

# CMS New Fermions and Gauge Interactions

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on behalf of the CMS Collaboration

Implications of LHC results for TeV-scale Physics: WG3, CERN, 30/8/11

# Introduction

- CMS has strong search program for new Gauge Bosons and fermions
  - nine 2011 results out already + more on way!
  - <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO>
- Searches in
  - $W' \rightarrow e\nu, \mu\nu, WZ, \text{dijet}$
  - $Z' \rightarrow ee, \mu\mu, \tau\tau, t\bar{t}, \text{dijet}$ :
  - new fermions:  $b', t'$ , excited  $e/\mu$ , heavy  $\nu$ , leptoquarks
- Will not cover in detail:
  - $Z' \rightarrow t\bar{t}$  searches
  - $t' / b'$
  - extra dimensions

} covered in top-like session

} covered in extra dimensions

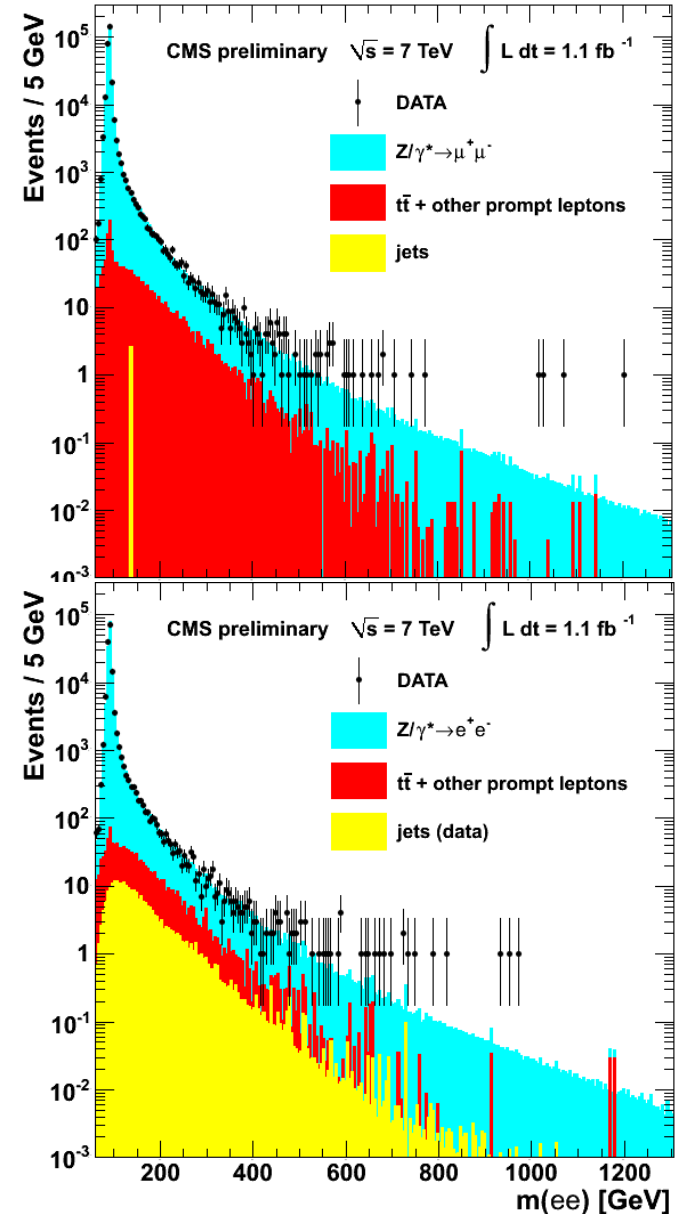
# General Search Strategy

- $W'/Z'$  searches are inclusive and model independent
  - just look for an excess above a background
  - all  $Z'$  searches assume a 'narrow' resonance
  - no specific topological cuts beyond basic ones
  - $\eta$  range  $< 2.5$  in most searches
  - use simple selection which is well modeled in MC
    - data/ MC efficiencies differ by less than  $< 2\%$  for electrons and muons
- analyses use data driven approaches where possible
  - MC normed to data in control regions (ie Z peak)
  - jet backgrounds estimated using data driven methods
  - MC estimated backgrounds checked in control channels
    - eg  $t\bar{t}$  background to  $Z \rightarrow ee$  confirmed by studying e-mu spectrum
  - fits to data to model background also used when appropriate

# $Z' \rightarrow ee / \mu\mu$

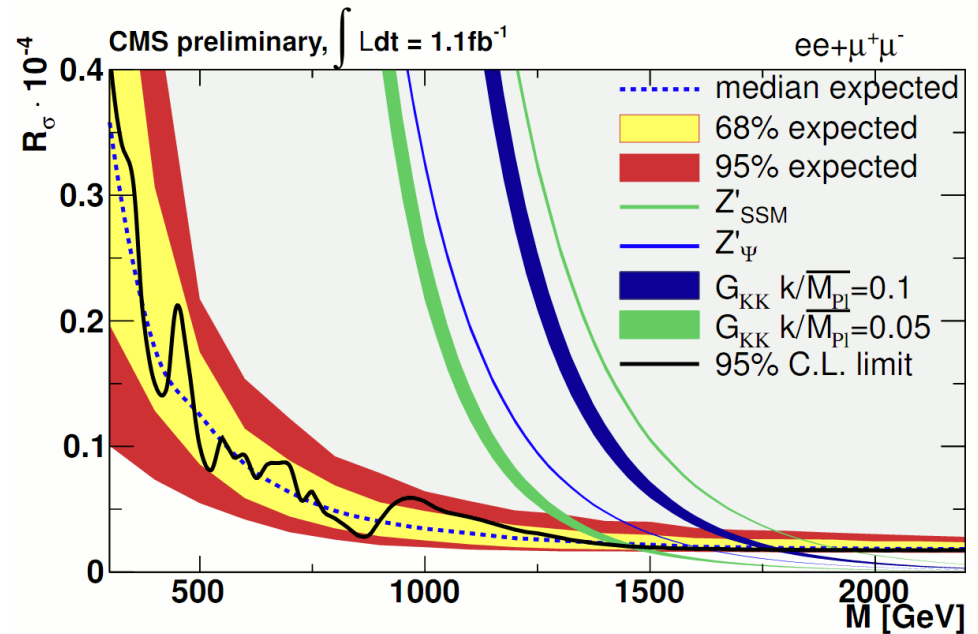
EXO-11-019

- search strategy:
  - excess with mass  $>200$  GeV
  - inclusive search: mass of 2 leptons  $|\eta| < 2.5$ , no cuts on MET / other activity in event
  - no OS required eles / OS required muons
- at 1 TeV:
  - ele: Acc x Eff:  $\sim 64\%$ , resolution 2.4%
    - improvable but not by much
  - muons: Acc x Eff:  $\sim 80\%$ , resolution 7%
- no magic bullet to improve sensitivity
  - so if no excess hint in 2011, a long time before any discovery could occur at same  $\sqrt{s}$
- most significant excess:
  - 970 GeV with Z (1sided  $\sigma$ )=2.1
  - to observe such excess somewhere between 600-1800:  $Z = 0.2$



