20th Annual RDMS CMS Collaboration Conference

Search for a new physics with the CMS detector at the LHC

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Lots of searches in work:

- ✓ *Non-standard Higgs bosons (extended Higgs sector, composite Higgs, non-standard Higgs couplings, process rates etc.);*
- ✓ *Extra dimensions and TeV-scale gravity (or extended) models;*
- ✓ *Extra gauge bosons and extended gauge sector, vector-like quarks and leptons;*
- ✓ *Compositeness, excited quarks/leptons;*
- ✓ *GUT and leptoquarks;*
- ✓ *Exotic possible quark configurations;*
- ✓ *New non-local physics at TeV scale (string excitations, microscopic multidimension black holes, sphlaleron transitions etc.);*
- ✓ *Dark matter particles and mediators;*
- ✓ *… (?)*

Many theoretical approaches to calculate processes under investigation – exact calculations, effective field theory methods, simplified models, constrained models etc. – strong model dependence of predictions, treatments and retreatments of results obtained.

Search for new (nonstandard) Higgs bosons:

- **Higgs with (possible) non-SM interactions: accurate measurements of the Higgs (m_H = 125 GeV) properties**

- **Extended Higgs sector, models and interpretations**

Search for new high-mass resonances at the CMS

- Z'/W' in different models
- W_{KK}/Z_{KK} in extended TeV-scale gravity models (also complementary channels for RS1-gravitons)
- String excitations, excited quarks, scalar diquarks, axigluons/colorons etc.
- DM mediators

Z' production at the LHC: contributions to the DY process

Z' production cross section in dilepton decay channel (NWA)

$$\sigma_{l^+l^-} = \frac{\pi}{48s}[c_u w_d(s, M_V^2) + c_d w_d(s, M_V^2)]$$

Z' couplings to the up- and down-type quarks:

$$c_u = \frac{g'^2}{2}(g_V^{u2} + g_A^{u2})\mathcal{B}(l^+l^-)$$

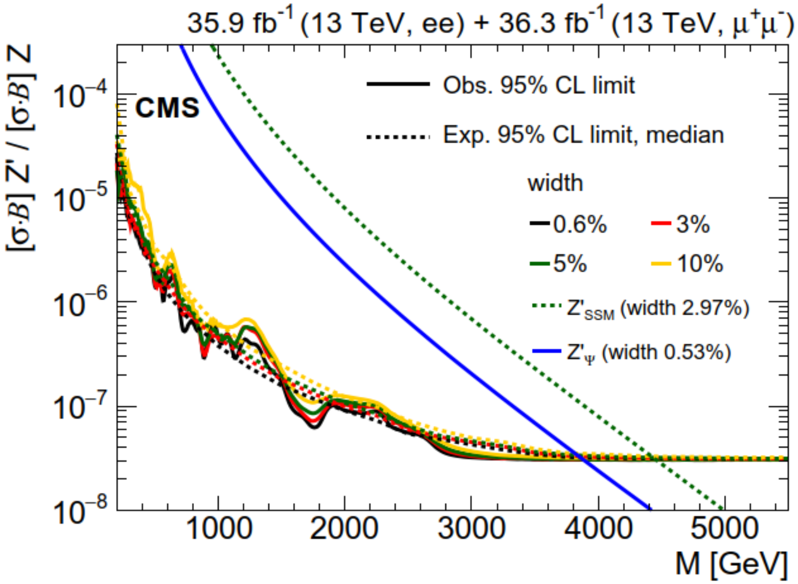
$$c_d = \frac{g'^2}{2}(g_V^{d2} + g_A^{d2})\mathcal{B}(l^+l^-)$$

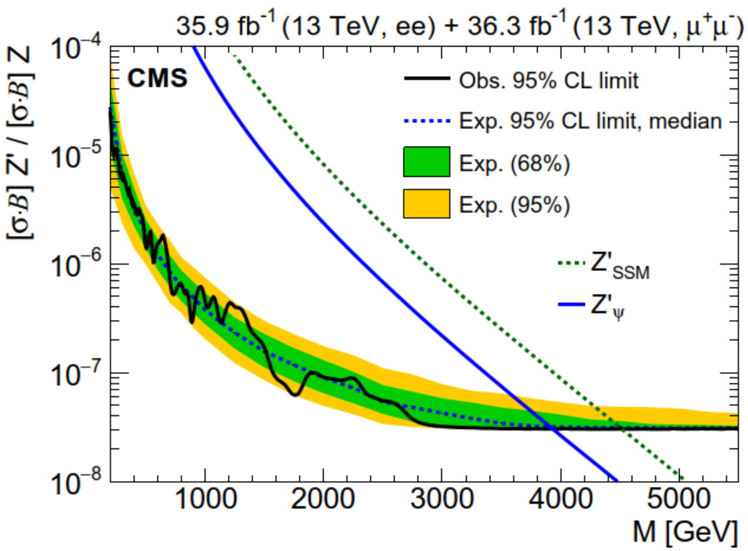
CMS EXO-16-047, arXiv:1803.06292v2

$U'(1)$ model	Mixing angle	$\mathcal{B}(\ell^+\ell^-)$	c_u	c_d	c_u/c_d	$\Gamma_{Z'}/M_{Z'}$
E_6						
$U(1)_\chi$	0	0.061	6.46×10^{-4}	3.23×10^{-3}	0.20	0.0117
$U(1)_\psi$	0.5π	0.044	7.90×10^{-4}	7.90×10^{-4}	1.00	0.0053
$U(1)_\eta$	-0.29π	0.037	1.05×10^{-3}	6.59×10^{-4}	1.59	0.0064
$U(1)_S$	0.129π	0.066	1.18×10^{-4}	3.79×10^{-3}	0.31	0.0117
$U(1)_N$	0.42π	0.056	5.94×10^{-4}	1.48×10^{-3}	0.40	0.0064
LR						
$U(1)_R$	0	0.048	4.21×10^{-3}	4.21×10^{-3}	1.00	0.0247
$U(1)_{B-L}$	0.5π	0.154	3.02×10^{-3}	3.02×10^{-3}	1.00	0.0150
$U(1)_{LR}$	-0.128π	0.025	1.39×10^{-3}	2.44×10^{-3}	0.57	0.0207
$U(1)_Y$	0.25π	0.125	1.04×10^{-2}	3.07×10^{-3}	3.39	0.0235
GSM						
$U(1)_{SM}$	-0.072π	0.031	2.43×10^{-3}	3.13×10^{-3}	0.78	0.0297
$U(1)_{T3L}$	0	0.042	6.02×10^{-3}	6.02×10^{-3}	1.00	0.0450
$U(1)_Q$	0.5π	0.125	6.42×10^{-2}	1.60×10^{-2}	4.01	0.1225

CMS results on Z' search with the 35.9 fb^{-1} (dileptons combined)

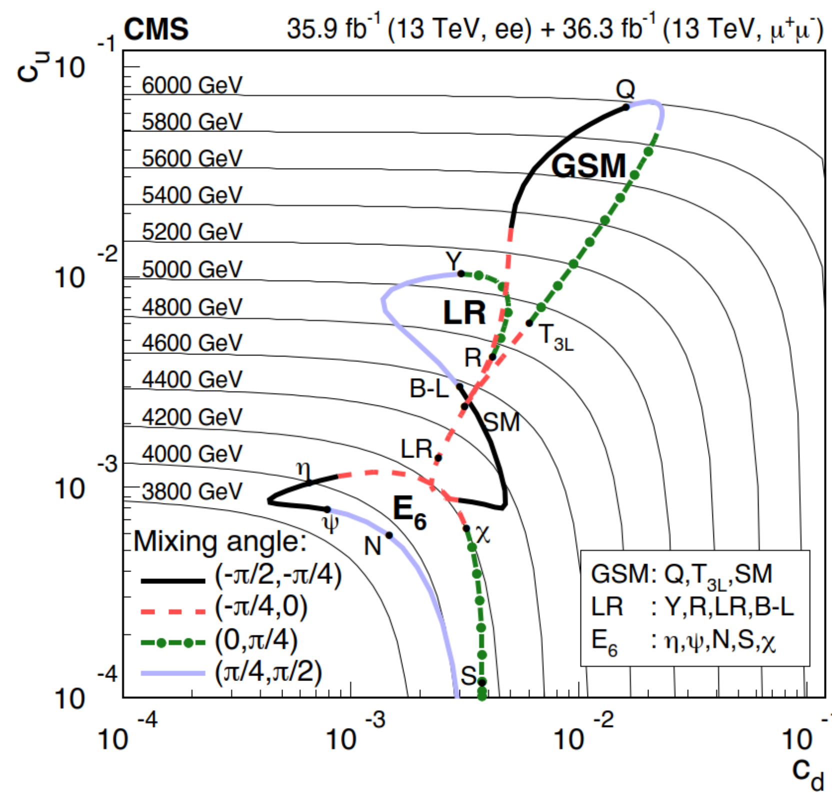
CMS EXO-16-047, arXiv:1803.06292v2





(c_u,c_d) - plane

- ✓ *The closed contours represent model classes.*
- ✓ *Each point on a thick line segment corresponds to a particular model.*
- ✓ *The location of the point gives the relevant Z' mass limit*

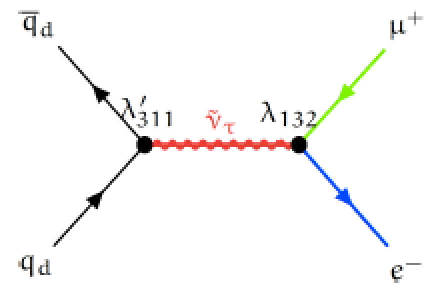


Z' with masses up to 3.9 – 4.5 TeV are excluded at 95 % CL with 2016 data

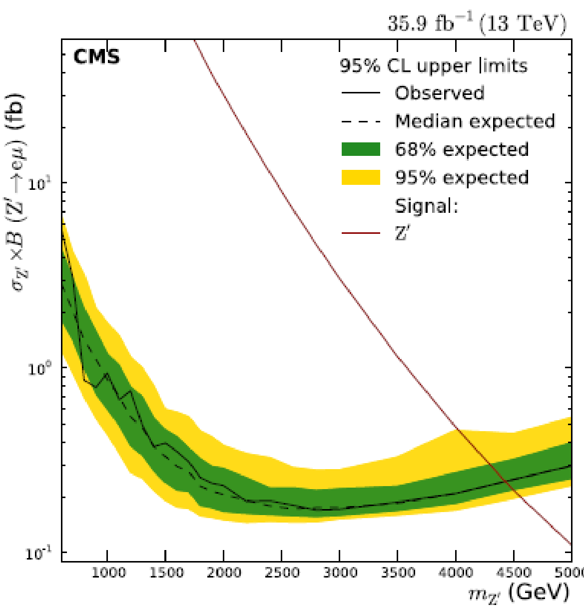
New resonance in the channel $X \to \mu e$ with the 35.9 fb^{-1}

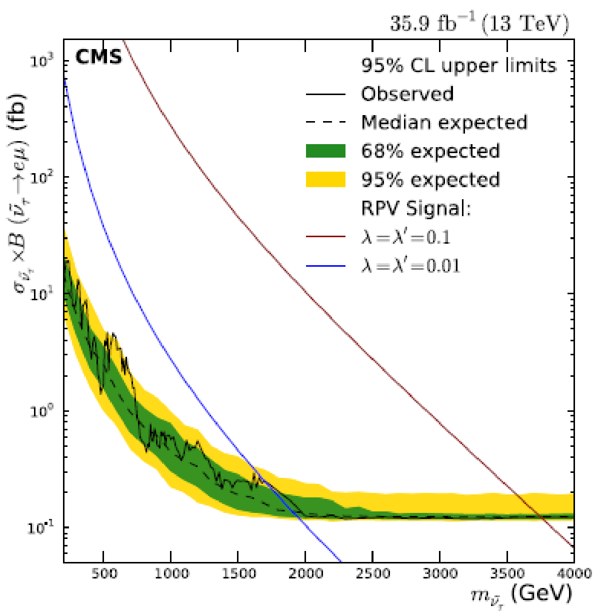
New!

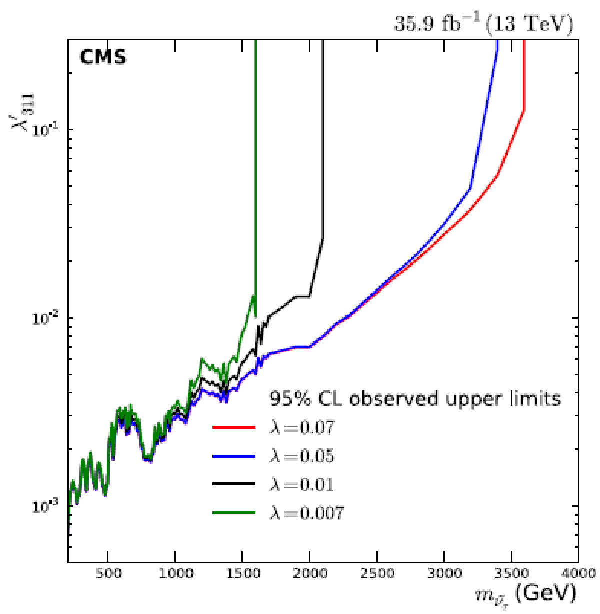
CMS EXO-16-058, JHEP 04 (2018) 073
(see also results for QBH)



- Results are interpreted in models with Lepton Flavour Violation
  - A heavy Z′ with LFV: **m(Z′)>4.4 TeV** where $\mathscr{B}(Z' \to e\mu)=10\%$
  - τ sneutrino in RPV SUSY: **m(X) > 1.7, 3.8 TeV** for RPV couplings $\lambda_{132}=\lambda_{231}=\lambda'_{311}=0.01, 0.1$
  - Non-resonant QBH (not shown here)
- In narrow width approximation the σ×BR scales with the RPV coupling
  - Using this information and observed bounds, limit contours in the $(M(\tilde{\nu}_\tau),\lambda'_{311})$ plane can be produced as a function of a fixed value of $\lambda_{132}=\lambda_{231}$

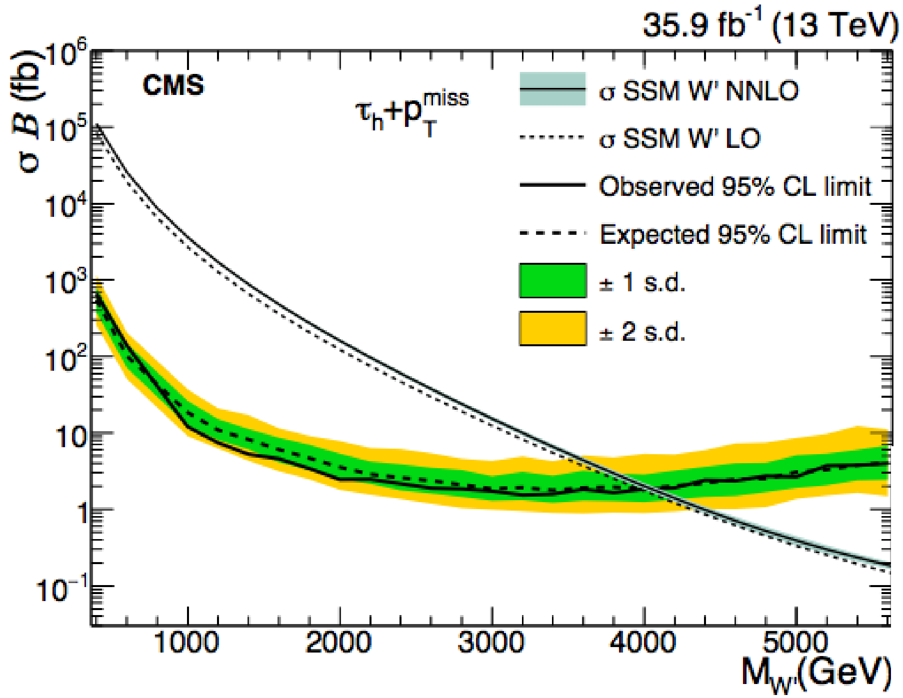




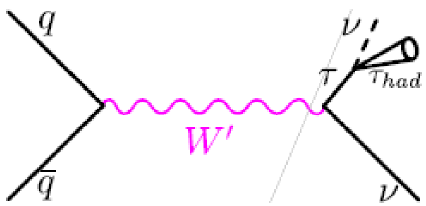


CMS results on W' search with the 35.9 fb^{-1}: $\tau\nu_\tau$ decay channel

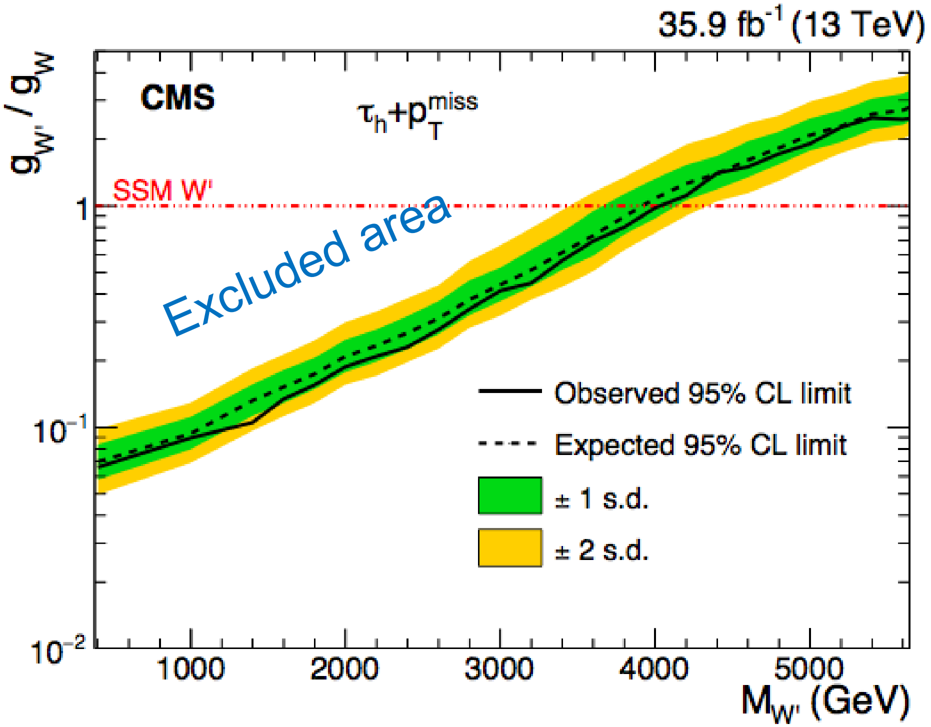
CMS-EXO-17-008, arXiv:1807.11421v1



$g_{W'}/g_W$ = 1 (SSM)



