Searches for Beyond the Standard Model Physics at DØ

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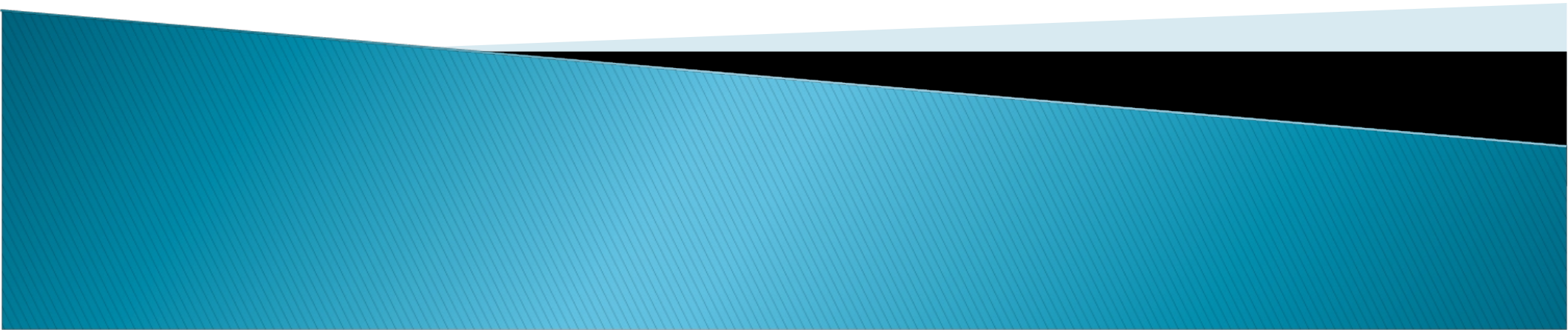
For the DØ Collaboration
DIS, April, 2011



Beyond the Standard Model Searches at DØ

- The DØ Collaboration has produced many new limits on BSM Theories
  - Search for diphoton events with large missing transverse energy (MET)
  - Search for events with leptonic jets and MET
  - Limits on heavy neutral gauge boson in the *ee* channel
  - Search for single vector-like quarks
  - Search for resonant *WW* and *WZ* production
  - Search for $W' \rightarrow tb$ resonances with left- and right-handed couplings to fermions
  - Search for new fermions ('quirks')
  - Search for pair production of scalar top quarks in the $e\mu$ final state

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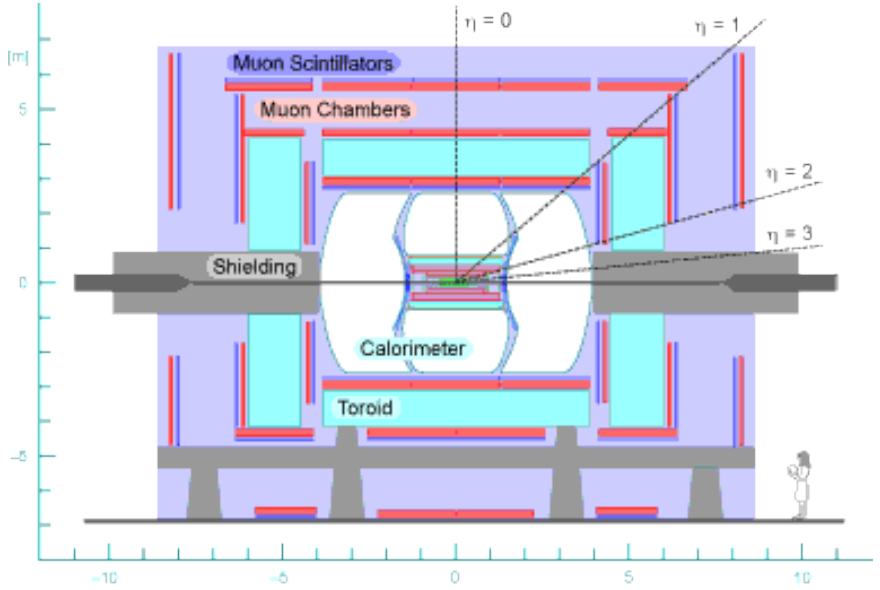
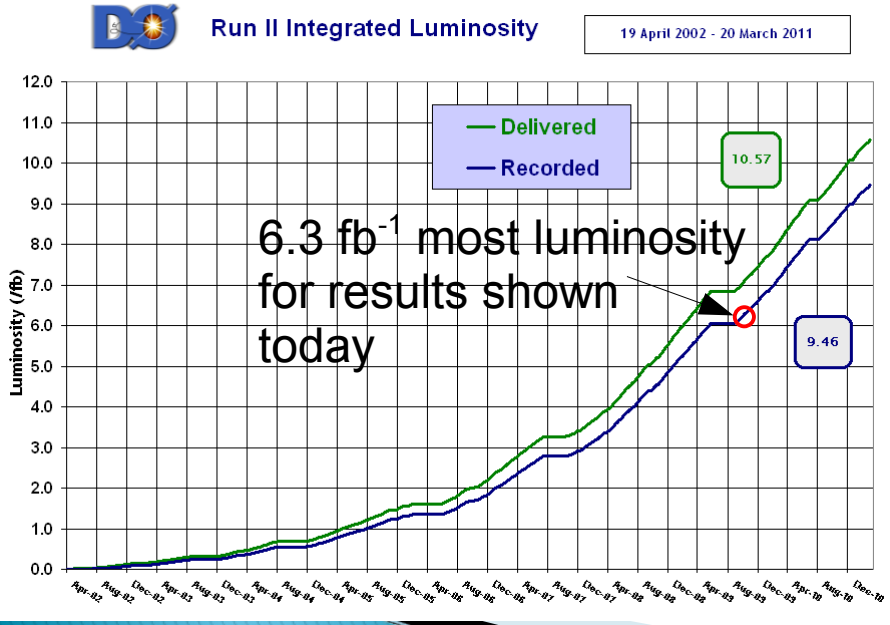
DØ Detector

