Z'-explorer 2.0:

In the quest of dark matter.

arXiv: 2019.13194, 2005.05194

Z'-explorer collaboration: E. Álvarez, M. Estévez, VML, R. Sandá Seoane, J. Zurita.

Víctor Martín Lozano

victor.lozano@ific.uv.es

Z' boson and searches.

-Z' bosons are common in BSM theories (extra U(1)): U'(1), B-L, String theory...

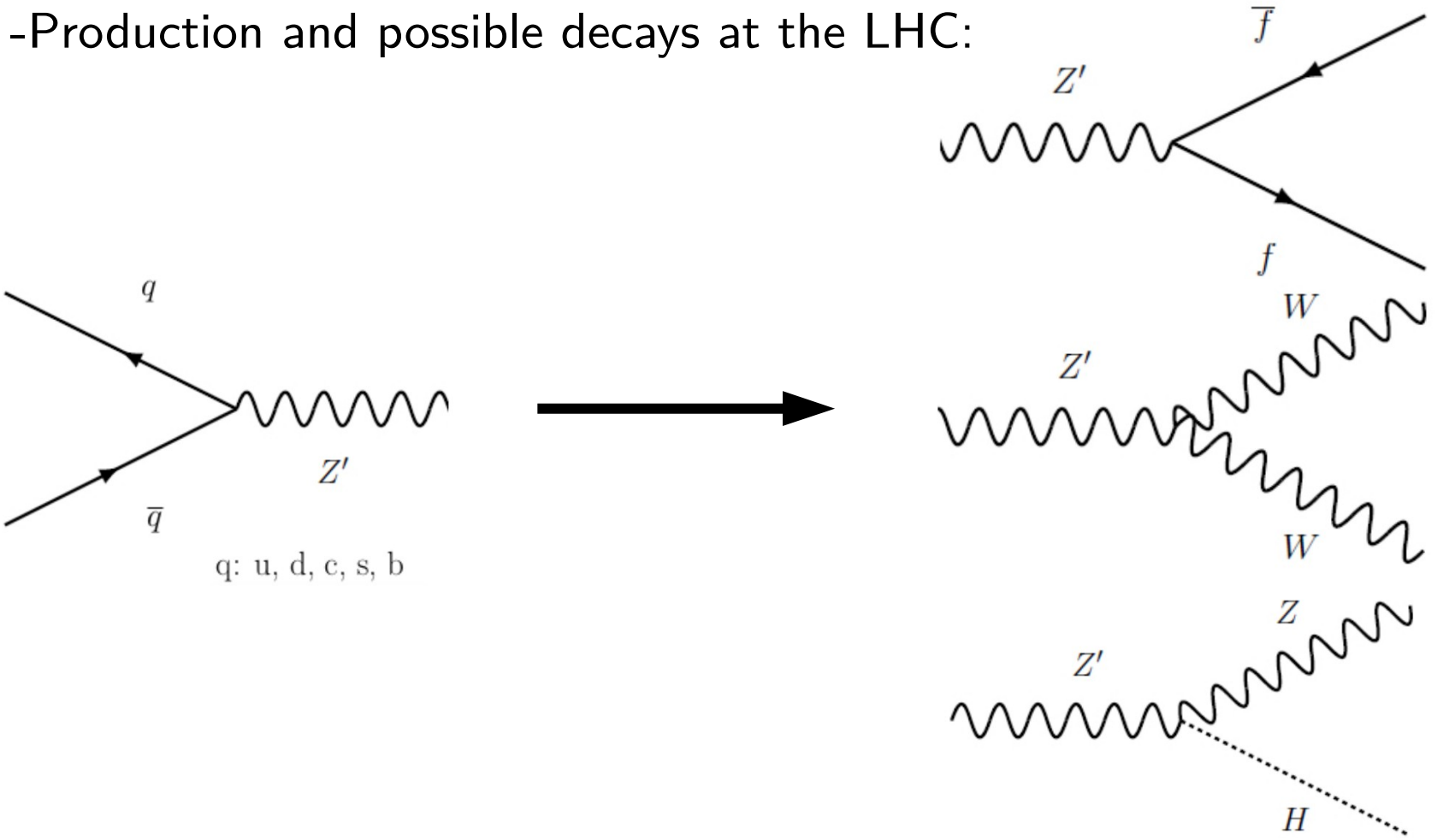
-Phenomenologically interesting: DM mediator, new signatures...

-Its coupling to SM particles determined by the specific model.

-If the Z' couples to quarks then it is possible to produce it at the LHC.

Z' boson and searches.

-Production and possible decays at the LHC:



Z' boson and searches.

At the LHC, there are both ATLAS and CMS searches looking for Z'.