- ✓ W'→τν, BR≈8.5% (SSM) (see also results in e(μ)ν; WZ, qq', tb W' decay channels)
- ✓ Γ/M (W') ~ 3%
- ✓ τ lepton decays hadronically, τ_h



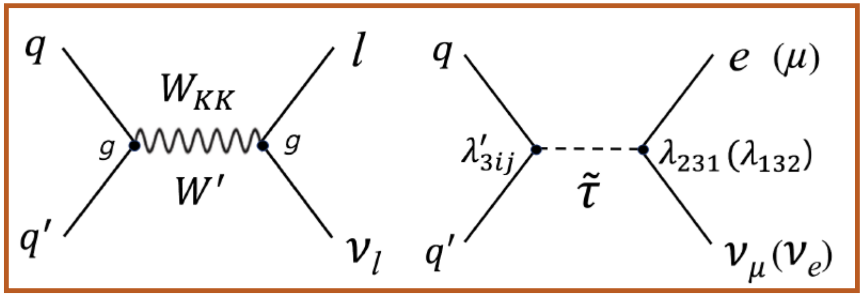
W' with masses up to 3.9 TeV are excluded at 95 % CL with 2016 data

W' search with the 35.9 fb^{-1} data, decay channel summary

Different W' decay channels:

✓ W' → $\tau\nu_\tau$, CMS-EXO-17-008, arXiv:1807.11421v1 : $M_{W'}$ is excluded up to 3.9 TeV (SSM)

✓ W' → $(e+\mu)\nu_{e,\mu}$, CMS-EXO-16-033, JHEP 06 (2018) 128 :



- $M_{W'}$ is excluded up to 5.2 TeV (SSM);
- R_{ED} is excluded up to 2.9 TeV (split UED);

$$M(W_{KK}^{(n)}) = \sqrt{M_W + (n/R)}$$ n=2

- exclusion limits in the plane ($\lambda, M_{\tilde{\tau}}$) up to M_{stau}~5TeV (RPV SUSY, scalar mediator)

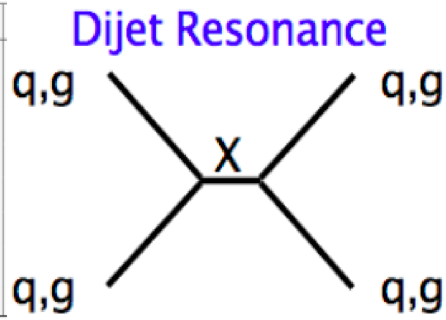
✓ W' → W(qq')Z(ν ν) (see also channel Z(νν)Z($\bar{q}$q) for Z'/G), CMS-B2G-17-005, JHEP 07 (2018) 075 :
$M_{W'}$ is excluded up to 3.1 / 3.4 TeV
(weakly coupl. – model A/ strongly coupl. – model B).

Model A = decay mostly to fermions,
Model B = nearly 100% decay to SM bosons.

✓ W' → tb (complementary to searches for W' → lν and W' → WZ), CMS-B2G-17-010, PLB 777 (2018) 39 :
$M_{W'}$ for right W' is excluded up to 3.6 TeV depending on the scenario considered

✓ W' → qq', CMS-EXO-16-032, PLB 769 (2017) 520
$M_{W'}$ is excluded up to 2.7 TeV

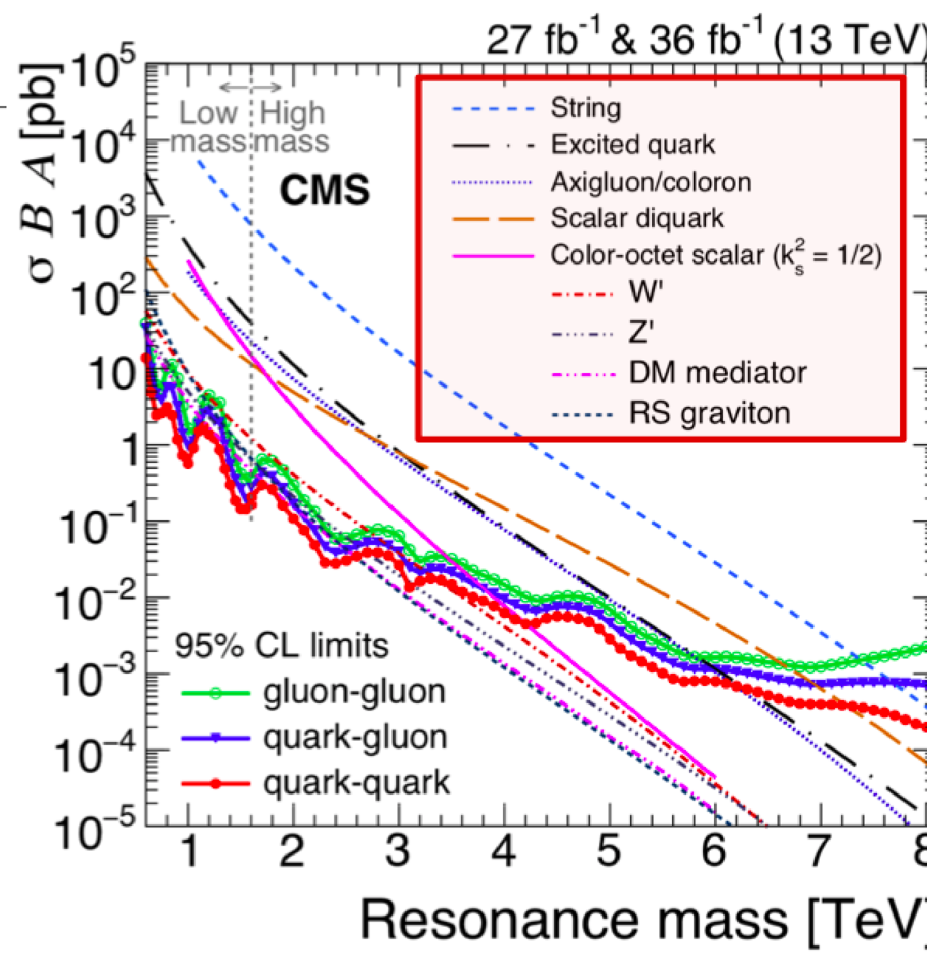
Model Name	Final-state Partons
String	$q\bar{q}$, qq, gg and qg
Axigluon	$q\bar{q}$
Coloron	$q\bar{q}$
Excited Quark	qg
E_6 Diquark	qq
RS Graviton	$q\bar{q}$, gg
Heavy W	$q\bar{q}$
Heavy Z	$q\bar{q}$



CMS-EXO-16-056, arXiv:1806.00843v1

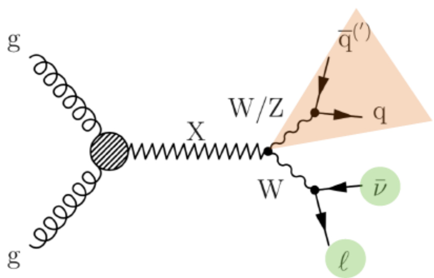
Look for a bump in dijet mass distributions

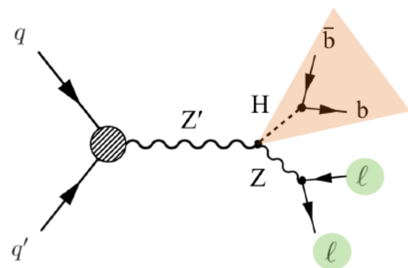
- ✓ *sensitive to the coupling of a new non-SM objects to quarks/gluons*
- ✓ *allows to separate by different FS – qq, qg, gg*
- ✓ *a way to observe directly DM mediator contributions (non-missing E_T search) in the case of narrow resonsnce (small and intermediate values of g_q)*

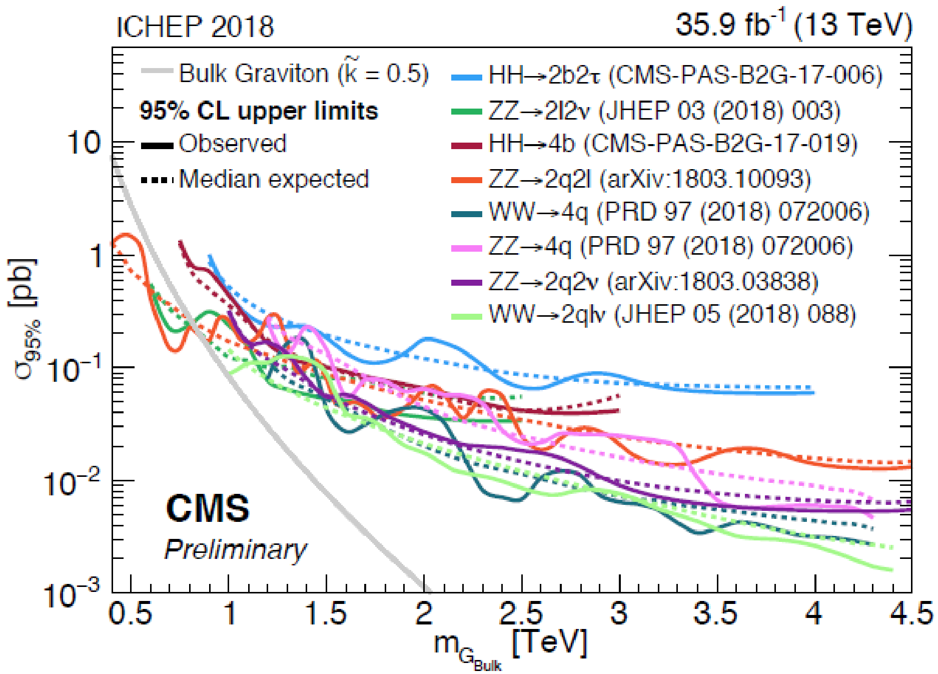


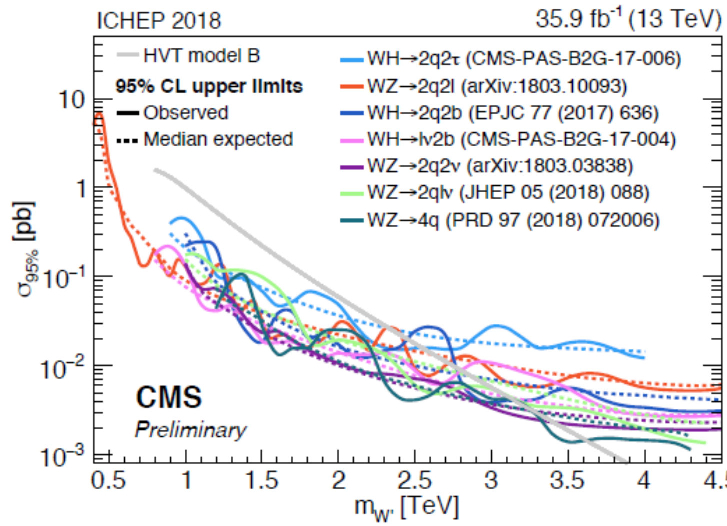
New resonances in diboson channel with the 35.9 fb^{-1} data

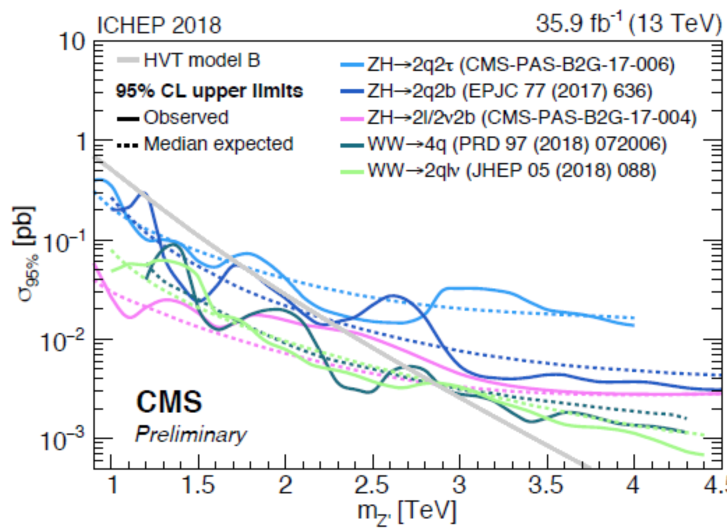
- ✓ *Gravitons s=2 in TeV-scale models or Z'*
- ✓ *Diboson FS (W,Z,H) – bump hunt in the diboson invariant mass spectrum*
- ✓ *Decay to quark/lepton pairs*











Pictures from ICHEP'2018 talk by Simon Regnard

TeV-scale gravity models: the CMS limits for ADD and RS1 scenarios

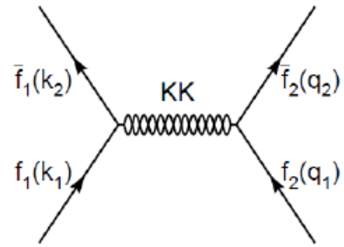
- Virtual exchange of KK-gravitons: contributions to Drell-Yan process, diphoton FS and dijet angular distributions (for non-resonant processes treated à la CI)

- Direct KK-graviton production, signals with missing E_T

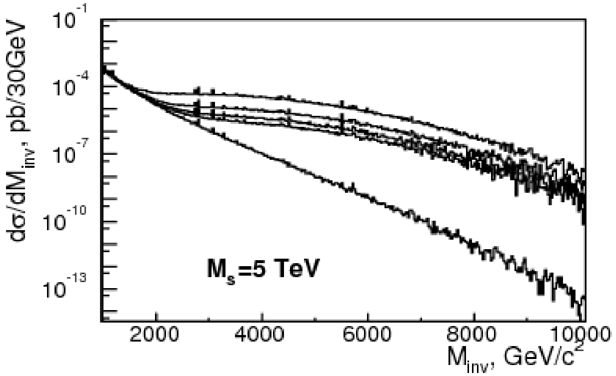
DY with contribution of the graviton KK modes

