

Exotics searches at CMS

*"28th Rencontres de Blois,
Particle Physics and Cosmology"*

29 May-3 Jun 2016, Blois (France)

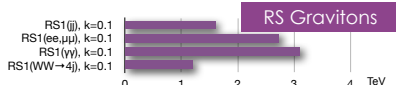
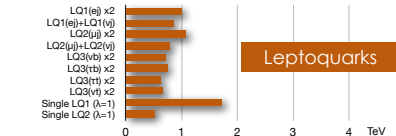
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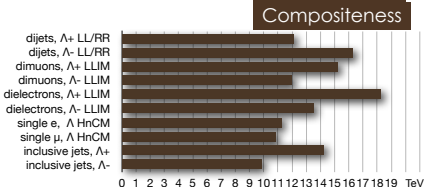
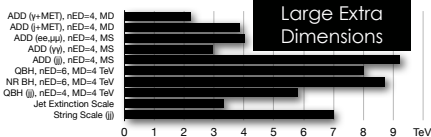
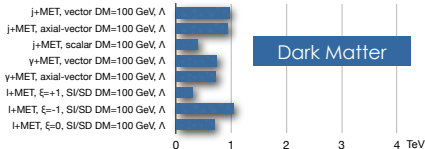
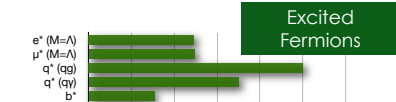
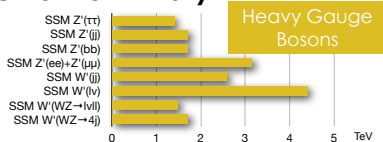
Introduction

- The Standard Model (SM) has been enjoying amazing experimental successes (Higgs boson discovery).
- Unexplained problems: dark matter, how incorporate gravity, hierarchy problem, ...
- Beyond the Standard Model (BSM) physics is required to accurately describe the Universe.
- As convention, we divide the BSM searches in two main groups: BSM = SUSY (SUS) + Exotics (EXO).
- Not-SUSY searches are split over between: **Exotics** and **Beyond 2 generations** (B2G). This includes decays of new resonances to heavy standard model objects (t,b,W,Z,H).

EXO summary

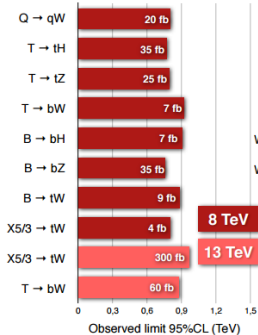


CMS Preliminary

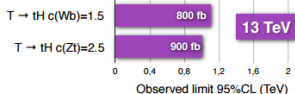


B2G summary

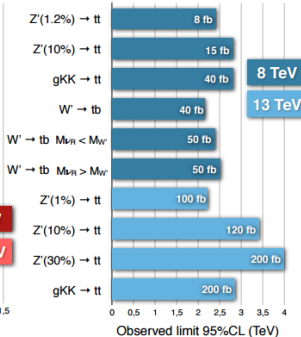
Vector-like quark pair production



Vector-like quark single production

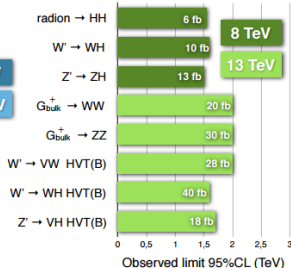


Resonances to heavy quarks



B2G: new physics searches with heavy SM particles

Resonances to dibosons



Excited quarks



Outline

The most recent results of CMS, in EXO and B2G, at 13 TeV, will be presented, categorized by search method more than by models:

- Heavy boson searches: Z' and W' ,
- Diphoton resonance,
- Dijet resonance.

Only the results:

- Vector-like quarks,
- Dark matter.

Very briefly:

- Other signatures.

On Tuesday, "Search for Exotics" - Claire Lee

Z' resonance

New heavy neutral spin-1 gauge boson, Z' .