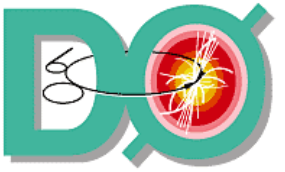


- $p\bar{p}$ collisions
  - $\sqrt{s} = 1.96$ TeV
  - 1 collision per 396 ns



Di-Photon Search

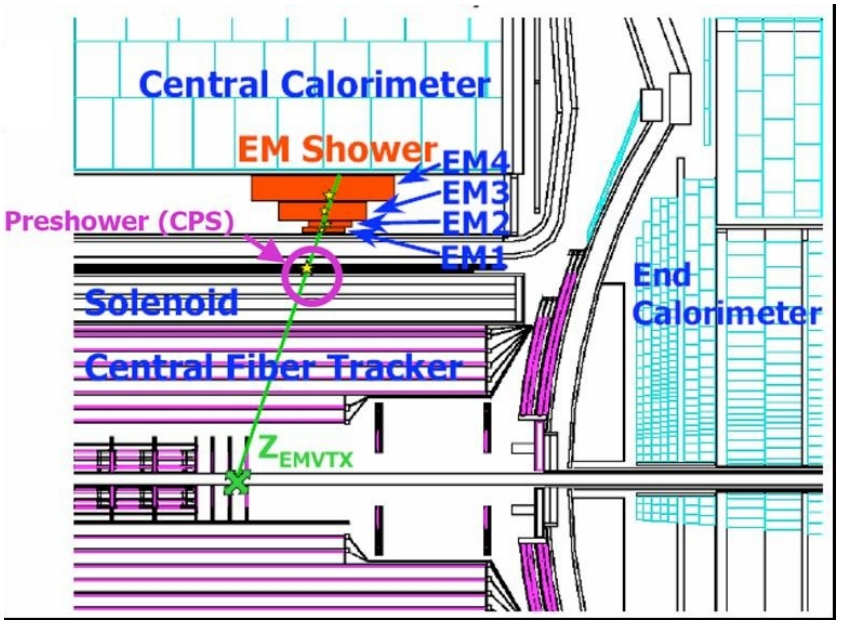
$\int \mathcal{L} dt = 6.3\ fb^{-1}$



- In Supersymmetry (SUSY), every particle has superpartner
  - In some Gauge Mediated Symmetry Breaking (GMSB) Models, SUSY particles $\rightarrow \tilde{\chi}^0 \rightarrow \gamma +$ gravitino
  - R-parity conserved
    - pair production
    - gravitino stable with m~1keV
- For Universal Extra Dimensions (UED) models
  - Compact extra dimension of radius R_c
  - Tower of KK excitations with masses separated by R_c^{-1}
  - With additional Gravity only ED, decay to $G\gamma$
- Signature for both models: $\gamma\gamma$ + MET

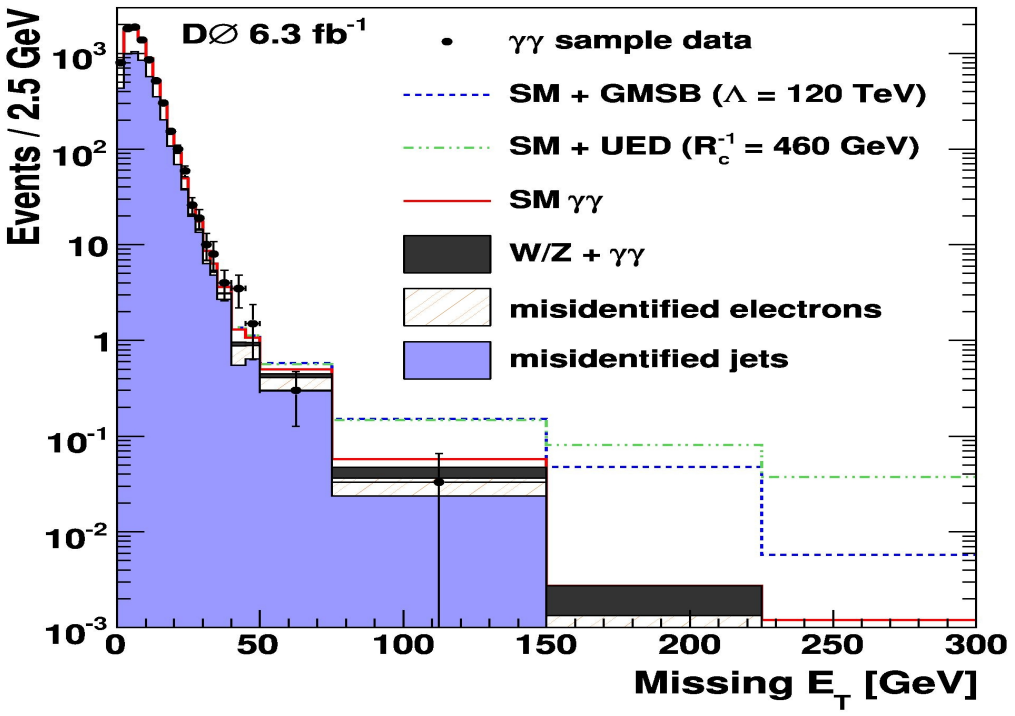
Photon Identification

- γ requirements
  - narrow energy deposition
    - Central Calorimeter only
  - 95% energy in EM calorimeter
  - Anti-track match
  - NN for γ–jet separation
  - Hollow cone track isolation
  - $E_T > 25$ GeV



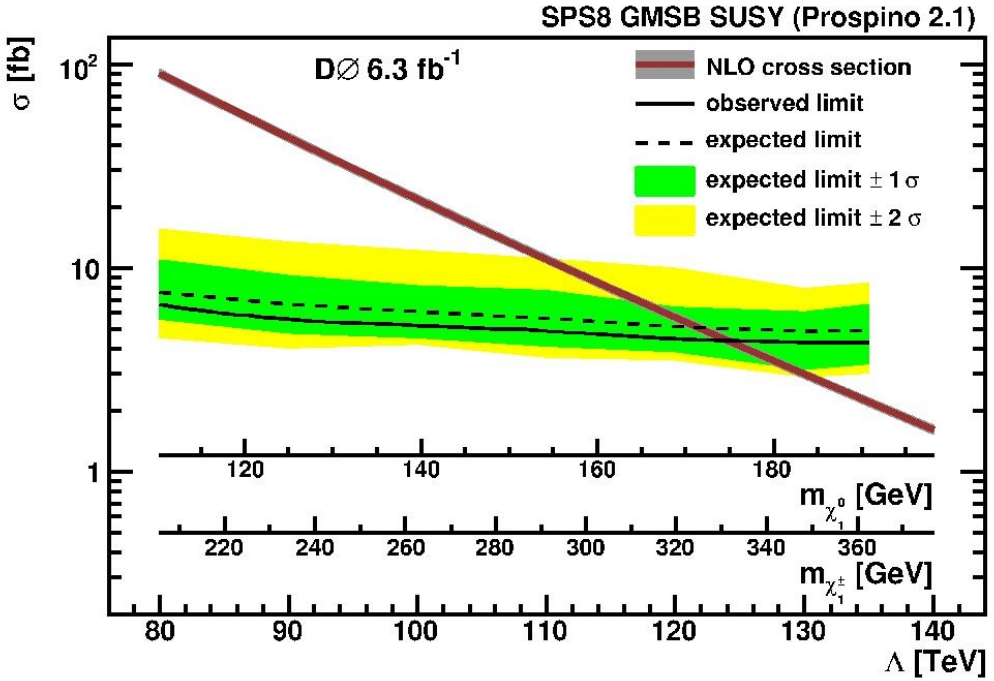
- The γ are required to point back to the same primary vertex to ensure proper MET calculation
  - Also require $\Delta\phi$ separation between MET and nearest γ, jet

