Recent exotic results from CMS

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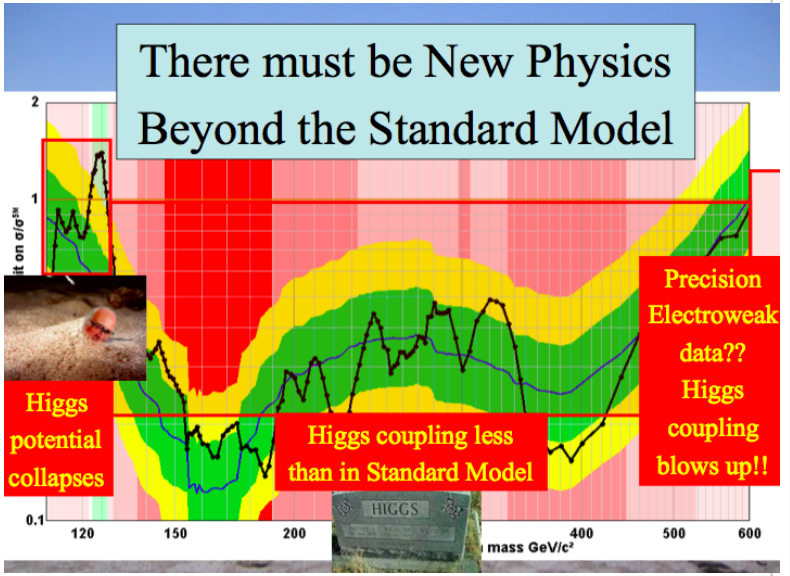
on behalf of the CMS collaboration

Implications of LHC results for TeV-scale physics

Introduction

- Very exciting news on new boson with ~125 GeV mass!
  - Whether it is the Higgs boson or a Higgs boson, or something entirely different – we cannot say yet…

John Ellis



- Even if it is SM Higgs, there must be New Physics beyond the SM
  - Mass of a Higgs candidate is a bit too low from comfortable 130-170 GeV range of the stability chimney.
  - Other puzzles: no dark matter candidate, neutrino masses, matter-antimatter asymmetry, number of generations, *etc.*
- Keep digging: study new boson + search for new physics!

Strategy for BSM searches

- Unlike Higgs/SUSY searches no well defined guide on the parameter space/signatures
  - Look for an interesting features in data
    - Resonant structure
    - Anomalous couplings
  - Look at all possible signatures for disagreement with expectations
    - Utilize the very efficient identification of physics objects
  - Probe interesting new BSM models

BSM searches at CMS

- New resonances
  - Z', W', dijet resonances
- Extra dimensions
  - Black holes, ADD/RS Gravitons
- New symmetries/interactions
  - Leptoquarks, heavy neutrinos
- Fourth generations
  - Heavy bottom/top – like quarks
- The latest public results from CMS can be found at https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Covering only new results after Moriond 2012

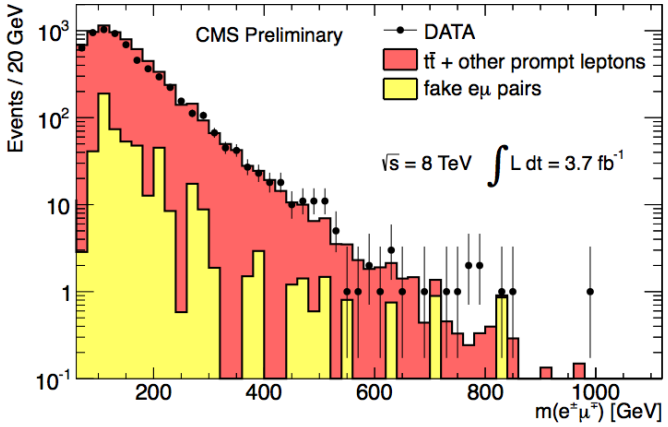
New heavy gauge bosons

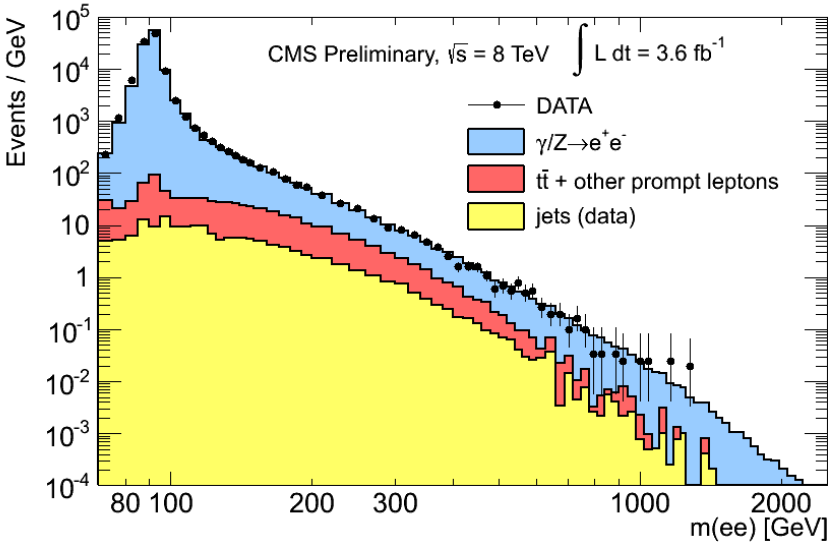
- The SM gauge group $SU(3)_C x SU(2)_L x U(1)_Y$ can be extended to solve some of the puzzles not explained by the SM
  - Additional U(1) group gives raise to new heavy neutral boson Z'
  - Additional SU(2) group gives raise to new heavy charge boson W'
- Various models predicting such new resonances
  - Sequential standard model – couplings to W and Z similar as in the SM
  - Superstring-inspired E_6 model
  - Left-right symmetric model $SU(2)_L x SU(2)_R$
  - More complicated models, such as technicolor or ED, predict a chain of new bosons

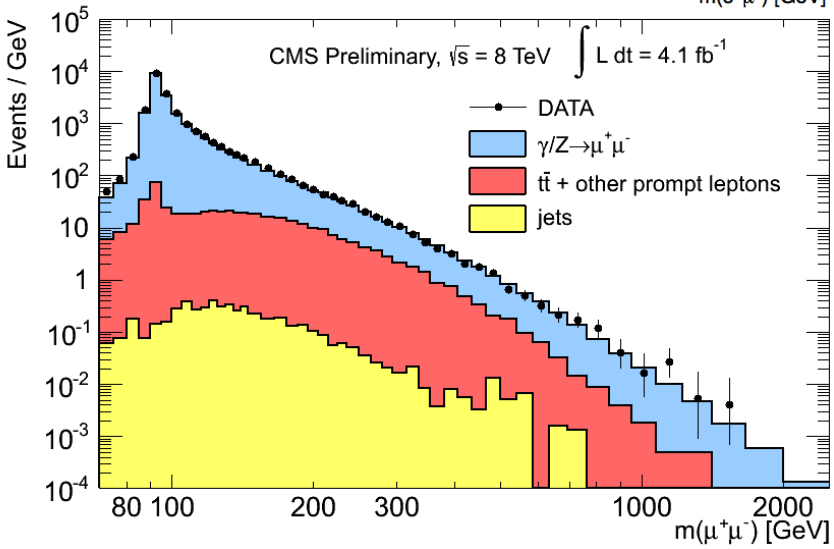
Z'→ee/μμ

- Signature with two energetic, isolated leptons
  - Electrons and muons
- Backgrounds
  - Drell-Yan, top, diboson, multijets
  - Estimated from data

EXO-12-015





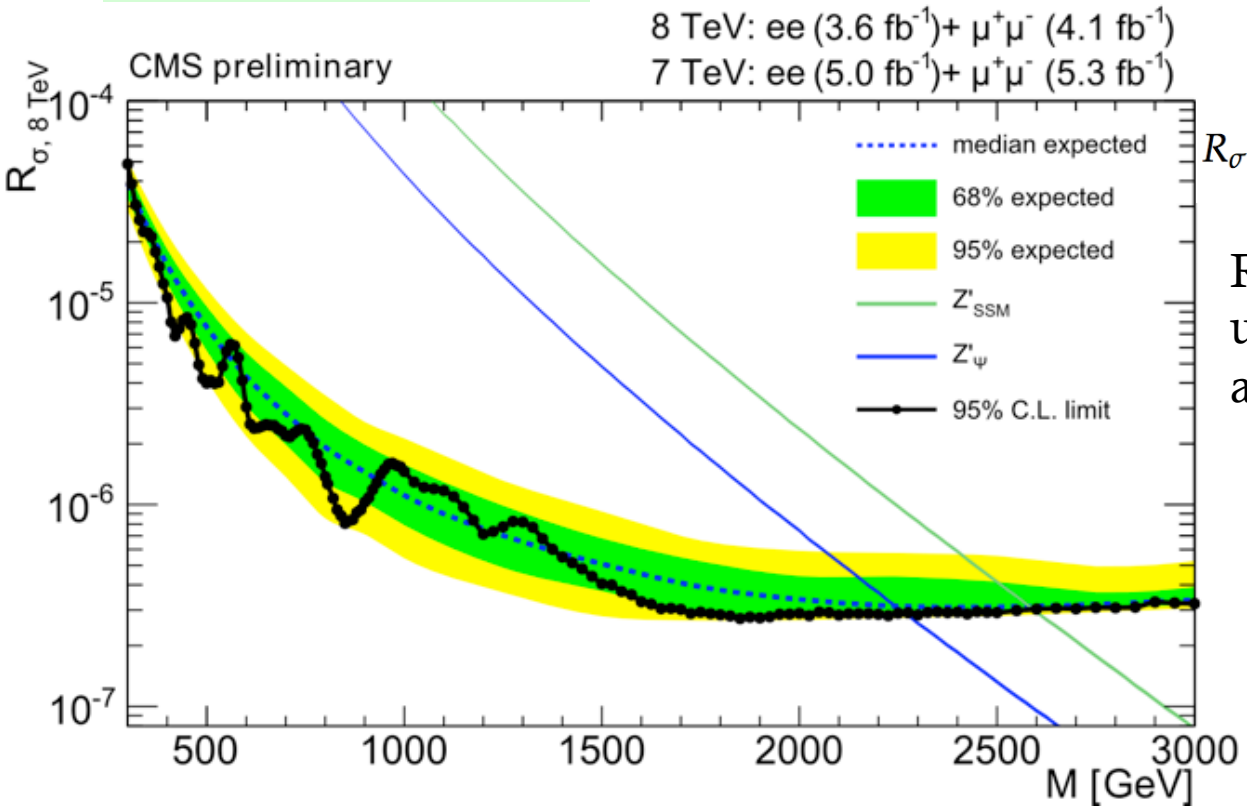


Z'→ee/μμ

- Limits from combined 2011-2012 data

$M(Z'_{ssm}) > 2590$ GeV
$M(Z'_{\psi}) > 2260$ GeV

EXO-12-015



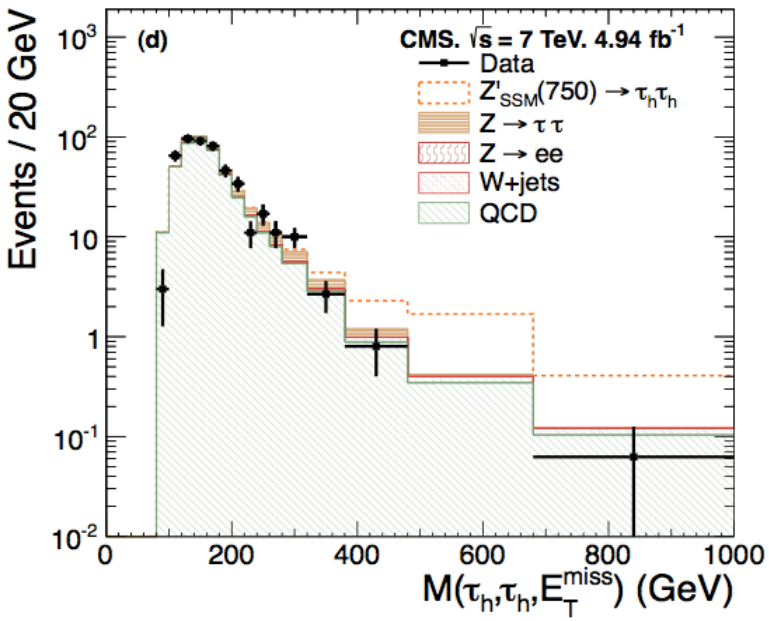
$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$