In extensions of SM: extra Abelian gauge group, Grand Unified Theories (GUTs), Randall-Sundrum graviton models and Kaluza-Klein excitation of extra dimensions.

Z'_{SSM} sequential standard model: same coupling of SM for Z' .

Z'_{ψ} superstring-inspired: not necessary the same SM couplings.

CMS PAS EXO-15-005:

$Z' \rightarrow ee$, 2 HEEP electrons, $E_T > 35$ GeV, $|\eta| < 1.4442$ (barrel),
 $1.566 < |\eta| < 2.5$ (endcap), at least one barrel ele, no charge requirements.

$Z' \rightarrow \mu\mu$, 2 high p_T muons, $p_T > 53$ GeV, $|\eta| < 2.4$, tracker iso, opposite sign.

CMS-PAS-B2G-15-002:

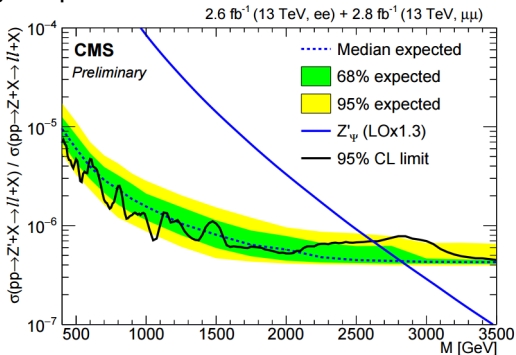
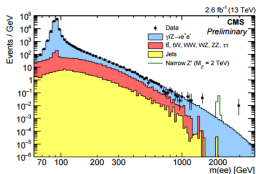
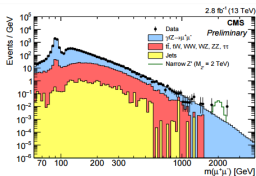
$Z' \rightarrow t\bar{t} \rightarrow (bW^+) + (\bar{b}W^-) \rightarrow (bjj)(\bar{b}\ell^-\bar{\nu})$, one muon (electron) with $p_T > 50$ GeV and at least two jets with $p_T(j_1) > 150(250)$ GeV and $p_T(j_2) > 50(70)$ GeV, $E_T > 50(120)$ GeV for muon (electron) channel, no isolation because of boosting, jet cleaning respect with leptons. Events splitted in 6 categories, according to: leptonic flavour, number of b and t jets tagged.

Results in $Z' \rightarrow ee, Z' \rightarrow \mu\mu$

CMS PAS EXO-15-005: search for a new massive neutral spin-1 particle decaying to ee ($\mu\mu$), using 2.8 fb^{-1} (2.6 fb^{-1}) of integrated luminosity.

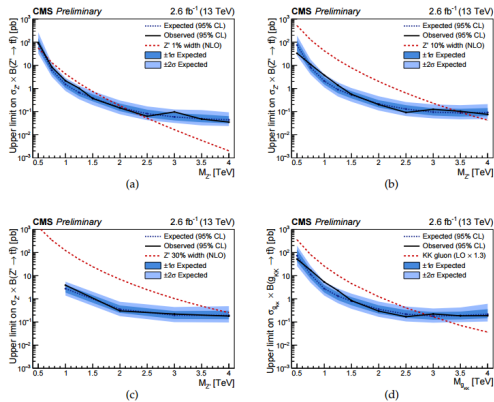
No significant excess observed.

Exclusion limits set on a Z'_{SSM} and Z'_{ψ} , with a mass less than **3.15 TeV** and **2.60 TeV**, respectively. Expected limits of 3.35 TeV and 2.80 TeV.



