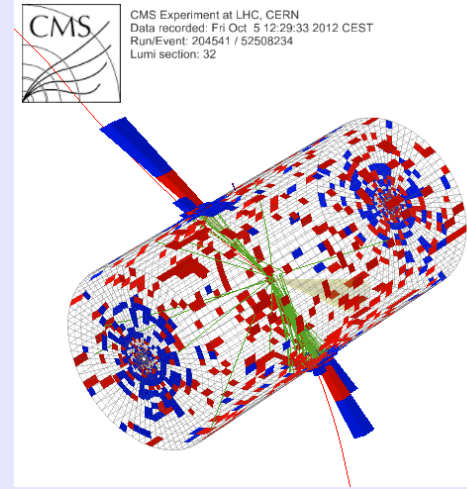
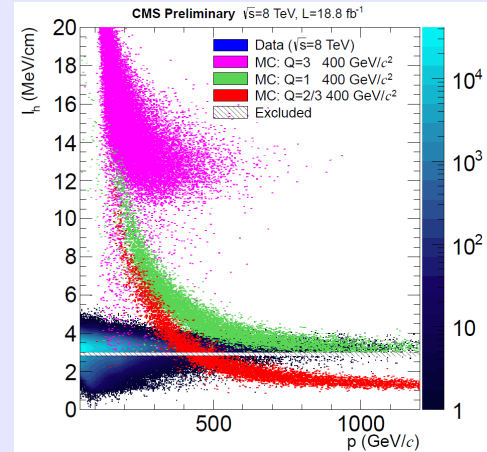


Searches for New Physics with Leptons and Jets at CMS

DIS 2013: XXI
Marseille

Carl Vuosalo
on behalf of the
CMS Collaboration



CMS

Total weight 12500 t
Overall diameter 15 m
Overall length 21.6 m

ECAL 76k scintillating
PbWO₄ crystals

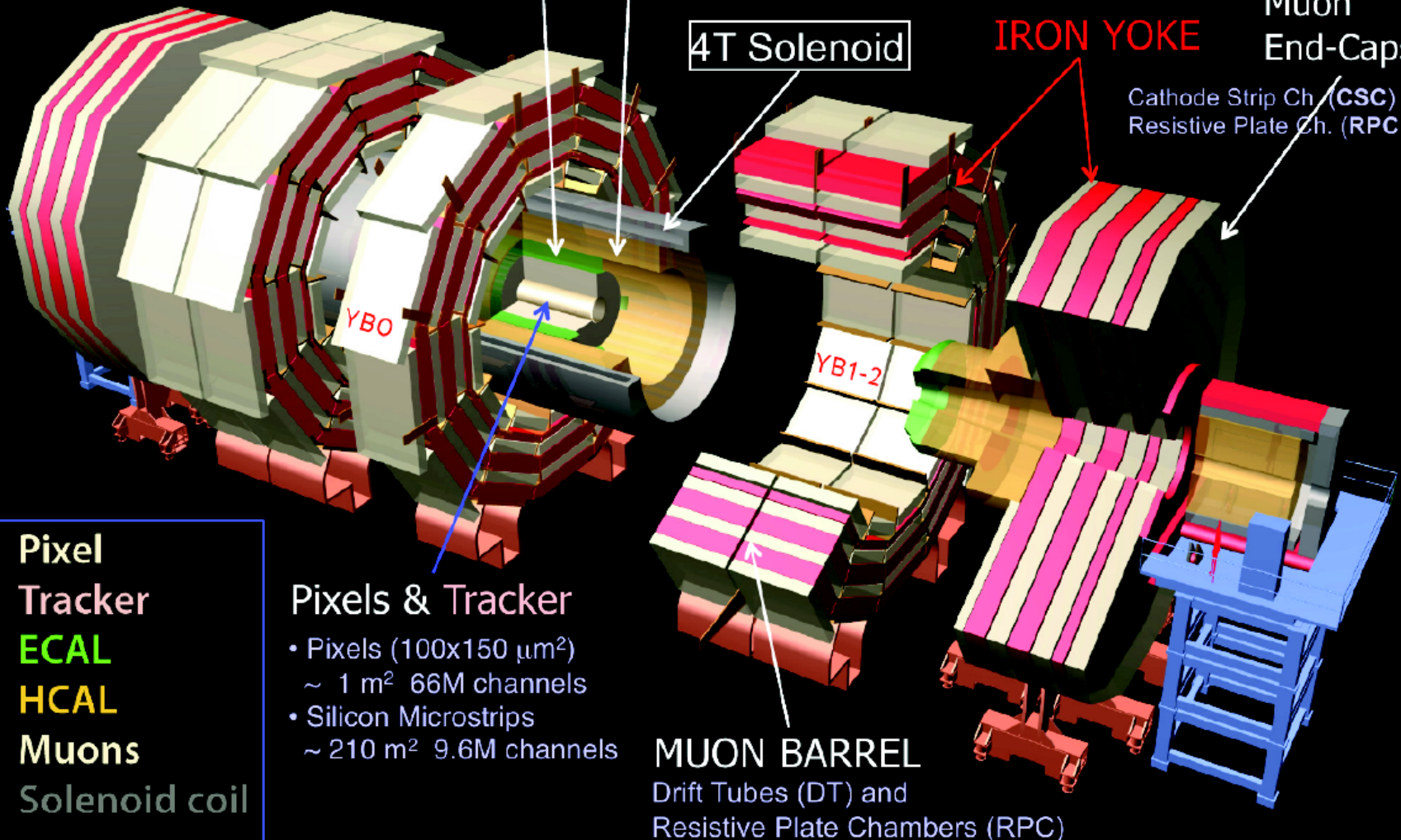
HCAL Scintillator/brass
interleaved

4T Solenoid

IRON YOKE

Muon
End-Caps

Cathode Strip Ch. (CSC)
Resistive Plate Ch. (RPC)



Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil

Pixels & Tracker

- Pixels (100x150 μm^2)
~ 1 m² 66M channels
- Silicon Microstrips
~ 210 m² 9.6M channels