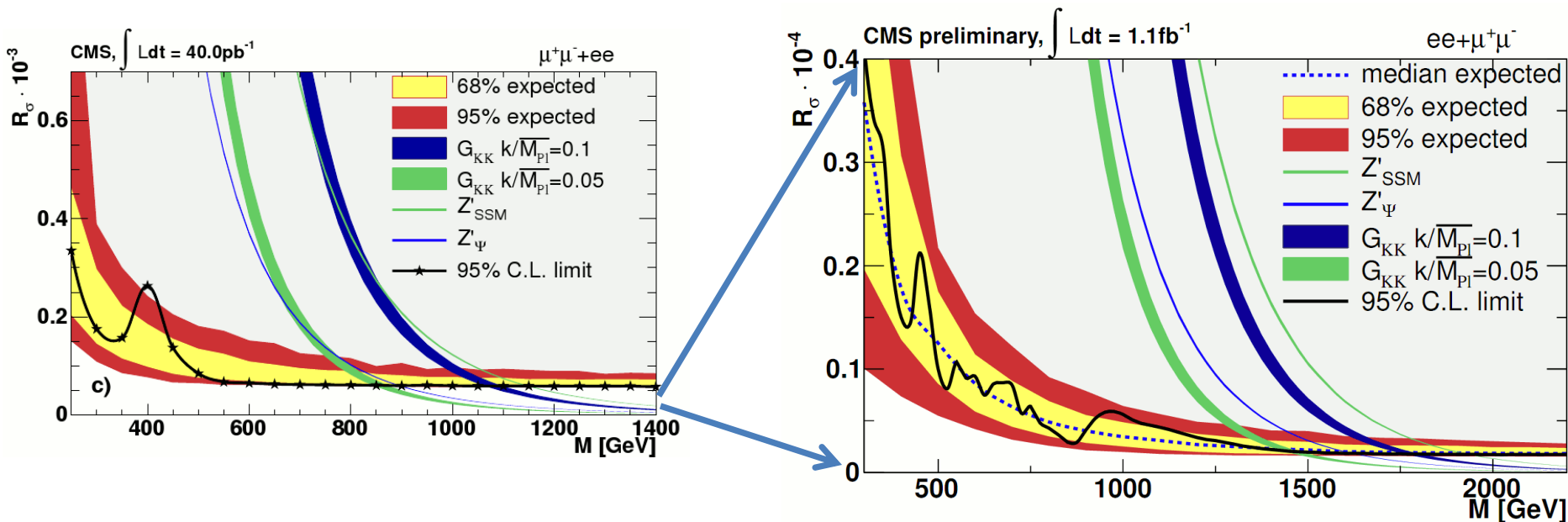
# $Z' \rightarrow ee / \mu\mu$

- limits are set using Bayesian unbinned likelihood in window of  $\pm 40\%$  of resonance mass
  - roostats implementation
- limits are ratio of  $Z'/Z \sigma \cdot \text{Br}$ 
  - reduces PDF uncertainties and removes luminosity dependence
- muons have better expected limits due to higher acceptance but worse obs. due to 1.2 TeV muon event



Model	Mass Limit (GeV)		
	ee	$\mu\mu$	ee+ $\mu\mu$
$Z'_{SSM}$	1730	1780	1940
$Z'_{\psi}$	1440	1440	1620

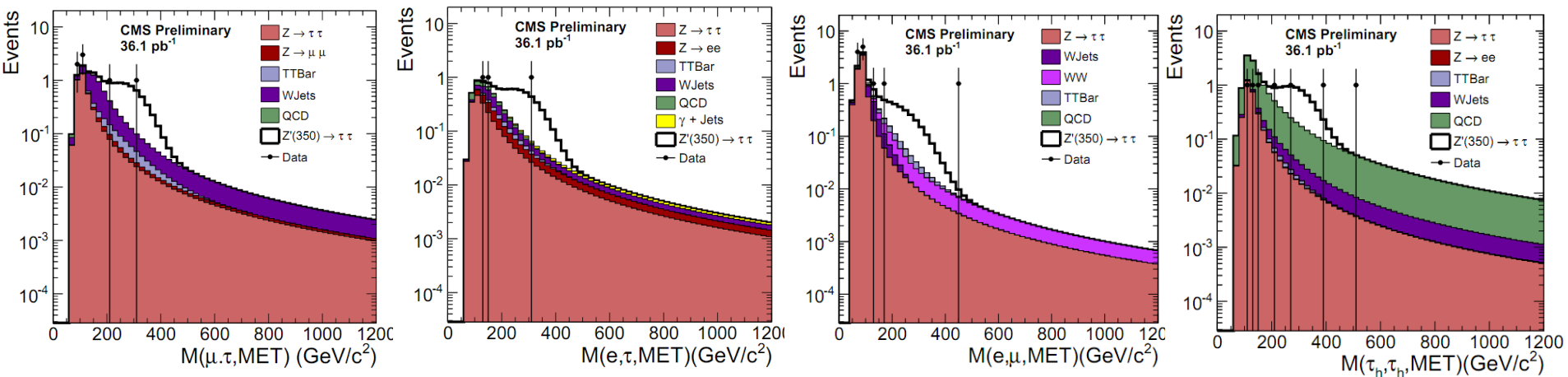
# 35pb<sup>-1</sup> to 1.1fb<sup>-1</sup>



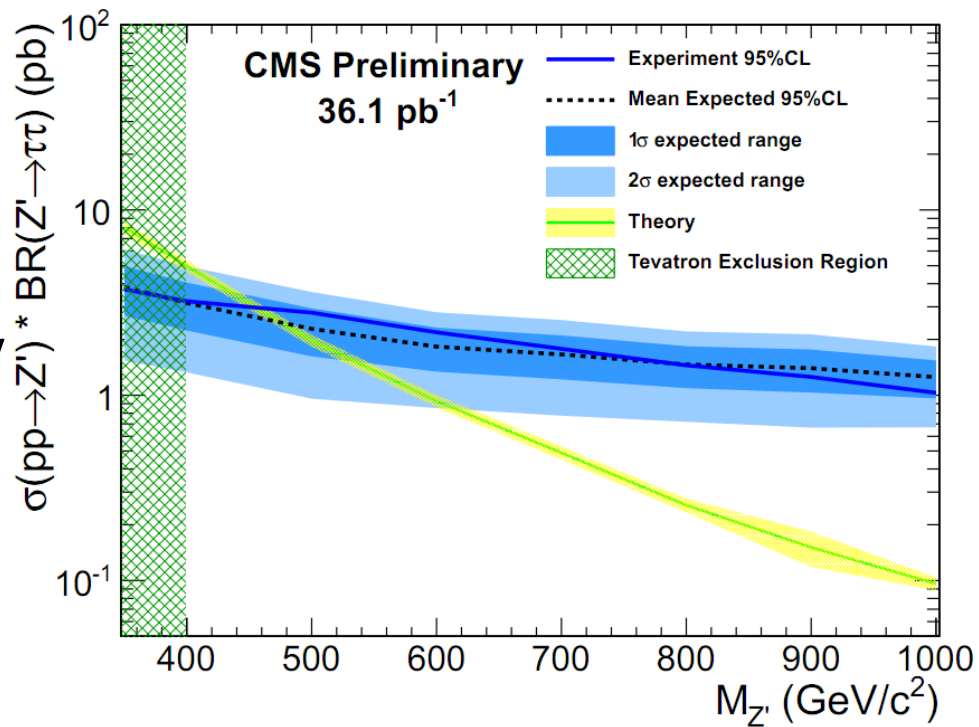
- $Z' \rightarrow ee/\mu\mu$  exclusion from 0.05pb to 0.002pb
- large jump in sensitivity
  - thanks LHC for the lumi!