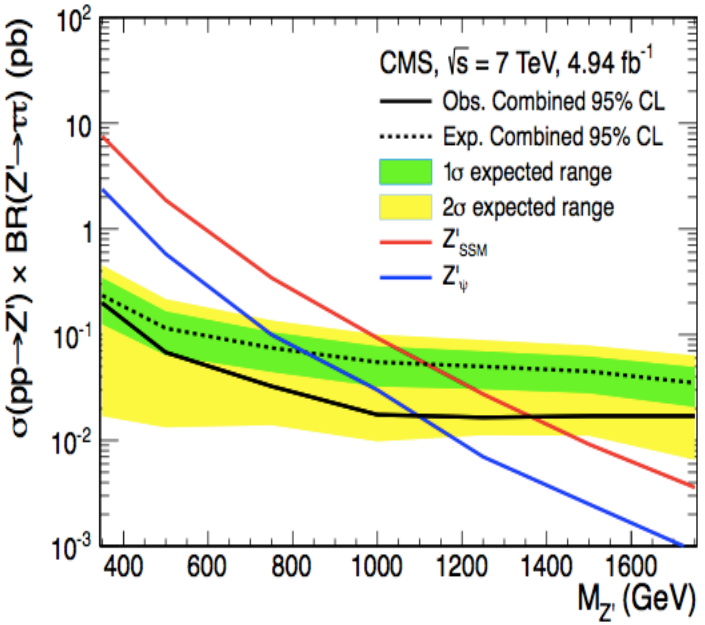
Reduces dependence on uncertainty in luminosity, acceptance and efficinecy

Z' →ττ

- There are models in which Z' preferentially couple to the 3rd generation fermions
  - Signature with eμ, eτ, μτ, ττ
  - Backgrounds from Drell-Yan Z->ττ, W+jets, Diboson, mujltijet -- estimated from data when possible

$M(Z'_{SSM}) > 1.4$ TeV
$M(Z'_{\psi}) > 1.1$ TeV



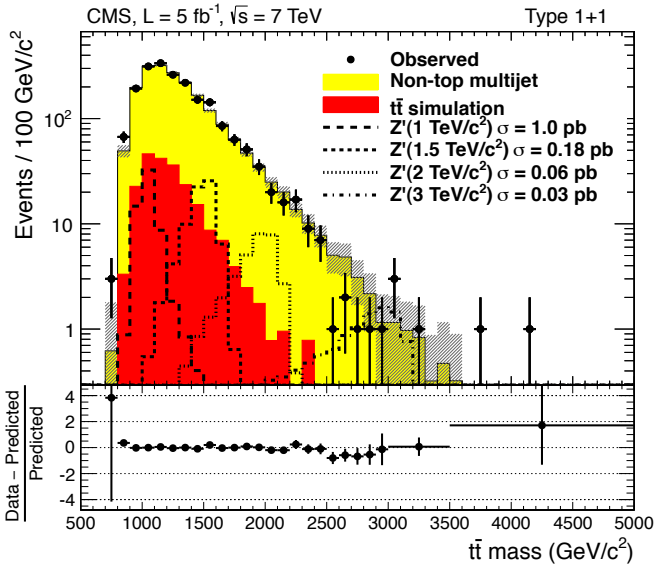


EXO-11-031

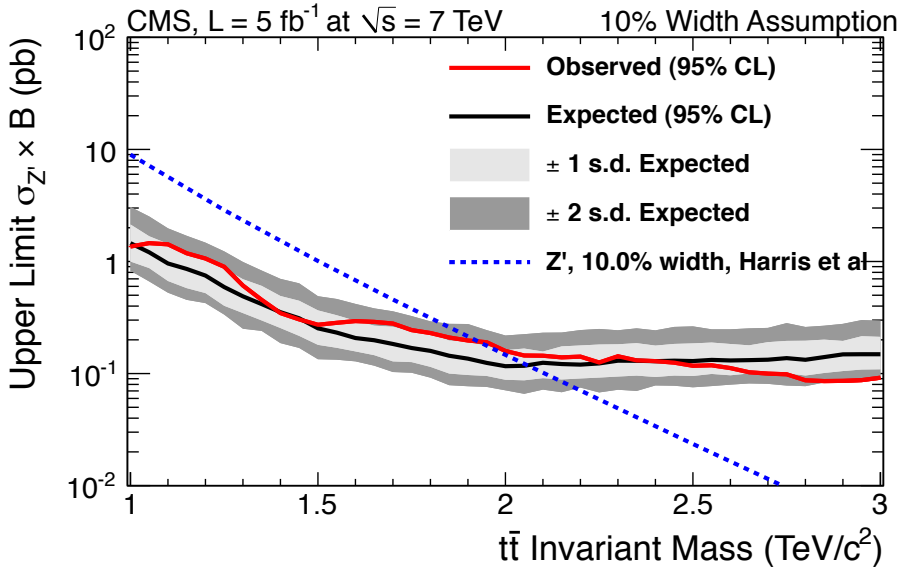
Z'→ttbar

- New physics at high M_{tt} scale would explain the observed FB asymmetry in ttbar events – focusing on M_{tt} > 1 TeV ***EXO-11-006***
  - Z' with 1% and 10% widths and RS KK gluon wide resonance
  - Signature with fully hadronic decays of ttbar events – two or three jets

Using jet substructure to identify boosted tops



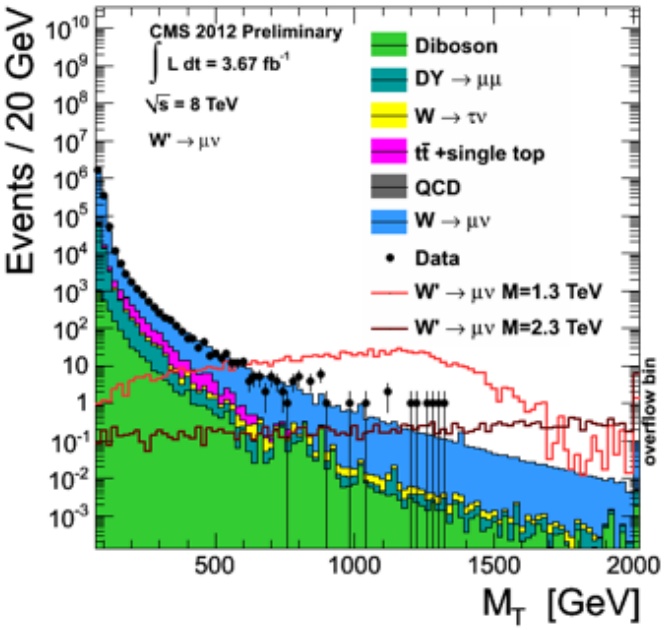
Limits are set on any generic process that would interfere SM tt production

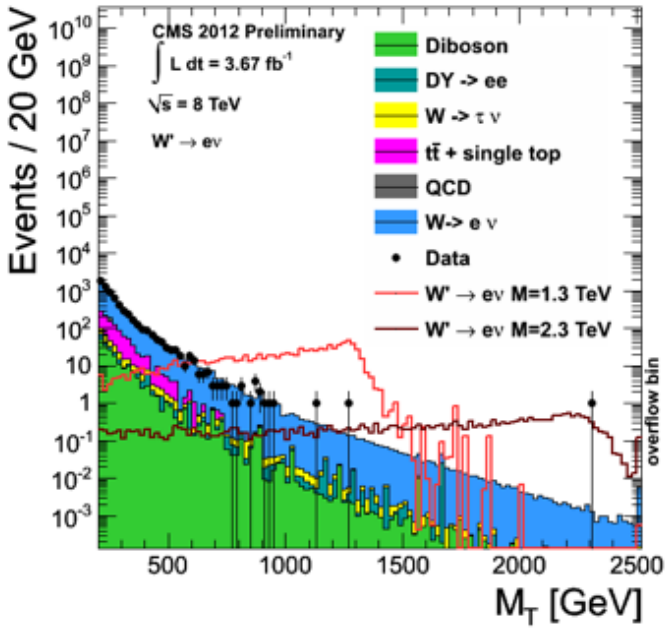


W'→lν

- New gauge boson decaying to a lepton and a neutrino
  - Signature of isolated, energetic lepton and large missing E_T
  - Backgrounds from W+jets, top, diboson, Drell-Yan
  - Data are found in agreement with the SM background prediction