Photon Background Estimates

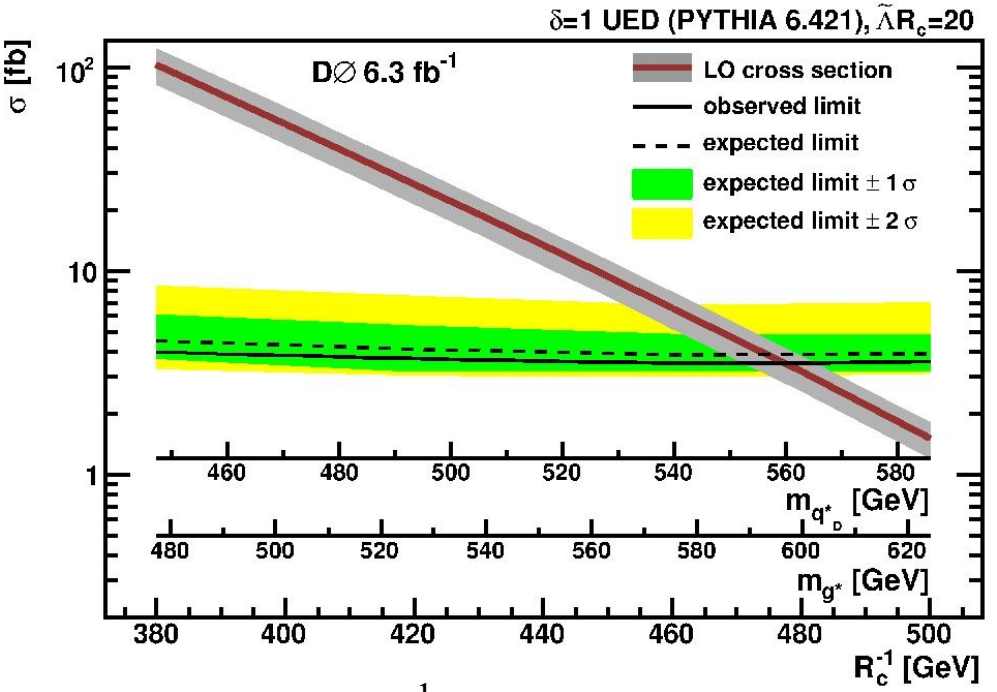


- $W\gamma\gamma$ and $Z\gamma\gamma$ from MC
- $W\gamma$ and Wj from $e\gamma$ data
  - Estimate $e\rightarrow\gamma$ mis-ID rate from tracking efficiency
- QCD backgrounds
  - $\gamma\gamma$ events with some calorimeter cuts reversed
  - Also look at $Z\rightarrow ee$ events
  - MET distributions agree within errors

95% Confidence Limits



$\Lambda > 124$ TeV, $m_{\tilde{\chi}^0} > 175$ GeV



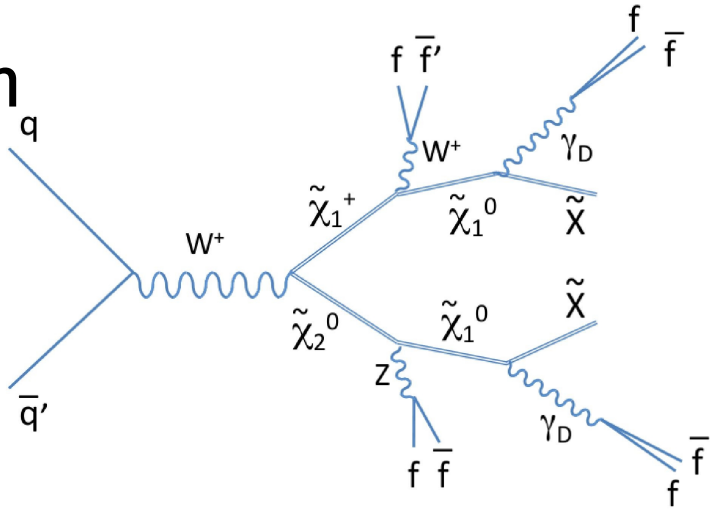
$R_c^{-1} > 477$ GeV

- SUSY signal based on GMSB Snowmass Slope SPS 8.
  - $N_m = 1$, $\mu > 0$, $\tan\beta = 15$, $M_m/\Lambda = 2$
- UED model considered has 6 extra dimensions and a fundamental Planck scale $M_D = 5$ TeV

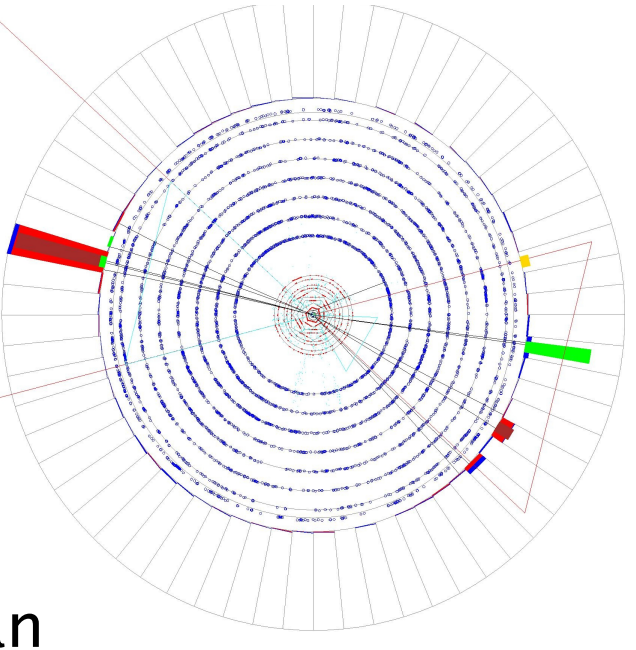
arXiv:1008.2133

Hidden-valleys and Supersymmetry

- Hidden-valley models have hidden sector weakly coupled to SM
  - Force carrier, γ_D, has mass $\leq$2GeV
- If SUSY exists, lightest SUSY particle (LSP) may decay promptly to hidden sector
  - Assume R-parity conservation, $m_{LSP-SM} > m_{LSP-hidden}$
  - Dark photons replace the photons of previous result
- Expect γ_D to decay to charged fermions
  - Unlike QCD jets, may contain only charged leptons
  - Search for tightly collimated jets of leptons with MET



Leptonic Jets

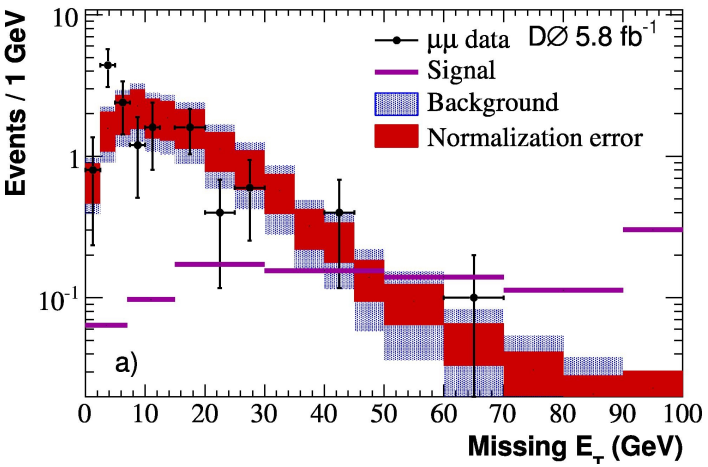


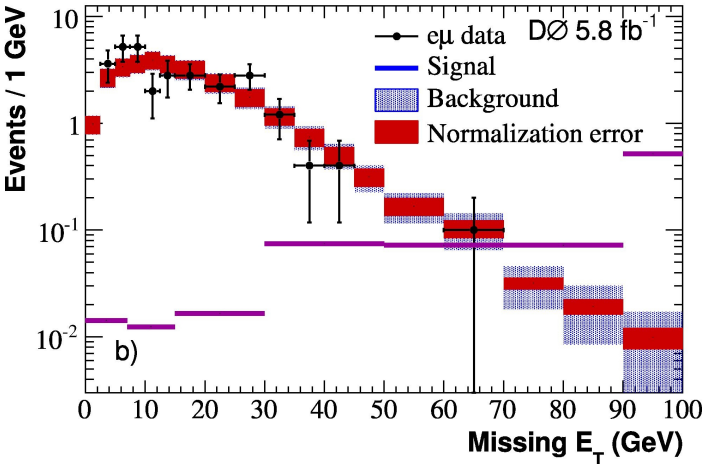
- To reconstruct leptonic jets (ℓ-jet), we start with the loose ID criteria for isolated electrons and muons
  - Electronic jets have a track pointing to an isolated cluster of EM energy in the central calorimeter
  - Muonic jets have a track matched to hits in the muon system and calorimeter isolation
  - If an ℓ-jet passes e and μ criteria, treat as μ-jet
- Require a second track with opposite charge within $\Delta R = \sqrt{(\Delta\phi^2+\Delta\eta^2)} < 0.2$ of seed track
  - If multiple tracks, choose one closest in ΔR to seed track
  - To reduce QCD impose hollow cone track isolation $0.2<\Delta R<0.4$ about seed track