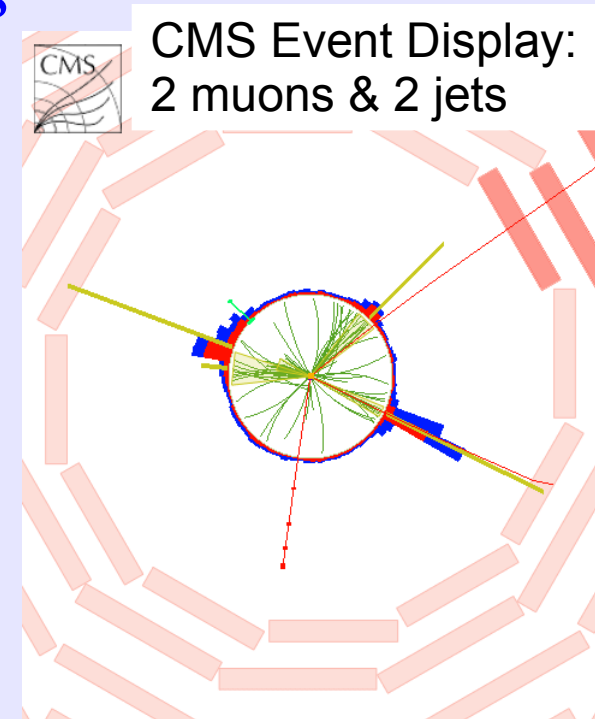
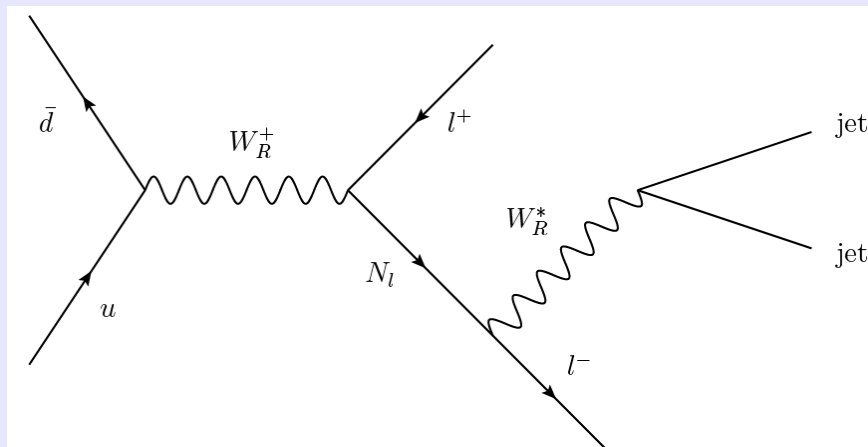
MUON BARREL
Drift Tubes (DT) and
Resistive Plate Chambers (RPC)

Outline

- New physics searches by CMS with 2012 data using leptons and jets:
- Search for a Heavy Neutrino & W_R
- Search for Pair Production of Second-Generation Scalar Leptoquarks
- Search for Long-lived Charged Particles
- Search for Dijet Resonances
- Search for Dijet Resonances Decaying to $b\bar{b}$ and $b\bar{g}$

Heavy Neutrino & $W_R(1)$

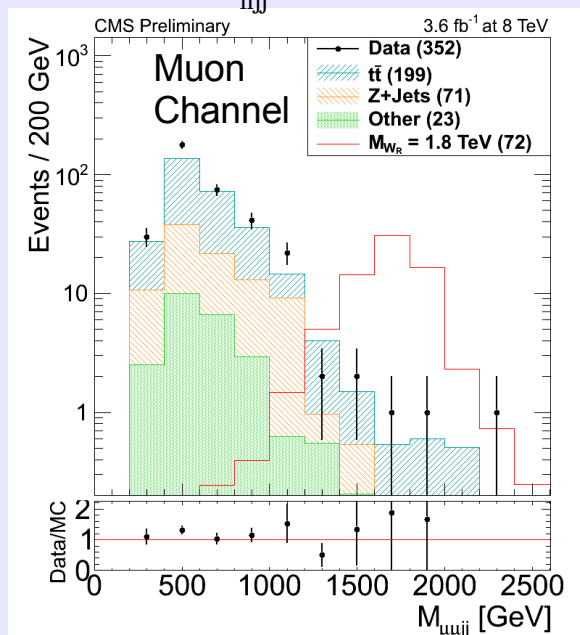
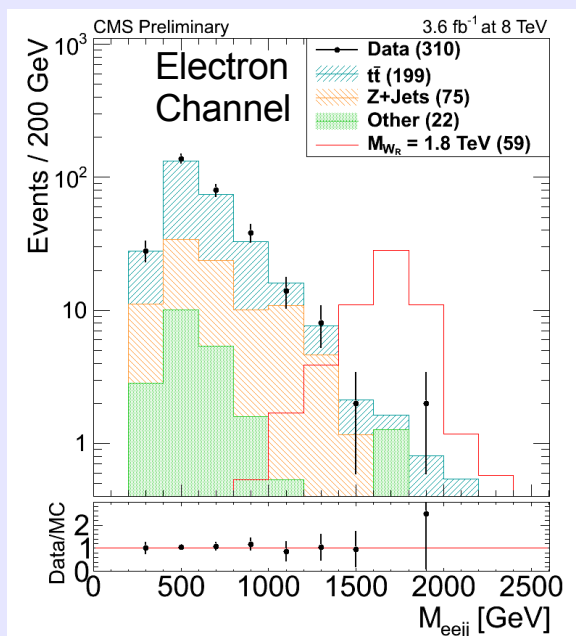
- EXO-12-017, Search for a Heavy Neutrino and Right-handed W of the Left-right Symmetric Model
- Proposed right-handed $SU_R(2)$ symmetry group creates W_R , Z' , and three heavy, **right-handed neutrinos**
- Analysis uses 3.6 fb^{-1} of 2012 8 TeV data
- Signature is **two leptons & two jets**