$$M_T = \sqrt{2 p_T^l E_T^{miss} (1 - \cos\Delta\varphi_{l,\nu})}$$





EXO-12-010

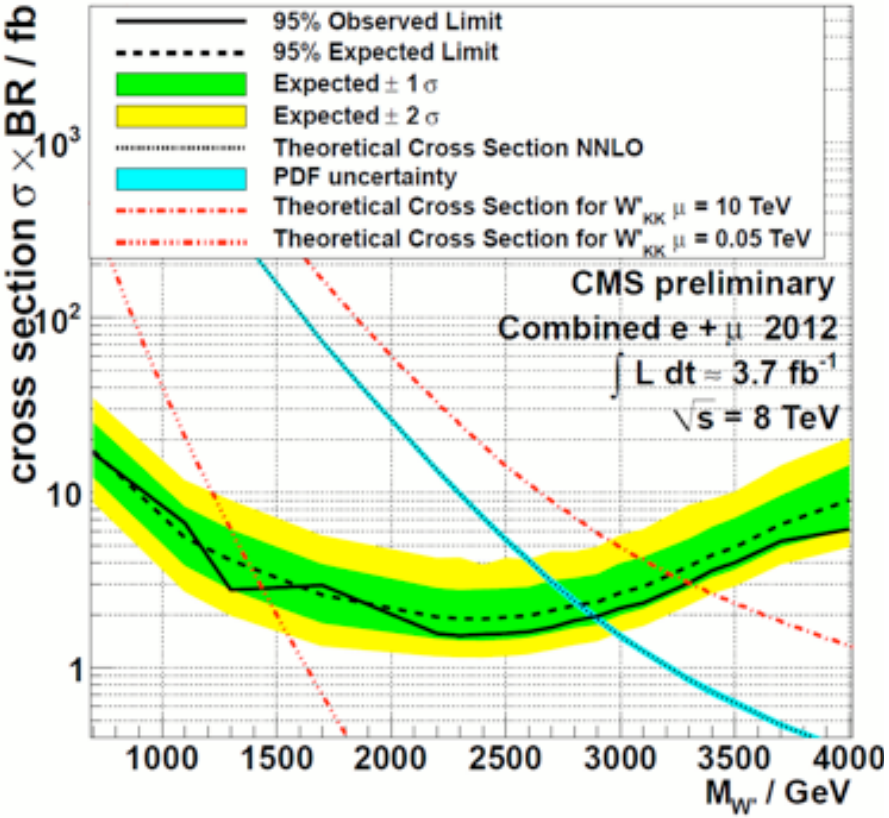
W'→lν

- Combined limits

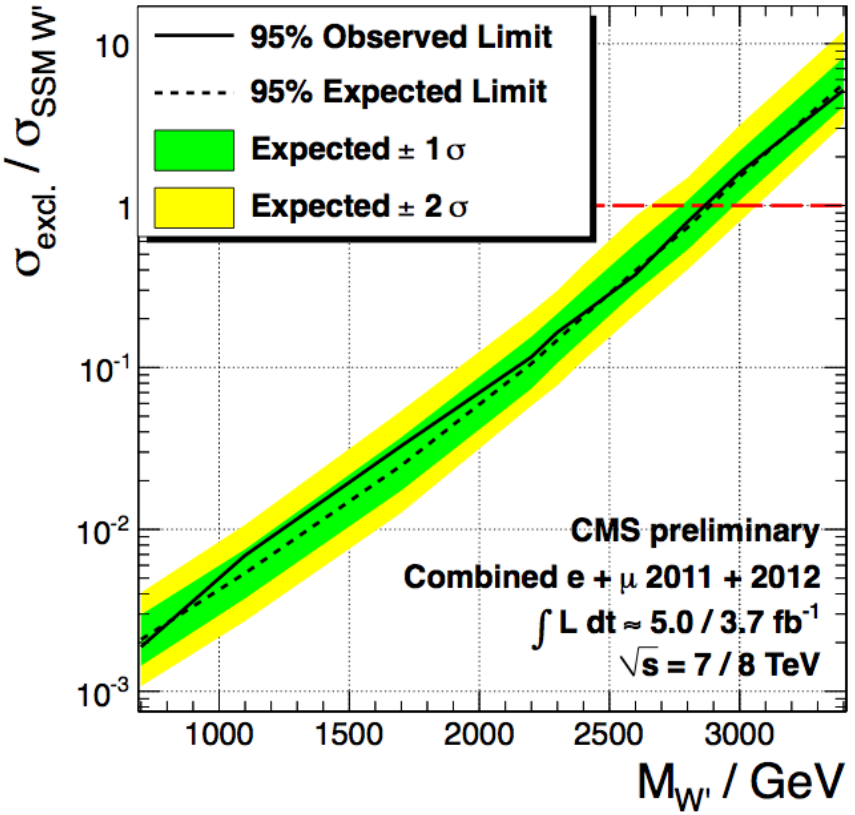
M(W'$_{SSM}$) > 2.85 TeV

EXO-12-010

Electron and muon channel



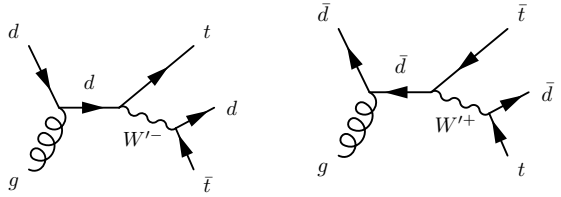
7 TeV and 8 TeV data



W'→td

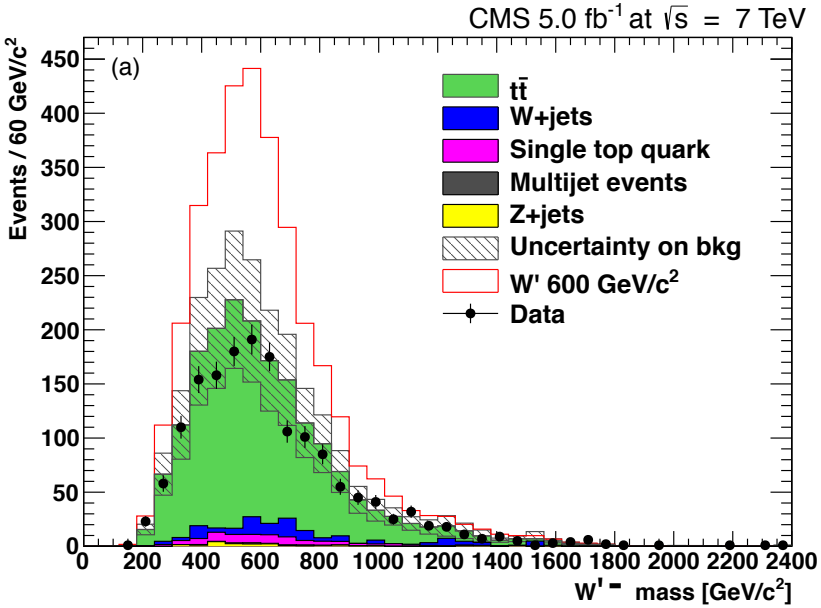
- Light W' production with an additional top – ttbar +jet
  - signature with lepton, jets, and missing transverse energy
    - At least 5 jets and at least 1 b-tagged jet

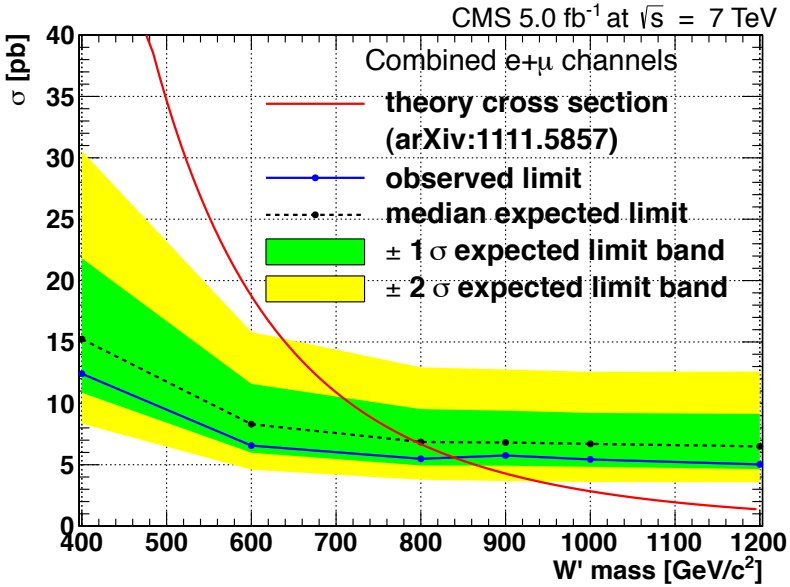
$$A_{FB}^{t} = \frac{N_t(\eta \geq 0) - N_t(\eta \leq 0)}{N_t(\eta \geq 0) + N_t(\eta \leq 0)}$$



M(W') > 840 GeV

EXO-11-056

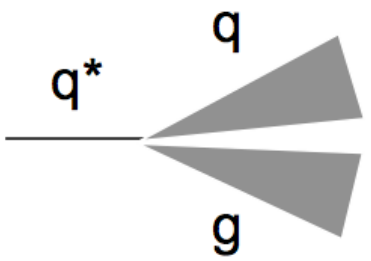




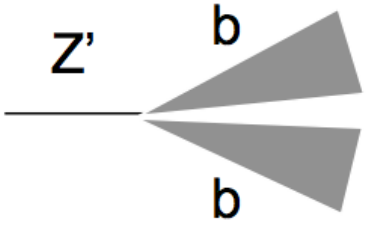
Hadronic resonances

- Many extensions of the SM predict new massive objects that couple to quarks and gluons
  - String resonances which decay to qg
  - Excited quarks decaying to qg, qW, qZ
  - Diquarks predicted by GUT decaying to quark-anti-quark
  - New gauge bosons predicted by new symmetries decaying to quark-anti-quark
  - Randall-Sundrum Graviton decaying to quark-anti-quark or gg
  - Color octet scalar decaying to gg or bb
  - Axigluon or coloron decaying to qq

dijets



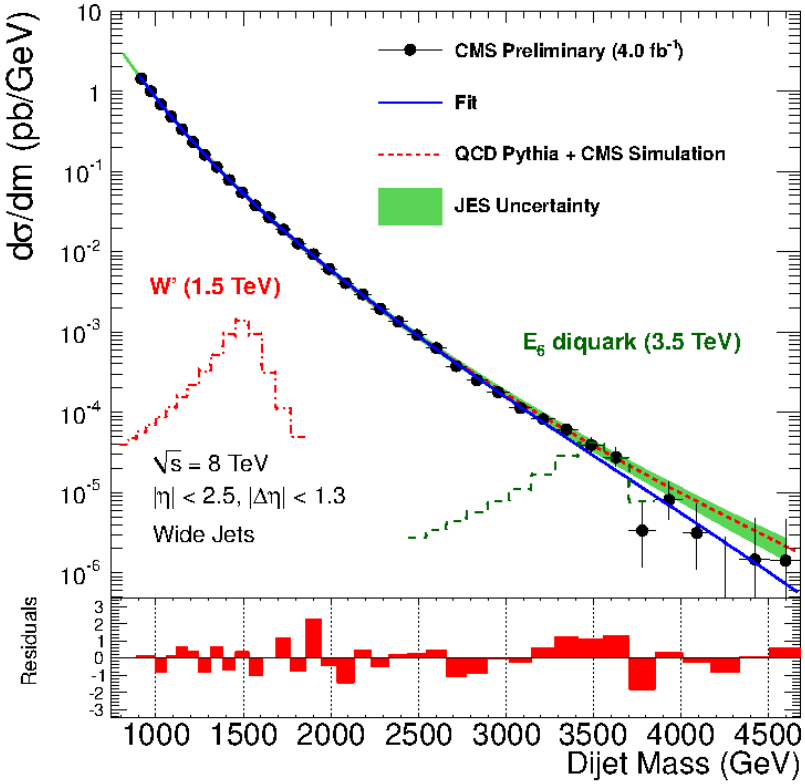
b-tagged dijets

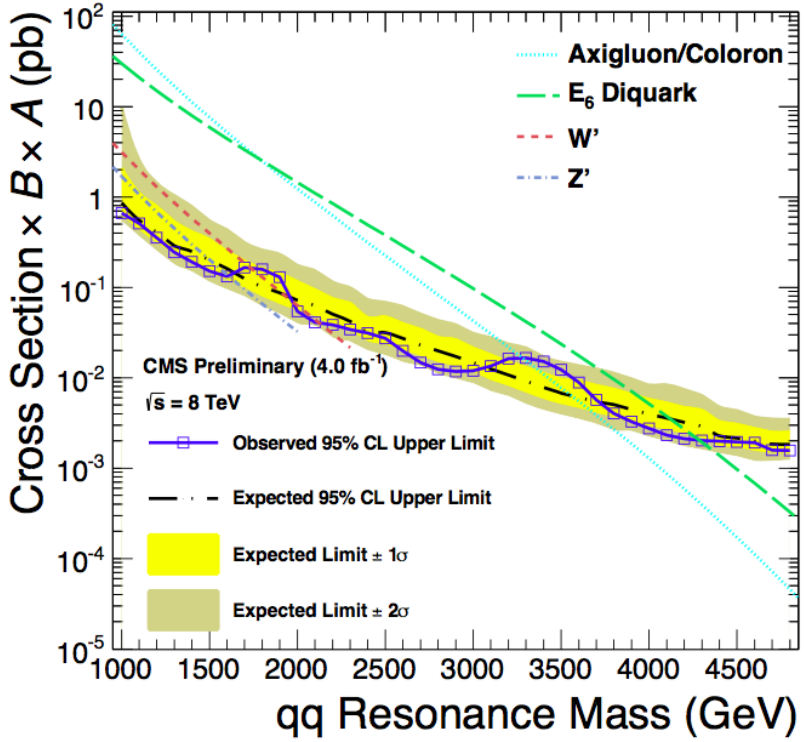


Dijet resonances

- Search for resonance in smoothly falling mass spectrum
- Background is estimated by fitting data

EXO-12-016



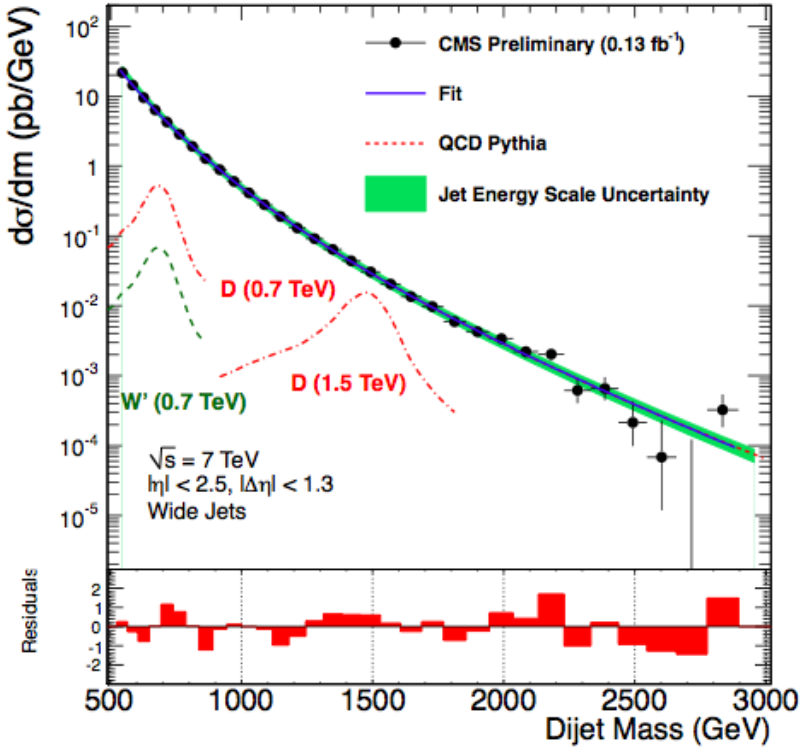


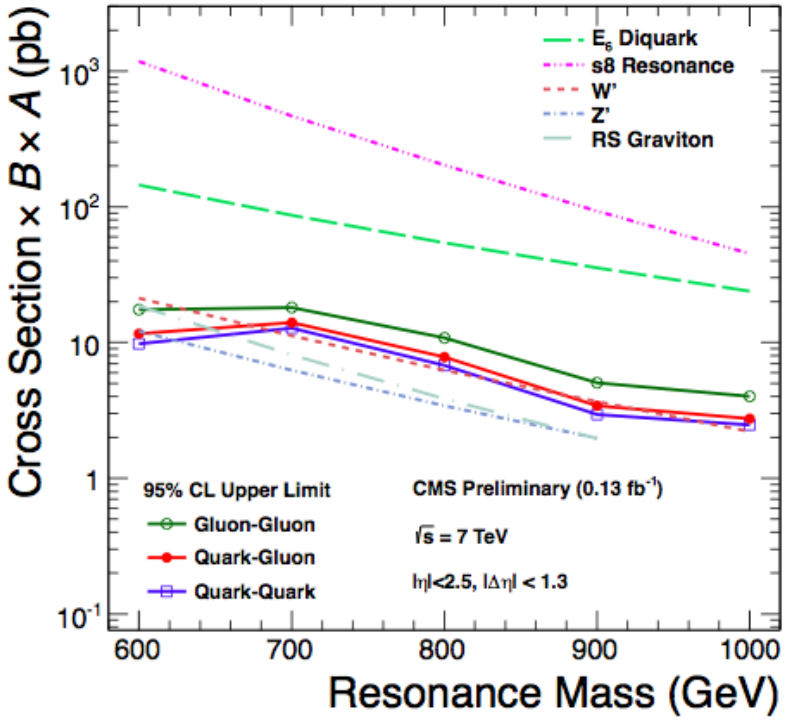
Dijet low mass

- Novel techniques for trigger, DAQ, analysis to search for dijet resonance with mass < 1 TeV