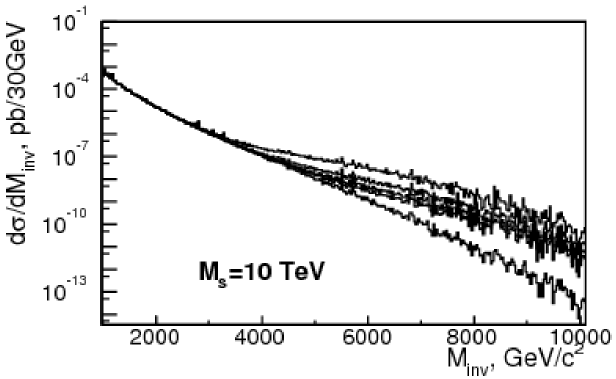
Effective four-fermion amplitude for KK modes exchange

$$\mathcal{M}_{4f}(\tilde{h}) = -\frac{\kappa^2}{16} D(\hat{s}) \left[(k_1 + k_2)\cdot(q_1+q_2)\overline{f}_2\gamma^\mu f_2 \, \overline{f}_1\gamma_\mu f_1 + \overline{f}_2(\not{k}_1+\not{k}_2) f_2 \overline{f}_1(\not{q}_1+\not{q}_2) f_1 - \frac{8}{3} m_{f_1} m_{f_2} \overline{f}_2 f_2 \overline{f}_1 f_1 \right]$$



ADD (HLZ parametrization)

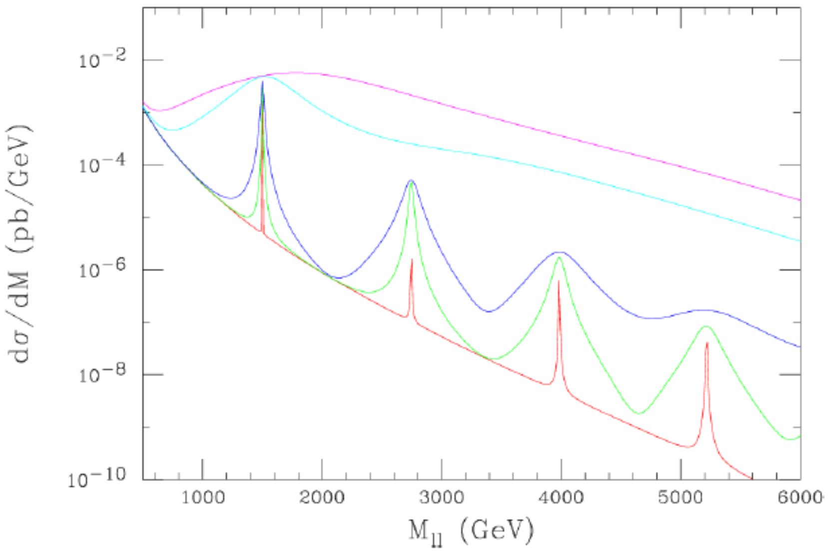




Effective four-fermion description has a limit of applicability

$$\sqrt{\hat{s}_{max}} \lesssim M_S \sim M_D$$

Graviton resonances in the RS1 model

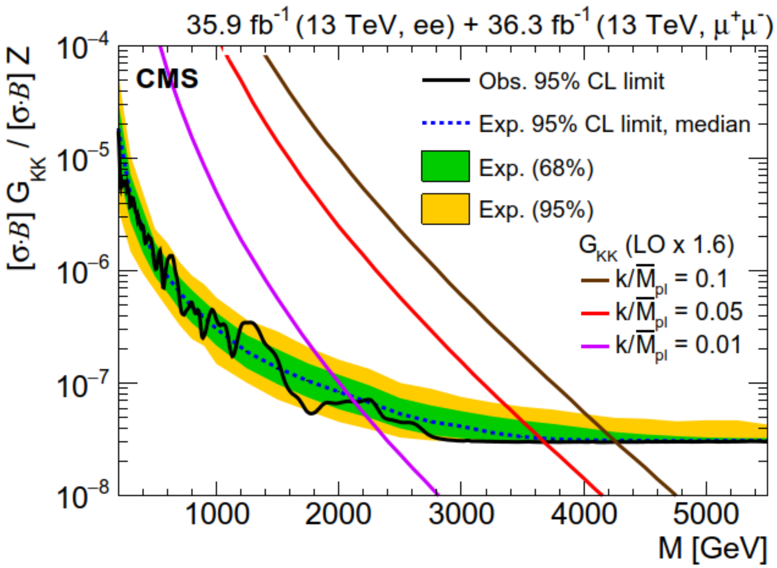


$$m_n = k\beta_n e^{-\pi kR}$$

$$\Gamma = \rho m_n \beta_n^2 \left(\frac{k}{M_{Pl}} \right)^2$$

c (coupling constant)

The CMS results on the narrow graviton resonances, RS1: 2016-2017 data of the Run II, dileptons (DY) and diphotons



Dileptons

CMS EXO-16-047, arXiv:1803.06292v2 [hep-ex]

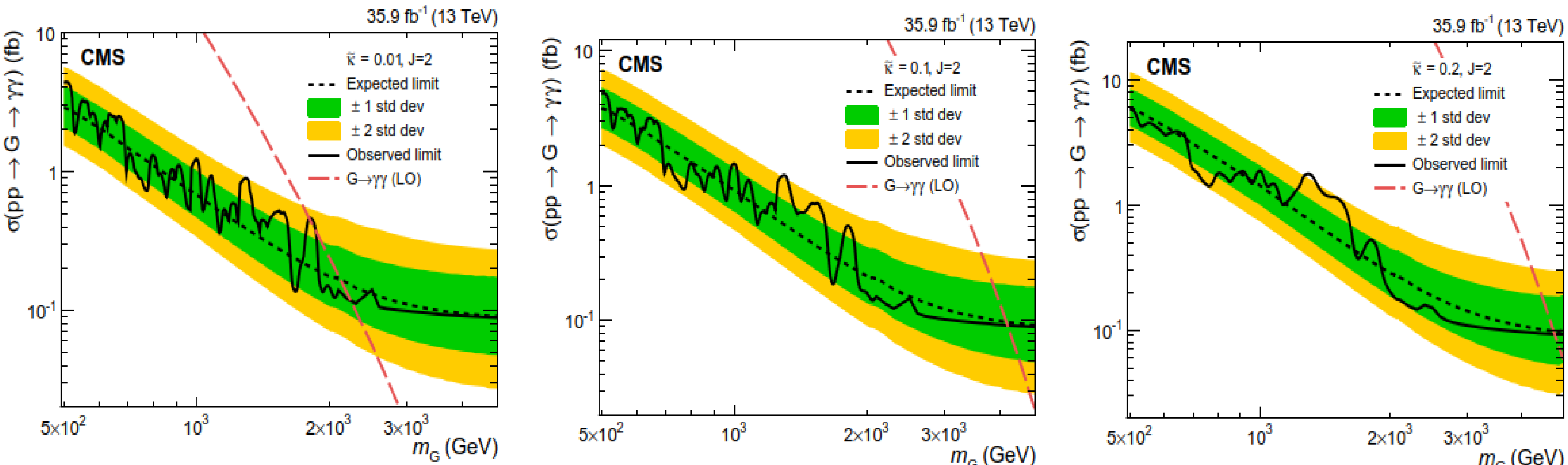
Diphotons

CMS EXO-17-017, arXiv:1809.00327v1 [hep-ex]

Masses of the first graviton resonance M_G^{KK} are excluded up to

***DILEPTONS**: 2.1 / 3.65/ 4.25 TeV (c=0.01/ 0.05 / 0.1)*

***DIPHOTONS**: 2.3 / 4.1 / 4.6 TeV (c=0.01 / 0.1 / 0.2)*

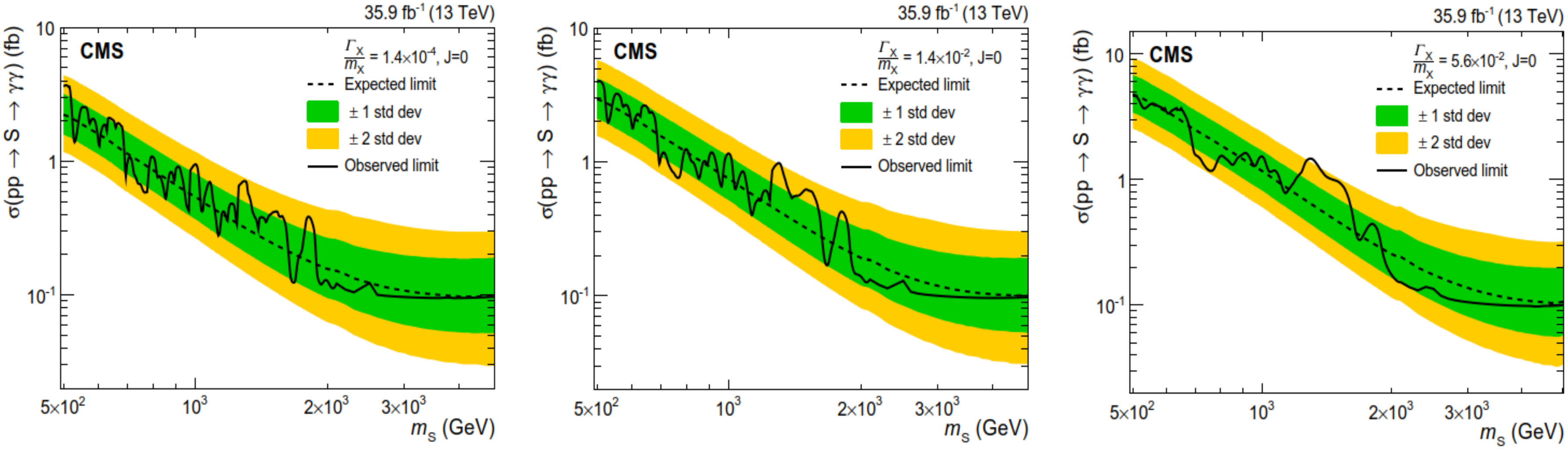


$$\Gamma_X / m_X = 1.4 \times 10^{-4}, 1.4 \times 10^{-2}, \text{and } 5.6 \times 10^{-2},$$

Heavy neutral Higgs boson, diphotons 35.9 fb^{-1}

CMS EXO-17-017,
arXiv:1809.00327v1 [hep-ex]

$$\Gamma_X / m_X = 1.4 \times 10^{-4},\ 1.4 \times 10^{-2},\ \text{and}\ 5.6 \times 10^{-2}$$



Expected and observed 95% CL upper limits on the production cross section for spin-0 resonances of mass m_S produced via gluon fusion for the three width hypotheses

The CMS results on ADD gravitons: 35.9 fb^{-1} (dijets)

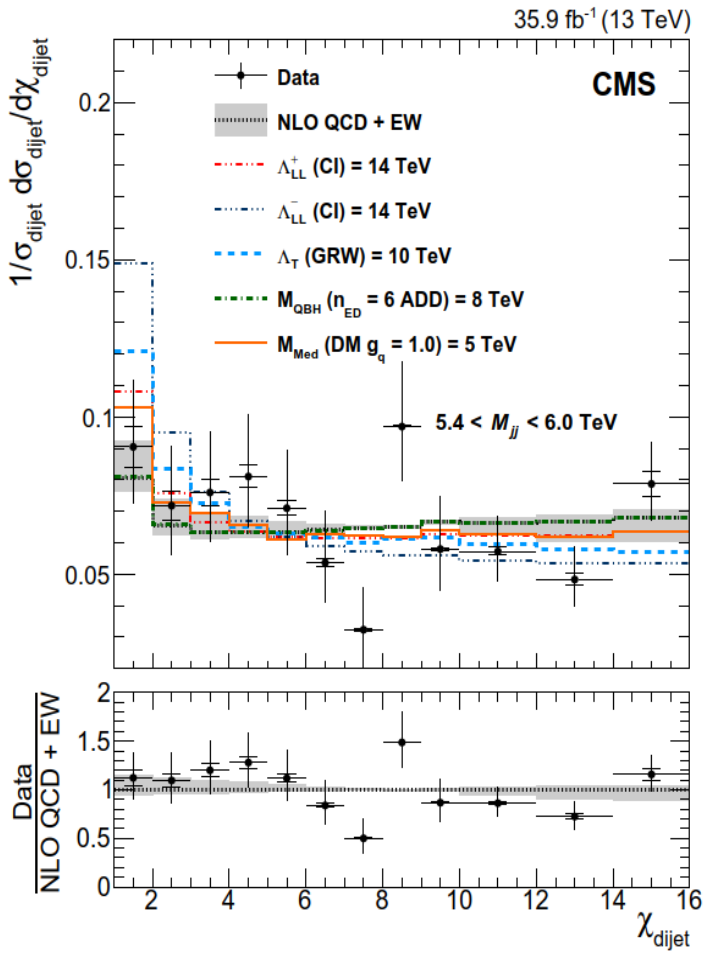
$$\chi_{dijet} = exp^{|y_1 - y_2|}, y \equiv \frac{1}{2} ln \frac{E + p_z}{E - p_z},$$

$$\chi_{dijet} = (1 + |cos\theta^*|)(1 - |cos\theta^*|).$$

CMS-EXO-16-046, arXiv:1803.08030v1 [hep-ex]

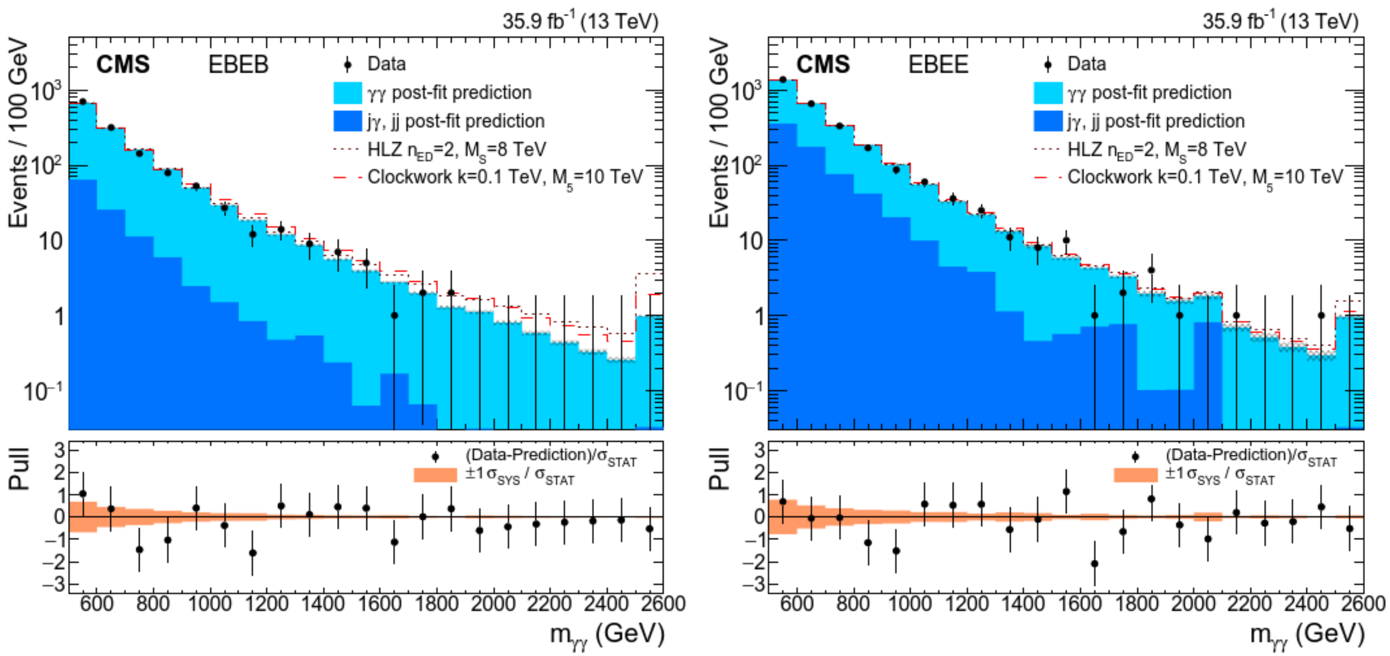
	Model	Observed lower limit (TeV)
CI	$\Lambda^+_{LL/RR}$	12.8
	$\Lambda^-_{LL/RR}$	17.5
	Λ^+_{VV}	14.6
	Λ^-_{VV}	22.4
	Λ^+_{AA}	14.7
	Λ^-_{AA}	22.3
	$\Lambda^+_{(V-A)}$	9.2
	$\Lambda^-_{(V-A)}$	9.3
ADD	Λ_T (GRW)	10.1
	M_S (HLZ) $n_{ED} = 2$	10.7
	M_S (HLZ) $n_{ED} = 3$	12.0
	M_S (HLZ) $n_{ED} = 4$	10.1
	M_S (HLZ) $n_{ED} = 5$	9.1
	M_S (HLZ) $n_{ED} = 6$	8.5
QBH	M_{QBH} (ADD $n_{ED} = 6$)	8.2
	M_{QBH} (RS $n_{ED} = 1$)	5.9
DM	Vector/Axial-vector M_{Med}	2.0–4.6