- They reach the TeV scale.
- Different visible channels: ee, $\mu\mu$, $\tau\tau$, jj, bb, tt, Zh, WW.

The sensitivity of a decay channel depends on:

- Energy scale of the resonance.
- Branching ratios.
- Backgrounds.
- Coupling structure.
- Acceptance and efficiencies.

Z' boson and searches.

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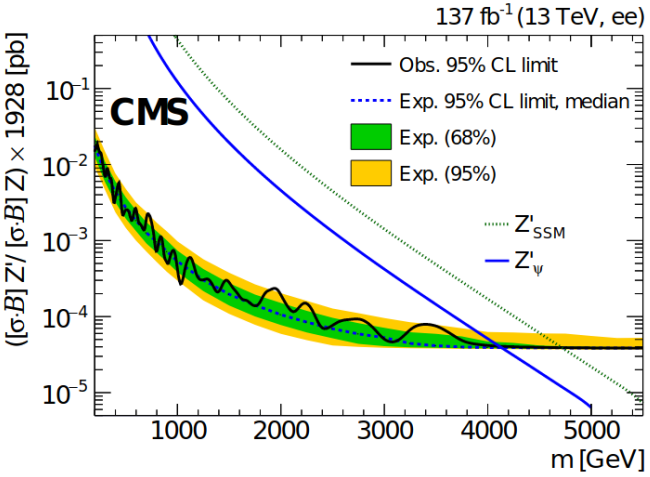