EXO-11-094

  - Store reduced data format → bandwidth under control



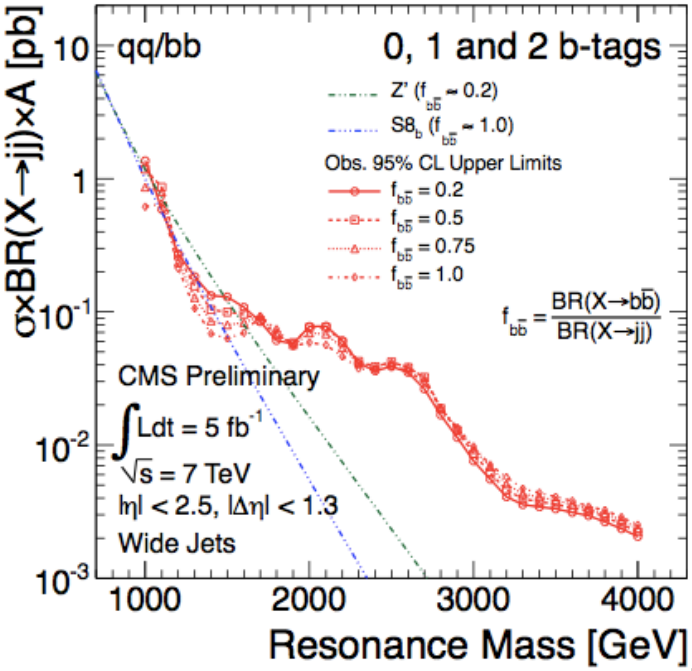


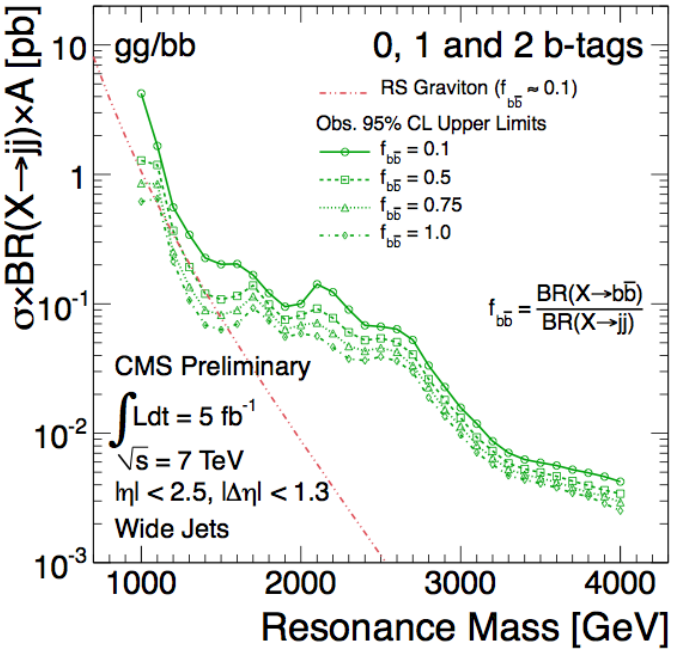
Dijet resonances with btag

- Search for resonance in b-enriched sample
  - Signature with 0, 1, 2-tag
  - Multijet background is reduced by factor 50
  - Set model-independent limit as a function of the signal branching ratio fraction

EXO-11-008

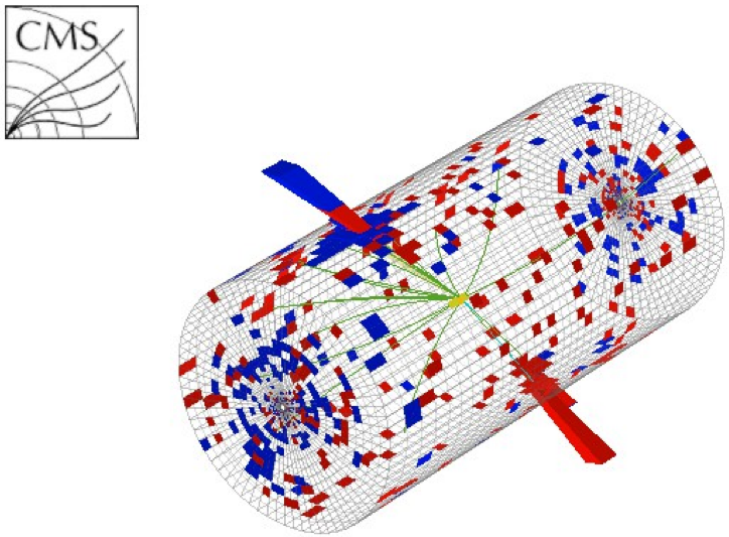
$$f_{b\bar{b}} = \frac{BR(X \to b\bar{b})}{BR(X \to jj)}$$

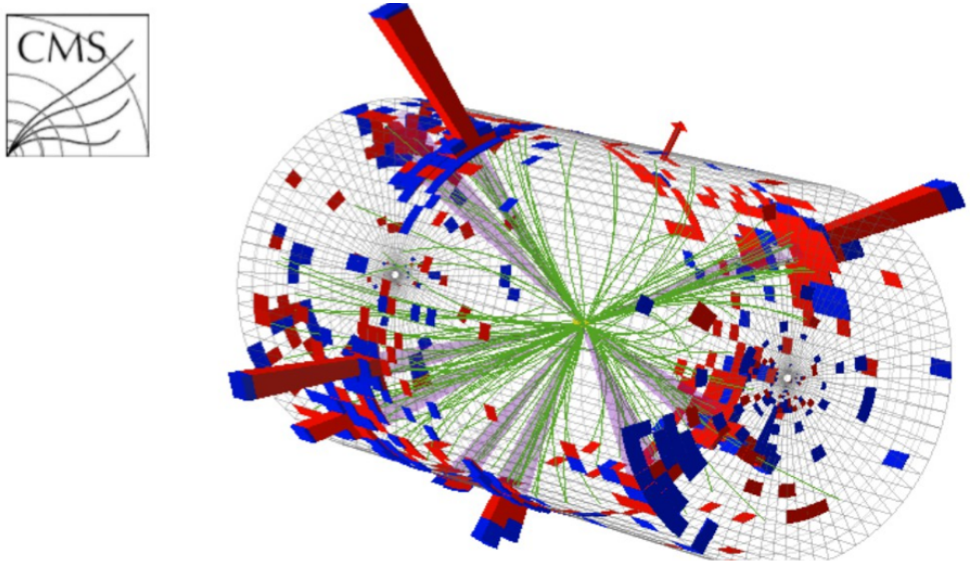




Extra dimension

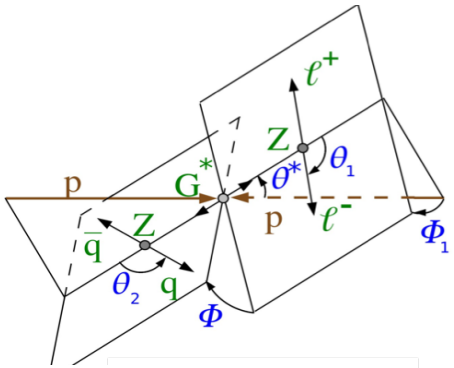
- Attractive extension of the SM
  - Explains hierarchy and several other problems
- Can be searched in both resonant and non-resonnant states

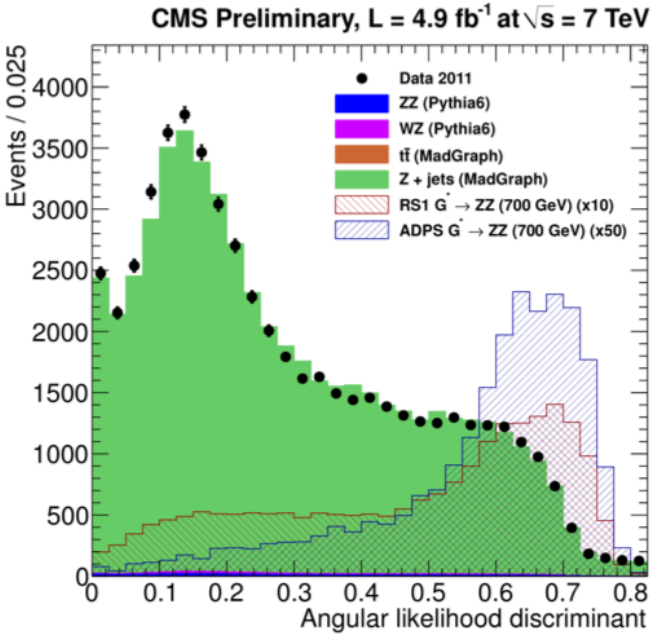


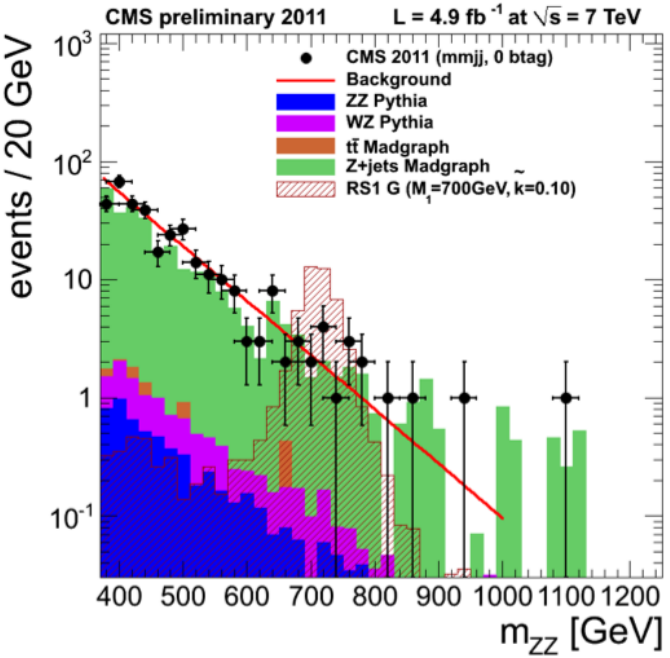


Graviton

- Search for G→ZZ→2l2j **EXO-11-102**
  - High branching fraction and high purity
  - Likelihood discriminant built from 5 helicity angles
  - Backgrounds estimated from sidebands in M_{ZZ}







