, 4.1fb^{-1}).

Constraining Hidden Symmetries: Lepton Jets

- both SM LSP's decay into γ_D - 2 pairs of close leptons and $\not{E}_T$ from $\tilde{X}$



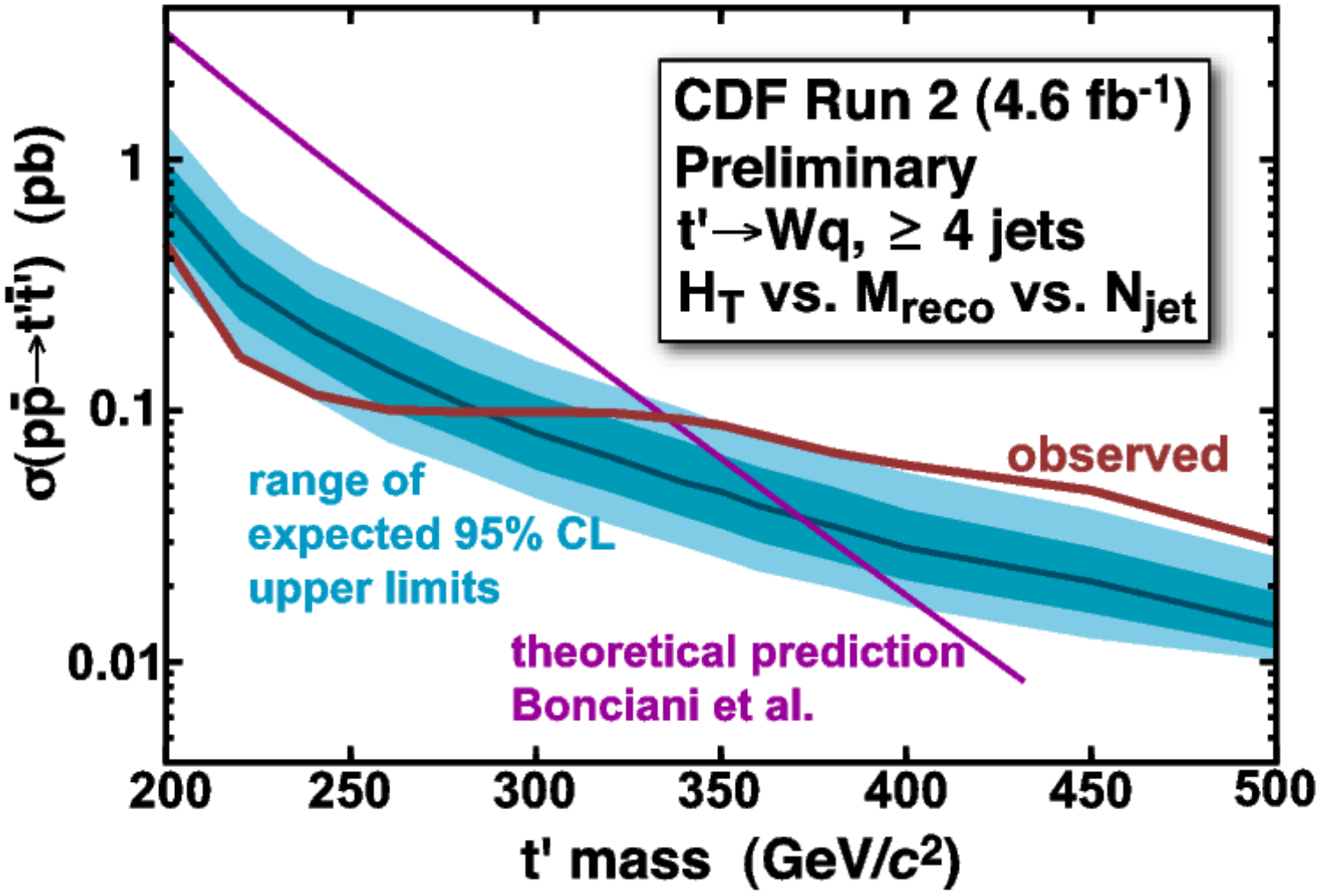




- $\sigma(p\bar{p}) \rightarrow \gamma_D\gamma_D\tilde{X}\tilde{X} + X \; <= \; 200fb, \; M_{\gamma_D} < 2.5GeV$