# $Z' \rightarrow \tau\tau$

EXO-10-022



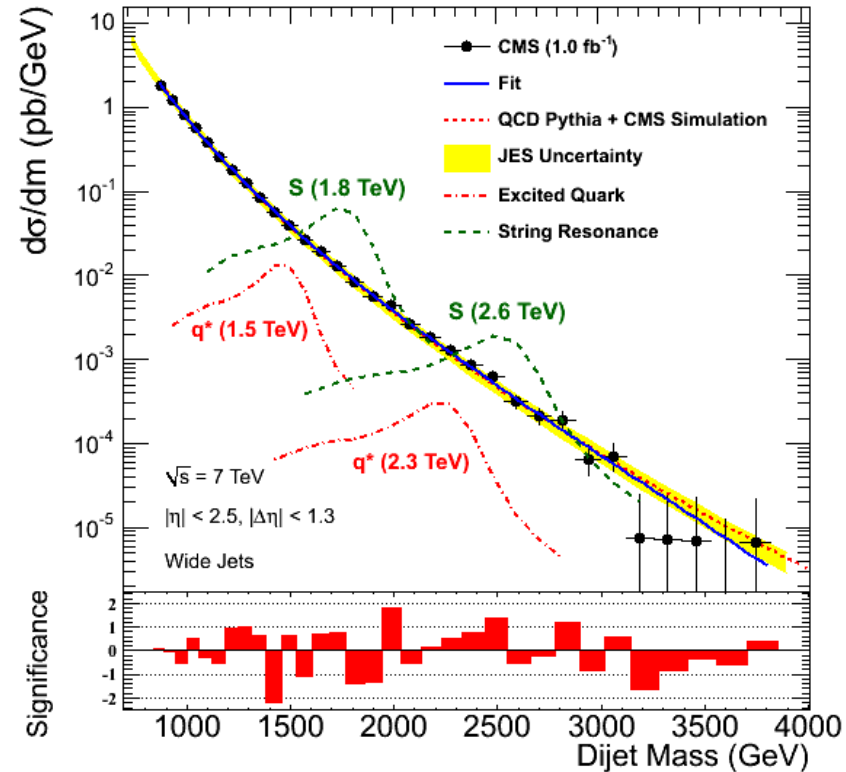
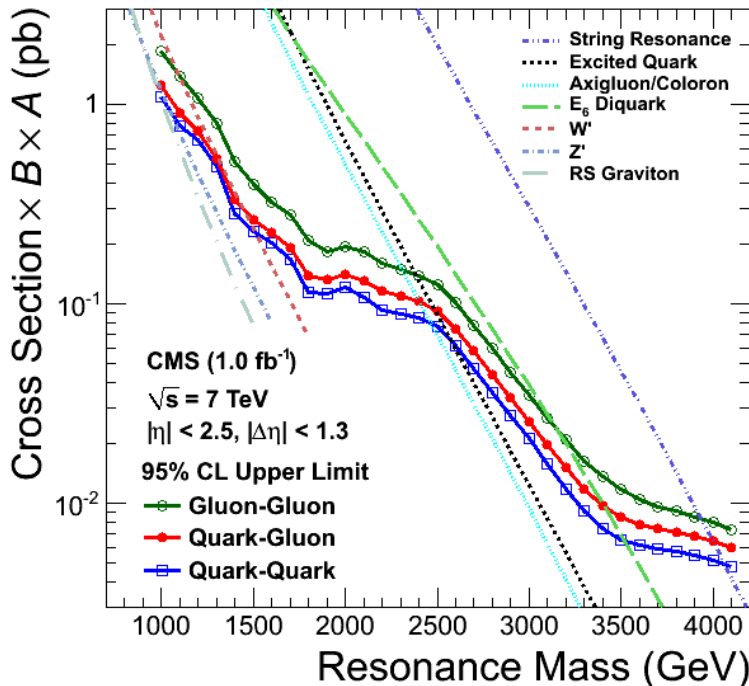
- actively being worked for 2011
  - stay tuned...
- low backgrounds but complicated final state
  - acceptance: of order  $\sim 15\%$  at 1 TeV over all channels
- MET in final state means  $Z'$  is wide, signal will not be as clear cut as in light leptons
- Bayesian binned likelihood for limits



# Z'/W' -> di-jet

arXiv:1107.4771  
submitted to PLB

- di-jet mass spectra measurement
  - 2 jets  $M > 0.84$  TeV,  $|\eta| < 2.5$ ,  $|\Delta\eta| < 1.3$
  - uses “wide jet” algo to recover FSR
- good agreement with data to fit para
  - $\chi^2/\text{d.o.f} = 27.5/28$
  - no evidence of any significant excess



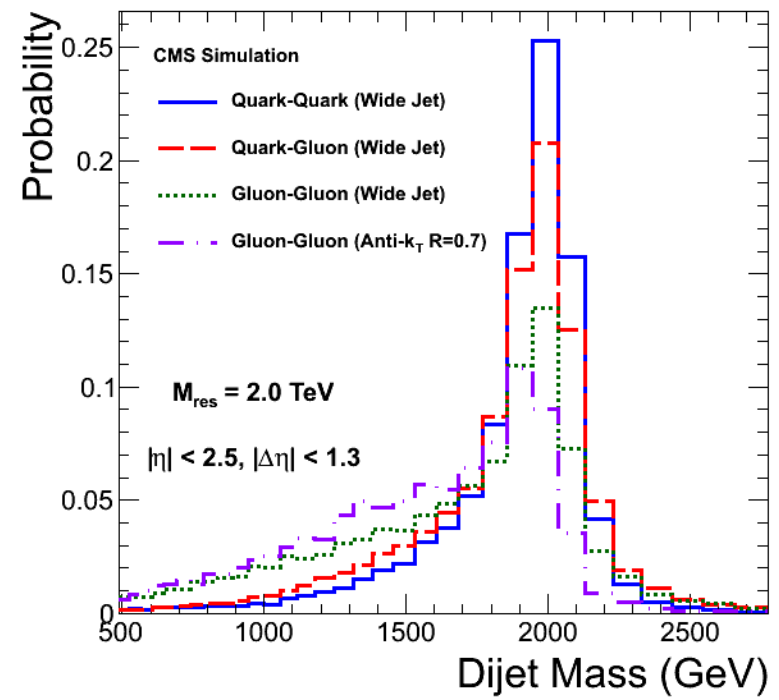
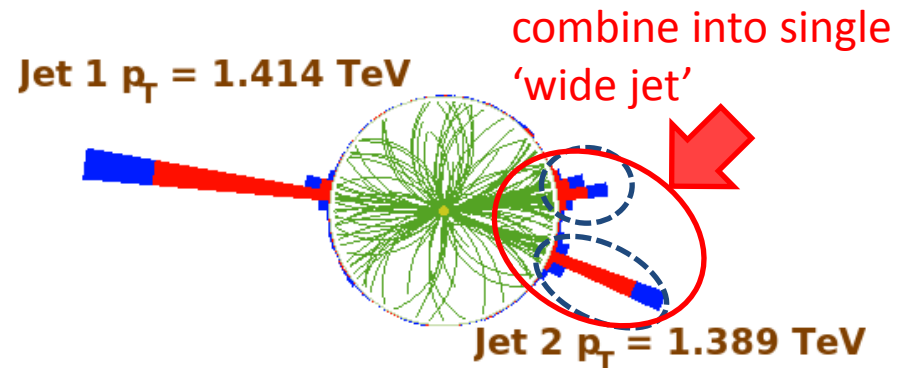
limits:

- Bayesian binned likelihood
- not yet sufficient to exclude SSM Z'
- excludes W' from 1.0-1.51 TeV
  - expected: 1.4 TeV



# Z'/W' -> dijet: Wide Jets

- inspired by recent jet grooming algos
- aim is to improve FSR recovery and therefore resolution
  - previously used Anti- $k_T$  0.7 jets
- wide jet algo starts with anti- $k_T$  0.5 jets
  - identifies two leading jets
  - for each of these jets, sums in all surrounding jets in  $\Delta R$  cone of 1.1
- gg states have more FSR
  - wide jet algo improves resolution
  - reduces differences between qq, qg and gg limits

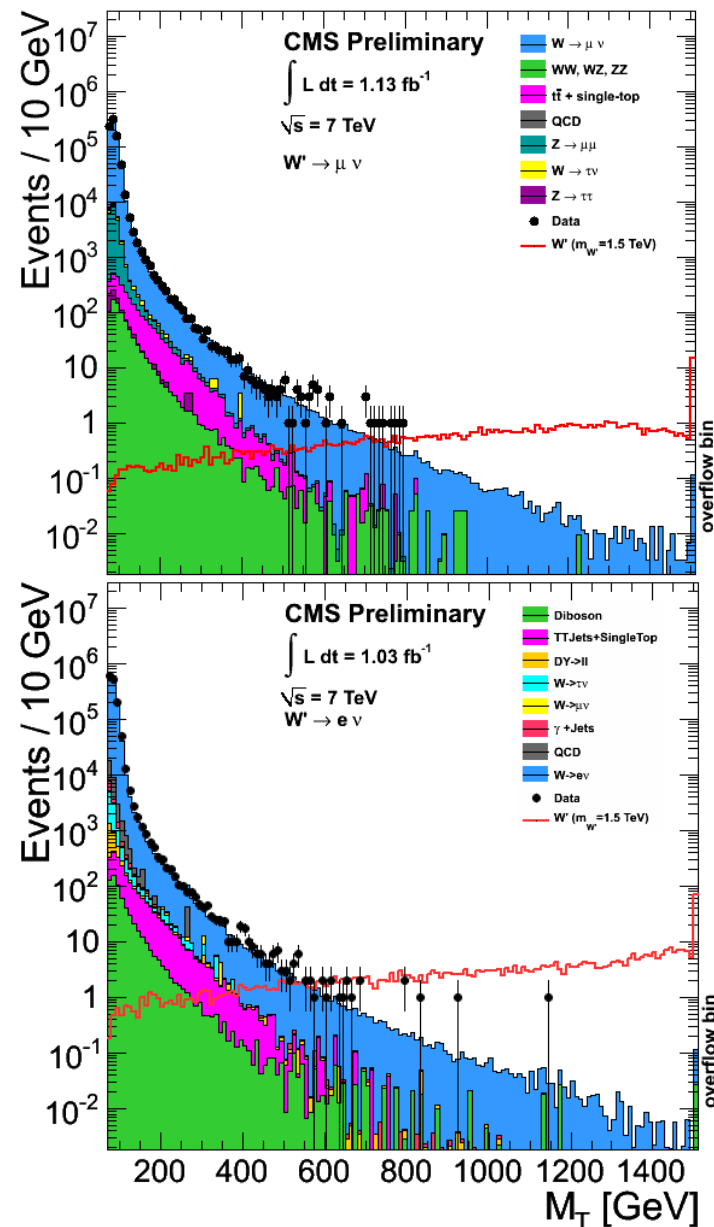


# $W' \rightarrow e\nu / \mu\nu$

EXO-11-024

- non-resonant signature due to MET
  - look for excess in high end tail
- similar to  $Z'$  analysis, just replace 1 lepton with MET
  - $0.4 < p_T / E_T^{\text{miss}} < 1.5$  ,  $\Delta\phi > 2.5$
  - acceptance: 80% in both channels
- excellent agreement between SM + data
  - no hint of any excess in  $1\text{fb}^{-1}$
  - see what 2011 dataset offers
- set limits using Bayesian cut and count
  - exclusion  $W'$  up to 2.27 TeV

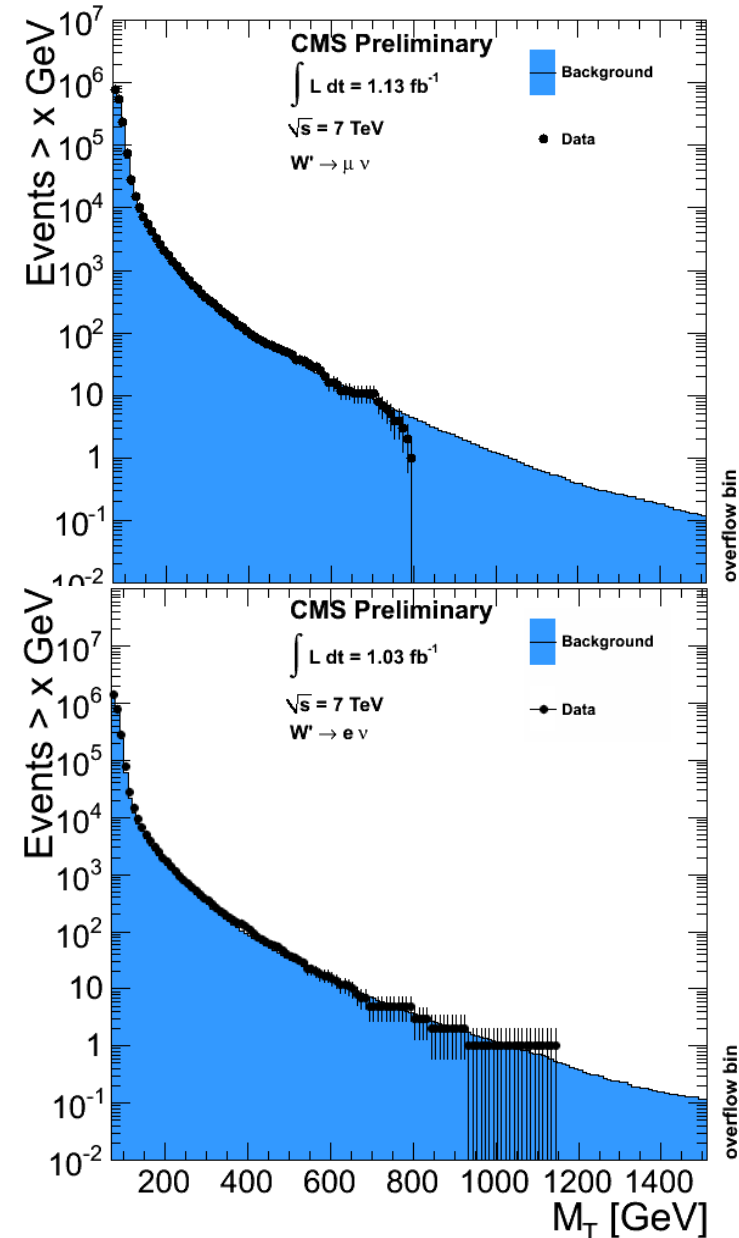
channel	$\sigma \cdot \text{Br}$ limit at 1.4 TeV (pb)	$\sigma \cdot \text{Br}$ limit at 2.5 TeV (pb)
$e\nu$	0.011	0.012
$\mu\nu$	0.006	0.008
combined	0.0042	0.0055