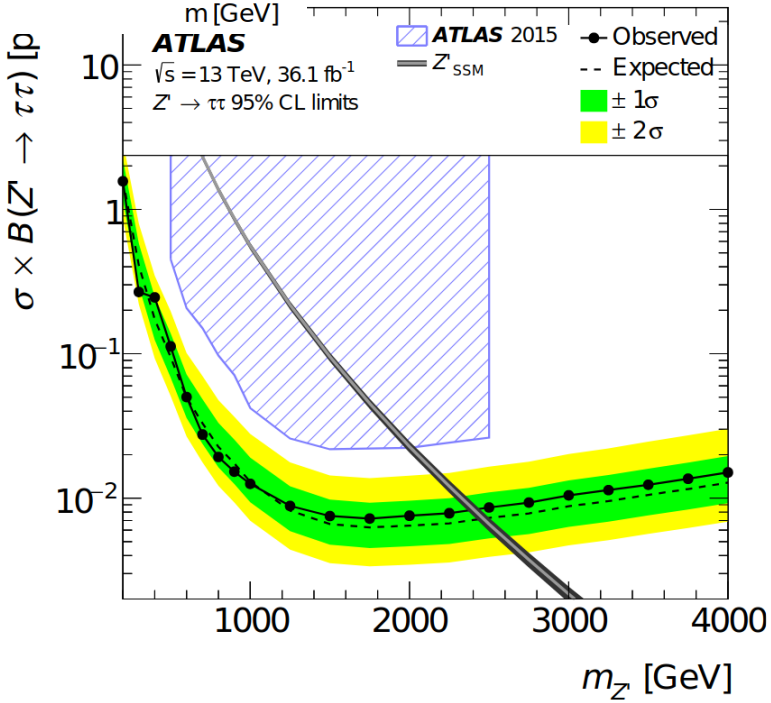

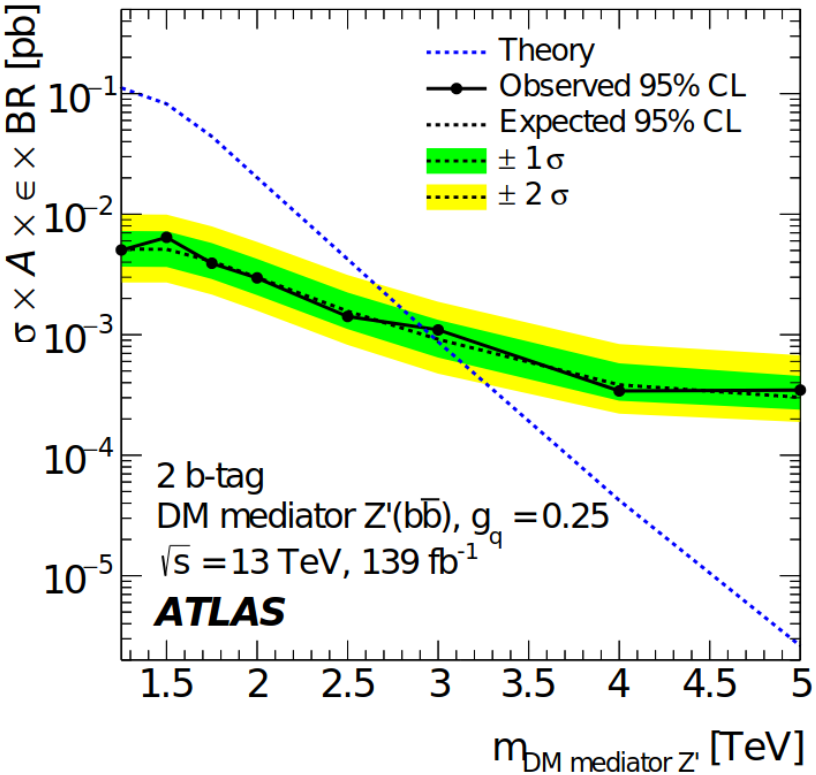

Z' boson and searches.

At the LHC, there are both ATLAS and CMS searches looking for Z'.

- They reach the TeV scale.
- D

Need to quickly compare the sensitivity of all channels at a fixed $M_{Z'}$

The
- E
- Branching ratios.
- Backgrounds.
- Coupling structure.
- Acceptance and efficiencies.

Z'-explorer 2.0.

Z'-explorer 2.0: reconnoitering the dark matter landscape

Víctor Martín Lozano [a,1], Rosa María Sandá Seoane [b,2], Jose Zurita [c,*]

[a] Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany
[b] International Center for Advanced Studies (ICAS)
UNSAM, Campus Miguelete, 25 de Mayo y Francia, (1650) Buenos Aires, Argentina
[c] Instituto de Física Corpuscular, CSIC-Universitat de València, E-46980 Paterna, Valencia, Spain

arXiv: 2109.13194

Z'-explorer: A simple tool to probe Z' models against LHC data

Ezequiel Alvarez*, Mariel Estévez, Rosa María Sandá Seoane

International Center for Advanced Studies (ICAS) UNSAM, Campus Miguelete, 25 de Mayo y Francia, 1650 Buenos Aires, Argentina

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arXiv: 2005.05194

https://github.com/ro-sanda/Z-explorer-2.0
https://gitlab.com/v.martin.lozano/Z-explorer-2.0

Z'-explorer 2.0.

Z'-explorer assumes the following framework:

$$\mathcal{L} \supset Z'_\mu \left[\sum_f \left(g_{f_L} \bar{f}_L \gamma^\mu f_L + g_{f_R} \bar{f}_R \gamma^\mu f_R \right) + g_{\chi_L} \bar{\chi}_L \gamma^\mu \chi_L + g_{\chi_R} \bar{\chi}_R \gamma^\mu \chi_R \right] ,$$

The SM is augmented with a new U(1) gauge boson, Z', and a SM singlet Dirac fermion, that remains stable due to a Z_2 symmetry and plays the role of the DM candidate.

This is a general Lagrangian for a vector mediator that also coincides with the one adopted by ATLAS and CMS collaborations, and the Dark Matter Working Group.

JHEP 01 (2015) 037 (1407.8257)

Phys. Dark Univ. 27 (2020) 100371 (1507.00966)

Each right/left – handed (vector/axial) couplings is treated as a free parameter by Z'-explorer. This could be problematic when unitarity and gauge invariance are imposed.

JHEP 02 (2016) 016. (1510.02110)

Phys. Rev. D 96 (9) (2017) 095006. (1705.03897)

Z'-explorer 2.0.

Z'-explorer software (runs on C++) is quick and simple to use. Incard (text file) must provide for each benchmark point (BP) in the BSM parameter space:

$$M_{Z'}\, g_{q_L}\, g_{q_R}\, g_{\ell_L}\, g_{\ell_R}\, \Gamma_{\nu\nu}\, \Gamma_{WW}\, \Gamma_{Zh}\, m_\chi\, g_{\chi L}\, g_{\chi R} \Gamma_{XX}$$

After running the program, the output is written in a text file and it gives the strength of the signal of each channel for each point:

$$S_{jj}\, S_{bb}\, S_{tt}\, S_{ee}\, S_{\mu\mu}\, S_{\tau\tau}\, S_{\nu\nu}\, S_{WW}\, S_{Zh}\, S_{\chi\chi}\, \Gamma_{Z'}\, \mathrm{WARNING} : \Gamma_{Z'} > 5\,\mathrm{GeV}$$

$$\mathcal{S} = \frac{\sigma_{pred}}{\sigma_{lim}}$$

$\sigma_{pred} = \sigma \times BR$

$\sigma_{lim} = \sigma \times BR$ 95% *CL UL*

S > 1 (in a given channel)
BP experimentally excluded

S < 1 (in all channels)
BP not excluded. Largest S, most sensitive channel

Z'-explorer 2.0.