Search for a Heavy t' quark

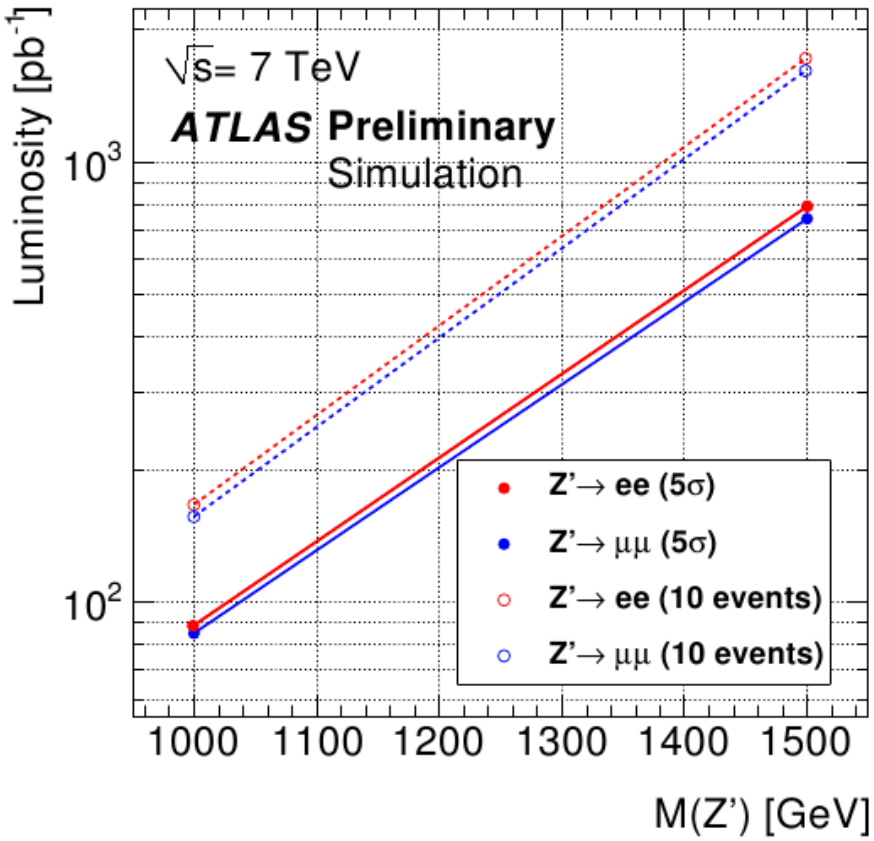
- 4th generation of fermions arises in a set of models
- a heavy top-like quark, pair produced, and decaying $t' \rightarrow Wq$ M(t')-M(b') <M(W)