Dijet angular distributions



The CMS results on ADD gravitons: 35.9 fb^{-1} diphotons & dijets

CMS EXO-17-017,
arXiv:1809.00327 [hep-ex]



Lower limits on the fundamental mass scale M_S or Λ_T in different parametrizations are

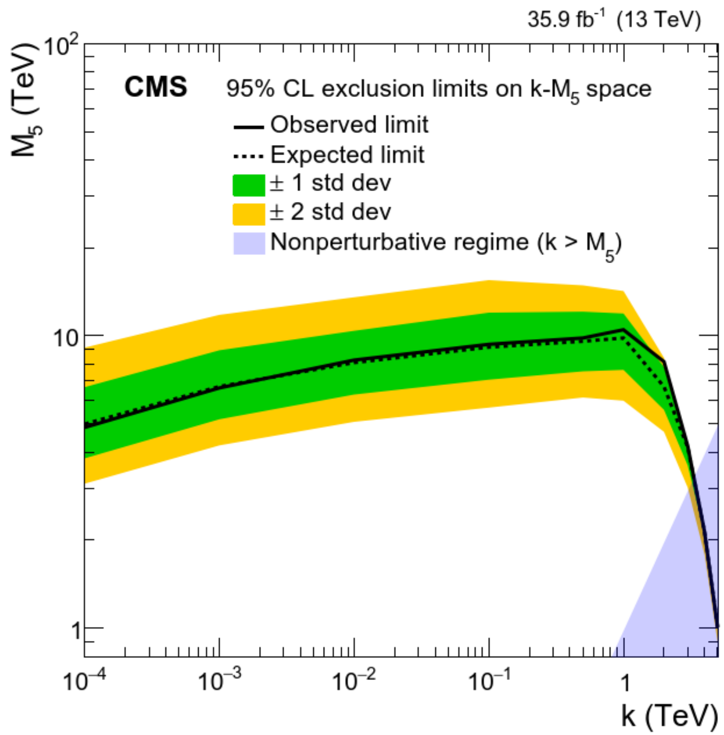
DIJETS: 8.5 – 12.0 TeV
DIPHOTONS: 5.6 – 9.7 TeV

Signal	GRW	Hewett		HLZ					
		negative	positive	$n_{ED}=2$	$n_{ED}=3$	$n_{ED}=4$	$n_{ED}=5$	$n_{ED}=6$	$n_{ED}=7$
Expected	$7.1^{+0.7}_{-0.5}$	$5.5^{+0.1}_{-0.3}$	$6.3^{+0.6}_{-0.4}$	$8.4^{+1.3}_{-1.1}$	$8.4^{+0.8}_{-0.6}$	$7.1^{+0.7}_{-0.5}$	$6.4^{+0.6}_{-0.5}$	$6.0^{+0.6}_{-0.4}$	$5.6^{+0.6}_{-0.4}$
Observed	7.8	5.6	7.0	9.7	9.3	7.8	7.0	6.6	6.2

The CMS results on a continuum clockwork model: 35.9 fb^{-1} (diphotons)

G. F. Giudice and M. McCullough, JHEP 02 (2017) 036;
D. E. Kaplan and R. Rattazzi, PRD 93 (2016) 085007

CMS EXO-17-017,
arXiv:1809.00327v1 [hep-ex]



- ***Continuum clockwork model*** ⟷ *5D gravitational theory on a linear dilaton background.*

  Large effective interaction scales from dynamics at much lower energies

- *An one-dimensional lattice in theory space from N copies of some particle content on different sites; physical mass spectrum consists of a single massless mode localized on the end site of the lattice and a set of massive modes ("gears") distributed along the sites; the continuum clockwork – N → ∞;*

- *KK modes of graviton ("gears") are all on shell – no interference effect;*

- *The first exclusion limits are set in the two-dimensional (k-M5) parameter space*

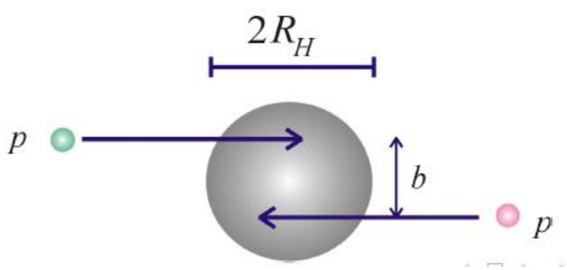
Multijet events:

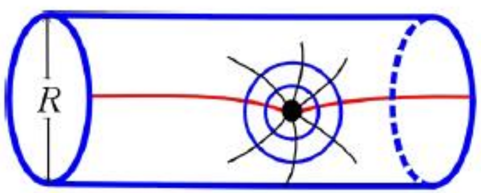
- Microscopic multidimensional black holes in TeV scale gravity models
- EW sphalerons

Production of microscopic BH in ultrarelativistic particle collisions

Thorne's conjecture

$$b < 2r_h(n, M, J)$$





BH size must be less than all characteristic scales under consideration

BH decay:

- *Multi-jet and hard leptons events*
- *High spherical*
- *High energy and p_T*

BH production and evolution stages:

- *Production cross section of multidimensional BH - "a black disk" in a simple approach.*

$$\sigma_{BH} = \pi {r_S}^2$$

(Mass and angular momentum) losses during horizon formation, suppression of cross sections by a few orders of magnitude.

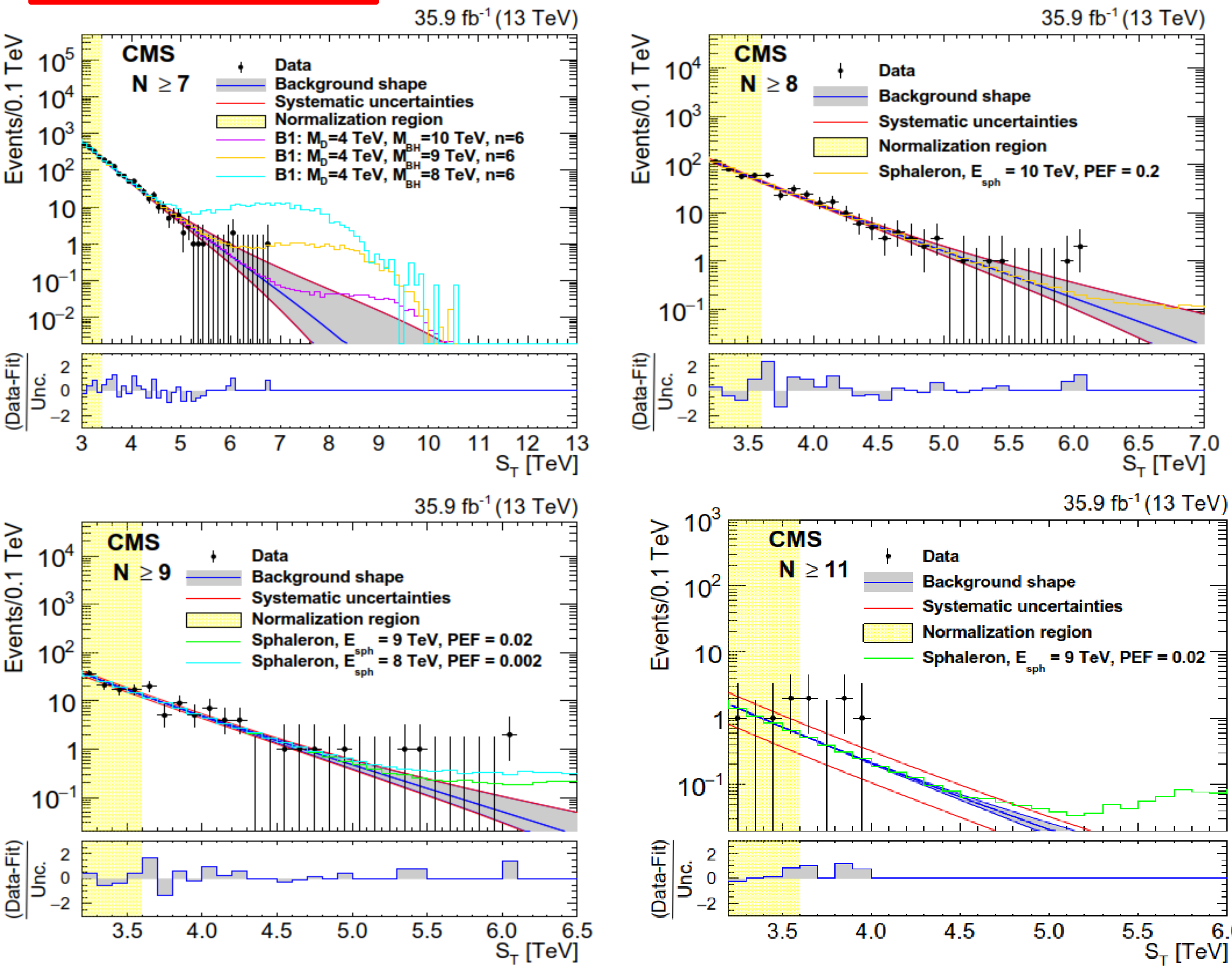
- *BH evolution stages: **spin-down phase, Hawking evaporation** of BH. Criteria for semiclassical description. BH entropy.*
- *Mass loss and approaching to the M_D threshold - **possible SB/BH transition and models for QBHs**.*
- ***Final Planck stage**, different options for FS:*

  "usual" decay on a few "fragments";
  non-observable stable remnant;
  B, L, B+L… non-conservation, violation of Lorentz invariance

Micro black hole search, shape analyses

$$S_T = p_T^{miss} + \sum_{i=1}^{N} p_T^i$$

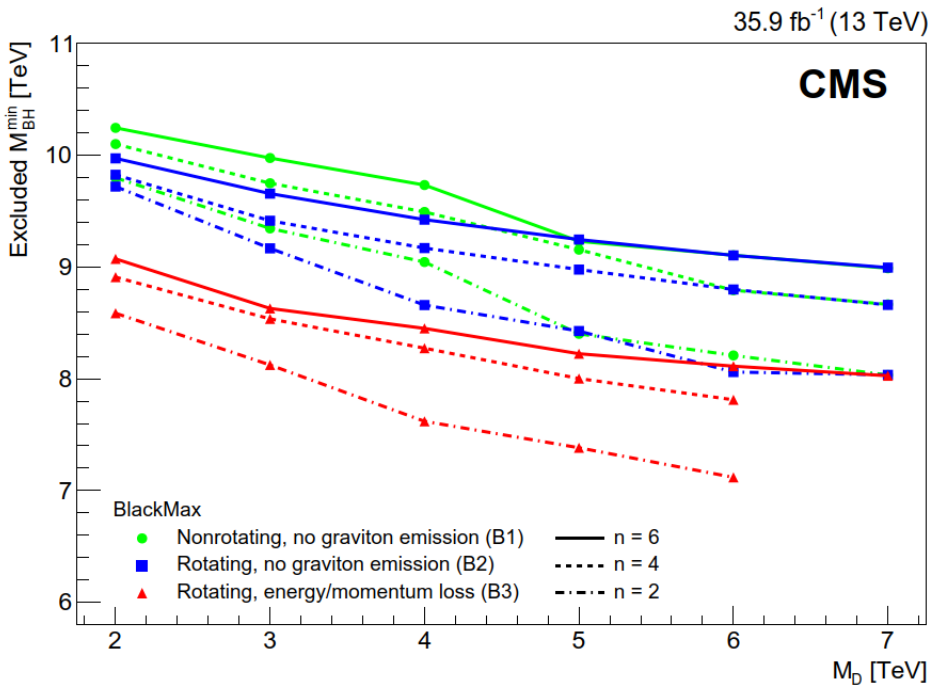
PLB 774 (2017) 279; CMS-EXO-17-023

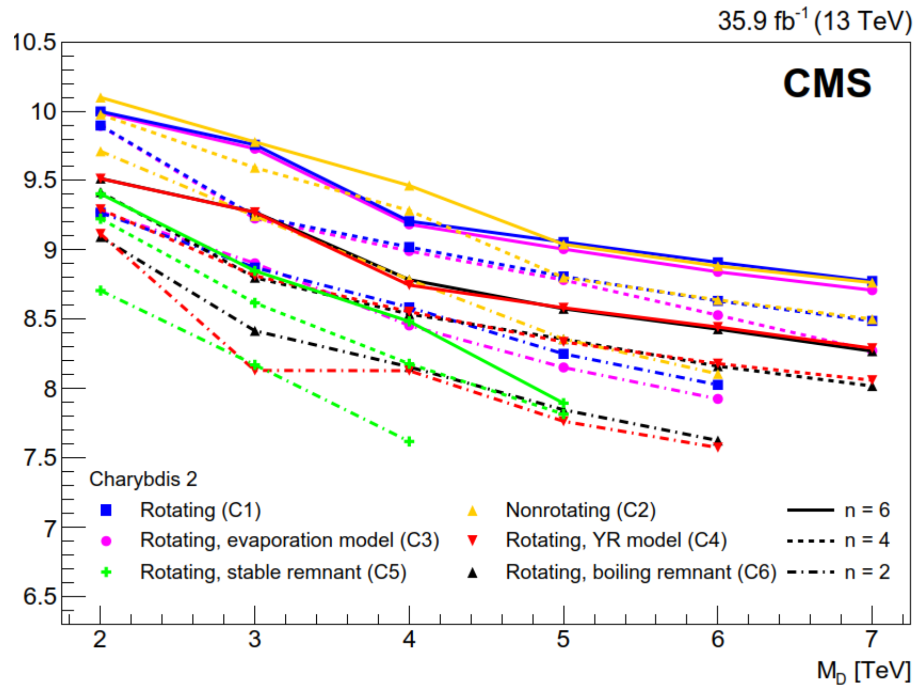


Micro black hole search, CMS results with the 35.9 fb^{-1}

Model dependent limits on BH

PLB 774 (2017) 279; CMS-EXO-17-023





Semiclassical black holes with minimum masses as high as 10.1 TeV are excluded with 2016 data

Near-threshold string ball / black hole transitions

SB as semi-classical BH precursors: formation of long, jagged string excitations, folded into "balls".

$$S_{string} \sim \sqrt{\alpha'} M_{SB} = \frac{M_{SB}}{M_S},$$

$$S_{BH} = \frac{4\pi}{n+2} f(n) \left(\frac{M_{BH}}{M_D}\right)^{\frac{n+2}{n+1}} \sim \frac{4\pi}{n+2} f(n) \frac{1}{g_S^2} \left(\frac{g_S^2 M_{BH}}{M_S}\right)^{\frac{n+2}{n+1}}$$

The correspondence principle:
at some point of a parameter space

$$S_{string} \approx S_{BH}, \quad T_{string} \approx T_H$$

$$M_{BH}^{\min} = M_s / g_s^2 \qquad M_D^{n+2} \approx M_S^{n+2}/g_S^2 \qquad r_h \leq l_S$$