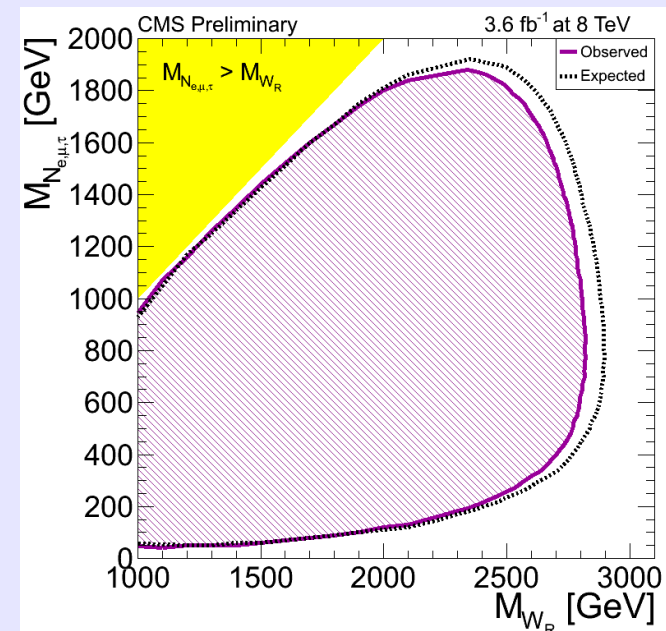
Heavy Neutrino & $W_R(2)$

- Data-driven background estimates, except for Z+Jets from MC
- Shape analysis for limits
- Systematic uncertainties: 15% for signal, mostly PDF; 20-50% for backgrounds, mostly shape uncertainties
- No significant excess observed
- Limits set on W_R mass up to 2900 GeV

Data, Background, & Signal Prediction for M_{lljj} Invariant Mass

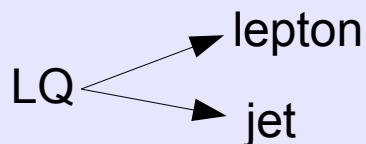


Combined electron & muon limits assuming $g_L = g_R$ and 3 heavy neutrinos

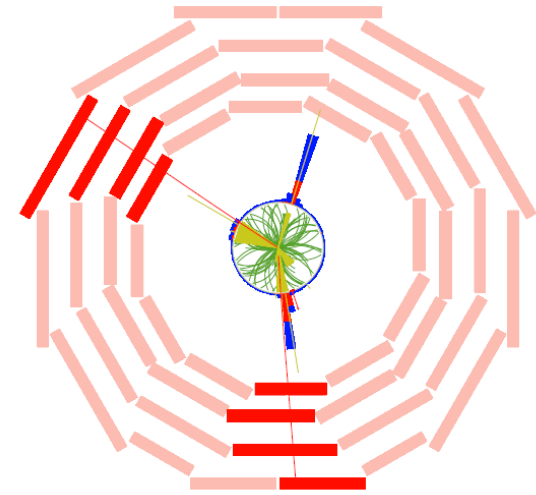


Scalar Leptoquarks (1)

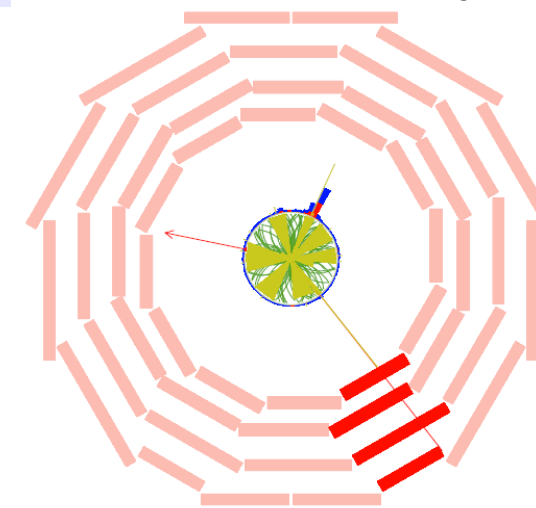
- EXO-12-042, Search for Pair Production of Second-Generation Scalar Leptoquarks
- Proposed leptoquark (LQ) couples to leptons & quarks, has fractional charge, and is scalar
- Analysis uses **full 2012 8 TeV dataset** (19.6 fb^{-1})
- Two signatures:
 - **Two muons & two jets** ($\mu j \mu j$)
 - **One muon, two jets, & missing energy** ($\mu j \nu j$)



Event Display:
2 muons & 2 jets



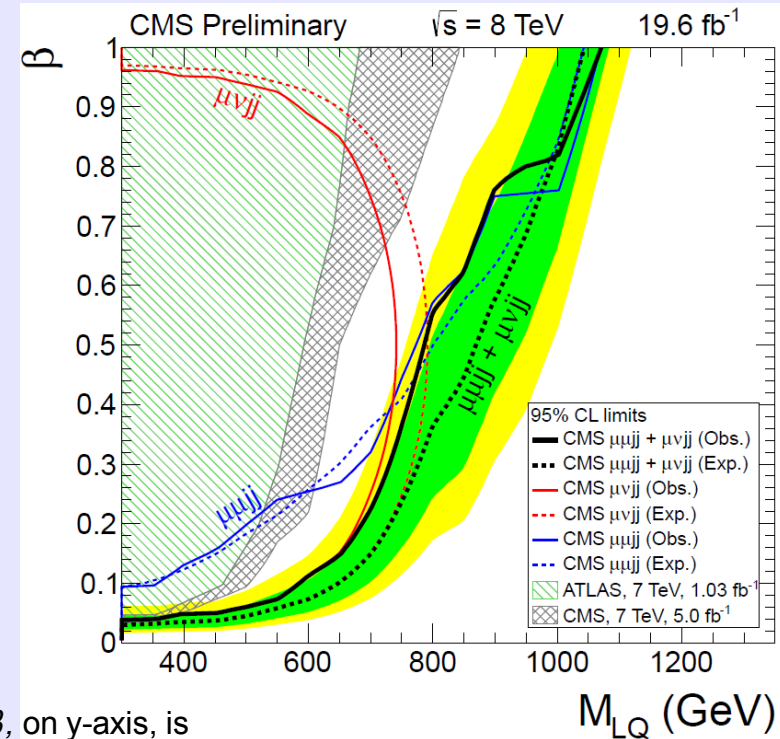
Event Display:
Muon, neutrino, & 2 jets



Scalar Leptoquarks (2)