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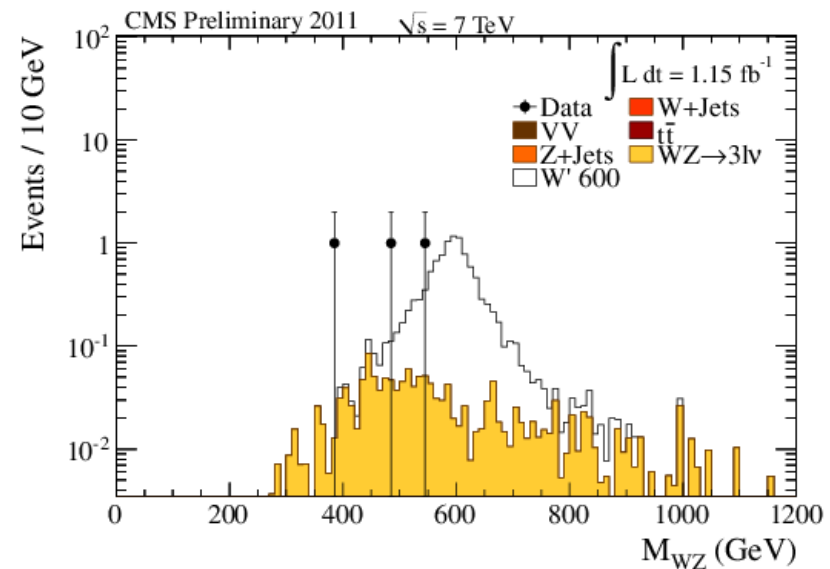
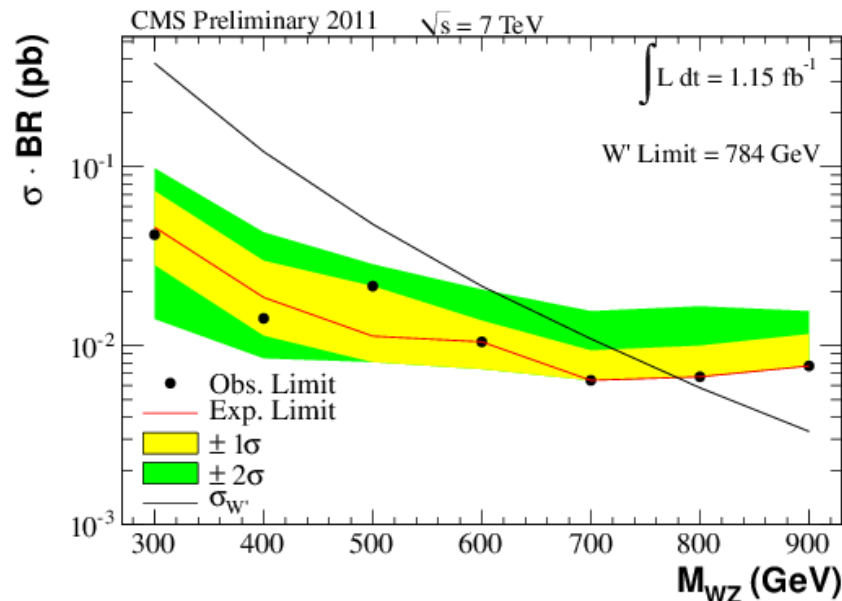
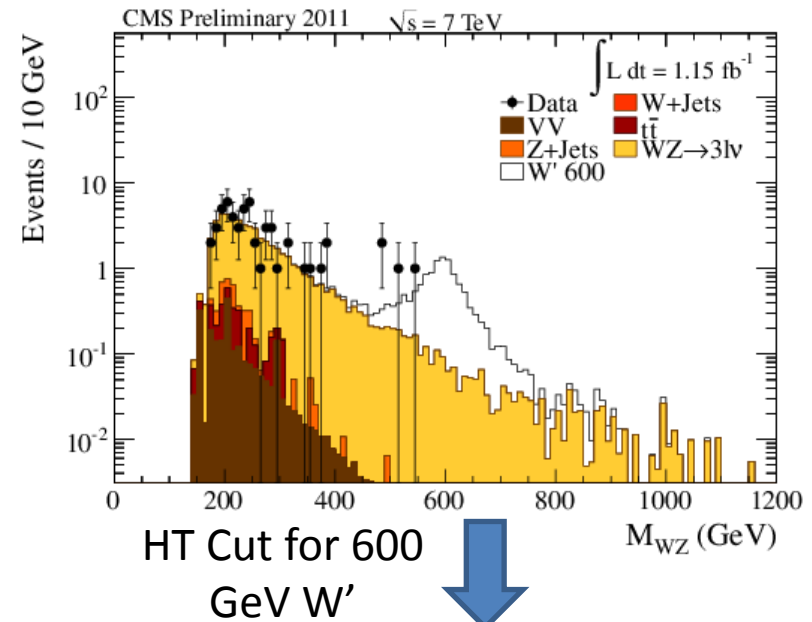
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# $W' \rightarrow WZ \rightarrow 3lv, l=e, \mu$