L.~Susskind, hep-th/9309145.
G. T. Horowitz and J. Polchinski, PRD 55, 6189 (1997)

$$\sigma(SB)\Big|_{M_{SB}=M_s/g_s^2} = \sigma(BH)\Big|_{M_{BH}=M_s/g_s^2}$$

$$M_{BH}^{\min} \sim \frac{M_S}{g_S^2} = x M_D$$

$$g_S^2 = 1/\xi^{\frac{n+2}{n+1}}$$

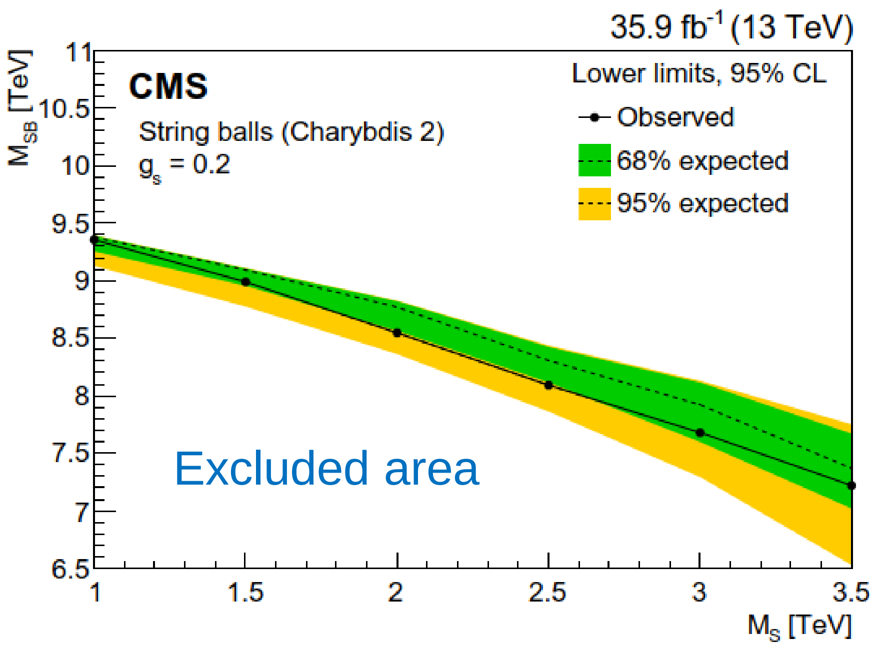
$$M_D = \xi^{\frac{1}{n+1}} M_S$$

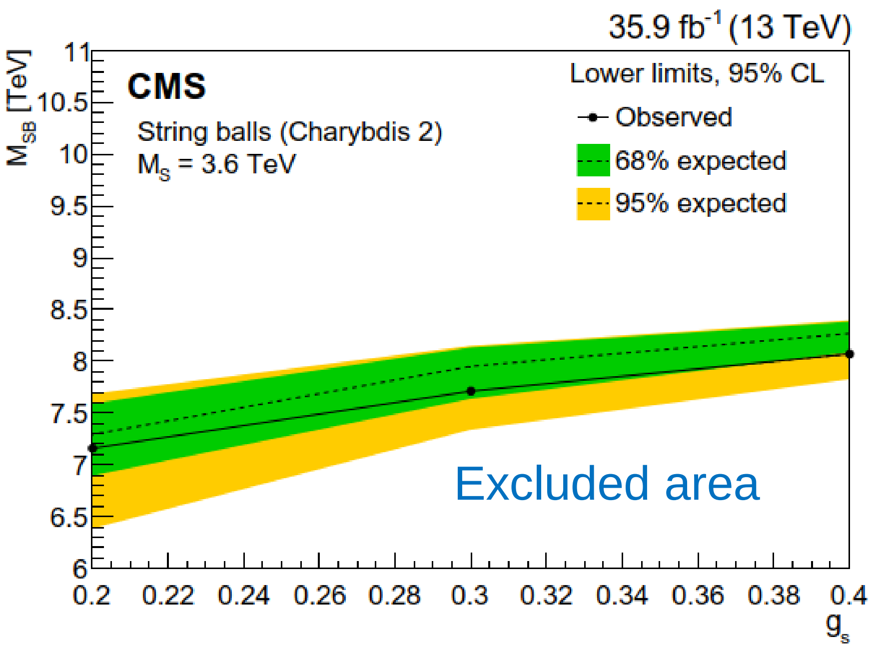
competitive regimes

$$M_S < M_D < \frac{M_S}{g_S} < \frac{M_S}{g_S^2}$$

String ball search CMS results with the 35.9 fb^{-1}

PLB 774 (2017) 279; CMS-EXO-17-023





String ball limits from the counting experiments for a set of model parameters (string coupling g_s and string scale M_s)

String balls with masses as high as 9.4 TeV are excluded at 95 % CL with 2016 data

"Quantum" BH : model approaches

QBH decay before they thermalize, resulting in low-multiplicity final states

$$\lambda_C \equiv 2\pi / M_{QBH} \geq r_S$$

- *No BH-emission equilibrium* T_H , $

- *Quantum effects (threshold suppression etc. ?)*

- *"A memory" of an initial state: color, charge, angular momentum as for parton-initiator combinations*

$$q,\ \bar{q},\ g \rightarrow \mathrm{Q}:\ \pm\frac{4}{3},\ \pm 1,\ \pm\frac{2}{3},\ \pm\frac{1}{3},\ 0.$$

$$3 \otimes \bar{3} = 8 \oplus 1$$
$$3 \otimes 3 = 6 \oplus \bar{3}$$
$$\bar{3} \otimes \bar{3} = \bar{6} \oplus 3$$
$$3 \otimes 8 = 3 \oplus \bar{6} \oplus 15$$
$$\bar{3} \otimes 8 = \bar{3} \oplus 6 \oplus \overline{15}$$
$$8 \otimes 8 = 1_S \oplus 8_S \oplus 8_A \oplus 10 \oplus \overline{10}_A \oplus 27_S\ .$$

- *For* $E \sim M_D \rightarrow r_S \sim 1/M_D,\ R_{\mathrm{int}} = b \sim 1/M_D$

$$J = \frac{2}{n+2} M_{BH} a \leq M_{BH} r_S \sim 1$$ – *small angular momentum*

- *No spherically symmetric final states !*
  2—3 particle FS, two particle state is the most probable

- *QBH production cross section – the "black disk" again*

$$\sigma_{QBH} = \sigma_{BH} \equiv \pi r_S^2 (M \leq M_{QBH}^{\max})$$

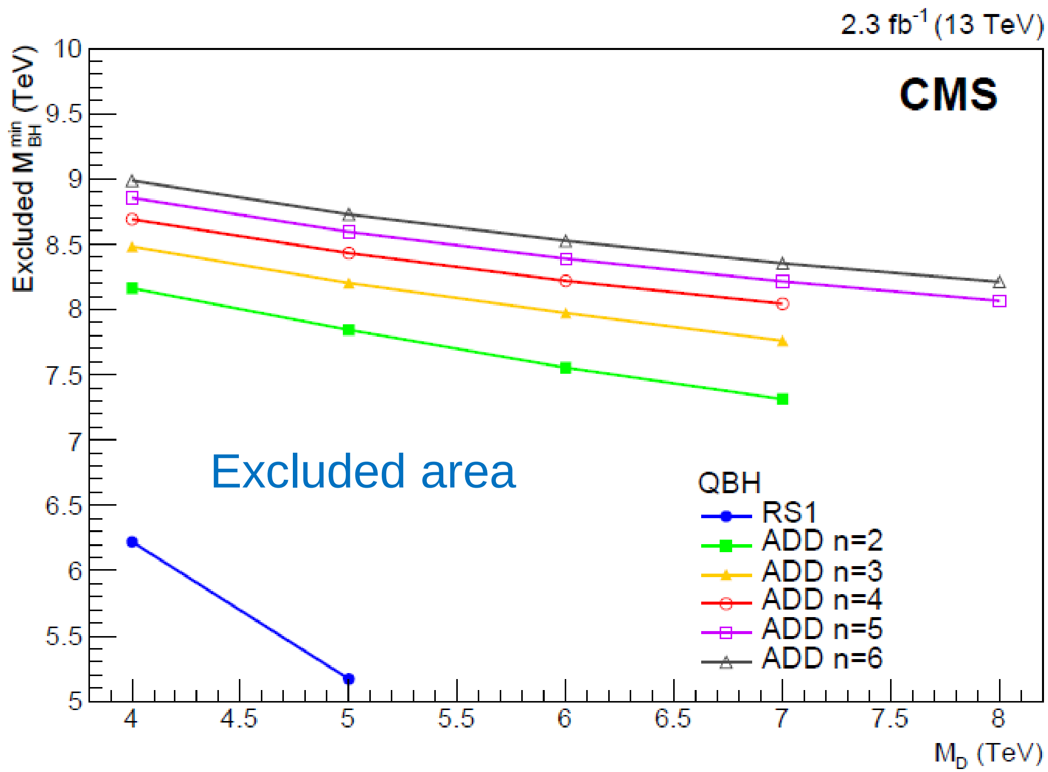
$$M_D \leq M_{QBH} \leq ?\,(M_{QBH}^{\max})$$

$$\left(\frac{1}{f(n)}\right)^{\frac{n+1}{n+2}} \lesssim \frac{M_{QBH}}{M_D} \lesssim \left(\frac{2\pi}{f(n)}\right)^{\frac{n+1}{n+2}}$$

$$\frac{1}{r_S} \leq M_{QBH} \leq \frac{2\pi}{r_S}$$

Quantum BH search CMS results with the first RUN2 data

PLB 774 (2017) 279;
arXiv:1705.01403v2 [hep-ex]
See also CMS-EXO-16-046, arXiv:1803.08030v1 [hep-ex]
(results from dijet angular distributions)



Limits obtained for ADD and RS type QBH

M_{min} is excluded from 7.3 to 9.0 TeV for ADD QBH (n>2) and from 5.1 to 6.2 TeV for RS1 QBH (n=1) for M_D up to 8 TeV at 95 % CL with 2016 data

To resume actual limits and result consistency on KK modes and BHs:

- Minimal masses of *semiclassical BHs are excluded up to 7.0 – 10.1 TeV in dependence on a number of ED n and production model details.*

- Masses of *quantum BHs are excluded up to 7.3 – 9.0 TeV (ADD, n=2–6) and up to 5.1 – 6.2 TeV (RS1, n=1). String balls are excluded with masses up to 7.1 – 9.4 TeV.*

- *For KK modes of graviton in two different multidimensional scenarios, ADD and RS1 we obtained lower mass limits of:*
  - *8.5 – 12.0 TeV in dijet angular distributions*
  - *5.6 – 9.7 TeV in diphoton channel*

    in dependence on a number of ED n for M_S or Λ_T in the ADD model;
  - *2.3 TeV (c=0.01), 4.1 TeV (c=0.1) and 4.6 TeV (c=0.2) for the mass of the first graviton resonance M_G^{KK} (connected directly with M_D) in the RS1 model.*

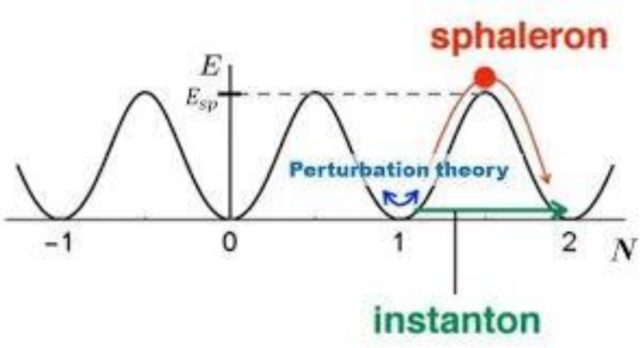
$$M_{\min}^{BH} = 4.1 M_D \quad \text{for ADD BH}$$
$$M_{\min}^{BH} \geq 16 M_D \quad \text{for RS1 BH}$$

Semiclassical BH production at the LHC lookes very unreal and inaccessible at the c.o.m. energy up to 14 TeV

⇩

"Quantum" black holes etc.?

EW sphaleron production in high energy particle collisions



$E > E_c = E_{sph} \sim 9\ TeV$

$$\mathcal{P} = A(g)\,\mathrm{e}^{-F/g^2}$$

PEF

Originally for EW theory:

$$e^{-\frac{4\pi}{\alpha_W}} \sim 10^{-162}$$

$$\alpha_W = g_W^2/4\pi$$

- ✓ In QFT sphaleron tunneling is a dominant mechanism for tunneling induced by ultrarelativistic particle collisions
- ✓ Non-stable sphaleron decays classically with the same probabilities into a wide spectrum of FS

S.-H. Henry Tye, Sam S.C. Wong, PRD 92, 045005 (2015); J. Ellis, Kazuki Sakurai, arXiv:1601.03654

Resonant tunneling in the presence of many minima – Bloch wave function for one-dimensional time-independent Schroedinger equation, a band structure for transitions

$$|n\rangle \longrightarrow |n + N_{CS}\rangle$$

$$\begin{cases} \Delta(B+L) = 6N_{CS} \\ \Delta(B-L) = 0 \end{cases} \iff \begin{cases} \Delta N_e = \Delta N_\mu = \Delta N_\tau = N \\ \Delta B = \frac{1}{3} \times 3 \times 3 \times N \end{cases}$$

$\Delta N = -1$

$$q_L + q_L \to \bar{l}_e \bar{l}_\mu \bar{l}_\tau \bar{q}\bar{q}\bar{q}\bar{q}\bar{q}\bar{q}\bar{q} + X$$

10 particles in FS

$\Delta N = +1$

$$q_L + q_L \to e^- \mu^- \tau^- bbbcccdddduu + X$$

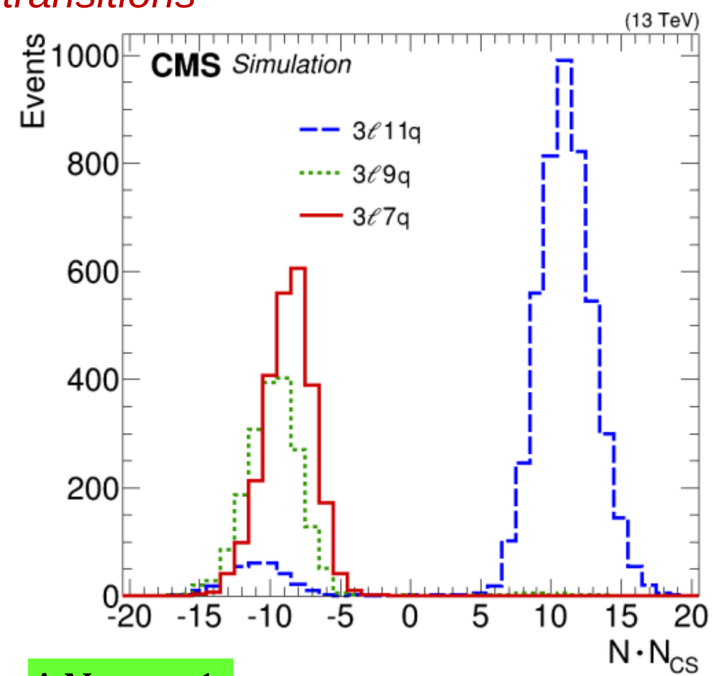
14 particles in FS

EW sphaleron search results with the 35.9 fb^{-1}

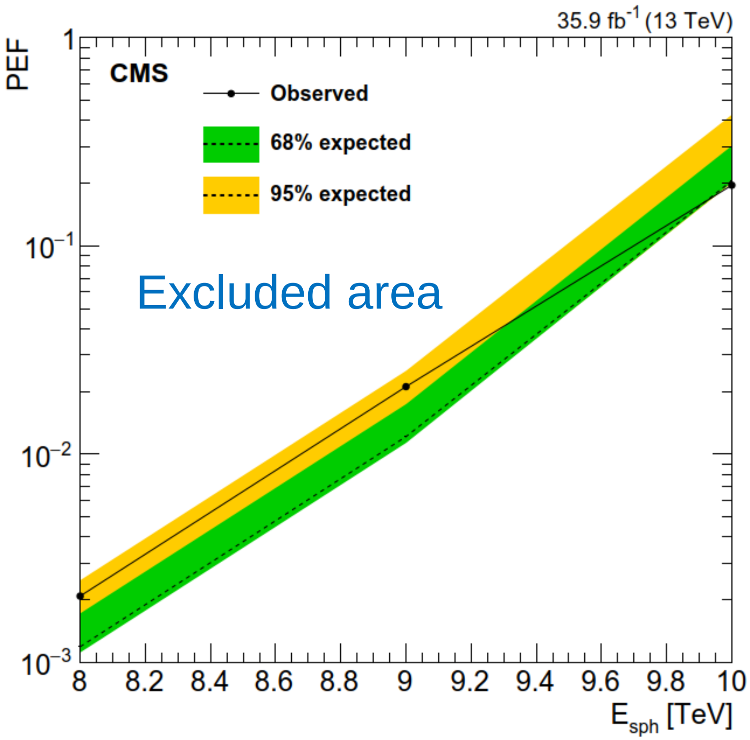
CMS-EXO-17-023,
arXiv:1805.06013v1 [hep-ex]

Probabilities for FS of sphaleron-induced transitions

$$\sigma(\Delta n = \pm 1) \;=\; \frac{p}{m_W^2} \sum_{ab} \int dE \frac{d\mathcal{L}_{ab}}{dE} \exp\left(c \frac{4\pi}{\alpha_W} S(E)\right)$$



$\Delta N = +1$



- ✓ *Results of the first dedicated search for electroweak sphalerons are presented with 2016 data.*
- ✓ *An upper limit of 0.021 is set on the fraction of all quark-quark interactions above the nominal threshold energy of 9 TeV resulting in the sphaleron transition*

Dark matter search at the CMS: a work in progress…

ICHEP'2018 subset of new CMS results and channels:

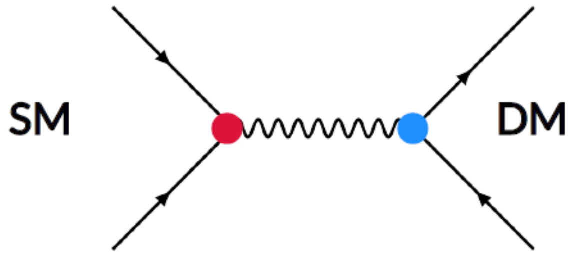
- Monophoton (EXO-16-053)
- DM + Top pair (EXO-16-049)
- Boosted mediator → bb (EXO-17-024)
- Mono-H → bb (EXO-16-050)
- Mono-Leptoquark (EXO-17-015)

New!