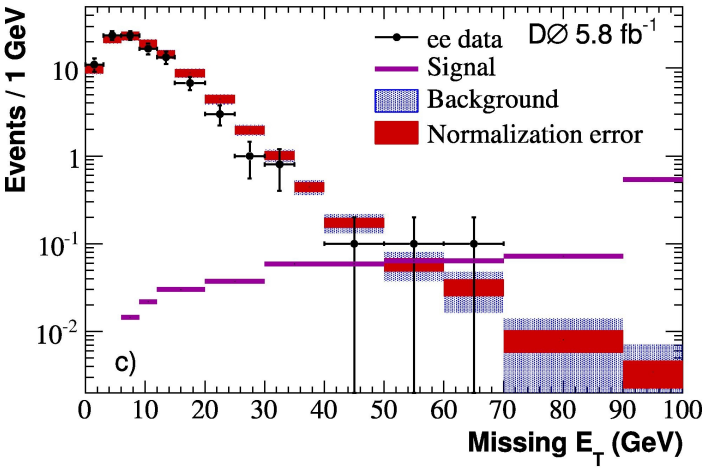
Leptonic Jets and MET Search

$\int \mathcal{L} dt = 5.8\ fb^{-1}$

- We require 2 ℓ-jets with seed track $p_T > 10$ GeV separated by $\Delta R > 0.8$ and MET > 30 GeV
  - MET calculated from the calorimeter energy with no μ p_T correction, as this is hard to determine in μ-jets
- Primary background is from QCD jets faking ℓ-jets
  - Estimated using data
  - background uses non-isolated ℓ-jets
  - Normalized to signal using events with MET <15 GeV







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Limits on SUSY Dark Photon Production

- Data is consistent with predicted SM background
  - Set limits for SUSY GMSB model with SPS8 parameters

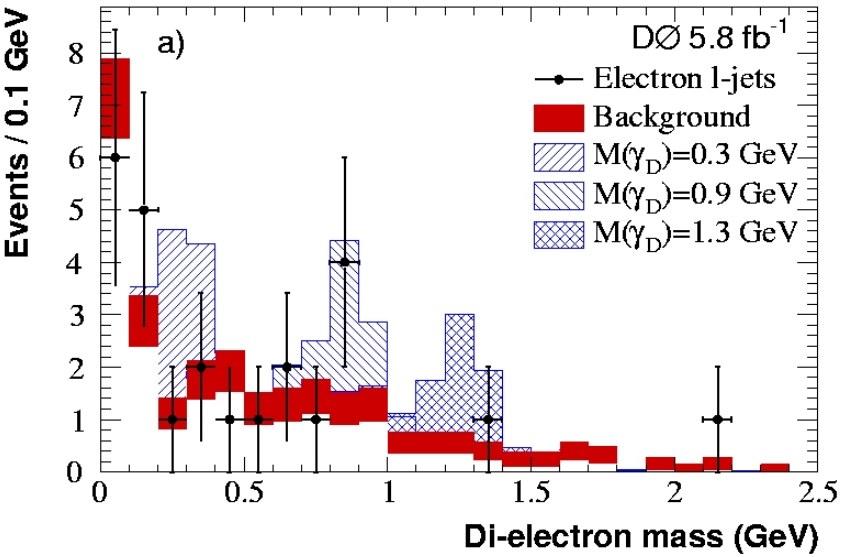
Final state	N_{obs}	N_{SM}	$\mathcal{A}\times\varepsilon$	$\mathcal{B}$	95% CL on $\sigma\times\mathcal{B}$	Expected limit
ee	7	10.2±1.7	0.09	$\mathcal{B}_e^2$	13 fb	19 fb
$e\mu$	11	17.5±4.2	0.0795	$2\mathcal{B}_e\mathcal{B}_\mu$	19 fb	30 fb
$\mu\mu$	3	8.6±4.5	0.03	$\mathcal{B}_\mu^2$	20 fb	35 fb

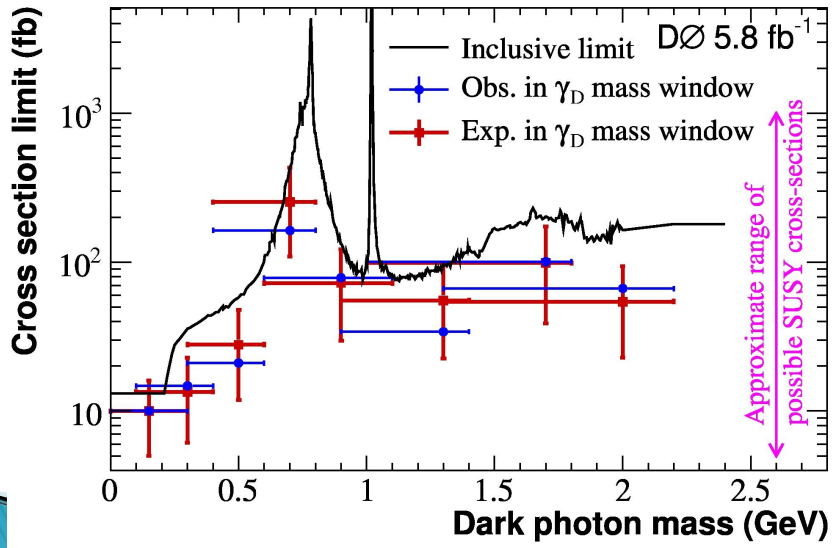
- Systematics include 20% on signal efficiency, 20-50% on background normalization, and 6.1% on integrated luminosity