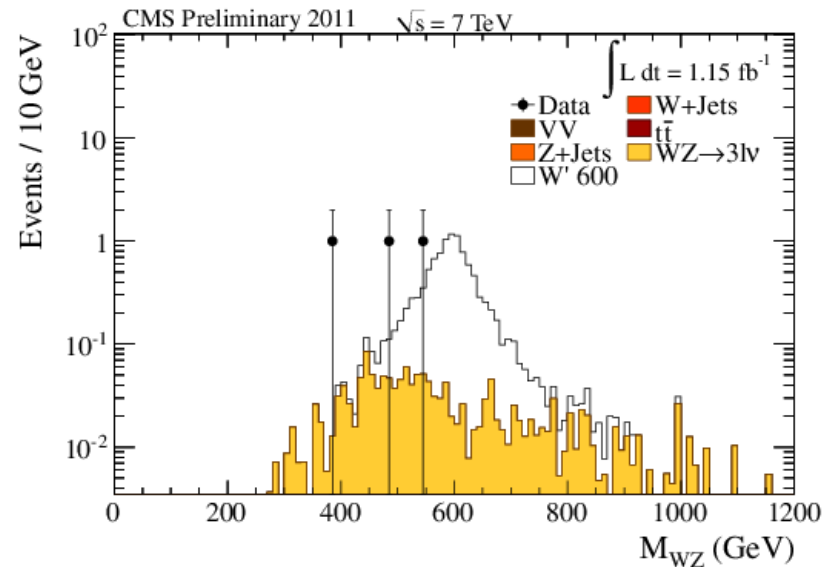
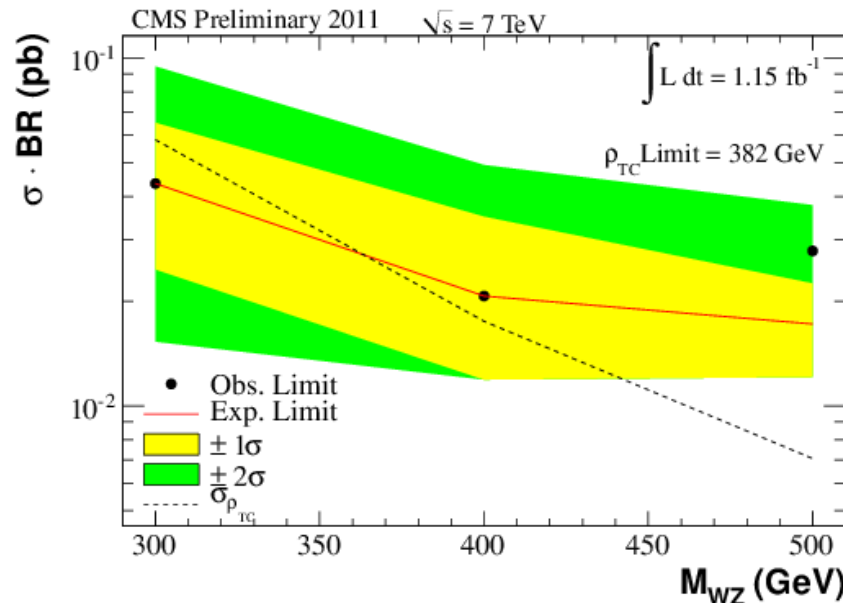
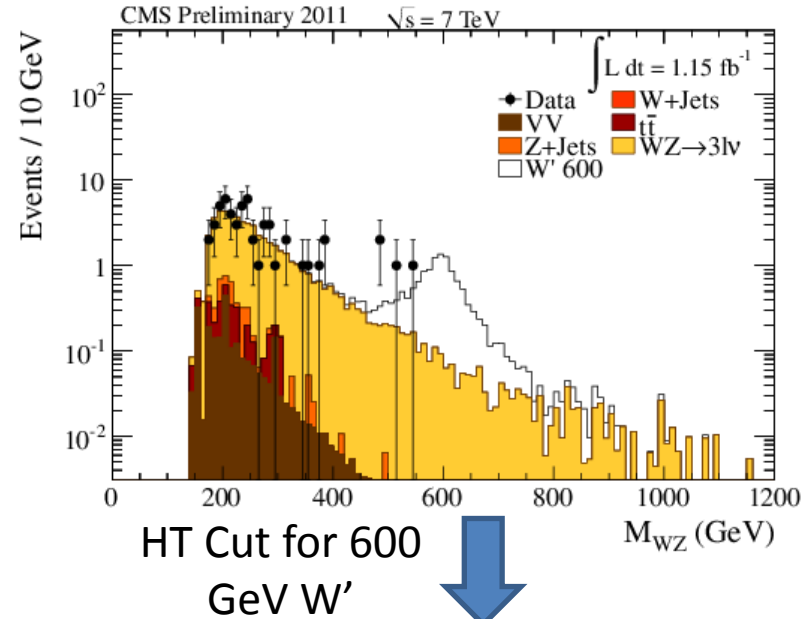
EXO-11-041

- event selection:
  - 2 same flavour opposite charge leptons with  $60 < M_{ll} < 120$
  - 1 more high  $p_T$  lepton +  $MET > 30$  GeV
  - $H_T$  cut, optimised for each  $W'$  mass
- analysis motivated by technicolor
- limits set by Bayesian cut and count technique



# $W' \rightarrow WZ \rightarrow 3lv, l=e,\mu$

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# W'/Z' Summary

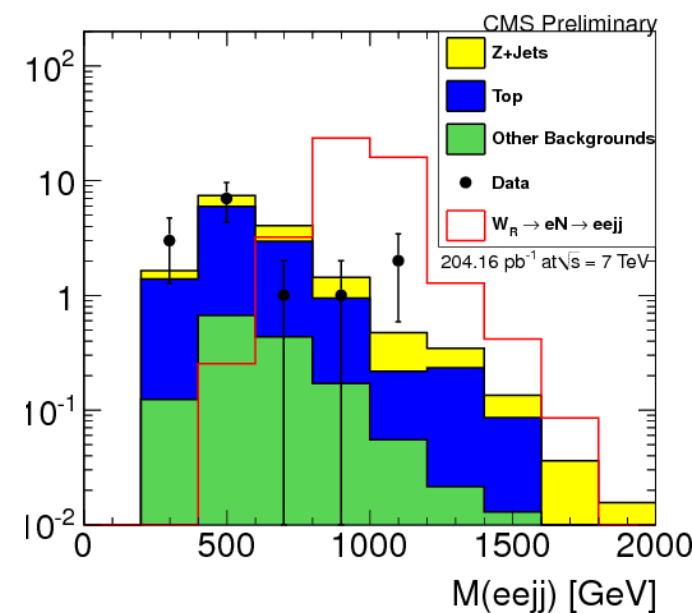
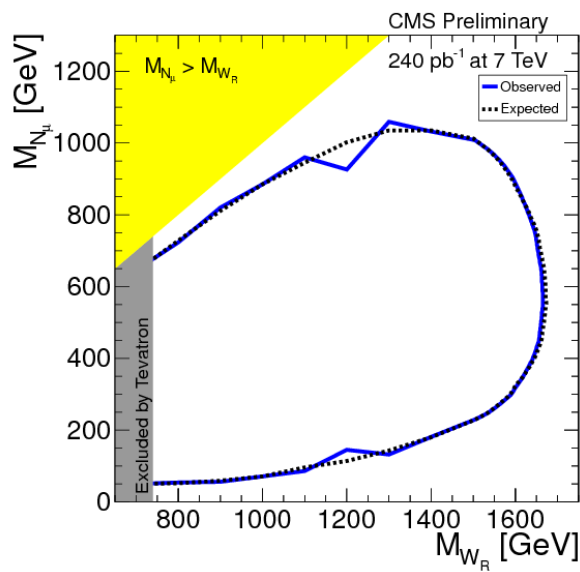
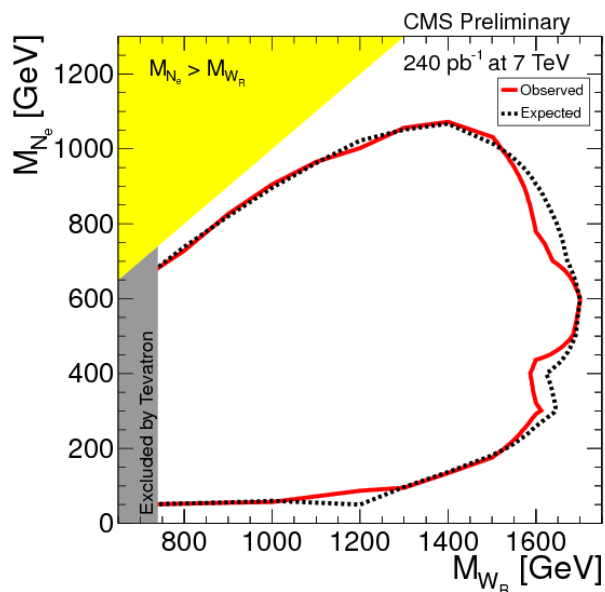
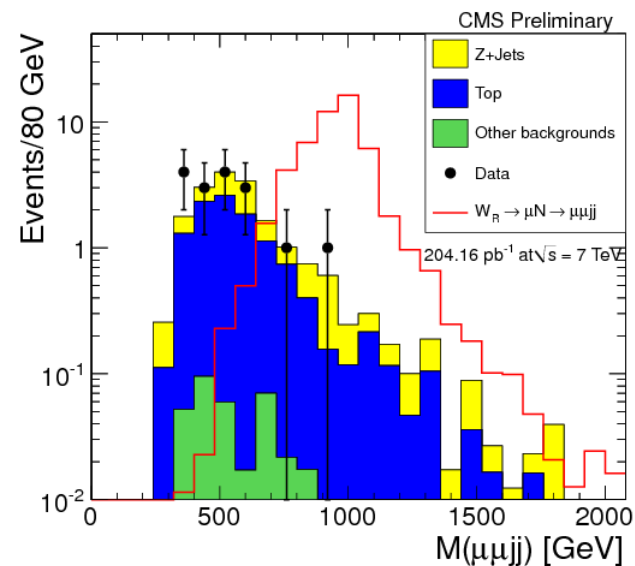
channel	$\sigma_{\text{br}}$ 95% CL limit (pb)			
	0.5 TeV	1 TeV	2 TeV	3 TeV
Z' $\rightarrow$ ee, $\mu\mu$	0.008	0.005	0.002	0.002
Z' $\rightarrow$ ttbar (had)	n/a	4	0.5	0.1
Z' $\rightarrow$ ttbar ( $\mu$ +jet)	n/a	3	0.2	0.1
Z' $\rightarrow$ $\tau\tau$ ( $35\text{pb}^{-1}$ )	3	1	n/a	n/a
Z'/W' $\rightarrow$ di-jet (qq)	n/a	1	0.1	0.02
W' $\rightarrow$ e $\nu$ / $\mu$ $\nu$	n/a	n/a	0.0045	n/a
W' $\rightarrow$ WZ $\rightarrow$ 3l 1 $\nu$	0.02	$\sim 0.008^*$	n/a	n/a