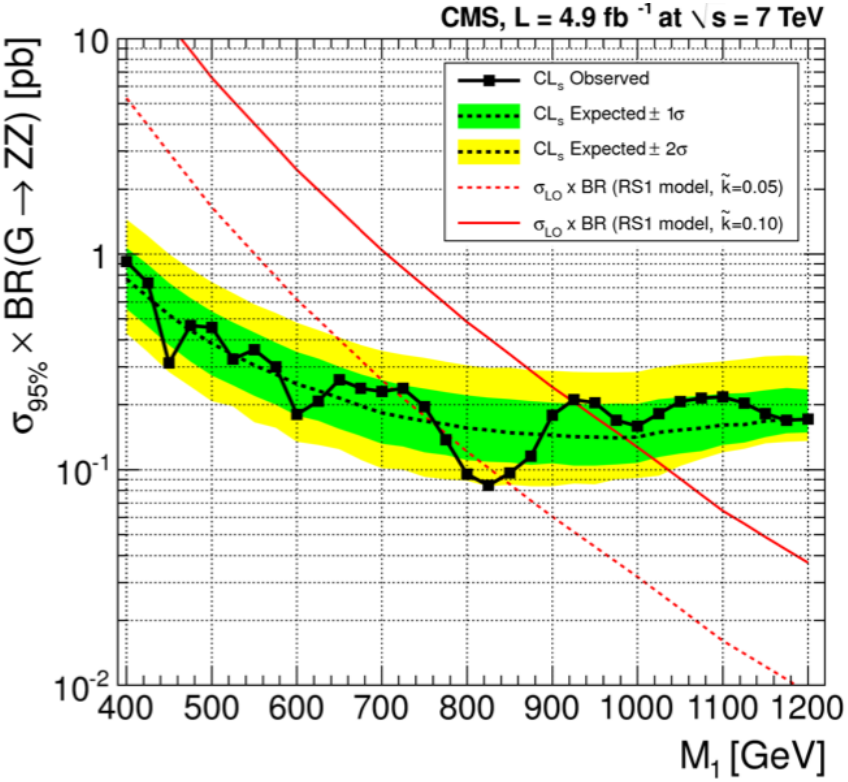
Graviton

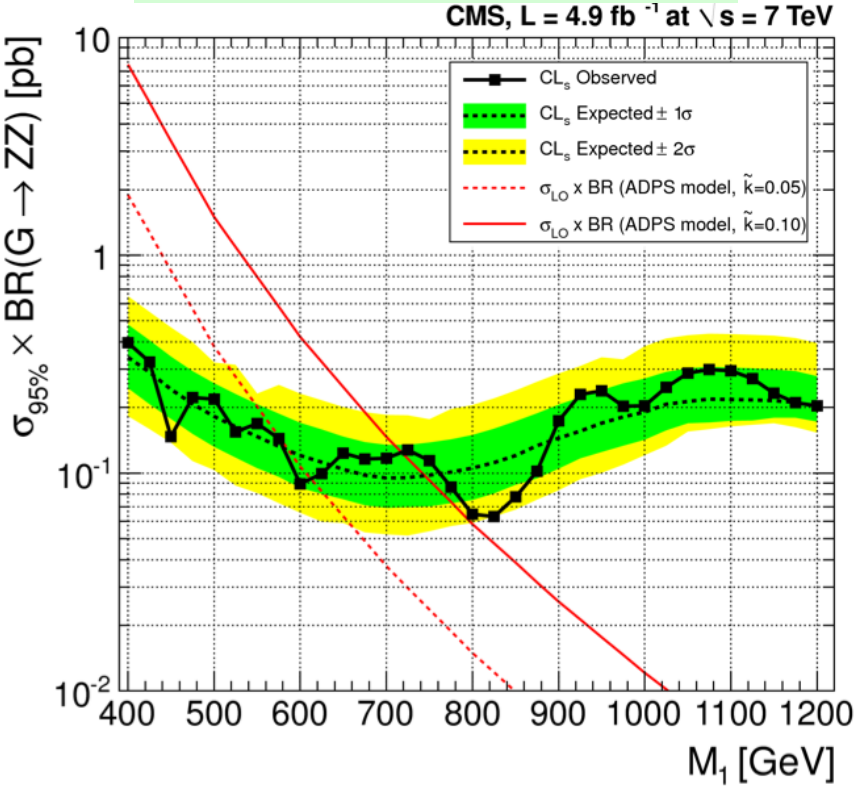
- Limit on RS1 and ADPS models

EXO-11-102

RS1:
M > 945 GeV for k= 0.05
720 < M < 760 GeV, M > 850 GeV for k=0.10

ADPS
M > 720 GeV for k= 0.05
M > 610 GeV for k=0.10

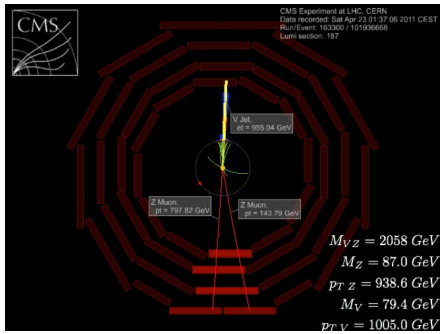




G→ZV

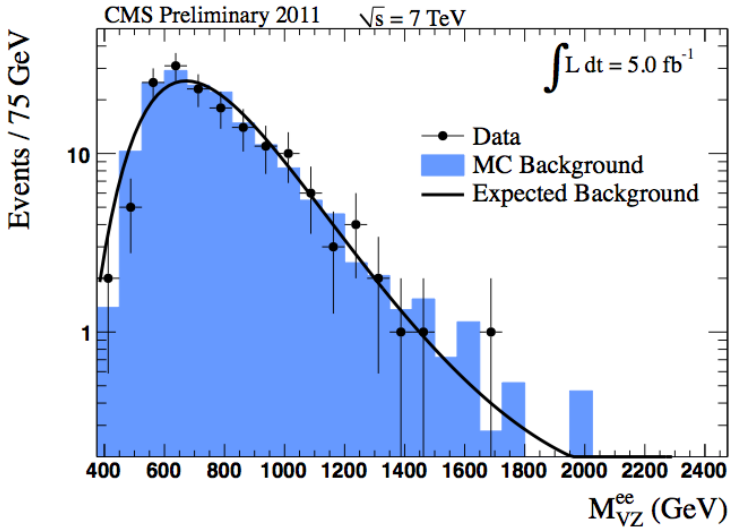
- V is highly boosted for heavy G resulting in signature with 2l+1 jet

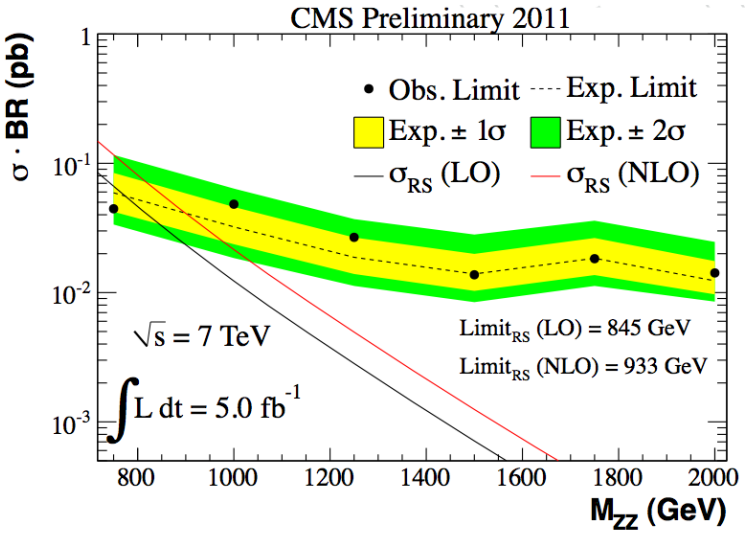
EXO-12-014



  - V is identified from highest pT jet $60<M_J<100$ GeV
  - M_J efficiency is determined in ttbar control sample
  - Limits set on RS1 G and W'

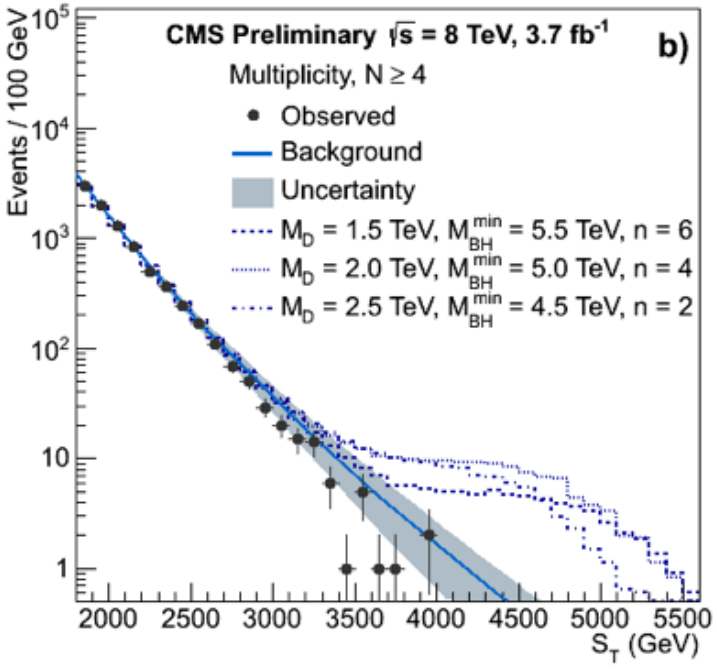
M(G) > 933 GeV for k/M_{pl} = 0.05

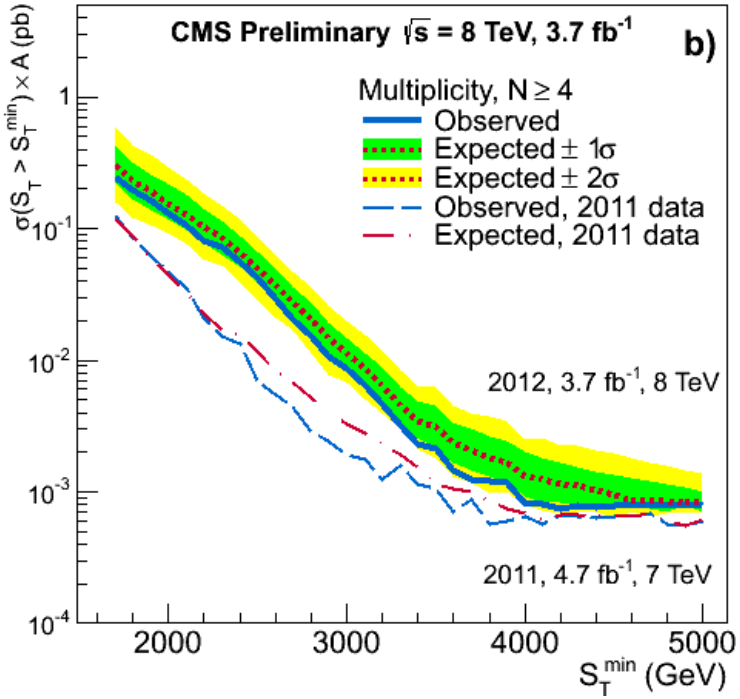




Black holes

- Signature of high multiplicity of high pT objects **EXO-12-009**
- Background from multijet process is estimated from the fit
  - For each multiplicity bin separately at ST = 1.8-2.2 TeV



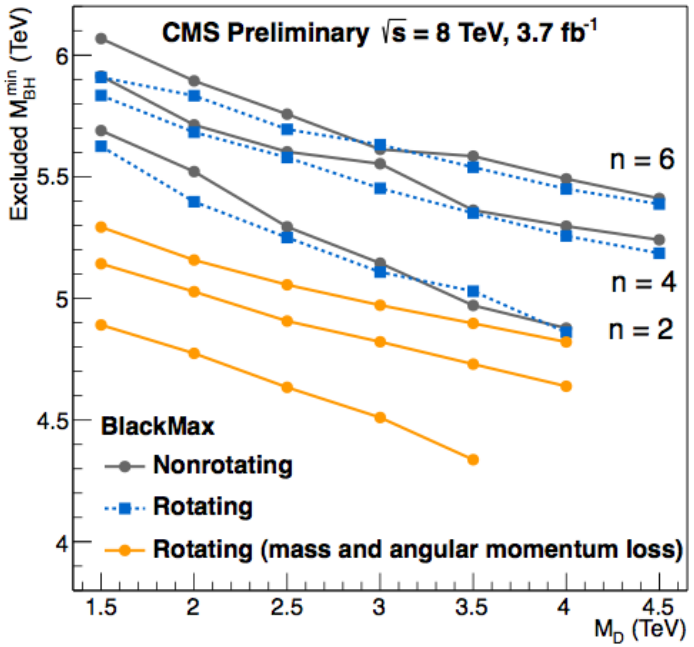


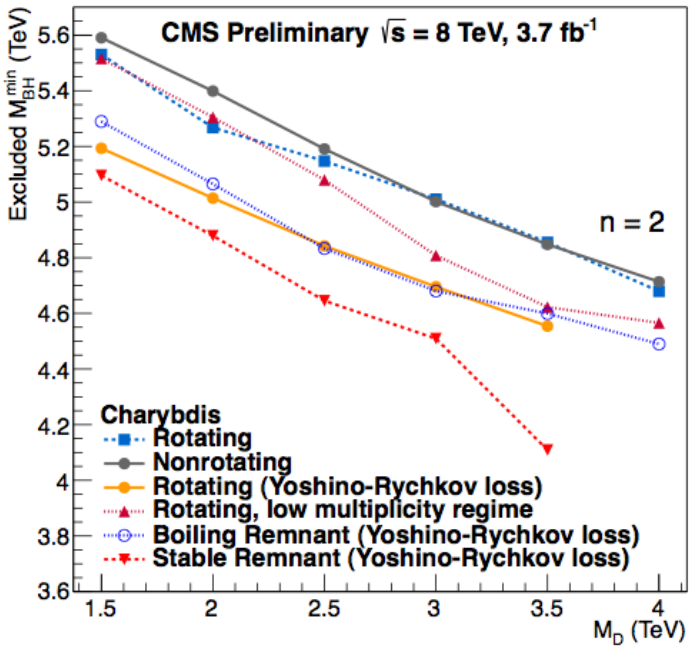
Black holes

- Model independent limit vs ST and multiplicity
- Setting limit on specific BH models