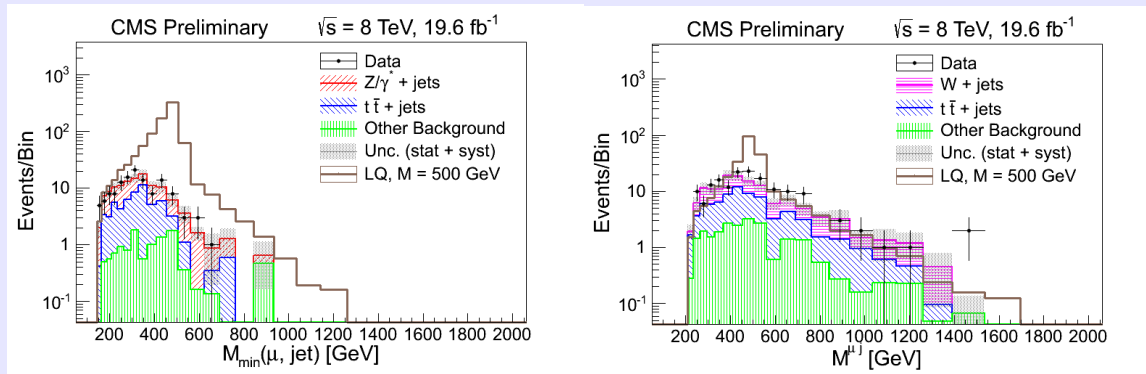
- Data-driven background estimates
- Systematic uncertainties:
 - 5% for signal, mostly luminosity uncertainty
 - 14-24% for backgrounds, mostly jet energy resolution & muon energy scale
- No significant excess observed
- Cut & count limits set on LQ mass up to 1070 GeV

Combined $\mu j \mu j$ & $\mu j \nu j$ limits by LQ mass and β



β , on y-axis, is leptoquark BR into lepton & quark

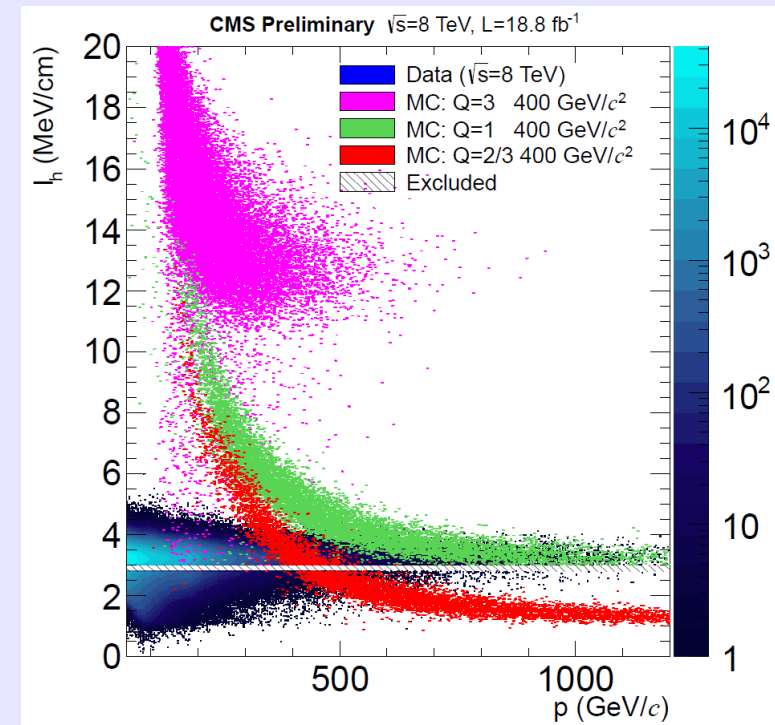
$\mu j \mu j$ μj Mass for LQ 500 GeV $\mu j \nu j$



Heavy, Stable, Charged Particles (1)

- EXO-12-026, Search for Long-lived Charged Particles
- Extensions to SM predict **massive** particles (>100 GeV) and particles with **fractional** charge or **charge $> 1e$**
- Such particles would show very **high or low dE/dx** from ionization loss, **long time-of-flight (TOF)** in detector, or switch between charged/neutral states in flight
- Search in five channels: **tracker**, **tracker+TOF**, **TOF (muon)**, **$|Q| > 1e$** , **$|Q| < 1e$**
- Data-driven background prediction
- Analysis combines 7 & 8 TeV 2011-2012 CMS data: 23.8 fb^{-1} total

dE/dx for New Physics Particles and Data



Heavy, Stable, Charged Particles (2)

EXO-12-026

Systematic Uncertainties

	$ Q < 1e$	tracker-only	tracker+TOF	$ Q > 1e$	muon-only
Signal acceptance	< 31%	< 32%	< 31%	< 29%	< 13%
Expected collision background	20%	20%	20%	20%	20%
Expected cosmic background	50%	-	-	-	80%
Integrated luminosity	2.2%(4.4%) for $\sqrt{s} = 7(8)$ TeV				

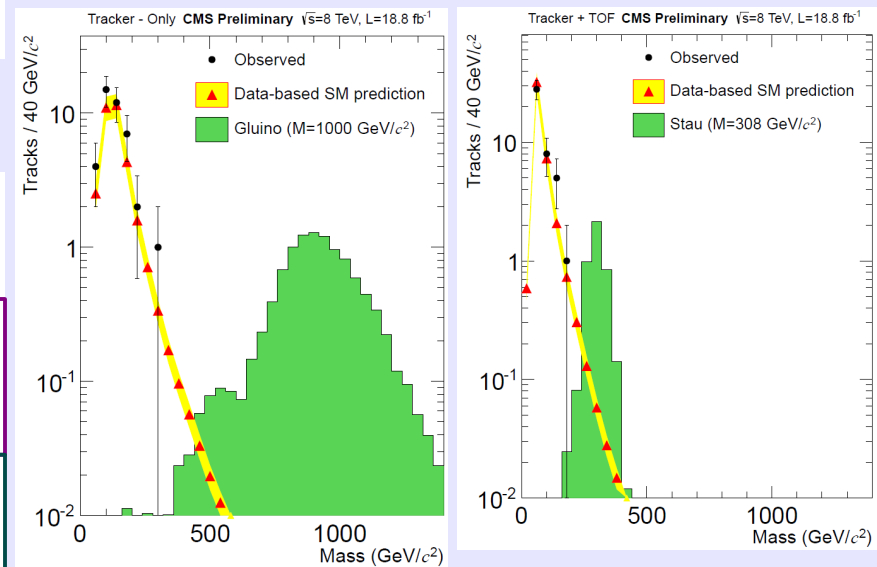
Selection, Background Prediction, & Results