\*limit at 0.9 TeV

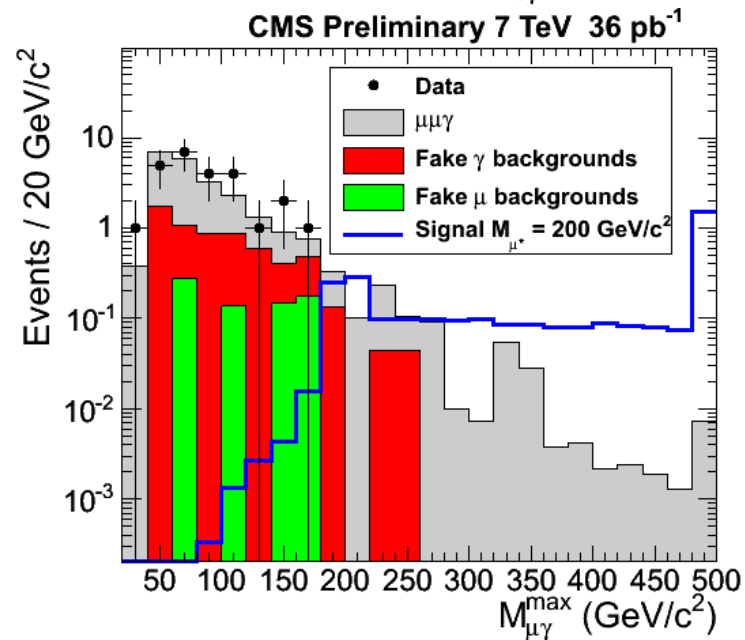
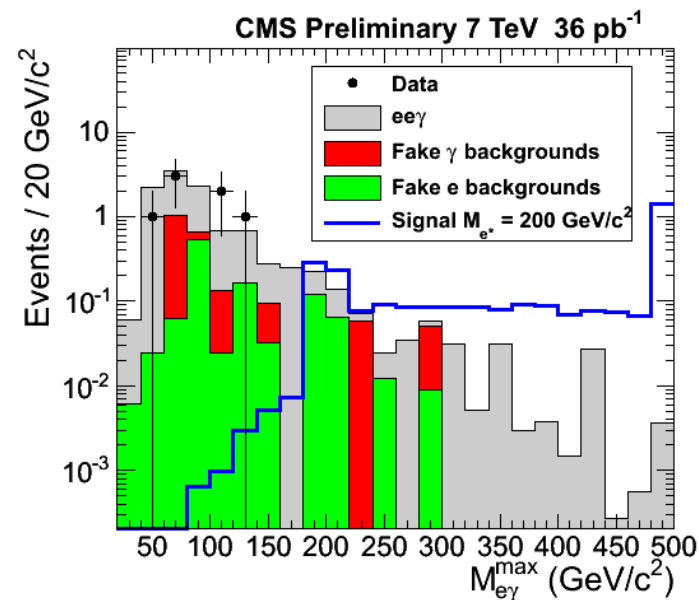
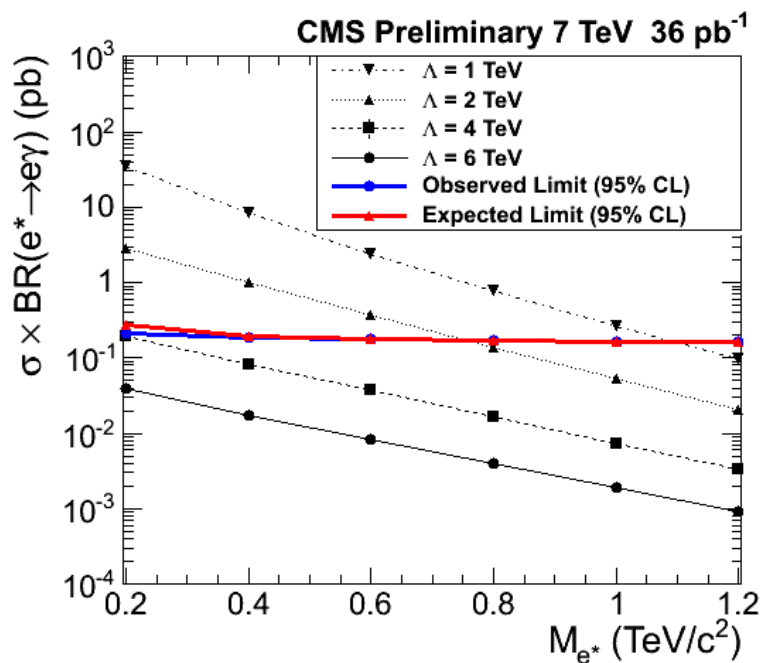
# $W_R$ + Heavy Neutrino

EXO-11-002

- searches for  $W_R$  to heavy  $\nu$  predicted by L-R SM extension
- signature:
  - two same flavour leptons + two jets