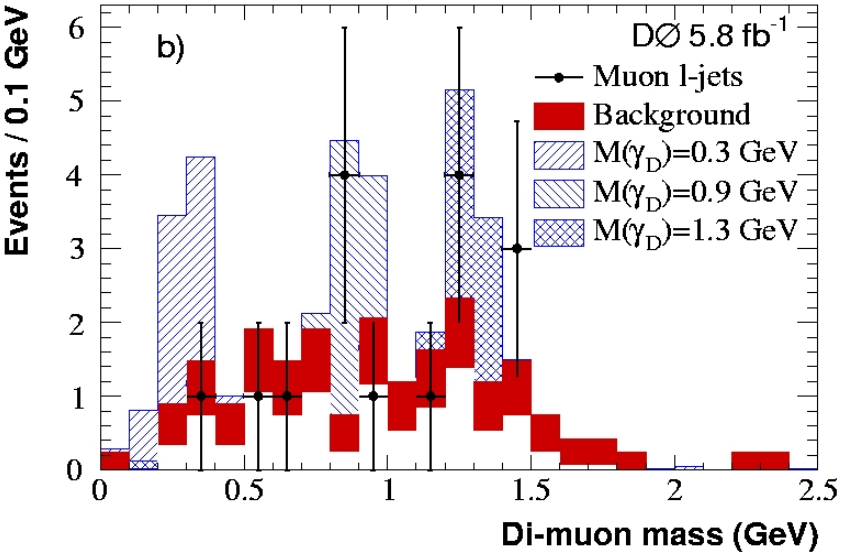
arXiv:1008.3356

Dark Photon Mass search

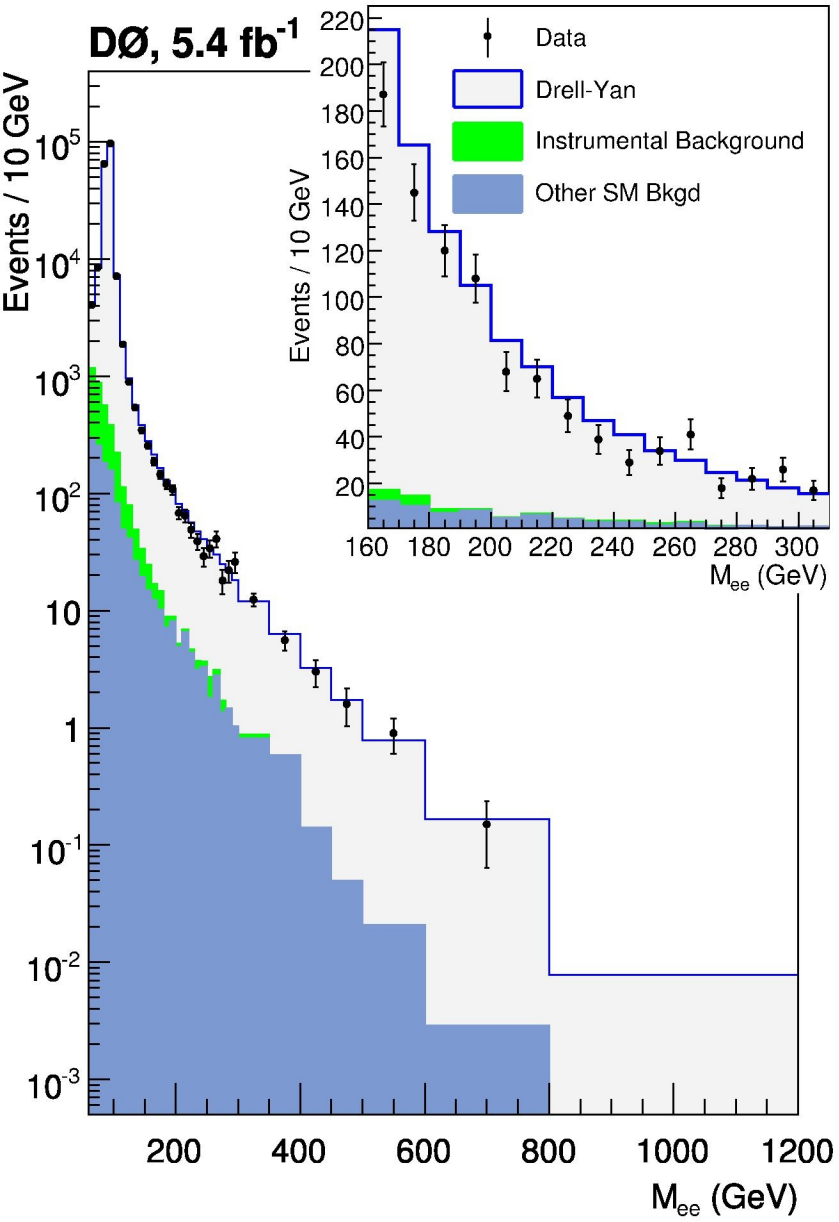
- We also search for a mass resonance in the invariant di-track mass within the ℓ-jets
  - No evidence of a resonance is found, so we place an upper limit on the γ_D σ vs γ_D mass.







Search for a Heavy Neutral Gauge Boson decaying to *ee*

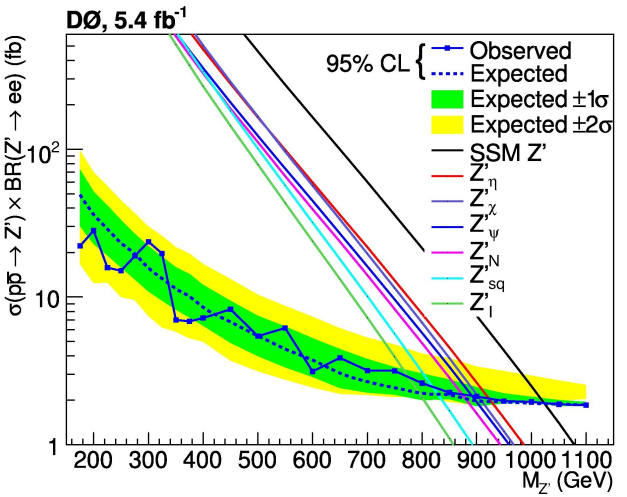


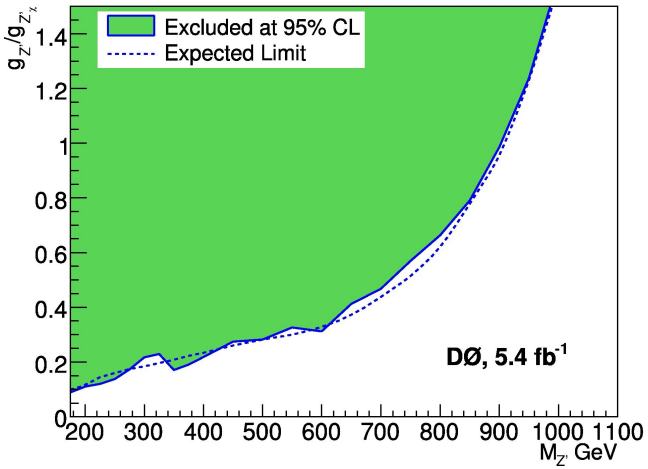
- Several new physics models predict a $Z' \rightarrow ee$
  - Electron definition similar to γ, but require either a track match or pattern of hits in CFT/SMT pointing to calorimeter cluster
- Main SM background $Z/\gamma^* \rightarrow ee$
  - Modeled with PYTHIA + NNLO mass-dependent k-factor
  - Multijet background modeled using data
  - Other SM background (WW,Wγ,etc) modeled using PYTHIA

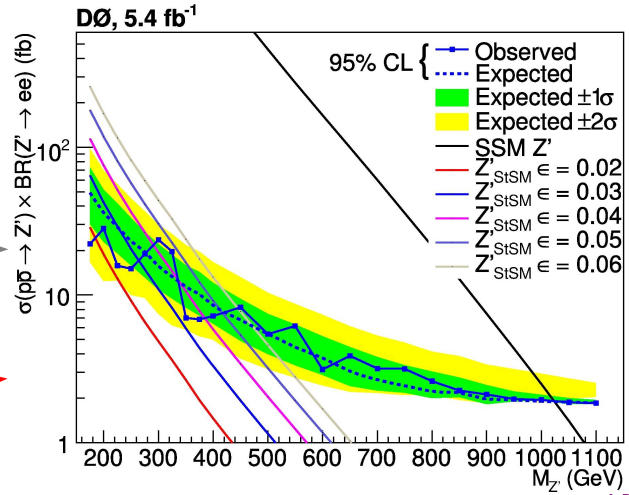
Limits on Z' arXiv:1008.2023

- No excess observed $\int \mathcal{L} dt = 5.4\ fb^{-1}$
  - Set limits in the Sequential Standard Model (SSM), E_6 models with varying mixing angles, and the Stueckelberg extension of the Standard Model (StSM)