	Selection criteria				Numbers of events			
	p_T (GeV/c)	dE/dx	$1/\beta$	Mass (GeV/c ²)	$\sqrt{s} = 7$ TeV		$\sqrt{s} = 8$ TeV	
					Pred.	Obs.	Pred.	Obs.
tracker-only	> 70	> 0.4	-	> 0	7.1 ± 1.5	8	32.5 ± 6.5	41
				> 100	6.0 ± 1.3	7	26.0 ± 5.2	29
				> 200	0.65 ± 0.14	0	3.1 ± 0.6	3
				> 300	0.11 ± 0.02	0	0.55 ± 0.11	1
				> 400	0.030 ± 0.006	0	0.15 ± 0.03	0
tracker+TOF	> 70	> 0.125	> 1.225	> 0	8.5 ± 1.7	7	43.5 ± 8.7	42
				> 100	1.0 ± 0.2	3	5.6 ± 1.1	7
				> 200	0.11 ± 0.02	1	0.56 ± 0.11	0
				> 300	0.020 ± 0.004	0	0.090 ± 0.02	0
muon-only	> 230	-	> 1.40	-	-	-	5.6 ± 2.9	3
$ Q > 1e$	-	> 0.500	> 1.200	-	0.15 ± 0.04	0	0.52 ± 0.11	1
$ Q < 1e$	> 125	> 0.275	-	-	0.12 ± 0.07	0	0.99 ± 0.24	0

Data, Background, & Signal Prediction

Tracker Only

Tracker+TOF



Mass in plots calculated from p and dE/dx and assuming $|Q| = 1e$

Data matches background prediction within uncertainties

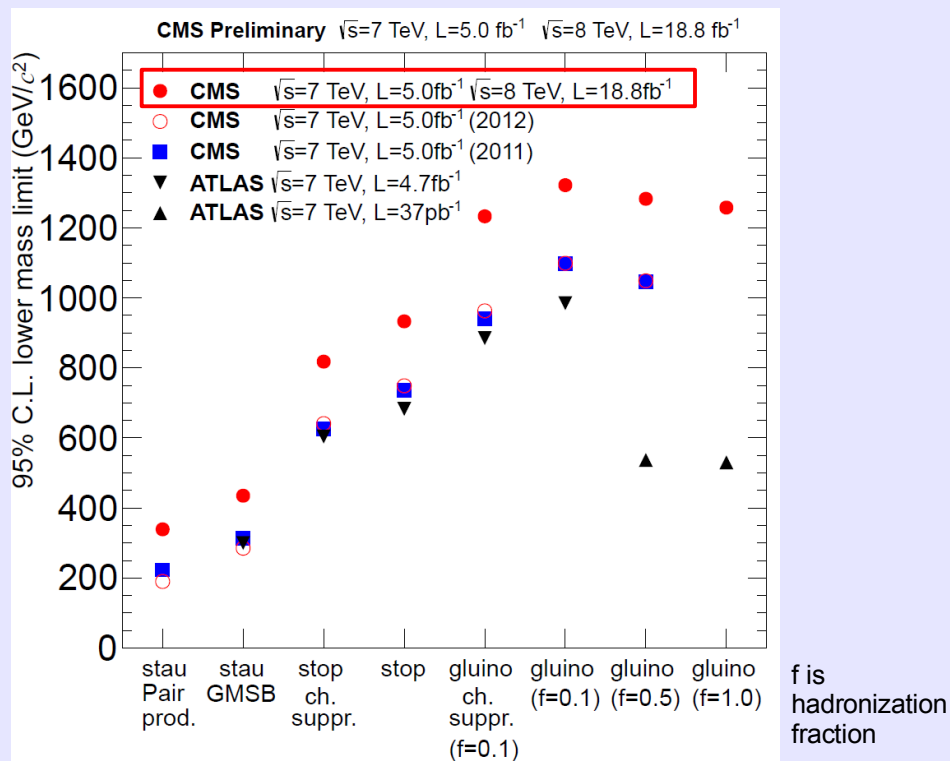
Heavy, Stable, Charged Particles (3)

- Limits obtained by shape analysis for tracker analyses, by cut & count for muon and charge $\neq 1e$ analyses