Results in $Z' \rightarrow t\bar{t}$

CMS-PAS-B2G-15-002: model independent search for heavy resonances decaying into $t\bar{t}$, using 2.6 fb^{-1} . **No evidence is found.**
 Combined results in e and μ channel:



Limits set for a Z' decaying exclusively to $t\bar{t}$, with relative decay width $\Gamma/M = 1\%$, 10% , 30% , and for a Kaluza-Klein gluon resonance in the Randall-Sundrum model.

signal	excluded mass regions [TeV]	
	combination	observed (expected)
a Z' (1% width)	0.6 – 2.3	(0.6 – 2.1)
b Z' (10% width)	0.5 – 3.4	(0.5 – 3.5)
c Z' (30% width)	0.5 – 4.0	(0.5 – 4.0)
d KK gluon	0.5 – 2.9	(0.5 – 2.9)

W' resonance

Many SM extensions predict additional heavy gauge bosons.

The Sequential Standard Model (SSM) predicts a new massive boson, W' , exhibiting the same couplings as the standard model W boson.

Decay channels: $W' \rightarrow \nu_e e$, $W' \rightarrow \nu_\mu \mu$, $W' \rightarrow \nu_\tau \tau$, $W' \rightarrow jj$

CMS-PAS-EXO-15-006, CMS-PAS-EXO-16-006:

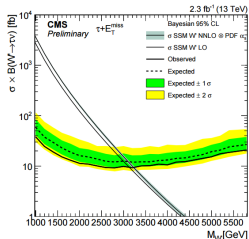
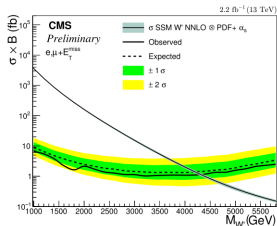
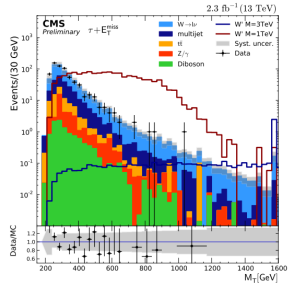
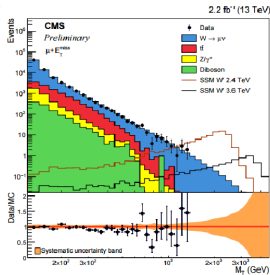
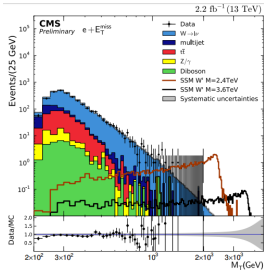
$W' \rightarrow \nu_\ell \ell$:

one high-energy, iso lepton with $p_T > (130, 53, 50)$ GeV for (e, μ , τ),
 missing transverse energy $E_T^{miss} > (130, 105, 120)$ GeV for (e, μ , τ),
 $|\Delta\phi(\vec{p}_T^\ell, \vec{p}_T^{miss})| > 2.5$ and $0.4 < p_T^\ell / E_T^{miss} < 1.5$

Variable for signal extraction:

$$M_T = \sqrt{2p_T^\ell E_T^{miss} (1 - \cos[\Delta\phi(\vec{p}_T^\ell, \vec{p}_T^{miss})])}$$

Results in $W' \rightarrow \nu e$, $W' \rightarrow \nu \mu$, $W' \rightarrow \nu \tau$



No significant excess

A SSM W' boson is excluded:

$1 < M_{W'} < 4.4 \text{ TeV}$

in e, μ channels combined

$1 < M_{W'} < 3.3 \text{ TeV}$

in τ channel, at 95% of CL.

Diphoton resonance

Hierarchy problem → *additional space-like dimensions*
→ *dilute gravity* → *low the effective Plank scale*

Two families of models:

- *Arkani-Hamed, Dimopoulos and Dvali (ADD),*
- *Randall and Sundrum (RS).*

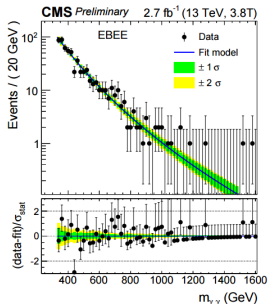
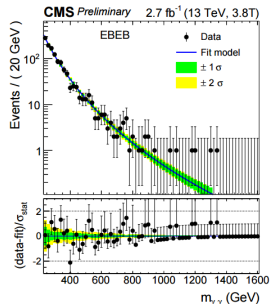
Diphoton is a sensitive signature for these models.