Model	Lower Mass Limit (GeV)	
	Expected	Observed
$Z'_{\rm SSM}$	1024	1023
Z'_{η}	927	923
Z'_{χ}	910	903
Z'_{ψ}	898	891
Z'_{N}	879	874
Z'_{sq}	829	822
Z'_{I}	795	772
$Z'_{\rm StSM}(\epsilon = 0.06)$	471	443
$Z'_{\rm StSM}(\epsilon = 0.05)$	414	417
$Z'_{\rm StSM}(\epsilon = 0.04)$	340	289
$Z'_{\rm StSM}(\epsilon = 0.03)$	227	264
$Z'_{\rm StSM}(\epsilon = 0.02)$	—	180

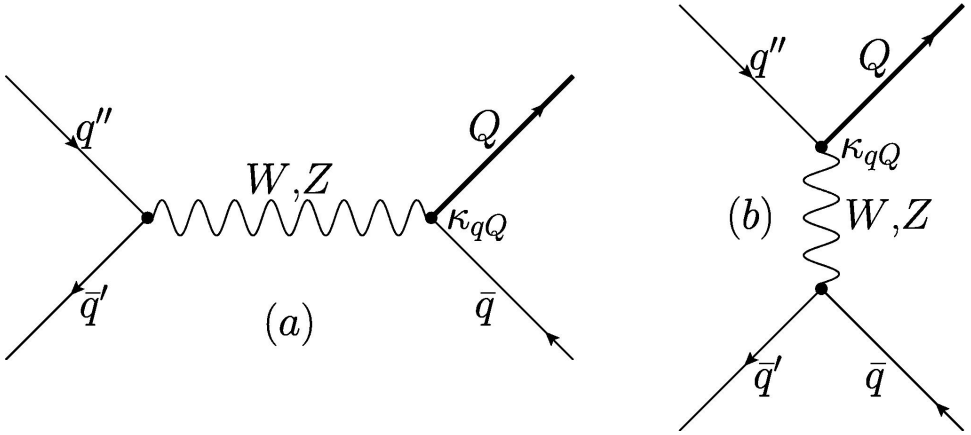






Single Vector Quark Search

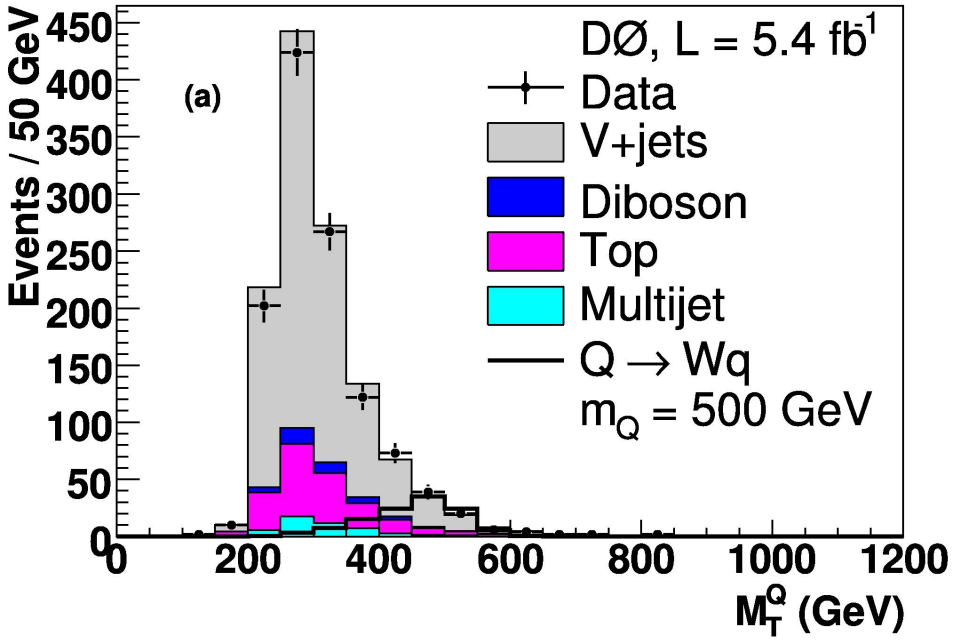
- Several BSM models predict vector-like quarks
  - Q_R and Q_L behave the same under SU(3)XSU(2)XU(1)
  - In some models, contributions to gauge boson couplings cancel out, allowing electroweak production with SM quark
- We search for a vector quark decaying to Vq
  - V=W,Z; W→$\ell\nu$,Z→$\ell\ell$
  - Assume U→Zu, D→Wu
  - Effect mass limits, not σ_Q