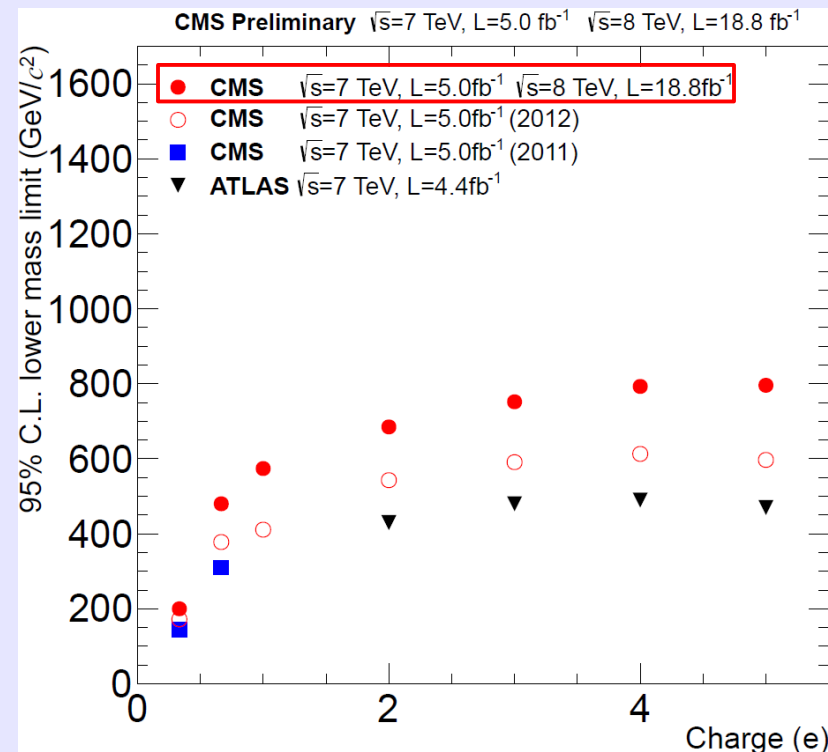
EXO-12-026

- No significant excess observed; new mass limits go up to **1322 GeV**

Limit Comparison by SUSY Model



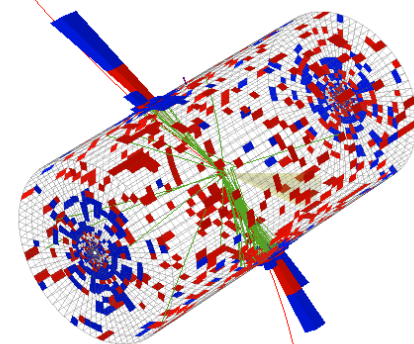
Limit Comparison by Charge



Dijet Resonances (1)

- EXO-12-059, Search for Narrow Resonances using the Dijet Mass Spectrum
- Many new physics models predict heavy resonances that couple to gluons and quarks and decay to **dijets**
- Search for string resonances, scalar diquarks, excited quarks, axigluons, color-octet colorons, technicolor s_8 resonances, W' , Z' , and Randall-Sundrum gravitons
- Uses **full 2012 8 TeV dataset**
- **Wide jet** technique adds close sub-leading jets to the two leading jets

CMS Event Display:
5 TeV dijet

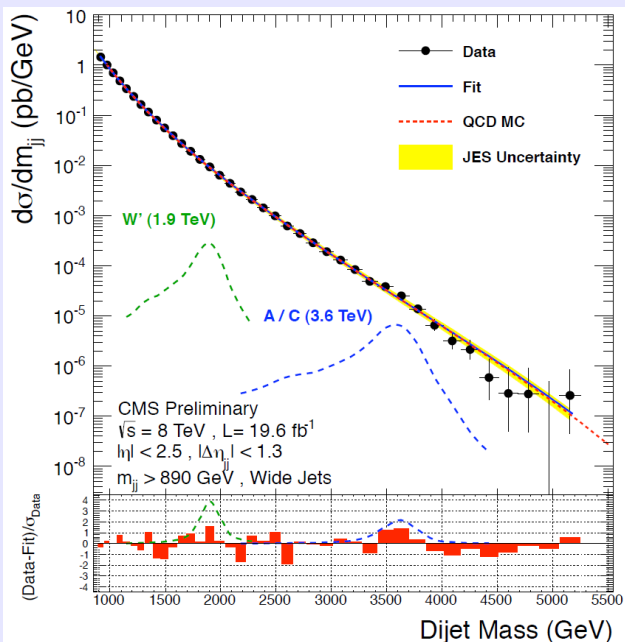


Dijet Resonances (2)

EXO-12-059

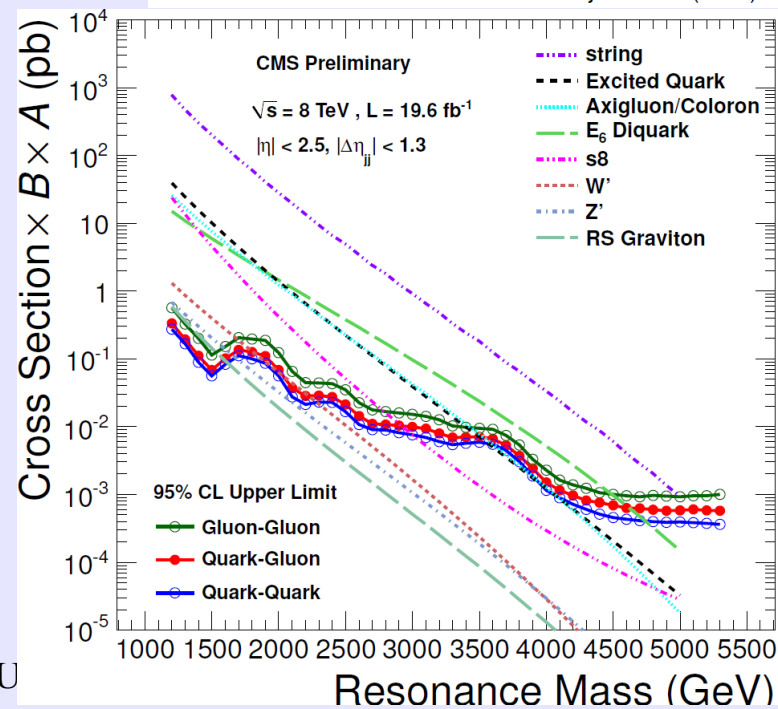
- Background prediction from **four-parameter fit to data**
- Systematic uncertainties: jet energy scale 1.25%, jet energy resolution 10%, integrated luminosity 4.4%, background parameterization
- No excess observed
- Mass limits best to date, up to **5.1 TeV**

Data & Background Prediction



Limits by Signal Model

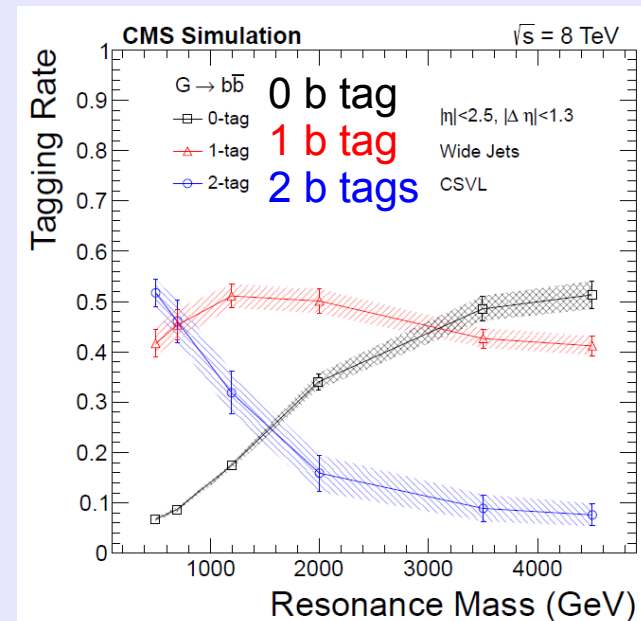
Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.20,5.08]	[1.20,5.00]
Excited Quark (q^*)	qg	[1.20,3.50]	[1.20,3.75]
E_6 Diquark (D)	q \bar{q}	[1.20,4.75]	[1.20,4.50]
Axigluon (A)/Coloron (C)	q \bar{q}	[1.20,3.60] + [3.90,4.08]	[1.20,3.87]
Color Octet Scalar (s8)	gg	[1.20,2.79]	[1.20,2.74]
W' Boson (W')	q \bar{q}	[1.20,2.29]	[1.20,2.28]
Z' Boson (Z')	q \bar{q}	[1.20,1.68]	[1.20,1.87]
RS Graviton (G)	q \bar{q} +gg	[1.20,1.58]	[1.20,1.43]