Production cross section ($\sigma_{pp->Z'}$): Sum of u, d, c, s, b contributions (calculated with MadGraph in the range $M_{Z'} \in [0.5, 8]$ TeV for $\sqrt{s} = 13$ TeV) and adjusted using the sum of the corresponding squared chiral couplings:

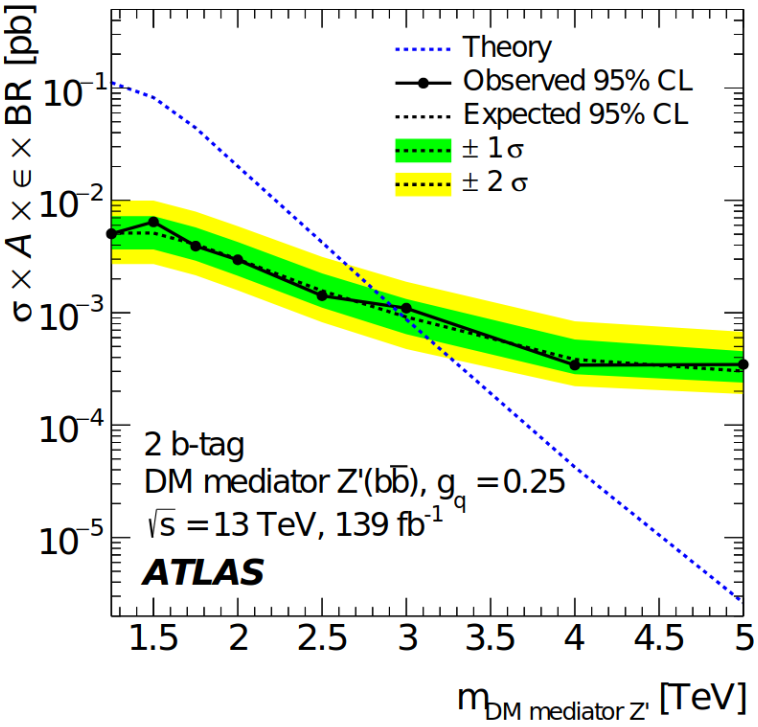
$$\sigma_{pp->Z'} = \sum_q \sigma^{g_q=1}_{q\bar{q}->Z'} \left[(g_q^R)^2 + (g_q^L)^2 \right]$$

Then in order to obtain the total cross section it computes

$$\sigma_{pred} = \sigma_{pp->Z'} \times BR(Z' -> XY)$$

Z'-explorer 2.0.

σ_{lim}: 95% C.L. expected upper limit $\sigma \times BR$ extracted from ATLAS and CMS results at $\sqrt{s} = 13$ TeV.



(1910.08447)

Channels included:

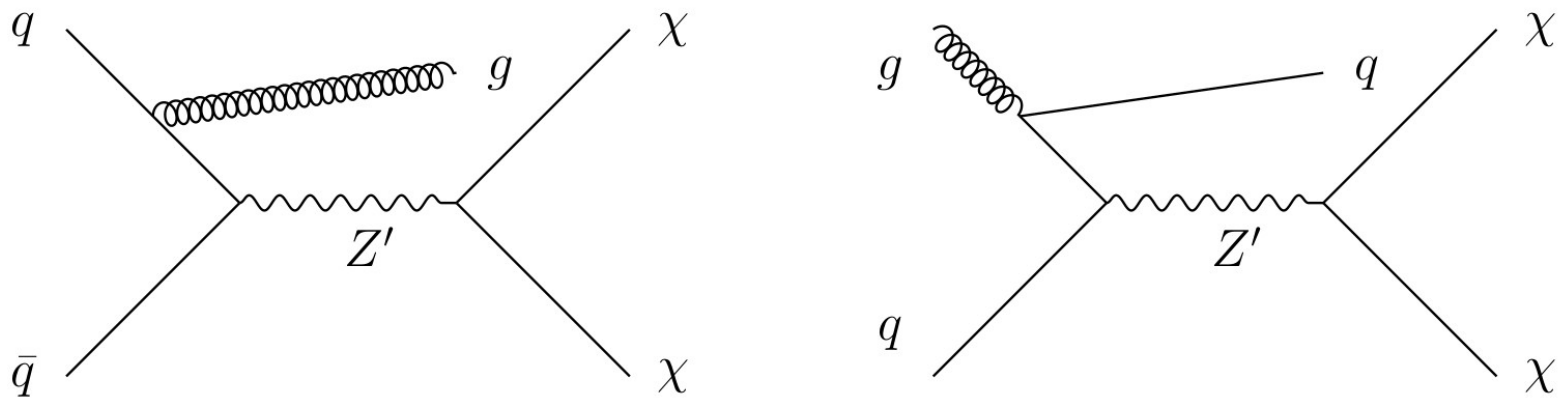
jj, ee, $\mu\mu$, $\tau\tau$, jj, bb, tt, Zh, WW

Finally we can compute:

$$\mathcal{S} = \frac{\sigma_{pred}}{\sigma_{lim}}$$

Z'-explorer 2.0.