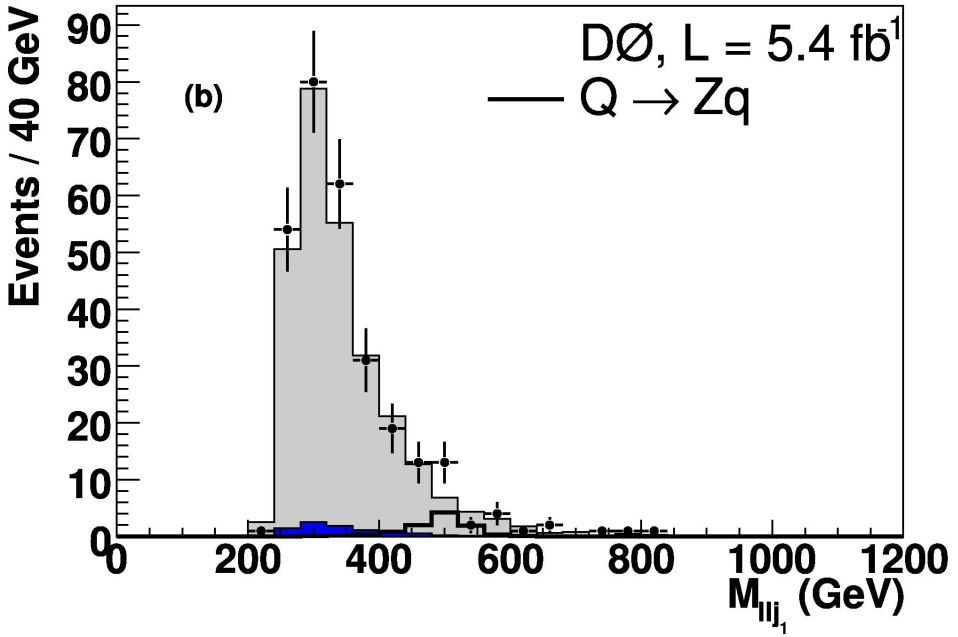


- Signature is di-lepton + jet or lepton + jet +MET
  - $\ell = e,\mu$

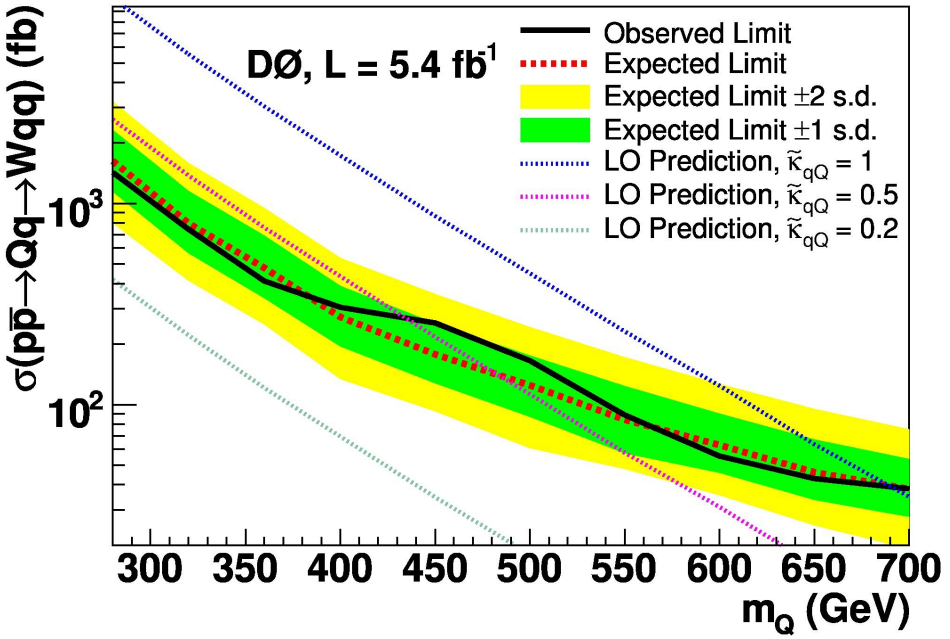
Vector Quark Signal and Backgrounds

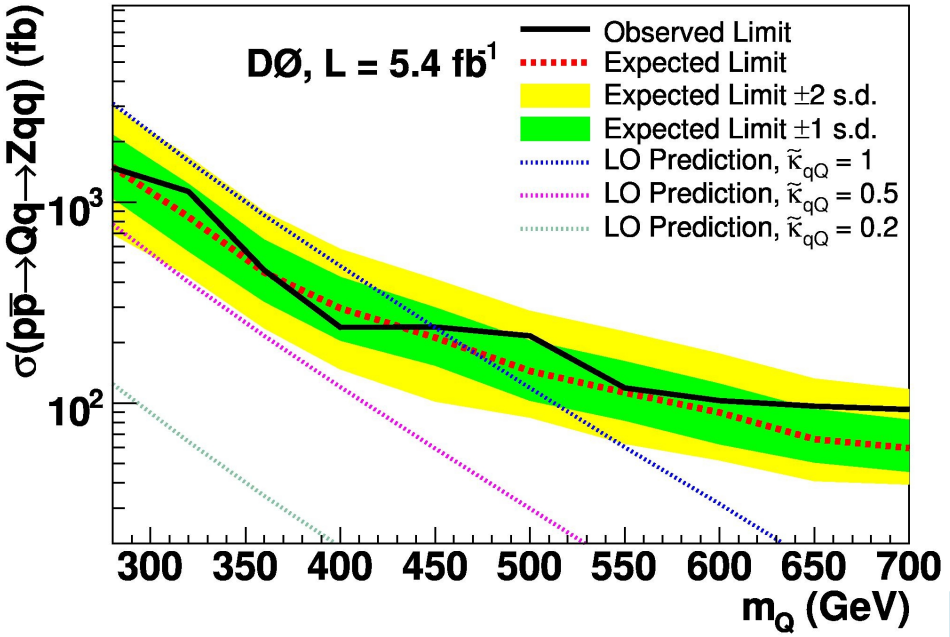
- To enhance signal, require high p_T events
- Generate signal MC with MADGRAPH between 280–700 GeV
- Primary backgrounds are Z+jet and W+jet
  - top, diboson, and multijet also contribute
  - V+jet, top from with ALPGEN
  - Diboson estimate from PYTHIA
  - Multijet estimate from data





Single Vector Quark Limits





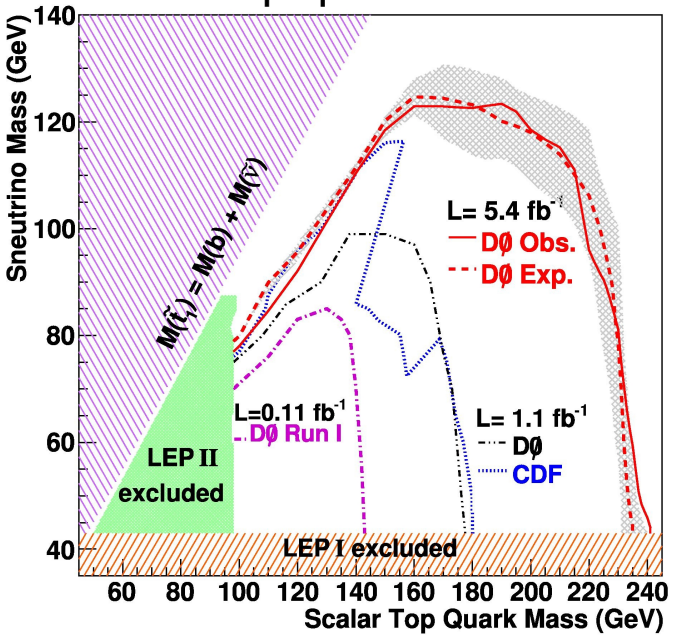
$\int \mathcal{L} dt = 5.4$ fb^{-1}

- No Significant excess is observed
- For a κ_{qQ} coupling constant of 1at 95% CL
  - with U→Zu, $M_U > 449$ GeV
  - with D→Wu, $M_D > 693$ GeV