CMS-PAS-EXO-16-018:

search for spin-0 and spin-2 (gravitons) resonances in diphoton
at least two photons both with $p_T > 75$ GeV,
 $M_{\gamma\gamma} > 500$ GeV explored.

8 and 13 TeV results combined and 0T events considered, improved
sensitivity of 20% respect with the previous analysis.

Diphoton resonance results



Dedicated talks on Thursday:
"Is there a X(750) signal?"

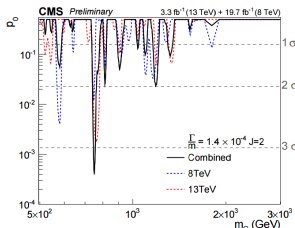
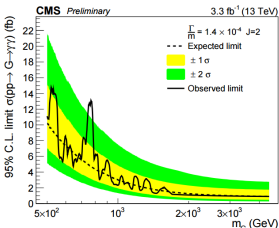
- Livia Soffi

"Theoretical interpretations of the diphoton excess"

- Sebastian Ellis

Limits set on scalar resonances and gravitons in: $0.5 < m < 4.5$ TeV

Largest **excess** observed for $m = 760$ GeV and $\Gamma/m = 1.4 \times 10^{-4}$ with local significance of **3.4 σ** after considering the elsewhere effect: **1.6 σ** .

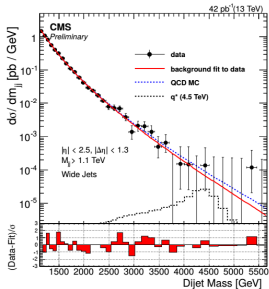


Most models with resonant diphoton should produce also ZZ and $Z\gamma$, but no evidence in these channels: see **EXO-15-002**, **EXO-16-019**.

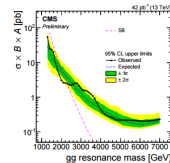
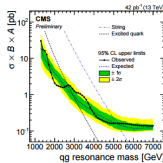
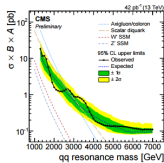
Dijet resonance

CMS-PAS-EXO-15-001: narrow dijet resonances at 13 TeV, with 42 pb^{-1} . More sensitive than previous searches for dijet mass greater than 5 TeV and less sensitive below 5 TeV.

All jets: $p_T > 30 \text{ GeV}$ and $|\eta| < 2.5$, two leading jet selected for reconstructing invariant mass, $\Delta\eta(j, j) < 1.3$



Model	Final State	Obs. Mass Limit [TeV]	Exp. Mass Limit [TeV]
String Resonance (S)	qg	5.1	5.2
Excited Quark (q^*)	qg	2.7	2.9
Scalar Diquark (D)	qq	2.7	3.3
Axigluon (A)/Coloron (C)	q \bar{q}	2.7	2.9
Color Octet Scalar (s8)	gg	2.3	2.0

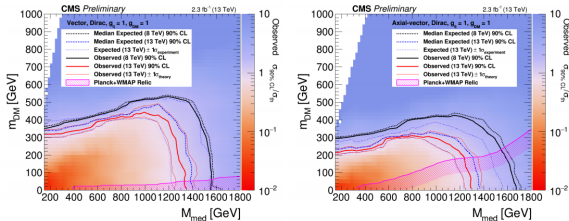


The resonance can decay in qq, qg or gg, lower limits are set on mass, for different models.

Dark matter results

A substance that gives its gravitational effect whose constituents have not been observed yet "Dark matter searches at CMS" - Ashok Kumar's, on Tuesday, No significant excess observed.