EXO-12-009

n=2, M_{BH} > ~4.8 -- 5.8 TeV
n=6, M_{BH} > ~5.2 – 6.1 TeV

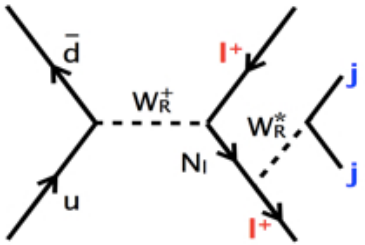


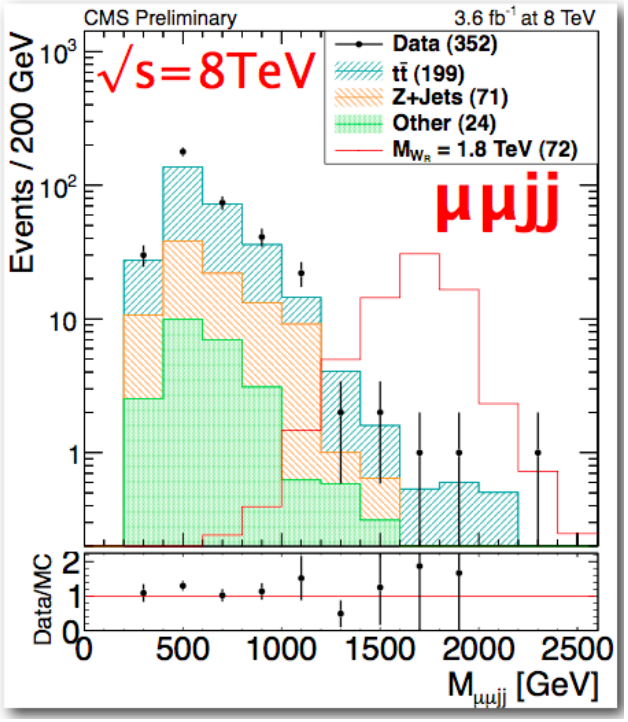


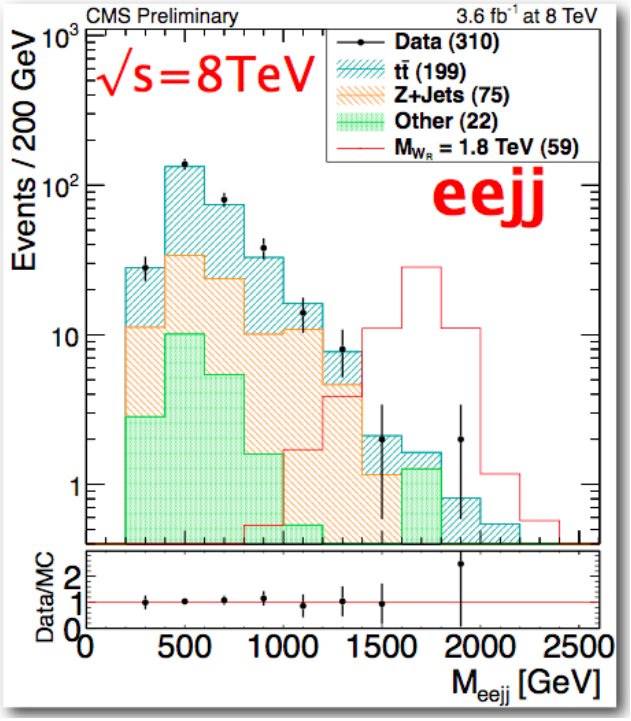
Heavy neutrino & W_R

- Predicted from left-right symmetric model
  - Signature of μμjj and eejj, with high p_T isolated leptons
  - Backgrounds from Drell-Yan, top, multijet estimated from data

EXO-12-017





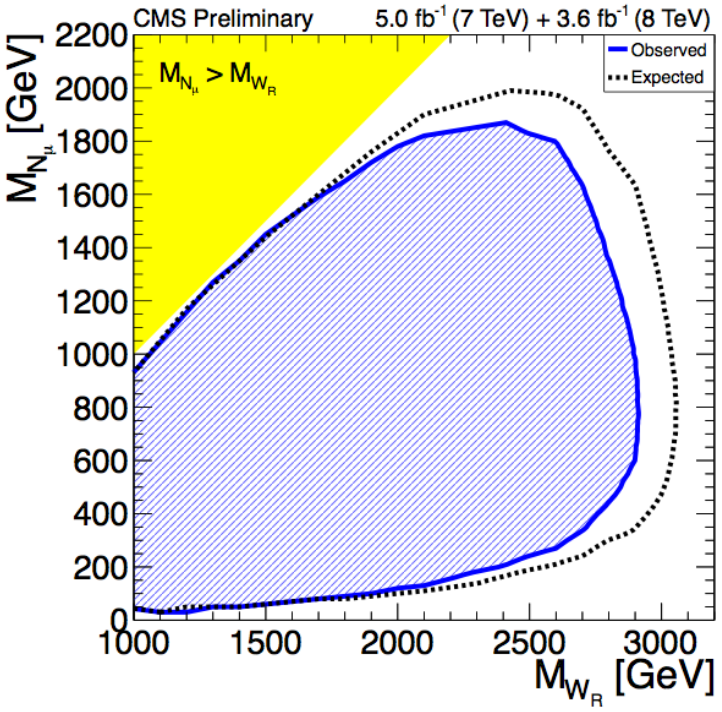


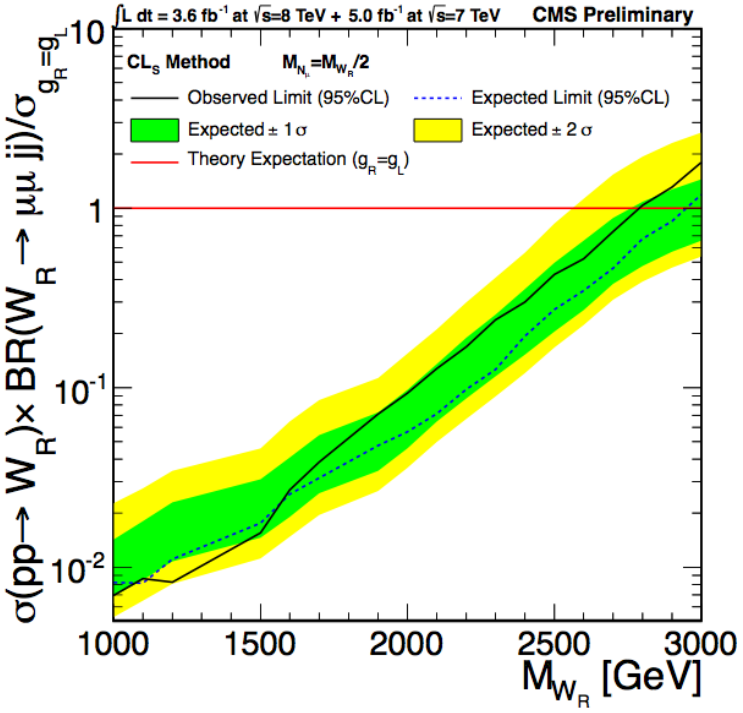
Heavy neutrino & W_R

- Combining 2011-2012 data for dimuon channel
  - Assuming small W_R-W_L and N_l-$N_{l'}$ mixing

EXO-12-017

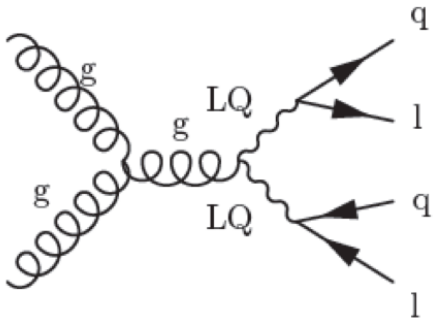
$M(W_R) > 2800$ GeV for $M(N_\mu)=1/2M(W_R)$



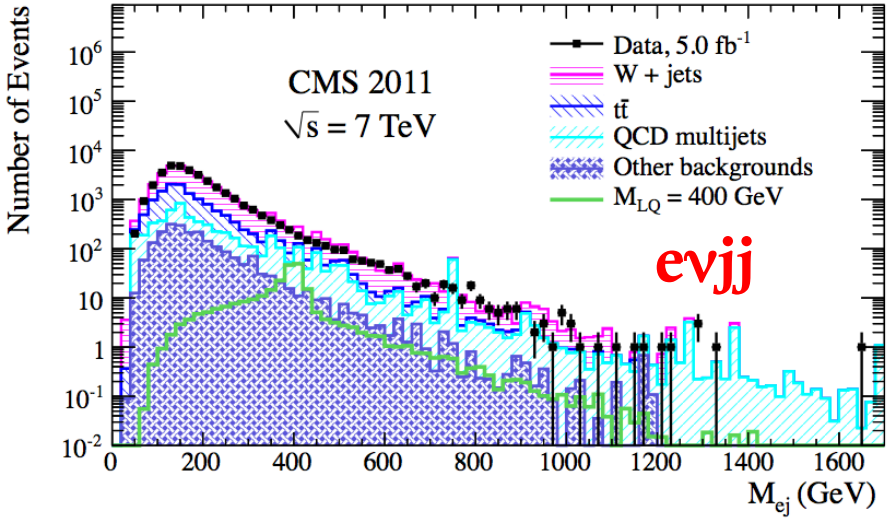


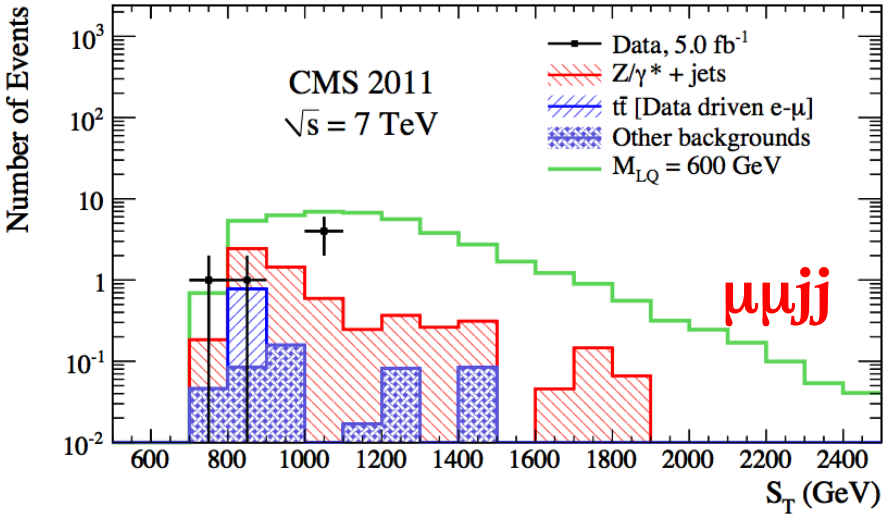
Leptoquarks

- Predicted by composite models, GUT, Technicolor
  - Two energetic leptons and two jets
  - Lepton, missing transverse energy and two jets
  - Backgrounds from DY+jets, ttbar, W+jets
    - Using M(lj), MET, ST to reject
    - Remaining background estimated from data