Also, when considering the Z' as a dark matter mediator the mono-jet signature can be crucial in order to set bounds.



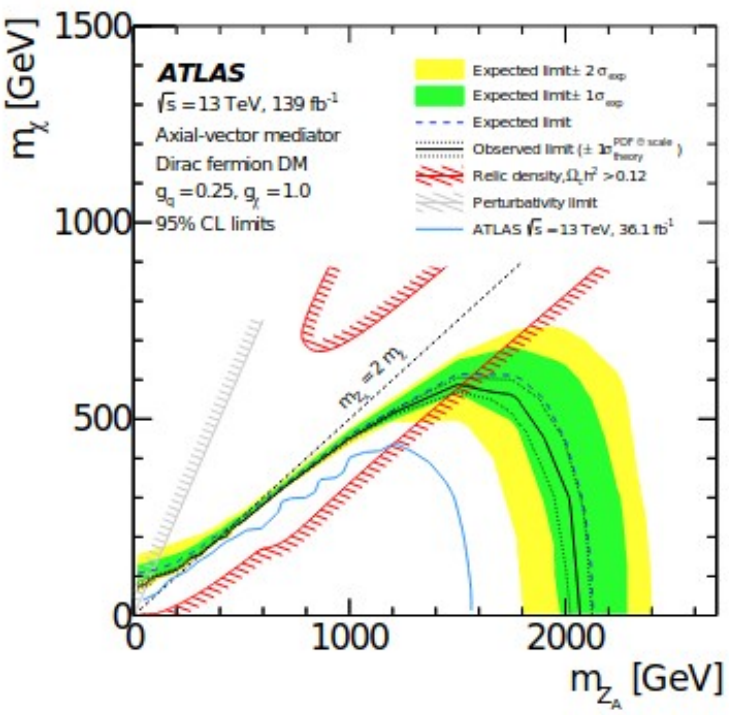
$$\sigma(pp \to Z' j) = \sum_{q_i} g_{q_i}^2 \left[\sigma(q_i \bar{q}_i \to Z' g) + \sigma(q_i g \to Z' q_i) + \sigma(\bar{q}_i g \to Z' \bar{q}_i)\right]$$

Z'-explorer 2.0.

Also, when considering the Z' as a dark matter mediator the mono-jet signature can be crucial in order to set bounds.

We have recasted the ATLAS mono-jet search:

$\longrightarrow$ Bounds for an axial-vector (Z_A) or vector (Z_V) dark matter mediator in the ($M_{Z'}$, m_χ) plane, with $g_\chi = 1$ and $g_q = 0.25$.



(2102.10874)

$$\mathcal{L} \supset -\sum_q g_q Z'_{A\mu} \bar{q}\gamma^\mu\gamma^5 q - g_\chi Z'_{A\mu} \bar{\chi}\gamma^\mu\gamma^5\chi$$

$\longrightarrow$ Event selection:

- $E_T^{miss} > 250$ GeV.
- Veto μ/e.
- $p_{T,j_1} > 250$ GeV, $|\eta_{j_1}| < 2.4$.
- $n_j \leqslant 4$, $p_{T,j} > 30$ GeV, $|\eta_j| < 2.8$, $\Delta\Phi(j, p_T^{miss}) > 0.4$.

Z'-explorer 2.0.

Also, when considering the Z' as a dark matter mediator the mono-jet signature can be crucial in order to set bounds.