Benchmarks: arxiv:1603.04156

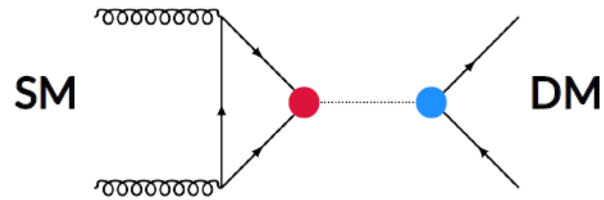
Interpretation: Simplified models

Spin-1 mediator



$$\mathcal{L}_{\text{vector}} = -g_{\text{DM}} Z'_\mu \bar{\chi}\gamma^\mu \chi - g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu q$$

Spin-0 mediator



$$\mathcal{L}_{\text{scalar}} = -g_{\text{DM}} \phi \bar{\chi}\chi - g_q \frac{\phi}{\sqrt{2}} \sum_{q=u,d,s,c,b,t} y_q \bar{q} q$$

Simplified models with few free parameters:

m_{med}, m_{DM}, mediator-quark coupling, mediator-DM coupling

minimal flavour violation

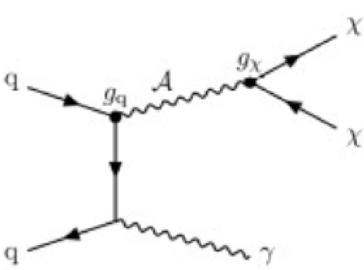
Benchmarks defined by LHC Dark Matter working group

Minimal flavor violation →
S=1: the same couplings to all quarks (universal g_q)
S=0: quark coupling are proportional to a quark mass

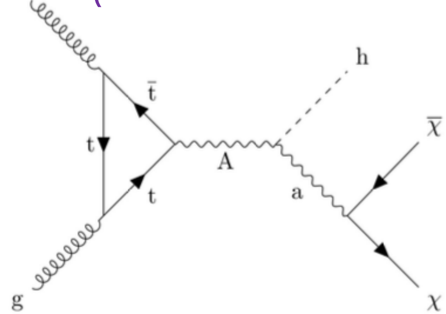
MET-based observations and direct observations (dijet and dilepton spectra)

- **$m_{med} > 2m_{DM}$**: *DM mediator can decay into DM particle pair (invisible at the LHC) –*
MET signatures: DM + monophoton/monojet/V(qq)/Z(ll)/H(bb)…

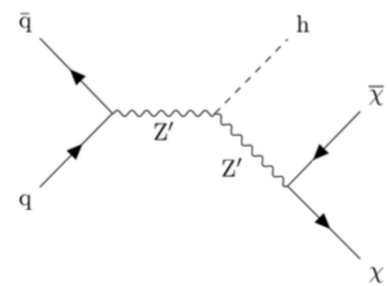
monophotons
(New: CMS-EXO-16-053)



mono-Higgs (→ bb, ττ, γγ ...)
(New: CMS-EXO-16-050, CMS-EXO-16-055)



Pseudoscalar + 2HDM



Baryonic Z'

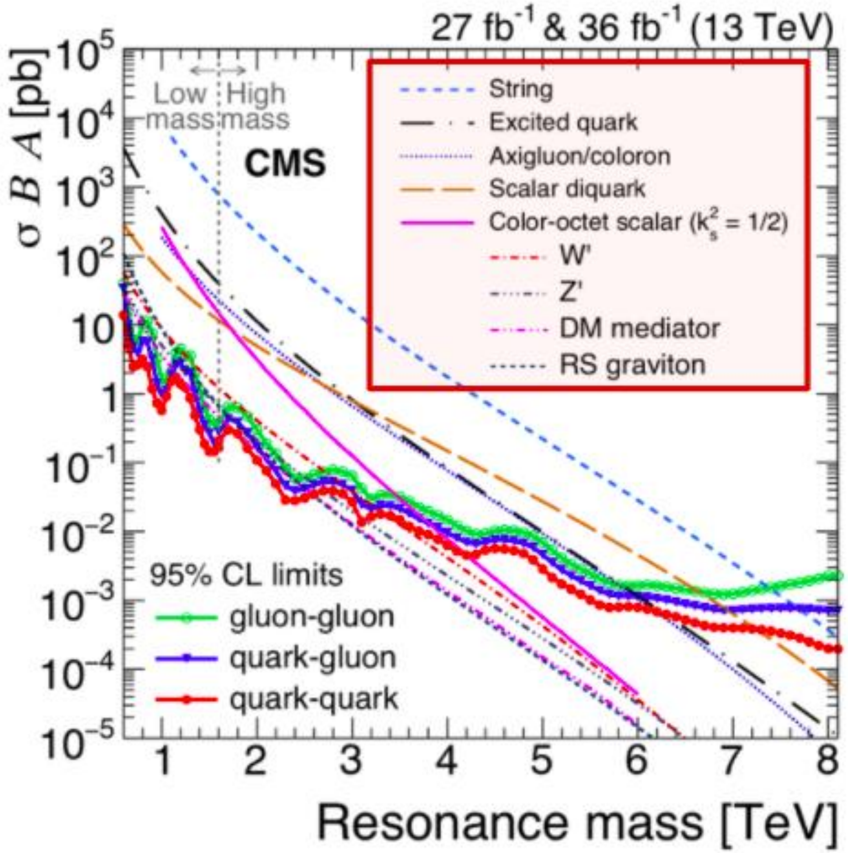
+ others (including the exotic like DM from LQ pair decay, CMS-EXO-17-015)

- **$m_{med} < 2m_{DM}$**: *DM decay is kinematically forbidden → DM mediator decays into SM particles*
→ can be observed directly in dijet and dilepton spectra.
→ strong constraints on g_q (= 0.25) and g_l (≤ 0.1) values

DM direct search in dijet resonance channel with the 35.9 fb^{-1}

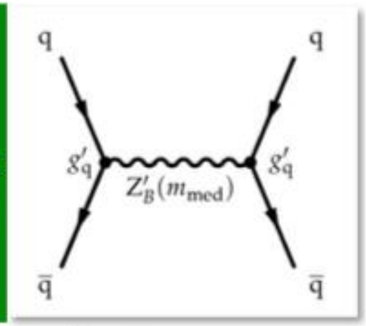
CMS-EXO-16-056, arXiv:1806.00843v1

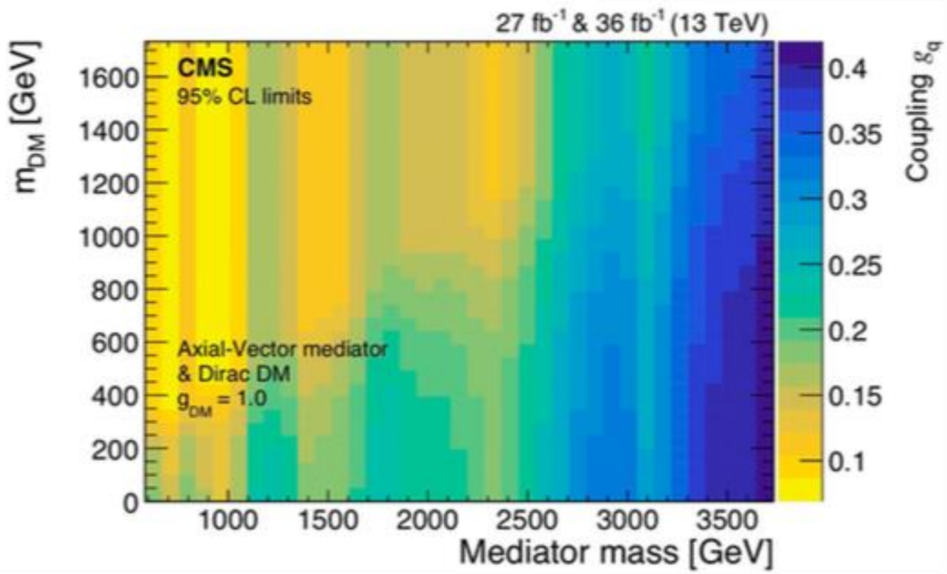
Leptophobic vector and axial-vector DM mediators



constraints on dark matter mediators

- DM mediator may directly produced a dijet resonance
- set limits on a quark coupling g_q in the plane of the DM particle mass vs mediator mass for an (axial-) vector mediator





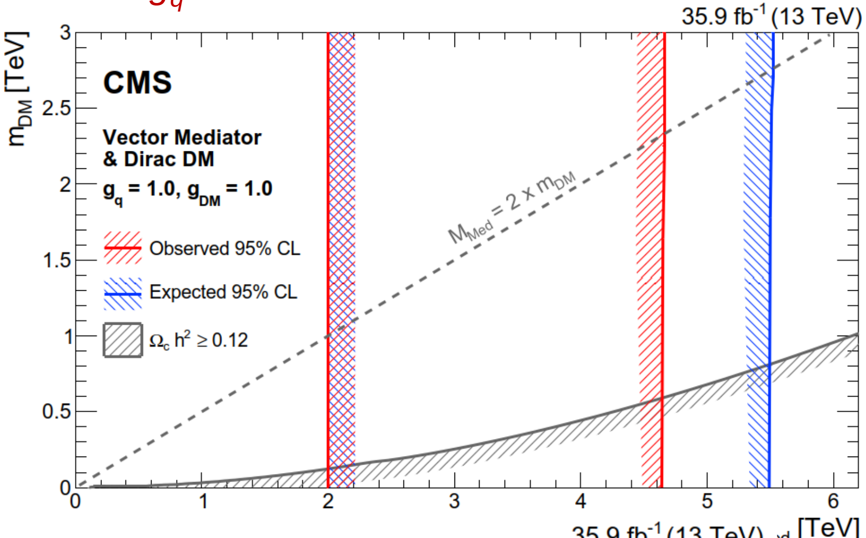
DM search with the 35.9 fb^{-1} (dijet angular distributions, reinterpretation)

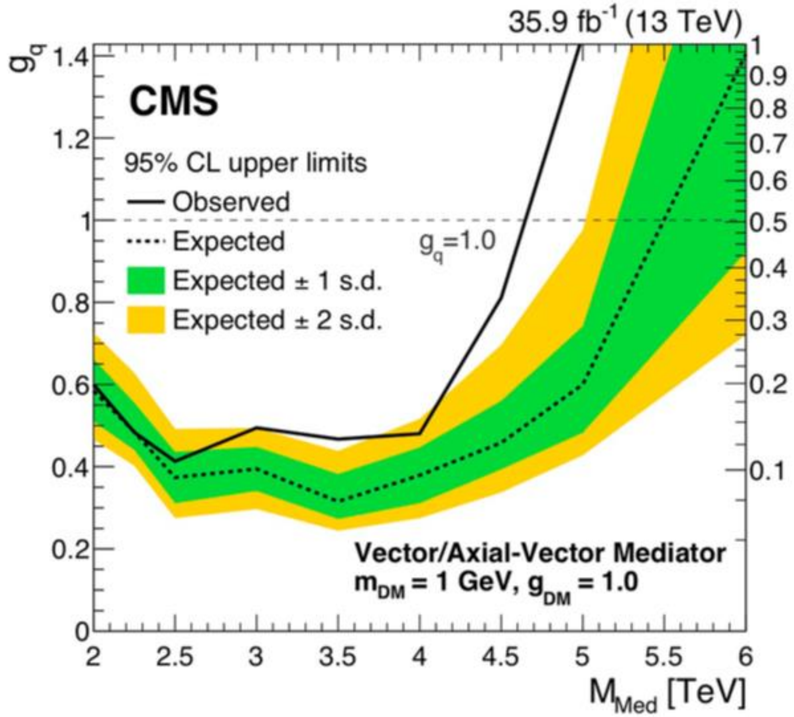
$$\chi_{dijet} = (1 + |cos\theta^*|)(1 - |cos\theta^*|).$$

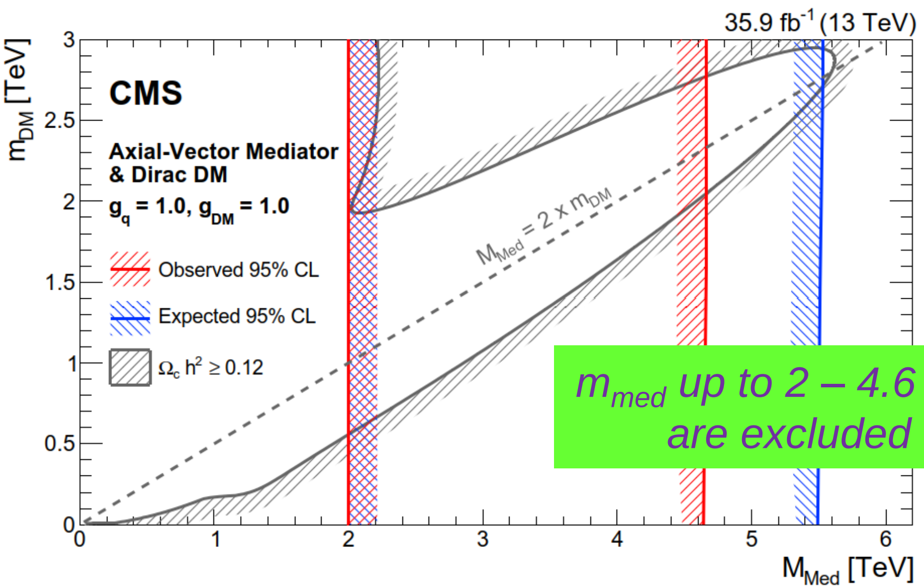
CMS-EXO-16-046, arXiv:1803.08030v1

DM mediator, spin 1

- ✓ Simplified DM model, 4 parameters: m_{med}, m_{DM}, g_{DM}, universal g_q
- ✓ DM mediator decays only to quark pairs or DM pairs
- ✓ Relative widths in the quark decay channel increase monotonically with g_q
- ✓ NWA (~3%) – narrow resonance search in dijet channel (see the slide above) ⇒
- ✓ Inceasing g_q → broadering up to 10 % for
- ✓ g_q > 0.45 → fading of sensibility in dijets ⇒ dijet angular distributions