EXO-11-028



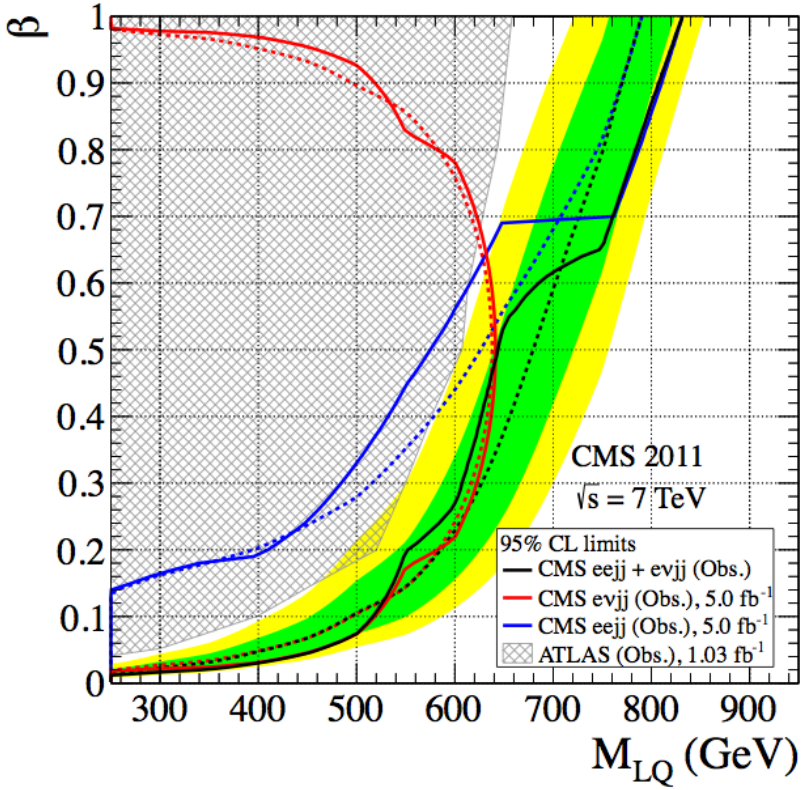


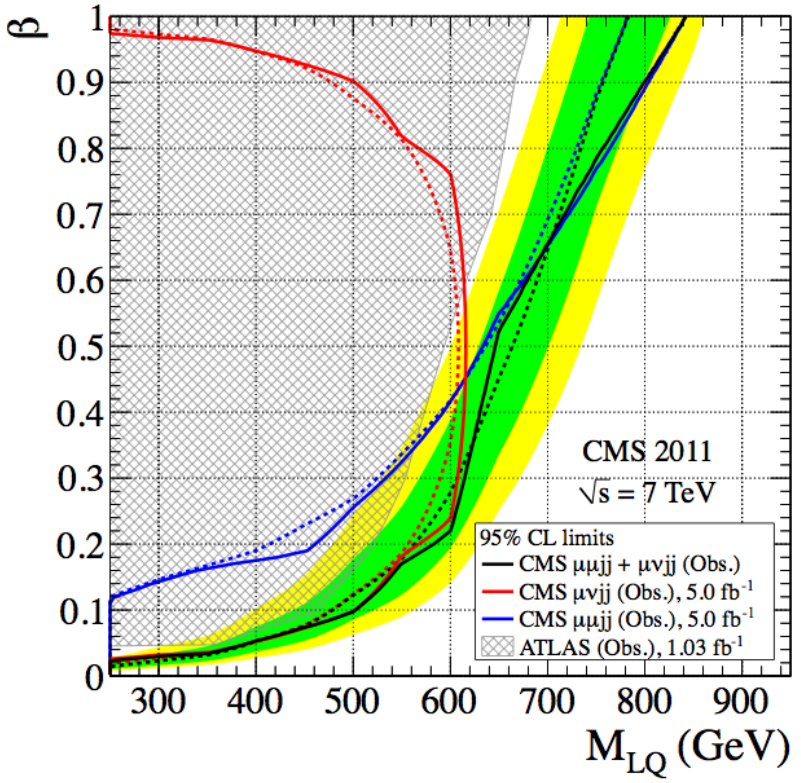
1st/2nd generation scalar LQ

- Limits on LQ mass and decay branching fraction
  - β = BR(LQ→lq)

EXO-11-028

M_{LQ1}> 830 (640) GeV for β=1 (0.5)
M_{LQ2}> 840 (650) GeV for β=1 (0.5)

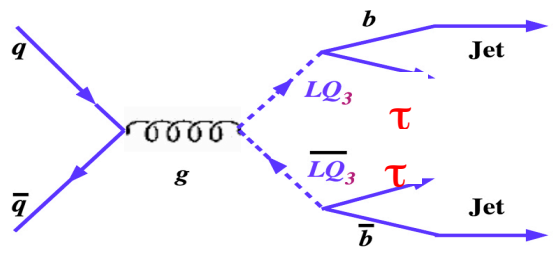


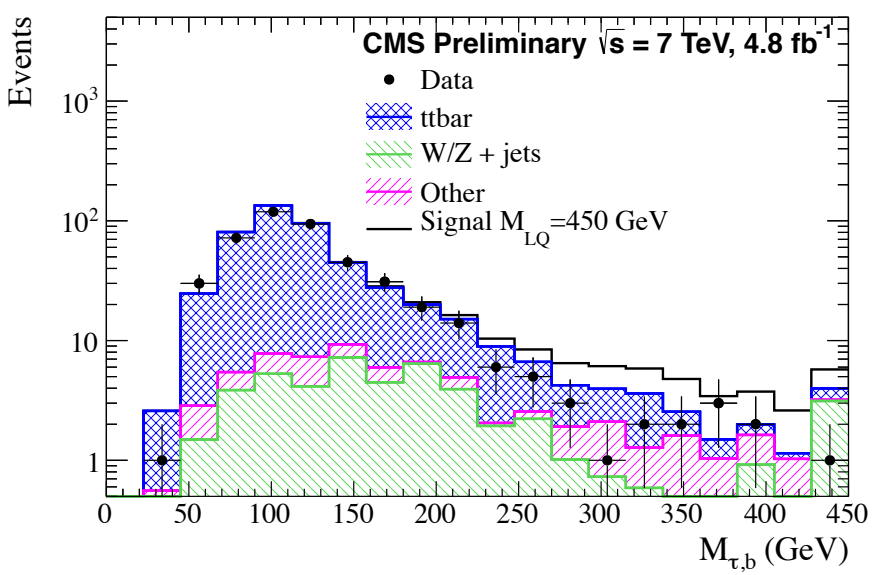


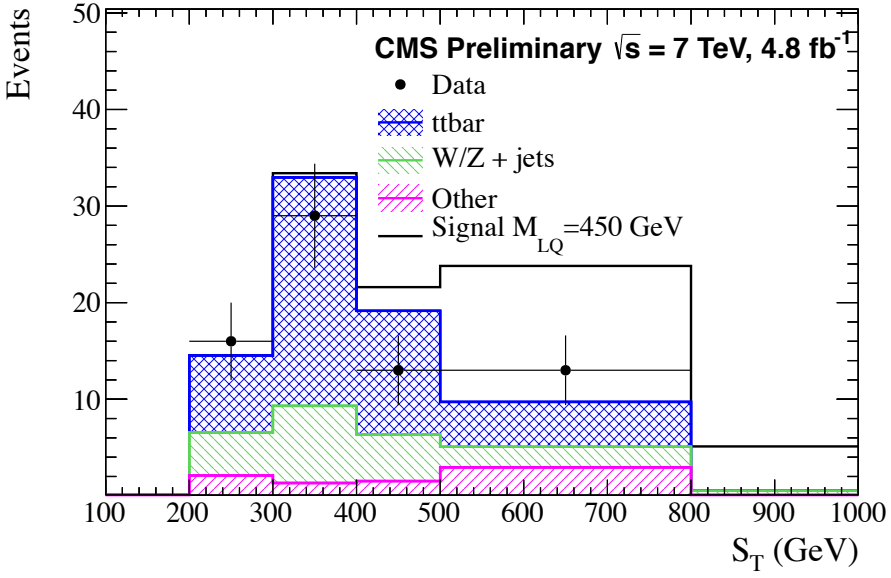
3rd generation LQ

- LQ decaying to tau and b quark
  - Signature with eτbb and μτbb
  - Major backgrounds from ttbar and V+jets
    - Rejected by M(τ,b)
    - Using ST distribution to extract limits

EXO-12-002



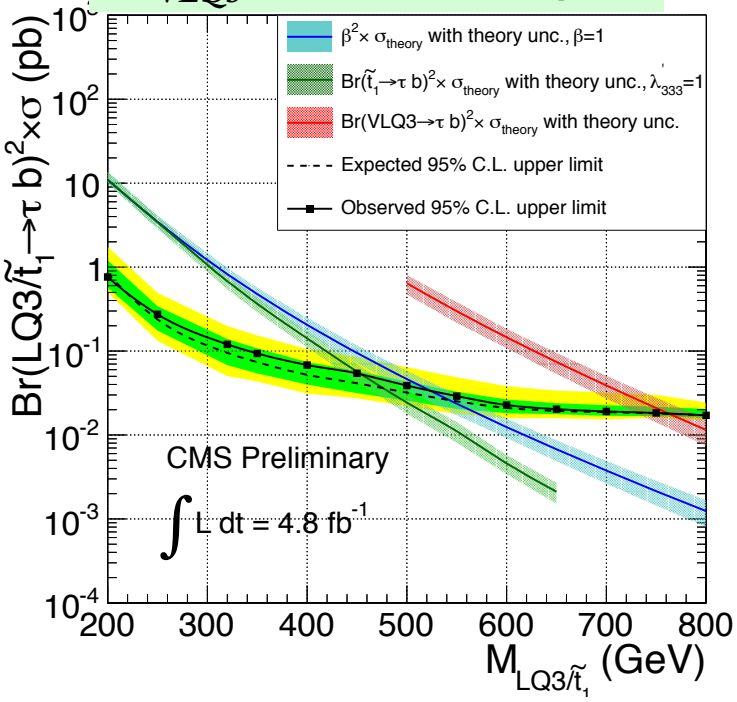




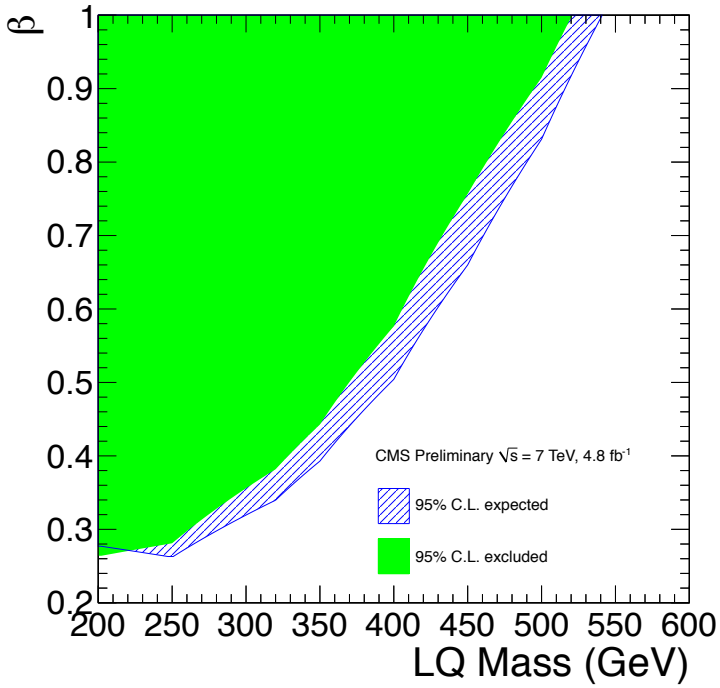
3rd generation LQ

- Limits set on both scalar and vector LQ
  - The difference in kinematics of vector and scalar LQ decay products have effect of a few percents on the selection efficiency

M_{SLQ3}> 525 GeV for β=1
M_{VLQ3}> 763 GeV for β=1



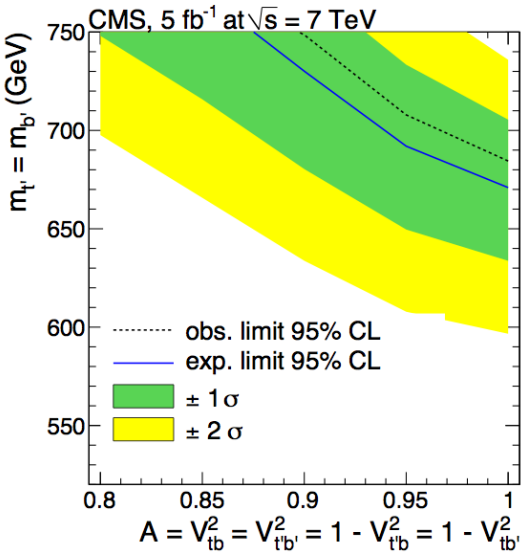
Limits are also interpreted for RPV stop