Dijet Resonances with b Tags (1)

- EXO-12-023, Search for Heavy Resonances Decaying into $b\bar{b}$ and bg Final States
- Adding **b-tag** requirement to dijet search reduces standard model (SM) backgrounds
- Search for excited b quarks, a sequential SM Z' , and Randall-Sundrum (RS) gravitons
- Uses **full 2012 8 TeV dataset**
- **Wide jet** technique adds close sub-leading jets to the two leading jets

b-tagging Rates for RS Graviton $b\bar{b}$ Final States



Dijet Resonances with b Tags (2)

EXO-12-023

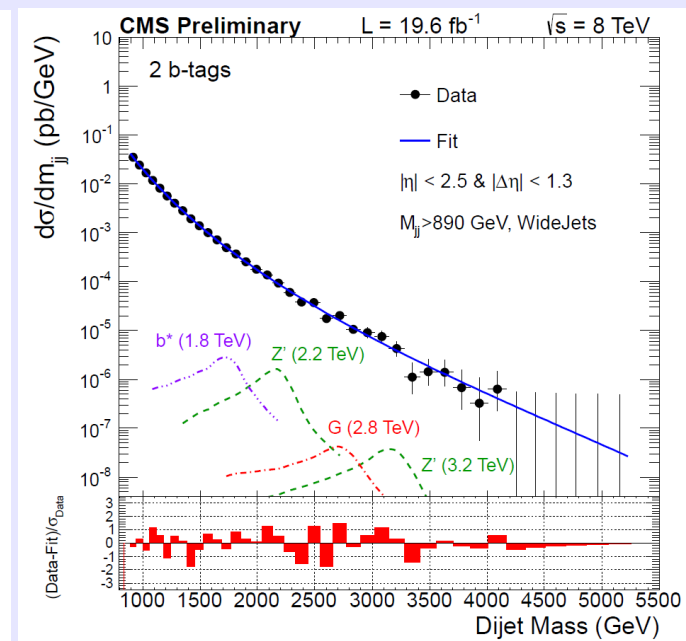
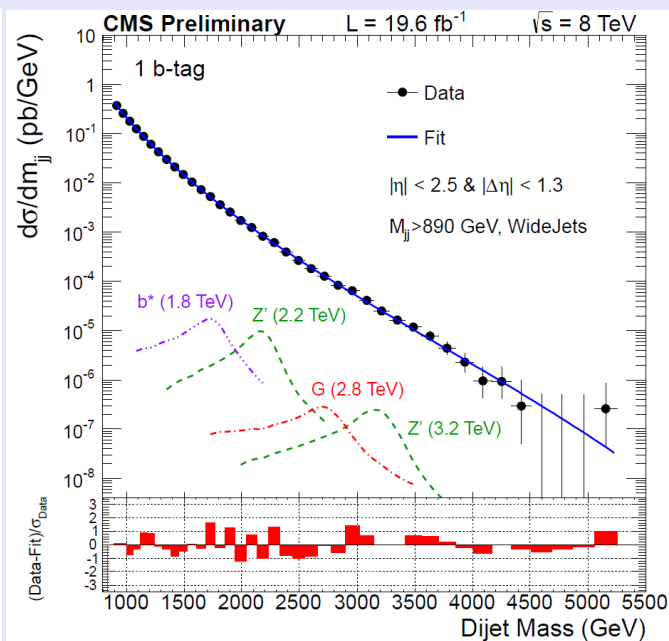
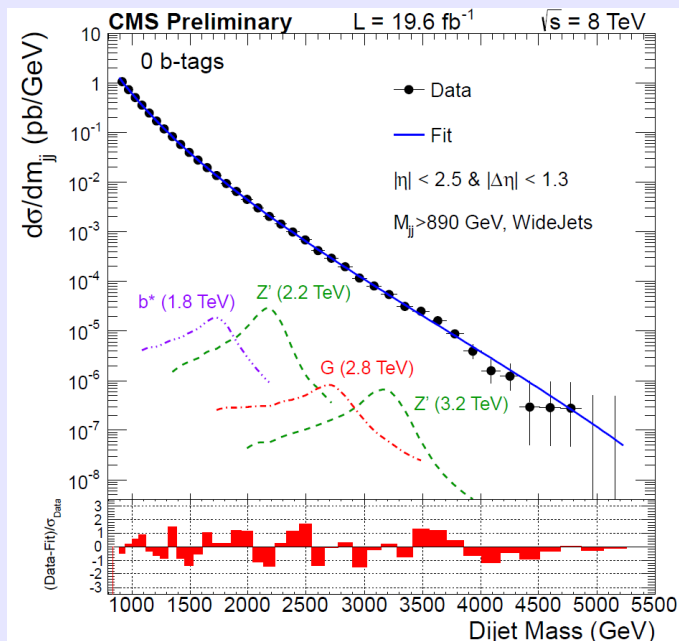
- Background prediction from **four-parameter fit to data**
- Systematic uncertainties: jet energy scale 1.25%, jet energy resolution 10%, integrated luminosity 4.4%, background parameterization, b-tagging scale factors 5-10%

Data, Background, & Signal Predictions

0 b tags

1 b tag

2 b tags



Dijet Resonances with b Tags (3)