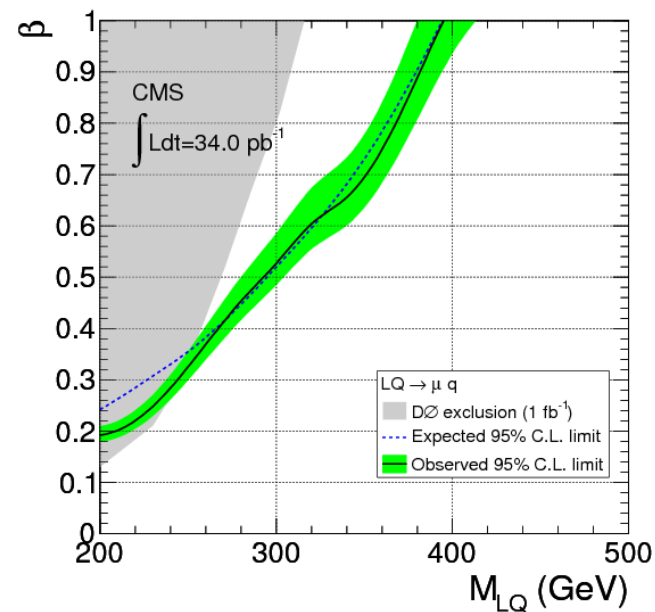
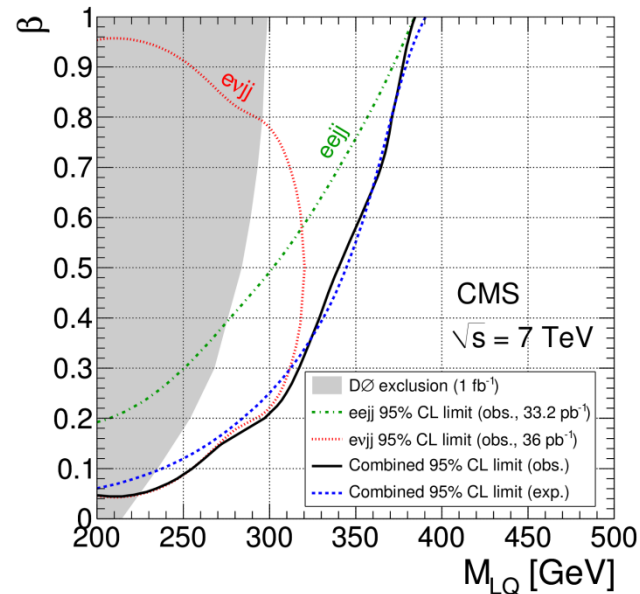
- searches for excited states of composite fermions with scale  $\Delta$ 
  - $pp \rightarrow l l^* \rightarrow l l \gamma$
- update in progress for 2011





# Leptoquarks

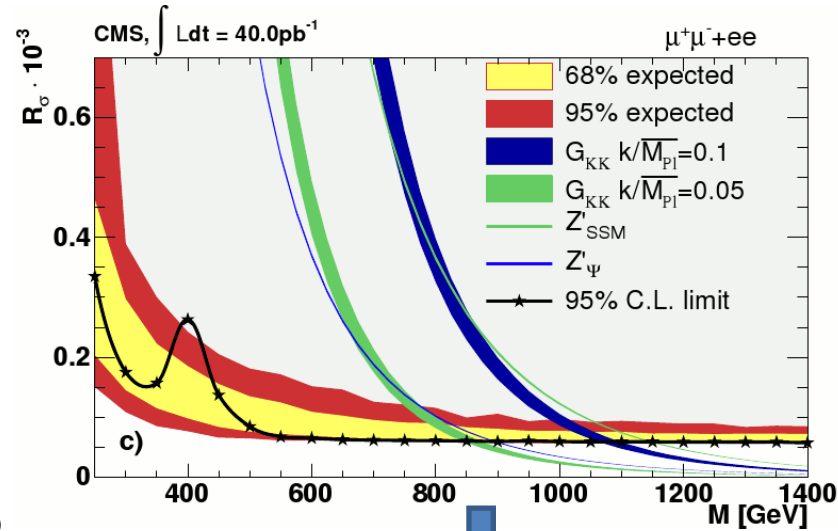
- search for pair production of lepto quarks
  - not yet updated to 2011 data
- search in following channels:
  - $eejj$ ,  $\mu\mu jj$ ,  $evjj$
- no excess is found



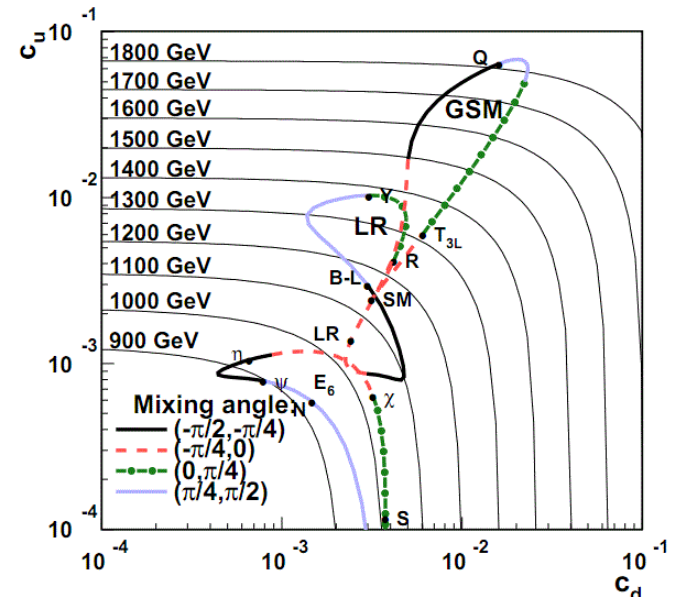
# Presenting Results

- in  $Z'/W'$  searches present results as  $\sigma \cdot \text{Br}$  limit or ratio
- for some benchmark models convert this  $\sigma \cdot \text{Br}$  limit to mass or mass vs 1 parameter limit
  - limited space and time means we cant do every model
- for  $Z' \rightarrow ee/\mu\mu$  also do  $c_u c_d$  limits
  - not done this update but planned for end of year update
  - we will continue to do this if considered useful

is there anything else we can to do make our results more useful?



$\int Ldt = 40 \text{ pb}^{-1}$   $\sqrt{s} = 7 \text{ TeV}$



# Summary

- CMS has searched in many channels for  $W$ 's,  $Z$ 's and new fermions
- no significant excess over SM seen so far
  - much more lumi still to come this year though!
  - factor 5 more lumi will extend cross-section limits by factor 5 at very high masses!

Search Object	channel	data analysed
$Z'$	$ee, \mu\mu$	$1\text{fb}^{-1}$
$Z'$	$tt$ hadronic + semi-leptonic	$1\text{fb}^{-1}$
$Z'$	$\tau\tau$	$35\text{pb}^{-1}$
$Z'/W'$	di-jet	$1\text{fb}^{-1}$
$W'$	ele, muon	$1\text{fb}^{-1}$
$W' / \text{TC}$	$WZ \rightarrow 3l + \nu$	$1\text{fb}^{-1}$
$t'$	$bW (l+j, ll)$	$1\text{fb}^{-1}$
$t'$	$tZ$	$0.2\text{fb}^{-1}$
$e^*$	$ee\gamma$	$35\text{pb}^{-1}$
$\mu^*$	$\mu\mu\gamma$	$35\text{pb}^{-1}$
$b'$	$tW$ (di, tri lept)	$1\text{fb}^{-1}$
heavy nu	$ll+jj$	$0.2 \text{fb}^{-1}$

# Backups

# $b' \rightarrow tW$

- signature:
  - 2 same sign leptons + 2 jets (1 b-tag)
  - 3 lepton (2 opp sign) + 1 b-tag jet
- looks for excess in  $S_T$  distribution