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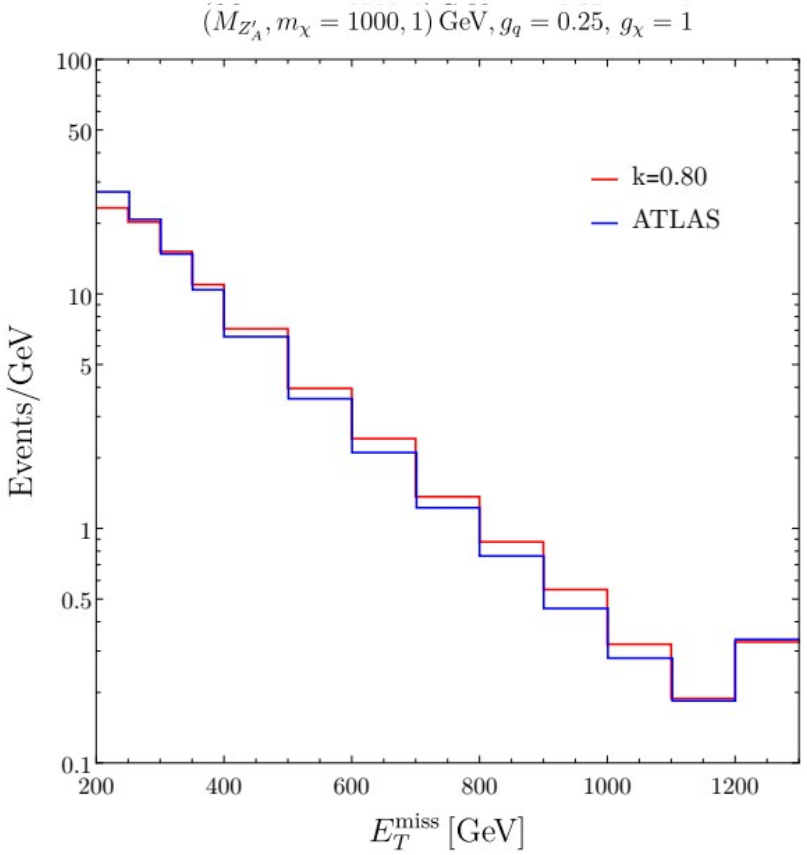
Exclusive	EM0	EM1	EM2	EM3	EM4	EM5	EM6
E_T^{miss} [GeV]	200-250	250-300	300-350	350-400	400-500	500-600	600-700
Predicted	1783000	753000	314000	140100	101600	29200	10000
Exclusive	EM7	EM8	EM9	EM10	EM11	EM12	
E_T^{miss} [GeV]	700-800	800-900	900-1000	1000-1100	1100-1200	> 1200	
Predicted	3870	1640	754	359	182	218	

(2102.10874)

Z'-explorer 2.0.

Simulations performed with MadGraph5_aMC@NLO, Pythia and Delphes (we used the UFO-model Dmsimp).



After event selection in order to match ATLAS distributions we need a k-factor of