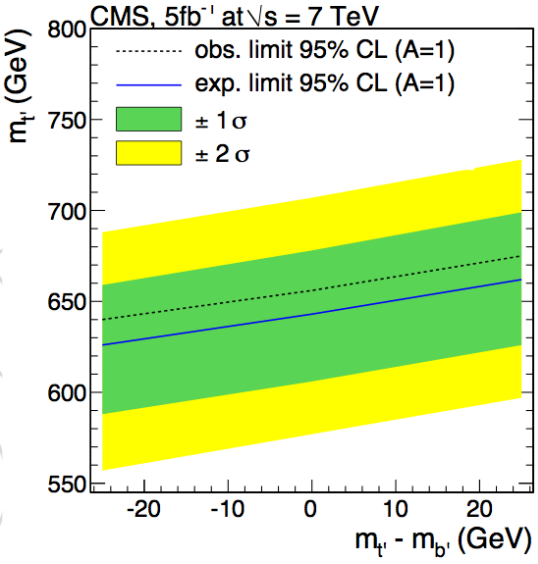


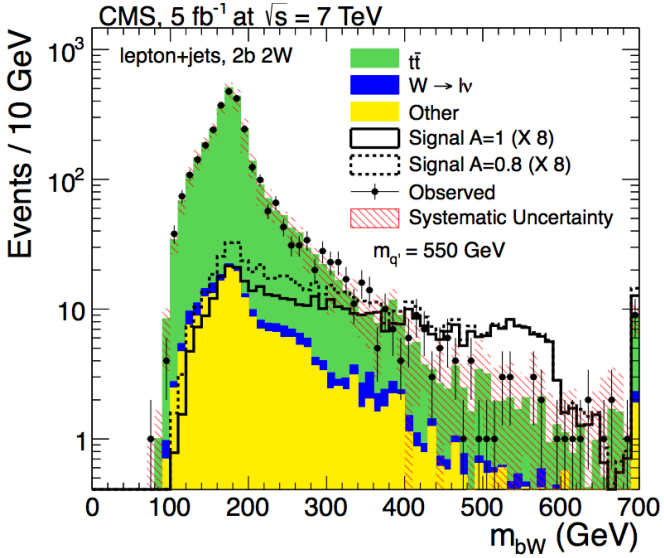
4^{th} generation

- Inclusive t' and b' search, assume $V^2_{tb}=V^2_{t'b'}=A$ $V_{CKM}{}^{4x4}=\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \sqrt{A} & \sqrt{1-A} \\ 0 & 0 & -\sqrt{1-A} & \sqrt{A} \end{pmatrix}$
  - Final topology with 1-4 W and 2 bjets
  - Signature with single, same-sign double, or triple leptons, jets, missing ET
  - Discriminator against backgrounds ST

EXO-11-098



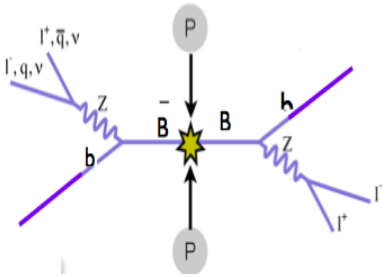




Assuming $m_{t'}=m_{b'}$,
$m_{q'} > 685$ GeV
Assuming A=1, Δm = 25 GeV
mass of up-type 4^{th} gen quarks > 640 GeV

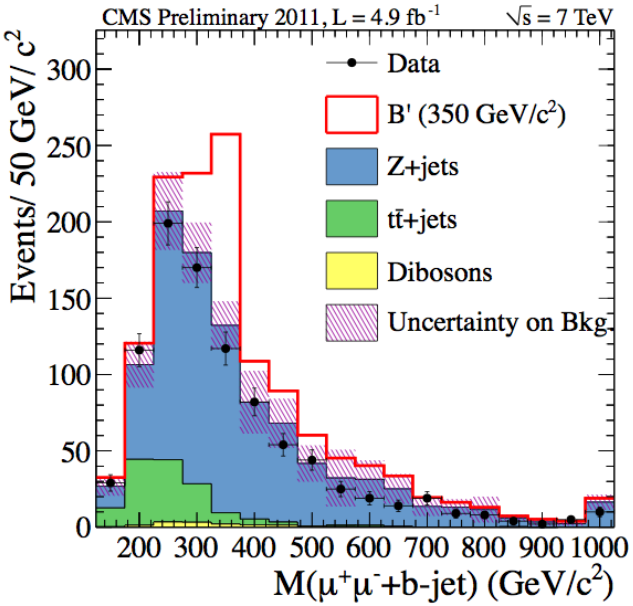
B'→Zb

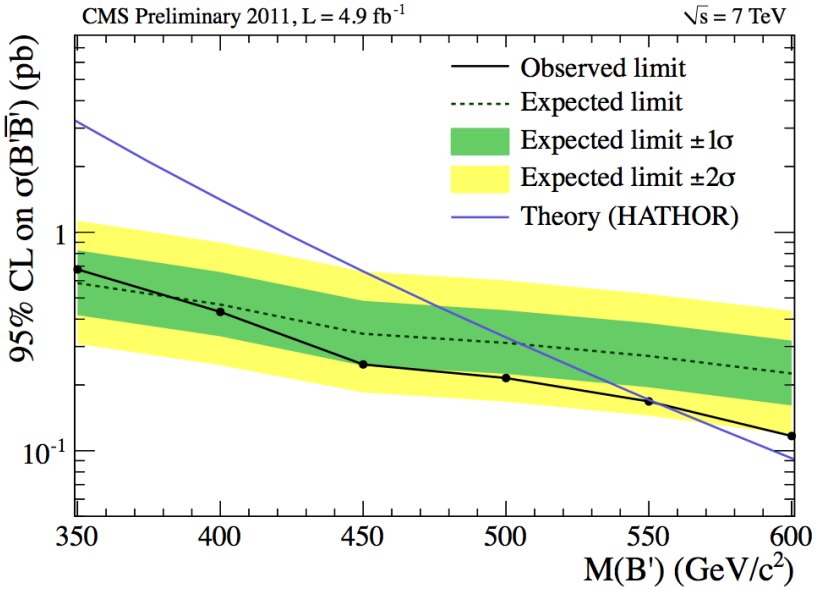
- Signature with dileptons and b jet
- Search for resonant peak in Zb mass spectrum
  - B candidate is reconstructed using leading Z and b jet



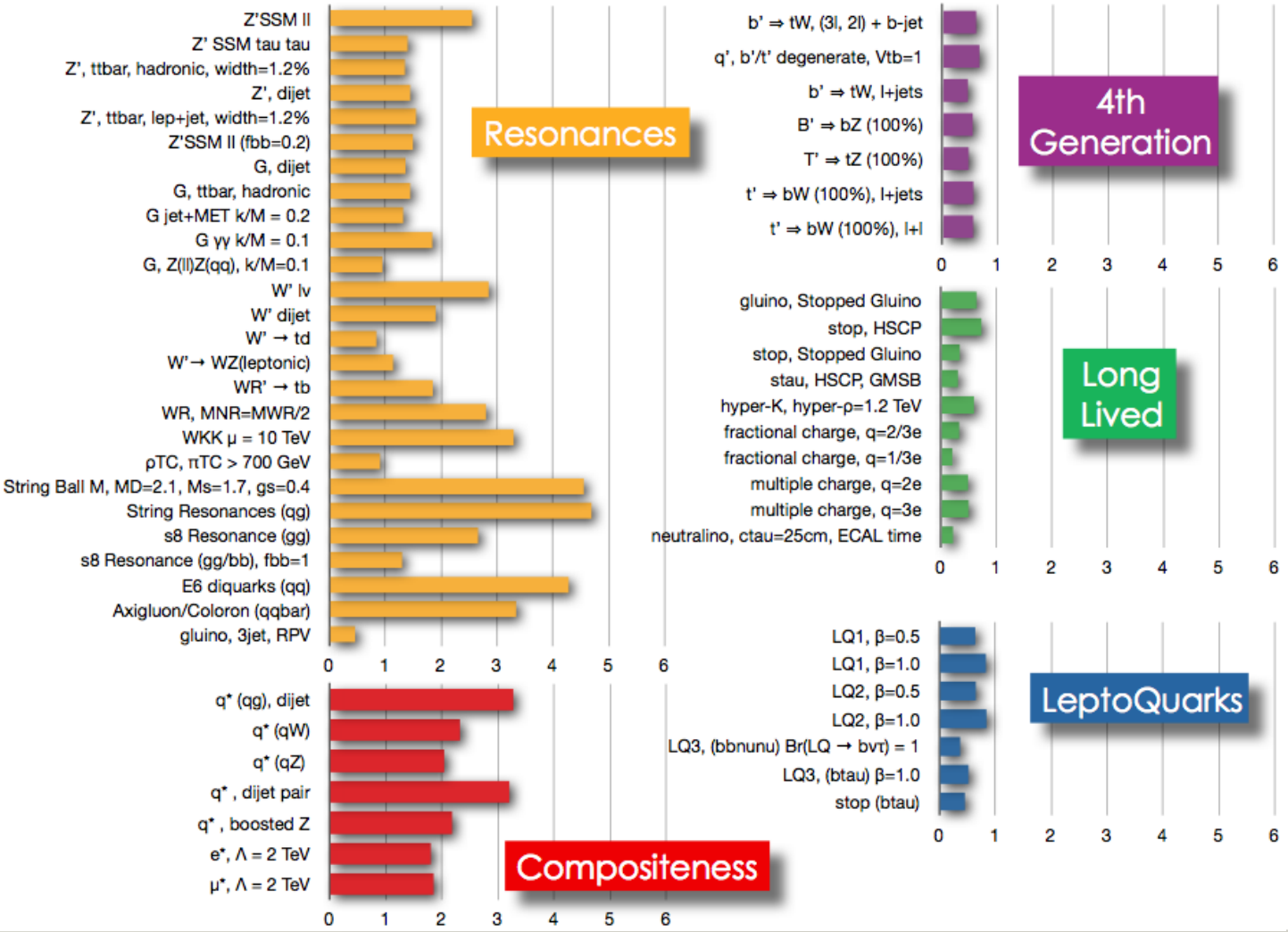
EXO-11-066

M(B') > 550 GeV assuming 100% Br.

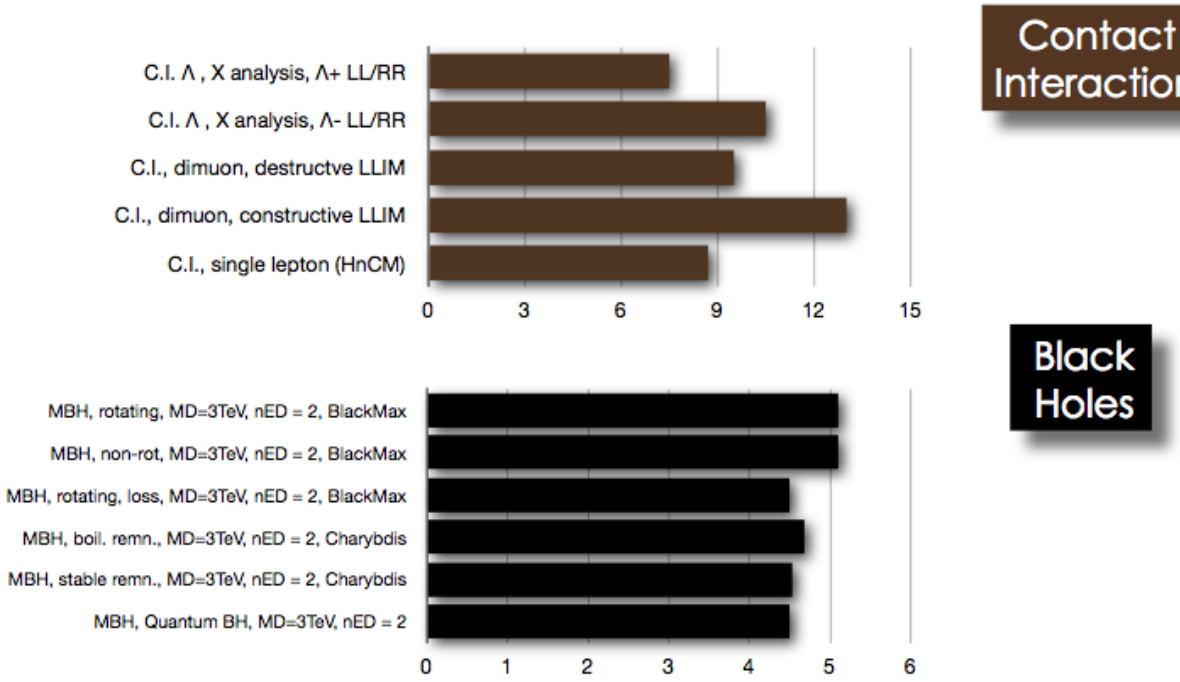




Summary of CMS searches



Summary of CMS searches



- A lot of results made public since Moriond 2012
  - Unfortunately no BSM discoveries (yet)
  - Note that a lot of updates with full statistics will follow shortly

Where we go from here

- These first results from CMS (LHC) is an "ouverture"
  - Excellent performance of detector, trigger, computing, object identification
- Is new physics too rare and too heavy for 7/8 TeV?
  - Higher statistics and higher center of mass energy is the way to go
- We should also think outside the box
  - Adequate coverage of "unusual" topologies is crucial
  - Important to have close collaboration with phenomenologists and theorists to test new models/ideas
- My hope that the discovery of a new boson is the first drop in the end of a long dry season!

BACKUP