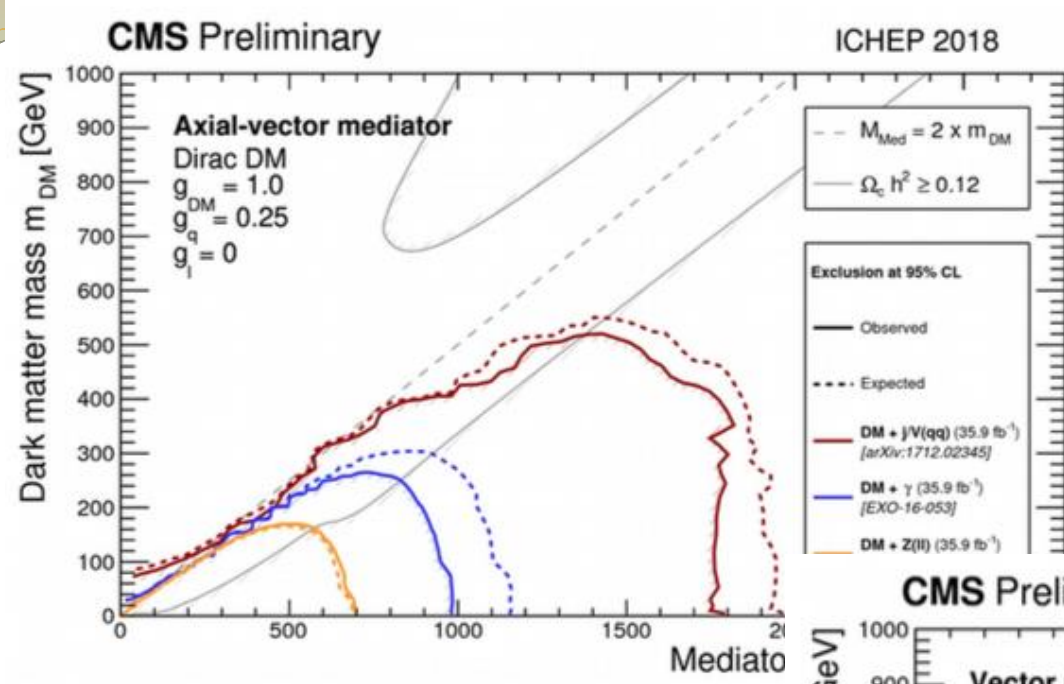






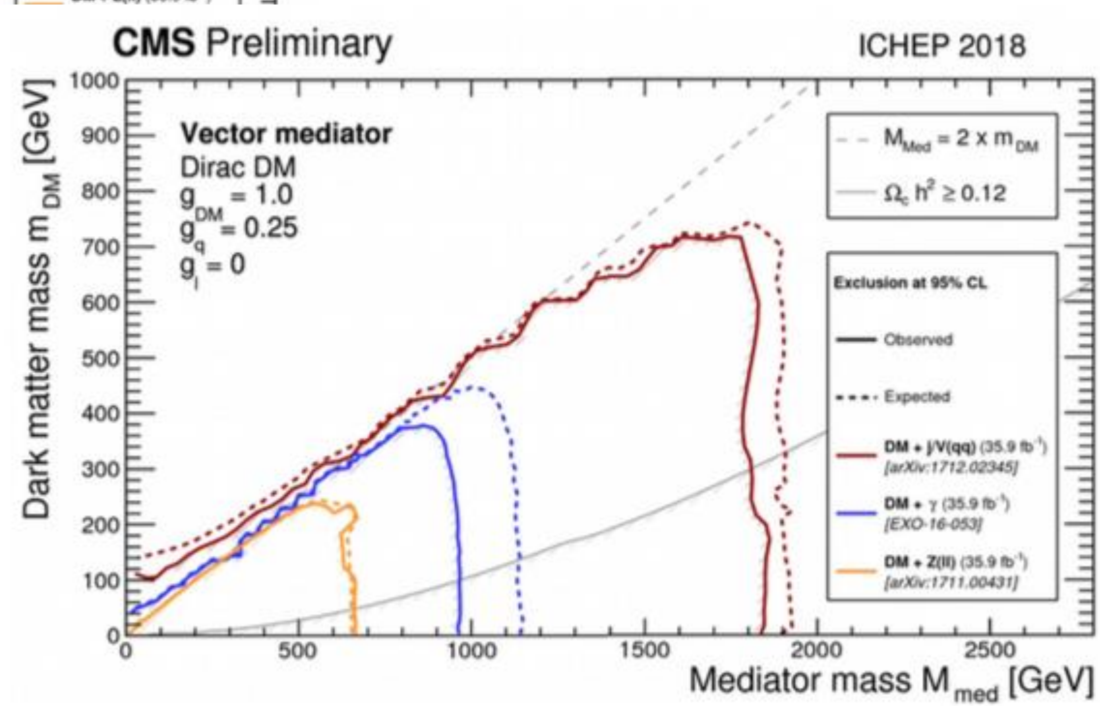
m_{med} up to 2 – 4.6 TeV are excluded

"Invisible" DM search: summary plots with the 35.9 fb^{-1}

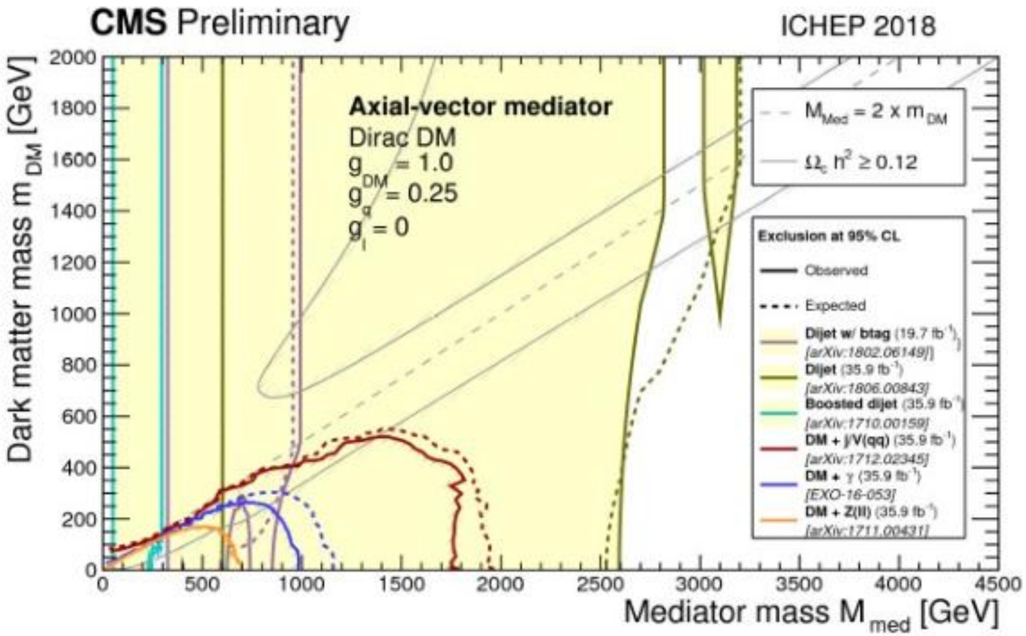


DM mediator **spin 1** via MET-based searches

DM production accompanied by mono-
- ✓ jet/V(qq)
- ✓ gamma
- ✓ Z(ll)



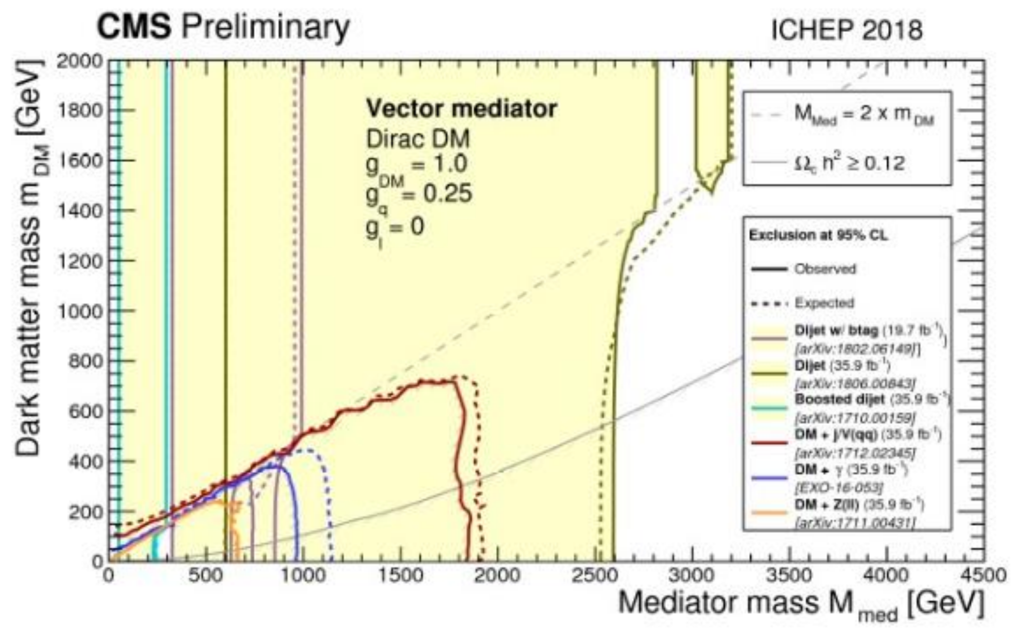
DM summary plots for the MET channels and direct observations (dijets)



DM mediator **spin 1**

Can probe the regime with
$m_{DM} > m_{med}/2$
(DM mediator can not decay into DM, only into SM particles) – an enhancement of a dijet rate.

The strongest constraints from dijet observations for DM mediator (although the g_q choice dependence)



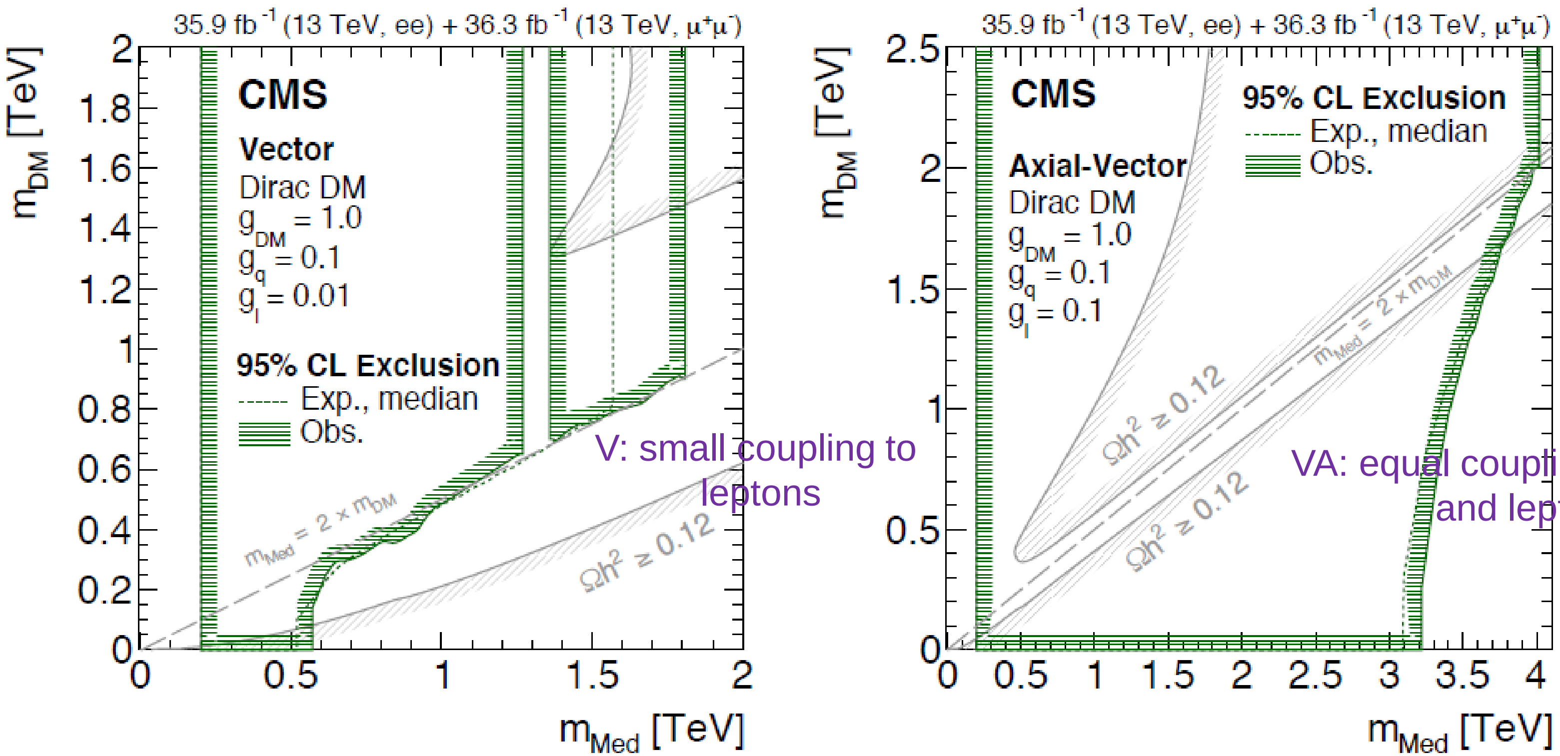
DM coupling to leptons (dilepton channel, reinterpretation)

$Z' \rightarrow \ell\ell$ (ℓ=e/μ) : *CMS EXO-16-047, arXiv:1803.06292v2 [hep-ex]*

- Easy reinterpretation is then possible such as within a simplified Dark Matter (DM) model

DM mediator, spin 1

- Here we assume the DM particle is a Dirac fermion and its associated mediator is either vector or axial vector



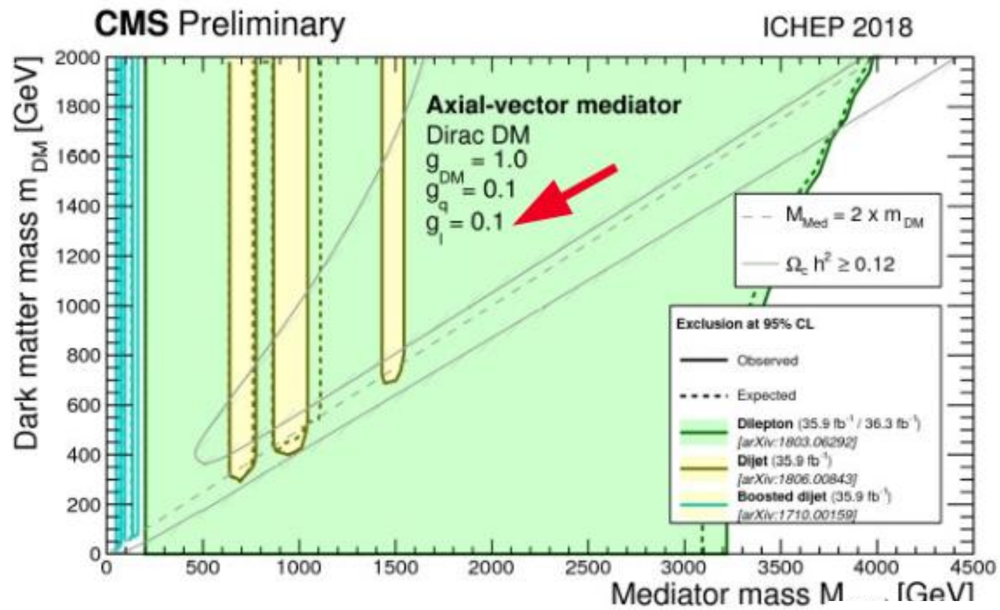
V: small coupling to leptons

VA: equal coupling to quarks and leptons

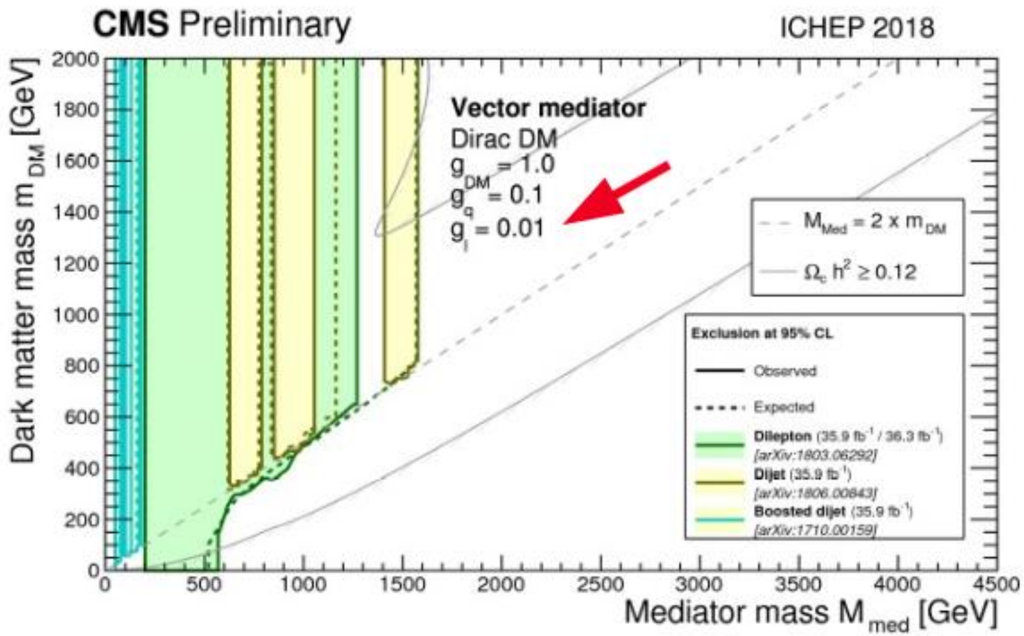
For each combination of the DM particle and mediator mass values, the width of the mediator is taken into account in the limit calculation.