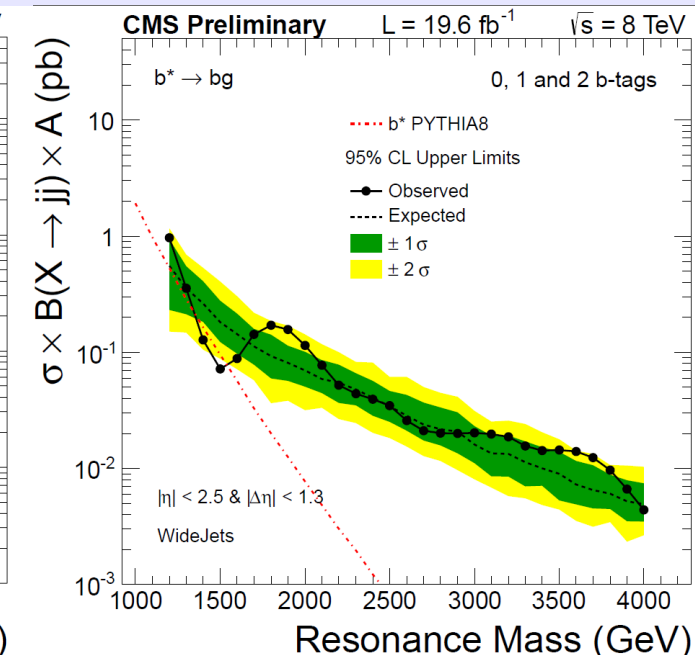
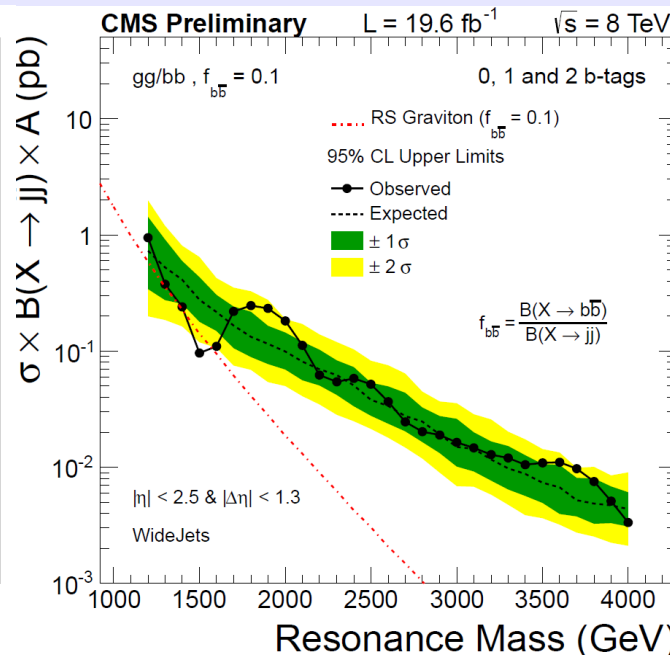
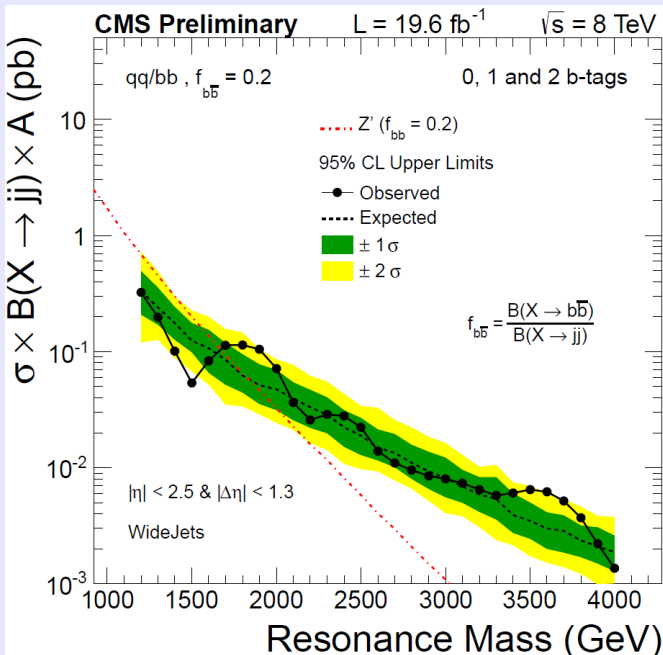
EXO-12-023

- Distributions for 0/1/2 b tags combined to obtain limits with assumed fraction of $B(X \rightarrow b\bar{b})/B(X \rightarrow jj)$
- No excess observed
- Mass limits best to date, up to **1.7 TeV** for Z' model

Z' Limits, $b\bar{b}$ Frac = 0.2

RS Graviton Limits, $b\bar{b}$ Frac = 0.1

$b^* \rightarrow bg$ Limits



Summary

- CMS performed several new-physics searches with 2012 data using leptons & jets
- No significant deviations from Standard Model observed
- New limits set on many new physics models:
- Up to 2.9 TeV on a W_R
- Up to 1.1 TeV on scalar leptoquarks
- Up to 1.3 TeV on high-mass SUSY particles with anomalous charges
- Up to 5.1 TeV on string resonances and other dijet resonances
- Up to 1.7 TeV on Z' , 1.6 TeV on RS gravitons, 1.5 TeV on b^*
- CMS new-physics searches are continuing, and more results will be coming out soon

Backup

Bibliography

- EXO-12-017, Search for a Heavy Neutrino and Right-handed W of the Left-right Symmetric Model: [CMS PAS EXO-12-017](#)
- EXO-12-042, Search for Pair Production of Second-generation Scalar Leptoquarks: [CMS PAS EXO-12-042](#)
- EXO-12-026, Search for Long-lived Charged Particles: [CMS PAS EXO-12-026](#)
- EXO-12-059, Search for Narrow Resonances using the Dijet Mass Spectrum: [CMS PAS EXO-12-059](#)
- EXO-12-023, Search for Heavy Resonances Decaying into $b\bar{b}$ and $b\bar{g}$ Final States: [CMS PAS EXO-12-023](#)

Latest ATLAS Limits

- W_R 2.5 TeV (7 TeV data)
- Leptoquark 685 GeV (7 TeV data)
- Dijet string resonance 3.81 TeV (7 TeV data)