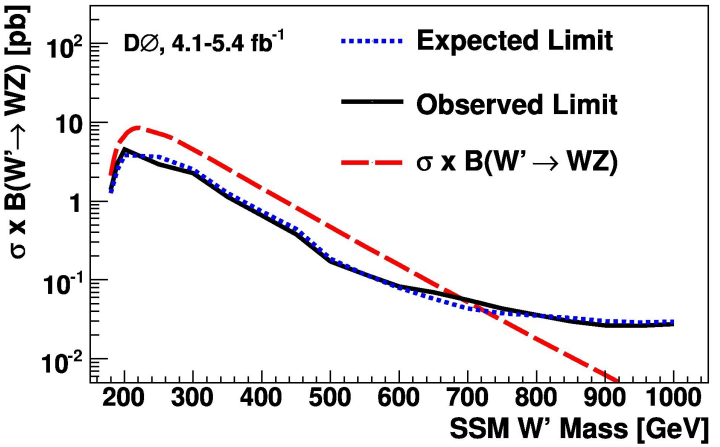
arXiv:1010.1466

Many Other New Limits

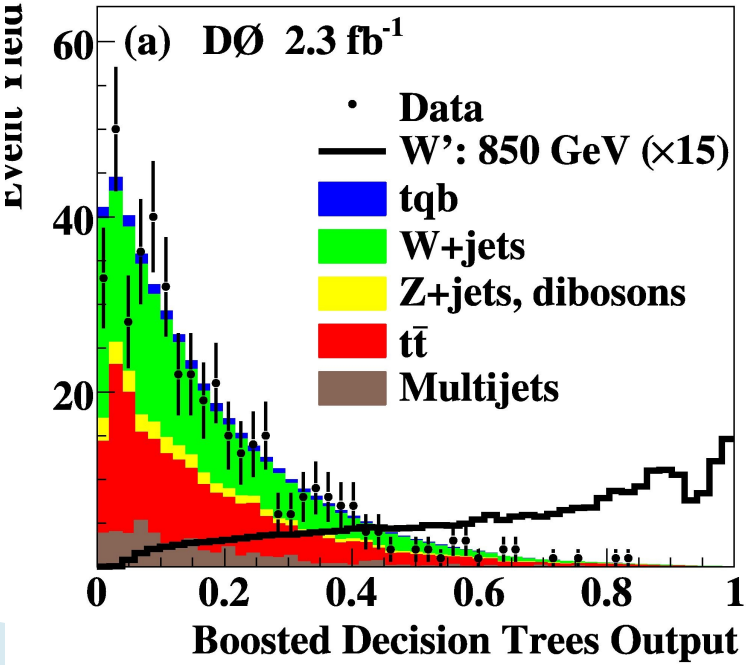
Scalar top quark arXiv:1009.5686



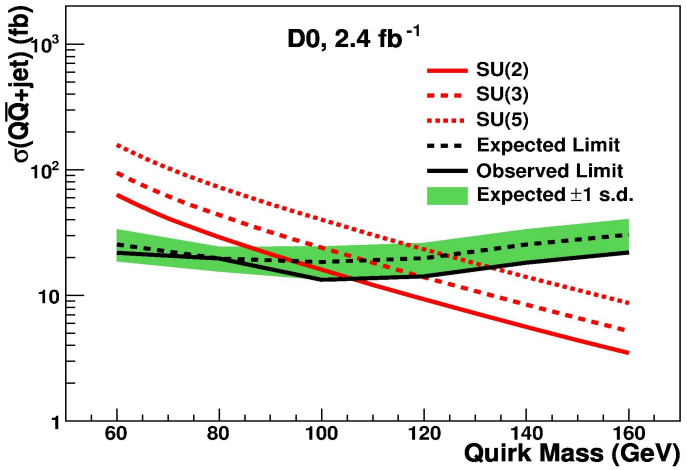
W'→WZ arXiv:1011.6278

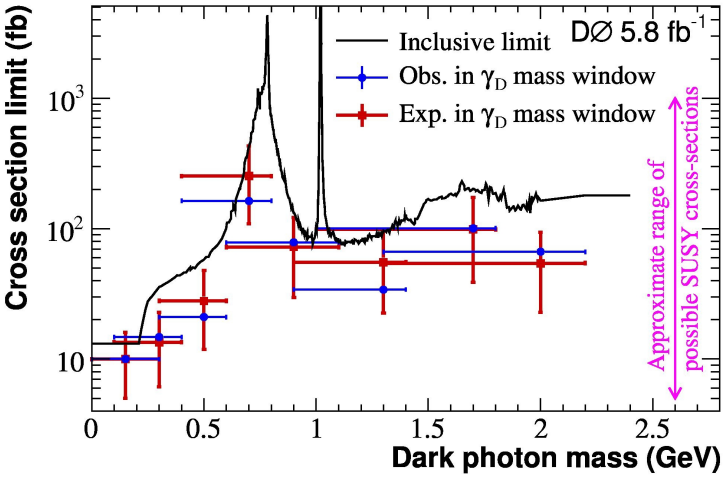


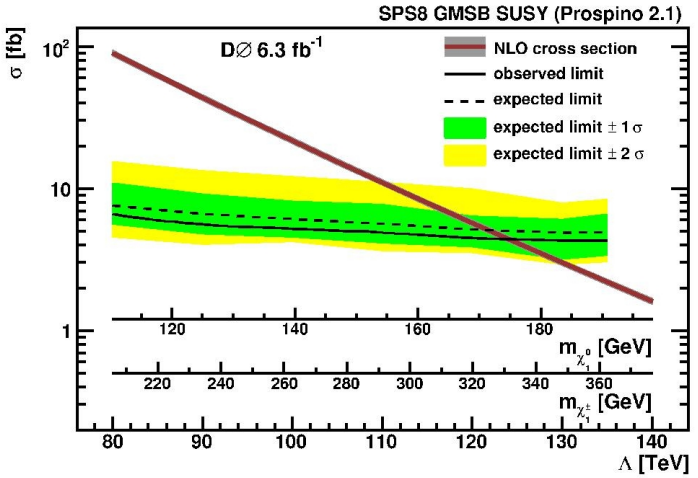
W'→tb arXiv:1101.086

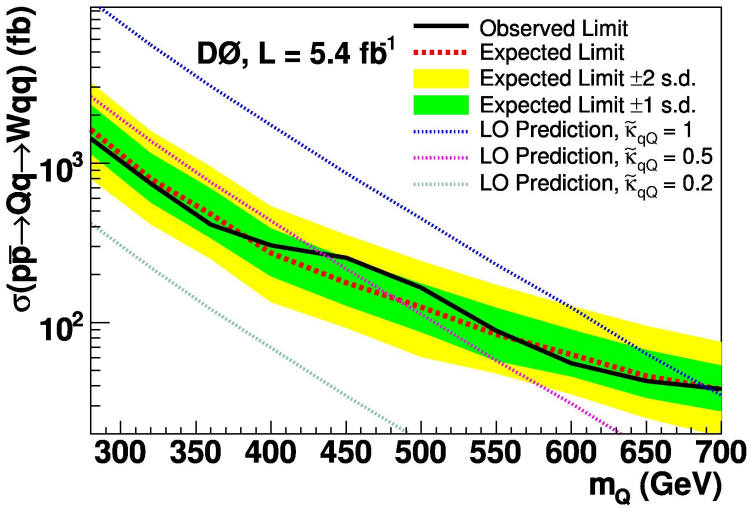


Quirks arXiv:1008.3547









Summary

- New limits on dark photon production

  $\sigma \times B < 13\text{-}20$ fb

- New GMSB/UED di-γ limits

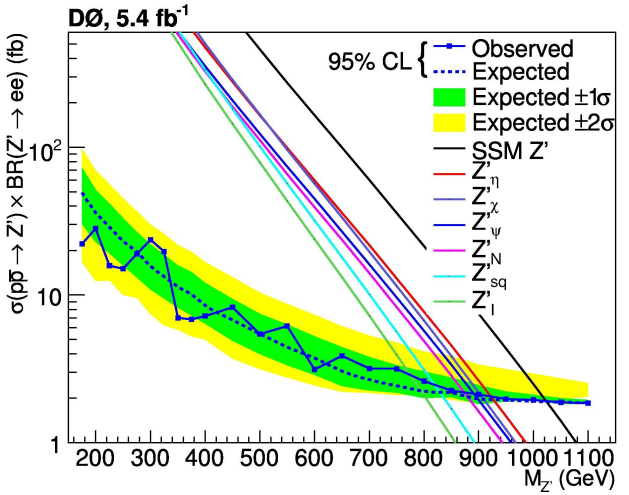
  $\Lambda > 124$ TeV

  $m_{\tilde{\chi}^0} > 175$ GeV

  $R_c^{-1} > 477$ GeV

- New Z' limit

  $M_{Z'_{SSM}} > 1023$ GeV



- New Vector Quark limits

  $M_U > 449$ GeV

  $M_D > 693$ GeV