CMS PAS EXO-16-013:

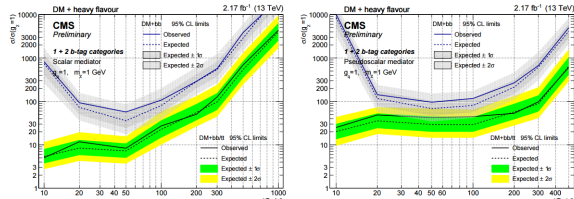


Vector and axial-vector mediators with masses down to 1.3 TeV are excluded

Sensitive to both DM+bb and DM+tt production, upper limits down to

$(26)5 \times \sigma/\sigma(g_x, g_q = 1)$ set for models with generic (pseudoscalar) scalar mediator.

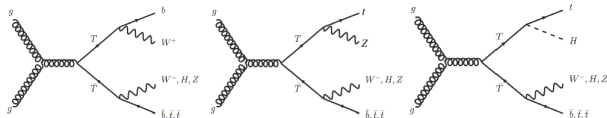
CMS PAS B2G-15-007:



Vector-like quarks results

B2G-16-002: vector-like T quark, with charge $2e/3$, pair-produced $T\bar{T}$, in extensions of the standard model that seek to preserve naturalness, such as Little Higgs and Composite Higgs models.

T quark can decay to
bW (50%), **tZ** (25%), and
tH (25%)



Final states: one iso charged lepton $p_T > 40$ GeV and at least 3 jets, thresholds $(p_T(j_1), p_T(j_2), p_T(j_3)) = (150 \text{ GeV}, 75 \text{ GeV}, 30 \text{ GeV})$

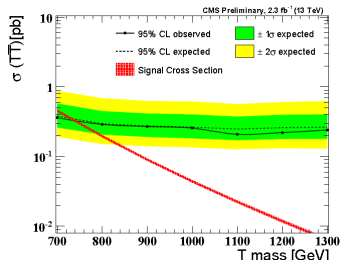
$E_T^{miss} > 60$ GeV to reduce multijet bkg

16 categories: lepton flavour, num of b tagged jets, num of tagged W (b-tagging, jet pruning).

Variable for extracting signal:

$\min[M(\text{lep}, b)]$ or $\min[M(\text{lep}, \text{jet})]$

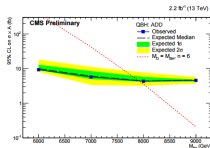
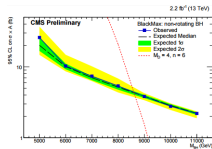
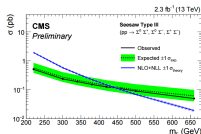
Lower limit for T quark $M < 750$ GeV.



Other searches

More briefly, but only for reasons of time ...

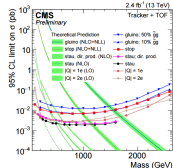
CMS PAS EXO-15-007: black holes in energetic multiparticle final states. Exclusion: semiclassical black holes $M < 8.7 \text{ TeV}$ and quantum black holes $M < 8 \text{ TeV}$.



CMS PAS EXO-16-002: heavy fermions within the *type-III seesaw model*, in events with three or more leptons, excluded $m_{\Sigma} < 430 \text{ GeV}$.

CMS PAS EXO-15-010: heavy, stable, charged, long-lived particles. Signatures: anomalously dE/dx in the tracker and long time-of-flight in the muon detectors. Limits set for gluinos, stops and staus.

CMS PAS EXO-16-007: second generation leptoquarks. Signature: two high p_T muons and at least two jets. $M_{LQ} < 1165 \text{ GeV}$.



Conclusions

- A review has been presented of the most recent results of CMS in the exotics sector;
- these searches looked for heavy gauge bosons, diphoton and dijet heavy resonances, dark matter and other signature;
- the first Run 2 data have not yielded any discovery;
- an interesting excess measured in diphoton signature at 750 GeV (also by ATLAS);
- a wide range of exotics scenarios has been greatly constrained;
- looking forward to seeing the new data.