DM summary plots for the MET channels and direct observations (dileptons)

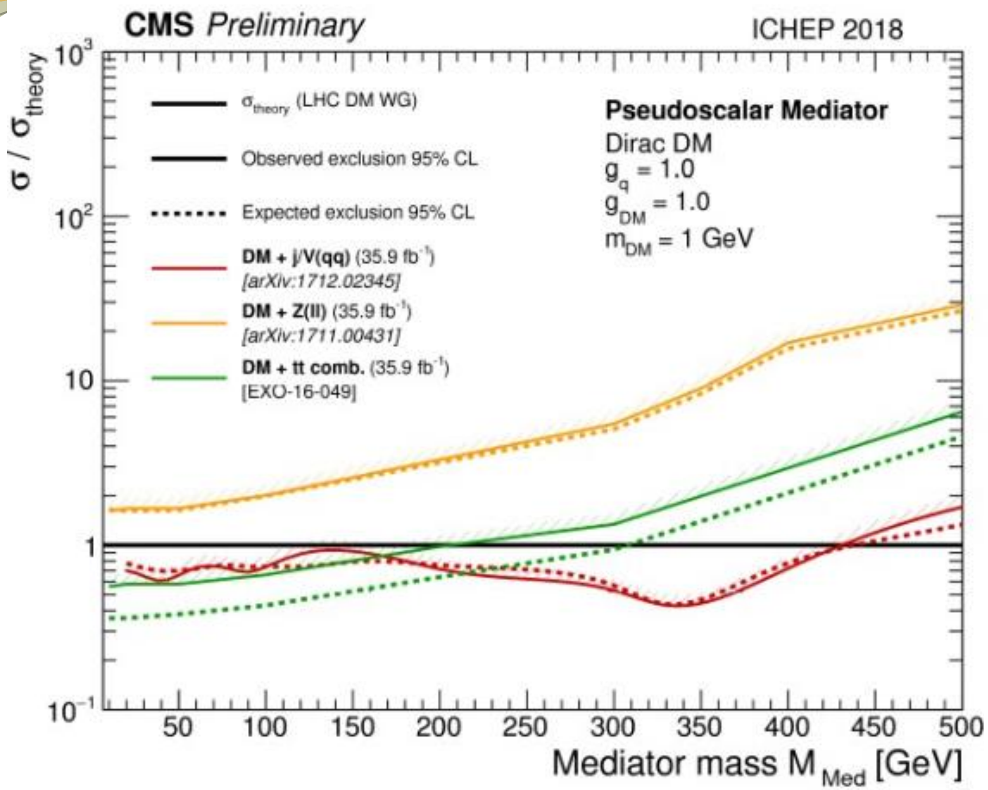
DM mediator **spin 1**



- ✓ *NWA for DM mediator*
- ✓ *g_l choice dependence, as for the previous dijet case*



"Invisible" DM search : summary plots with the 35.9 fb^{-1}

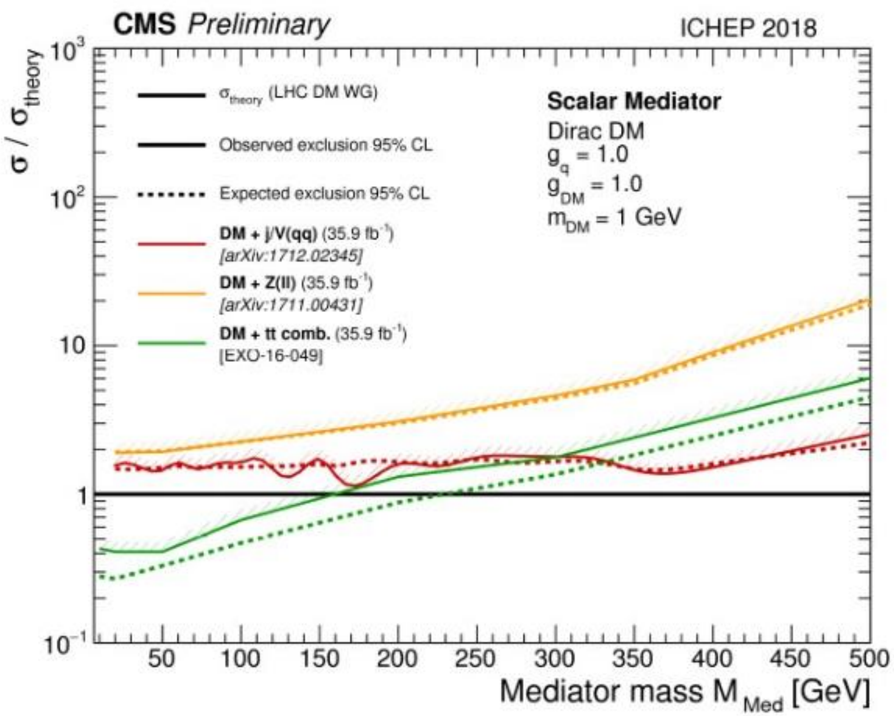


*DM mediator **spin 0***
via MET-based searches

DM production accompanied by mono-

- ✓ *jet/V(qq)*
- ✓ *gamma*
- ✓ *Z(ll)*
- ✓ *top pairs*

The strongest limitations come from DM + jet/V and DM + tt (no Z–DM mediator vertex)



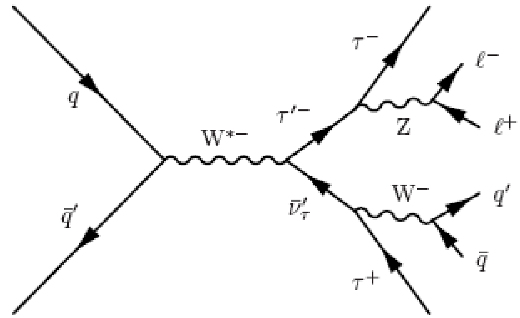
Non-resonant NP in the multilepton channel, 41.4 fb^{-1}

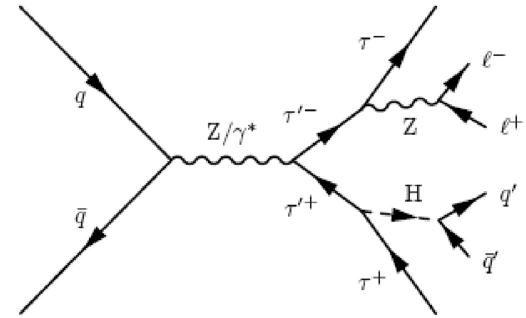
New!

CMS-PAS-EXO-18-005

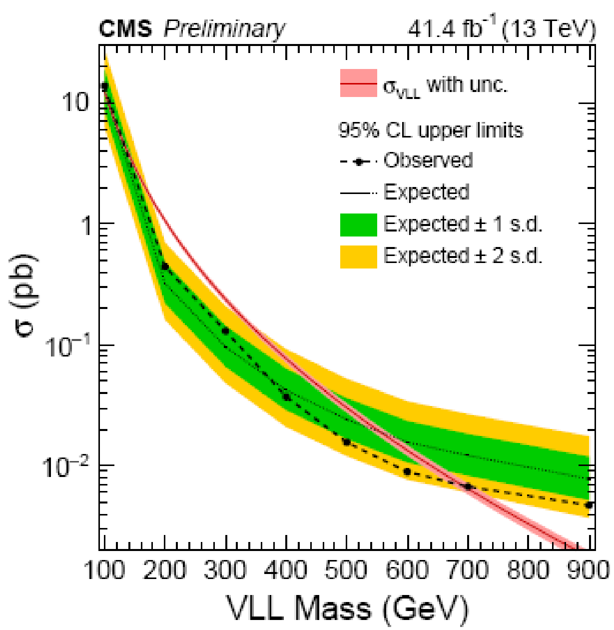
Search for vector-like leptons in multilepton final states

Color-singlet fermions with left- and right-handed components transforming similarly under the SM gauge symmetries.





Associated production of (τ', ν_τ') pairs via an off-shell W/Z boson; possible subsequent decay chains with multileptonic FS



Masses of vector-like leptons are excluded in the range of 130 – 690 GeV

Excited leptons in llγ channel, 35.9 fb^{-1}

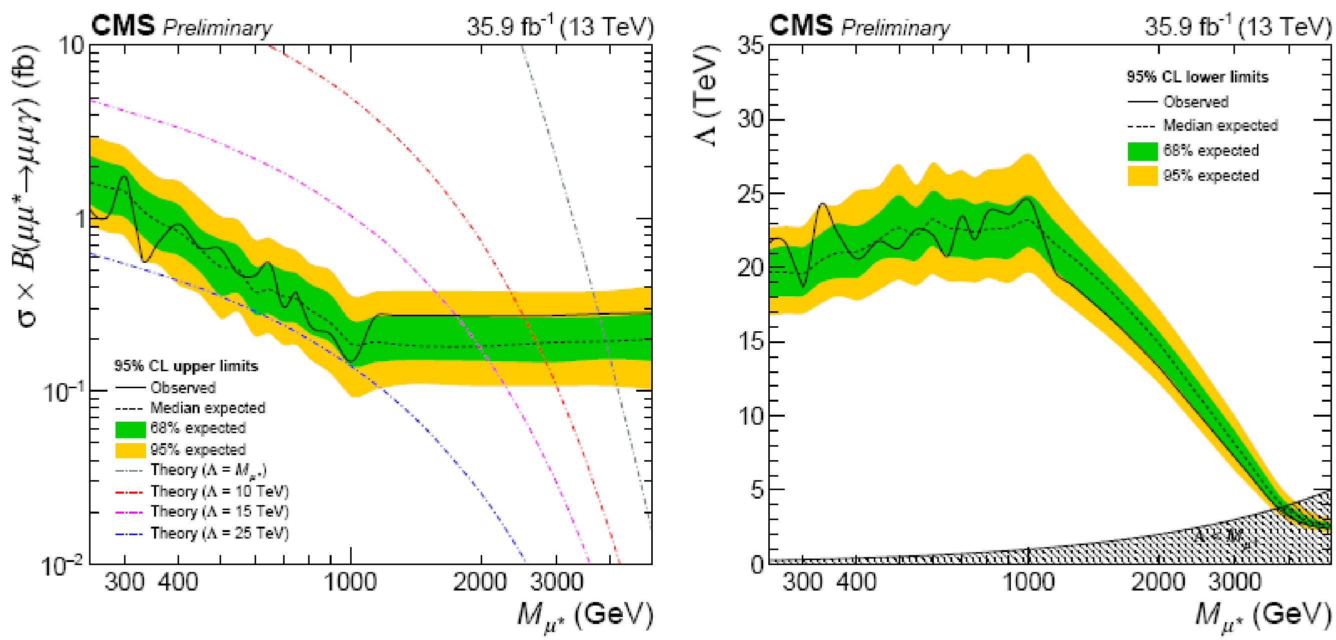
New!

Compositeness models → the existence of excited states of quarks and leptons

✓ *In proton-proton collisions, excited fermions could be produced via contact interactions (CI) and decay either through SM gauge interactions or via CI to SM fermions.*

✓ *The decay of the excited lepton is mediated by a photon,* $\ell\ell^* \rightarrow \ell\ell\gamma$

CMS-PAS-EXO-18-004



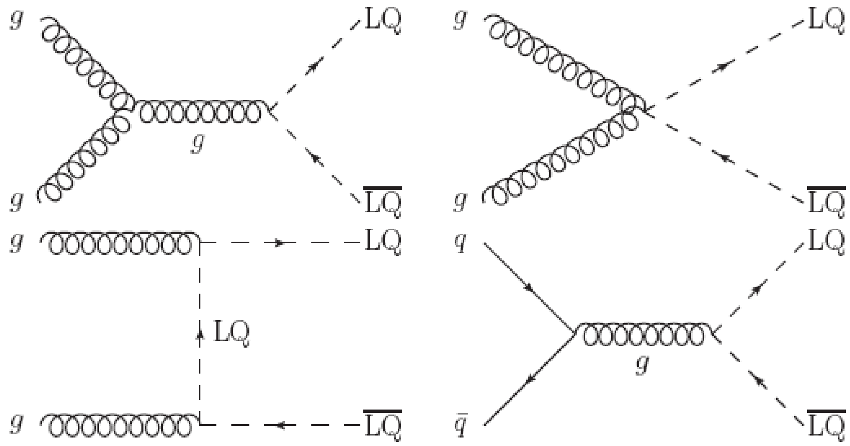
Channel	Observed (expected) exclusion for $M_{\ell^*} = \Lambda$, TeV	Best observed (expected) limit on Λ, TeV
$ee\gamma$	3.9 (3.8)	25 (23)
$\mu\mu\gamma$	3.8 (3.9)	25 (23)

Scalar leptoquarks in llγ channel, 35.9 fb^{-1}

New!

Leptoquarks ↔ GUT, technicolor, superstring-like models, models exhibiting quark and lepton substructure.

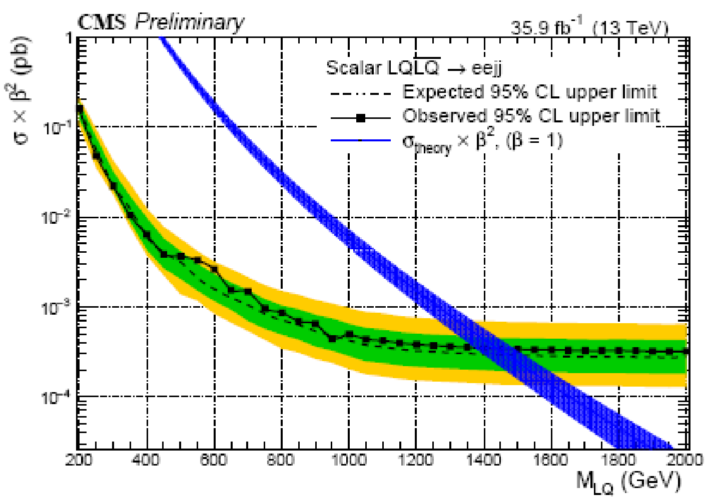
- ✓ *A new class of bosons, that carry both lepton (L) and baryon numbers (B).*
- ✓ *LQs have fractional electric charge and are color triplets under $SU(3)_C$. Other properties (spin, weak isospin, fermion numbers (3B+L), are model dependent.*
- ✓ *EFT approach for LQ searches at the LHC, constraints on their interactions.*

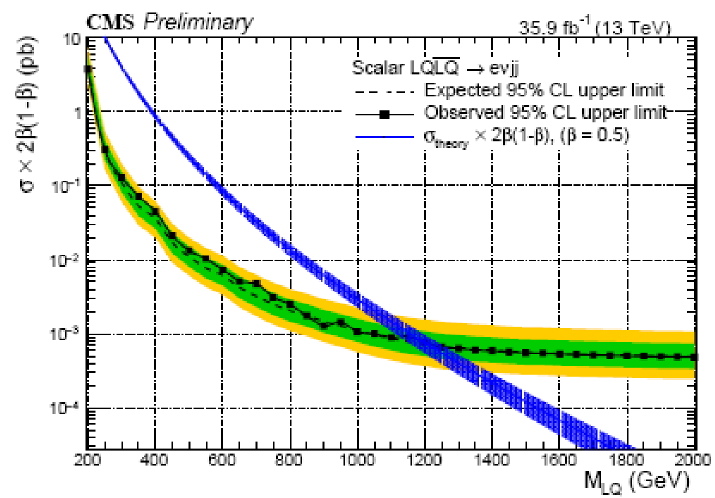


LO Feynmann graphs for the first generation scalar LQ

CMS-PAS-EXO-17-009

A free parameter of LQ decay – β: BR (q+l$^{\pm}$). The BR(q+ν)=1 – β





Instead of conclusion

- *Many searches for New Pysics have been performed with a fantastic quality –*

  thanks a lot, the LHC!!!
- *Atomic effort have been done in experimental study, reconstruction methods, systematic and background estimations, new computing etc.…*

  working methods represent an ongoing process that continues to evolve
- *Many results (limits, bounds and model constrains) have been obtained*

Look for the CMS EXO publications

- Preliminary results:
  - https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/EXO/
- Publications:
  - https://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/DM.html

No signals from New Physics and New Particles were observed…

BUT

It is not the end of a story

Stay tuned!