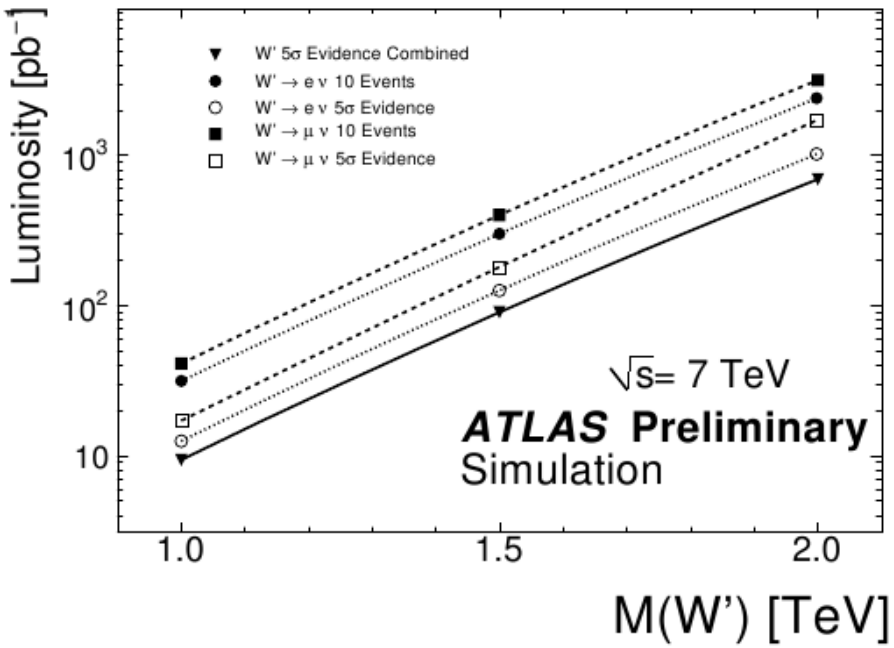


Quirks, if approved by D0

- $e\mu$ channel

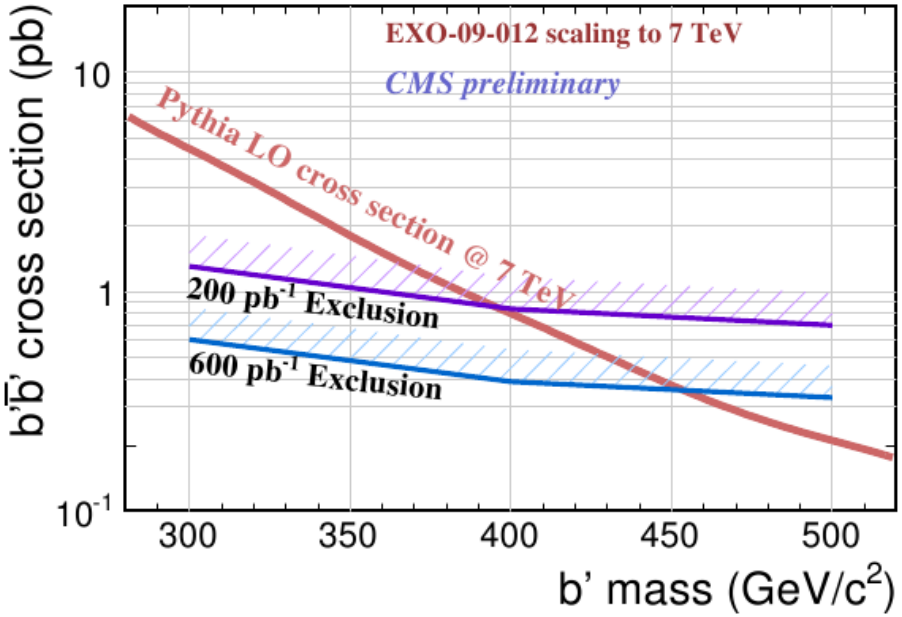
LHC: W' and Z' discovery potential

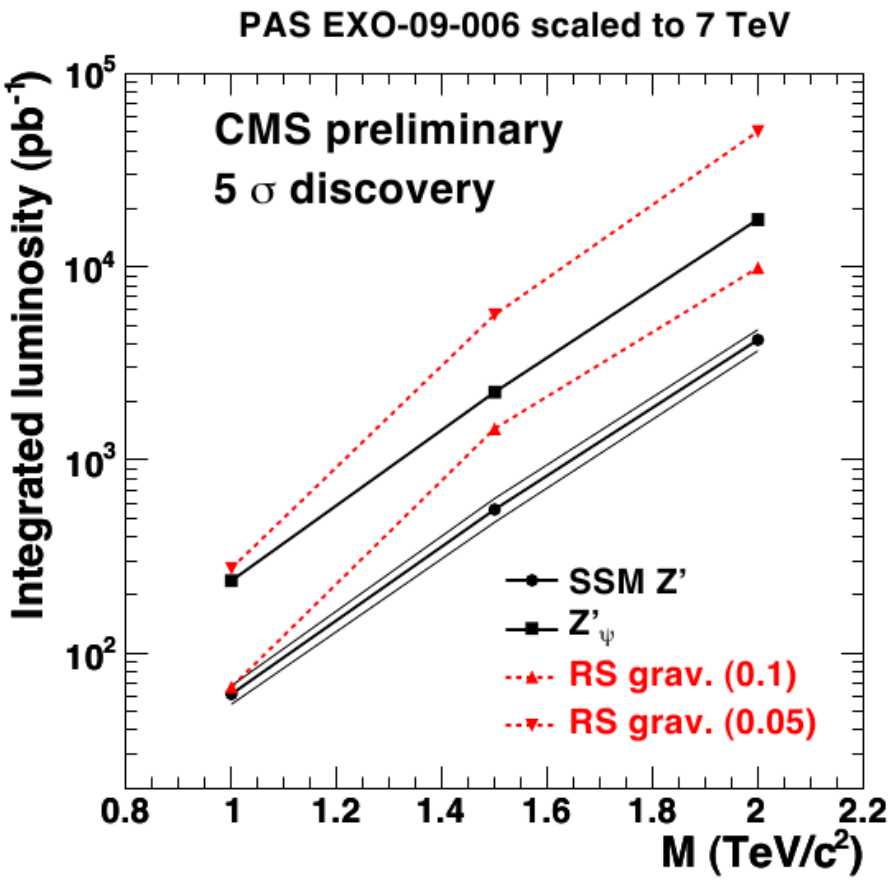




- with analyzed and understood data statitics of about $100 pb^{-1}$ LHC experiments reach and surpass M=1 TeV level

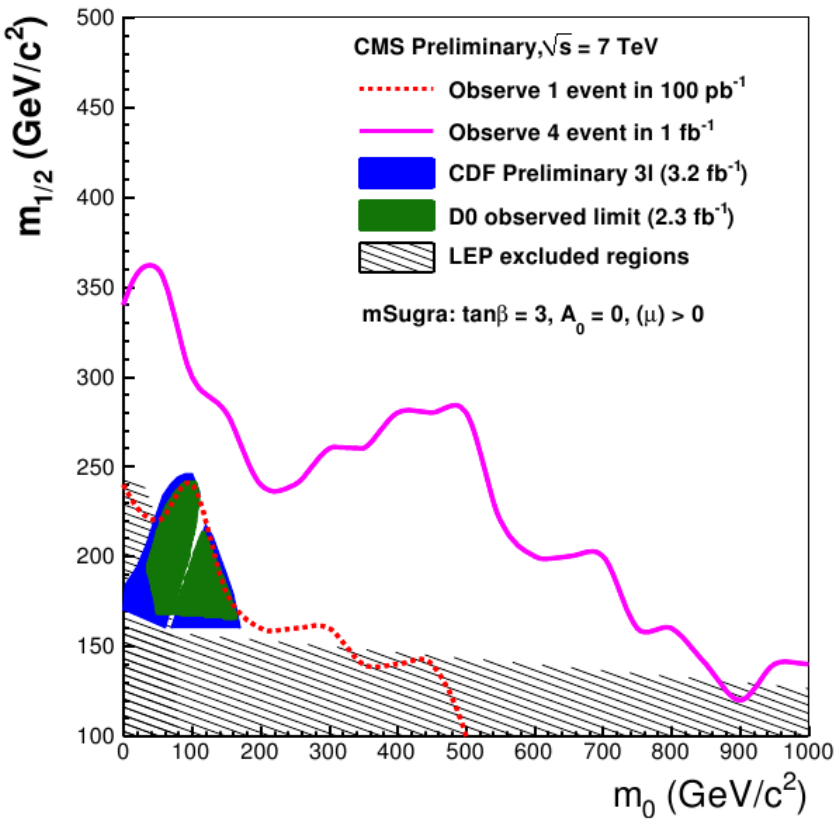
LHC Discovery Potential: Heavy quarks and RS Graviton





- with analyzed and understood data statitics of about $100 pb^{-1}$ LHC experiments reach and surpass M=1 TeV level

LHC Discovery Potential: Same Sign SUSY Dileptons



- SUSY observation in the like-sign dilepton mode will require more than 100 pb^{-1} of data

Summary

- extensive searches for physics beyond the SM pursued at the Tevatron
- multiple new constraints on the new physics, so far no non-trivial conclusions from combination of these constraints
- sophistication of the ongoing analyses continues to increase
- commissioning of the LHC progresses at full speed
- expect that with statistics about $100 pb^{-1}$ LHC will start taking over searches in the high mass range
- very high level of excitement and anticipation of the new results