k=0.80

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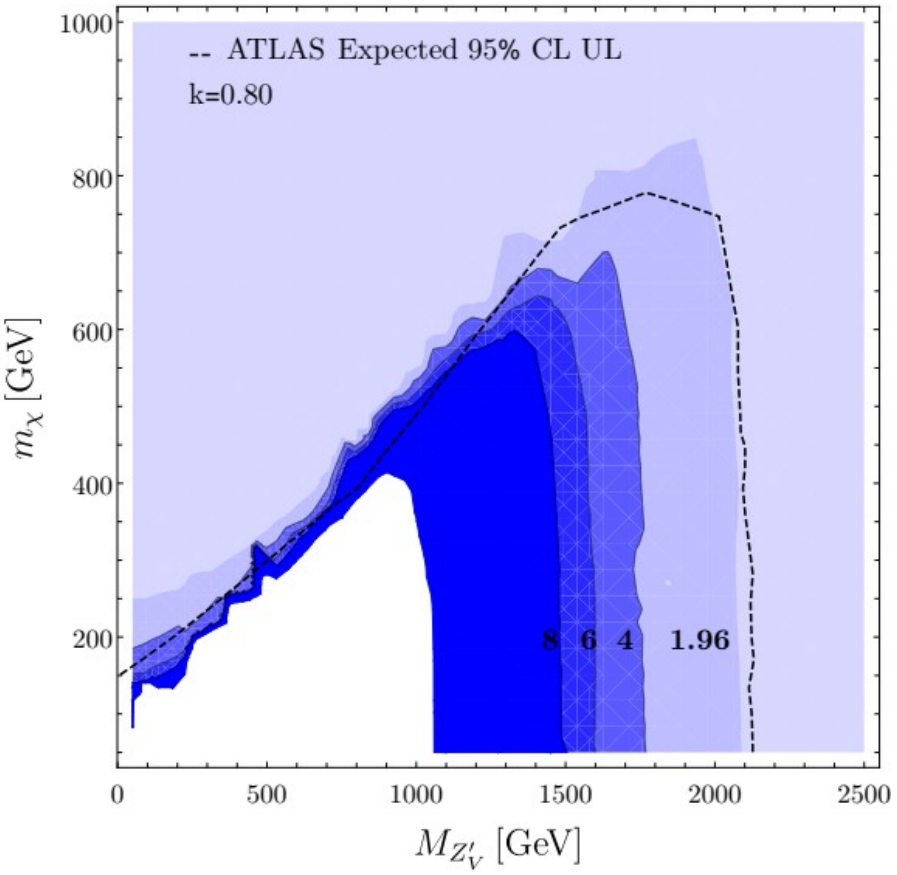
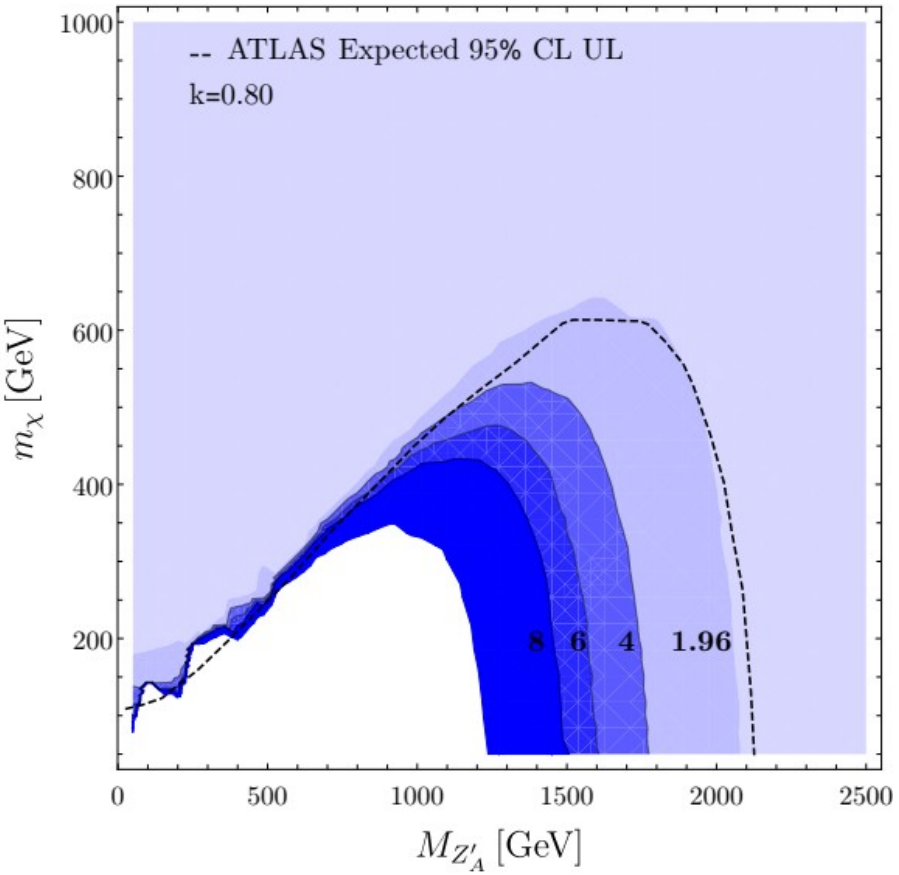
We can now validate our analysis (including the k-factor) against ATLAS results to see how well is the performance.

Our analysis matches pretty well the ATLAS monojet limits.





Z'-explorer 2.0.

Z'-explorer 2.0 has the following searches implemented:

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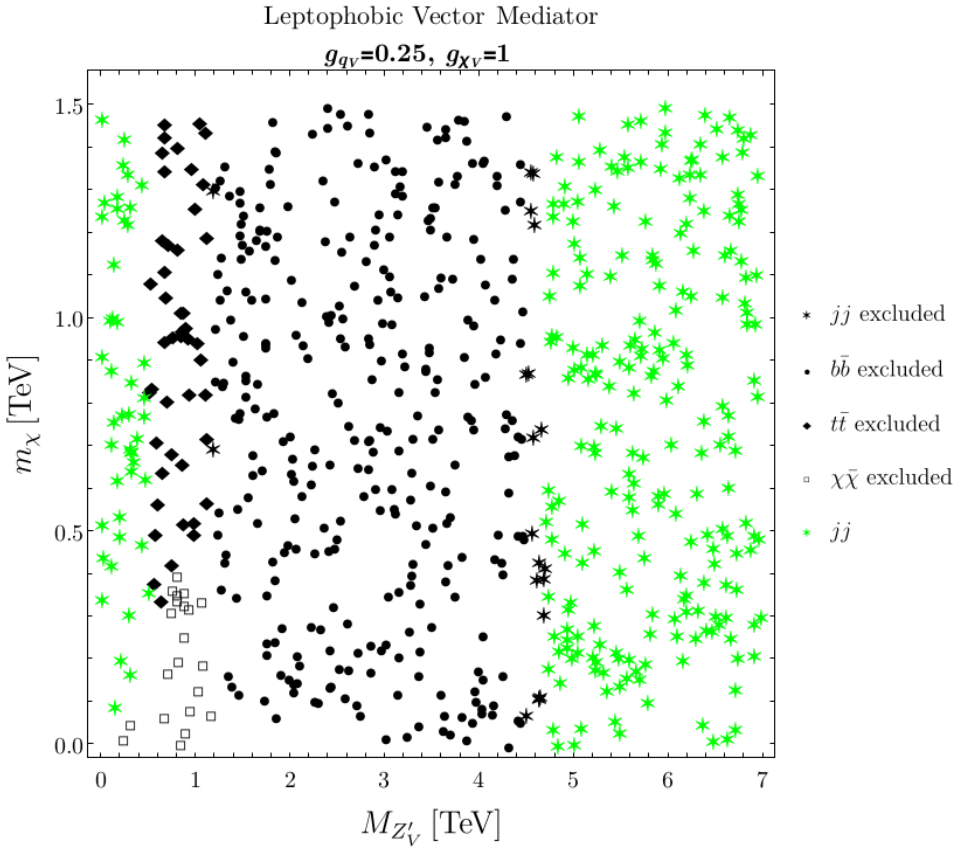
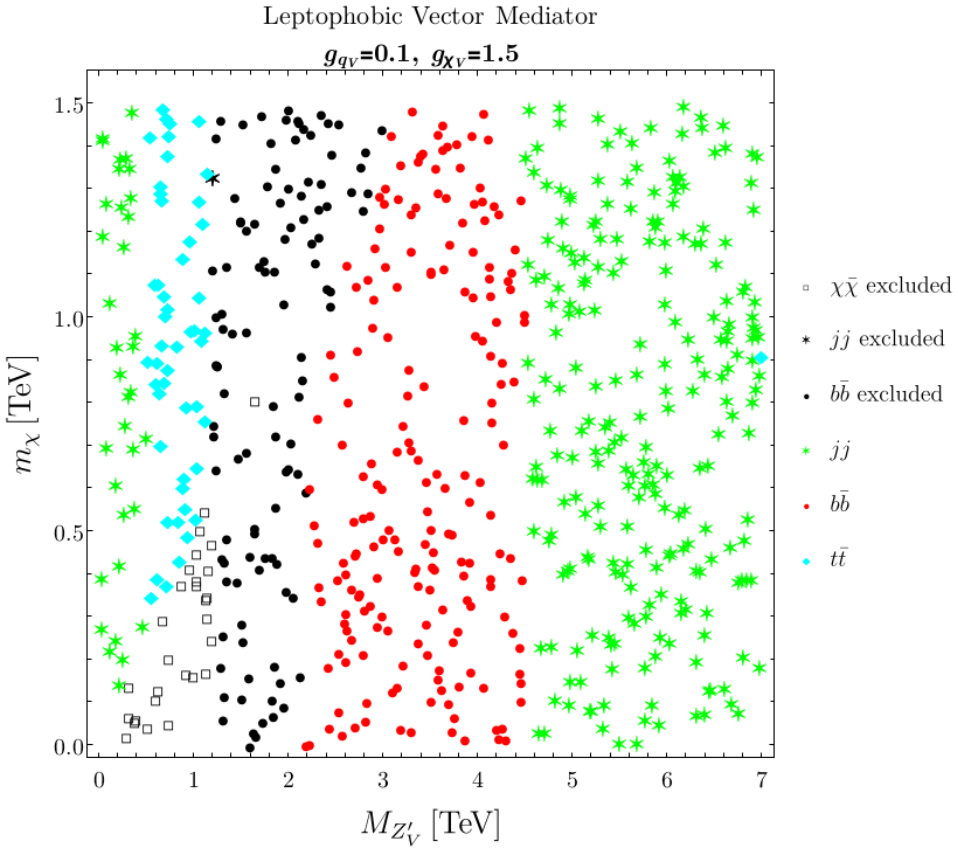
Channel	Luminosity	Collaboration	
jj (dijet)	139 fb^{-1}	ATLAS	(1910.08447)
$b\bar{b}$	139 fb^{-1}	ATLAS	(1910.08447)
$t\bar{t}$	35.9 fb^{-1}	CMS	(1810.05905)
e^+e^-	137 fb^{-1}	CMS	(2103.02708)
$\mu^+\mu^-$	140 fb^{-1}	CMS	(2103.02708)
$\tau^+\tau^-$	36.1 fb^{-1}	ATLAS	(2109.06055)
W^+W^-	36.1	ATLAS	
Zh	35.9 fb^{-1}	CMS	(1906.00057)
$\chi\bar{\chi}$ (monojet)	139 fb^{-1}	ATLAS	(2102.10874)

However, this list will be updated once new analysis and searches are performed for larger luminosities.

Results.

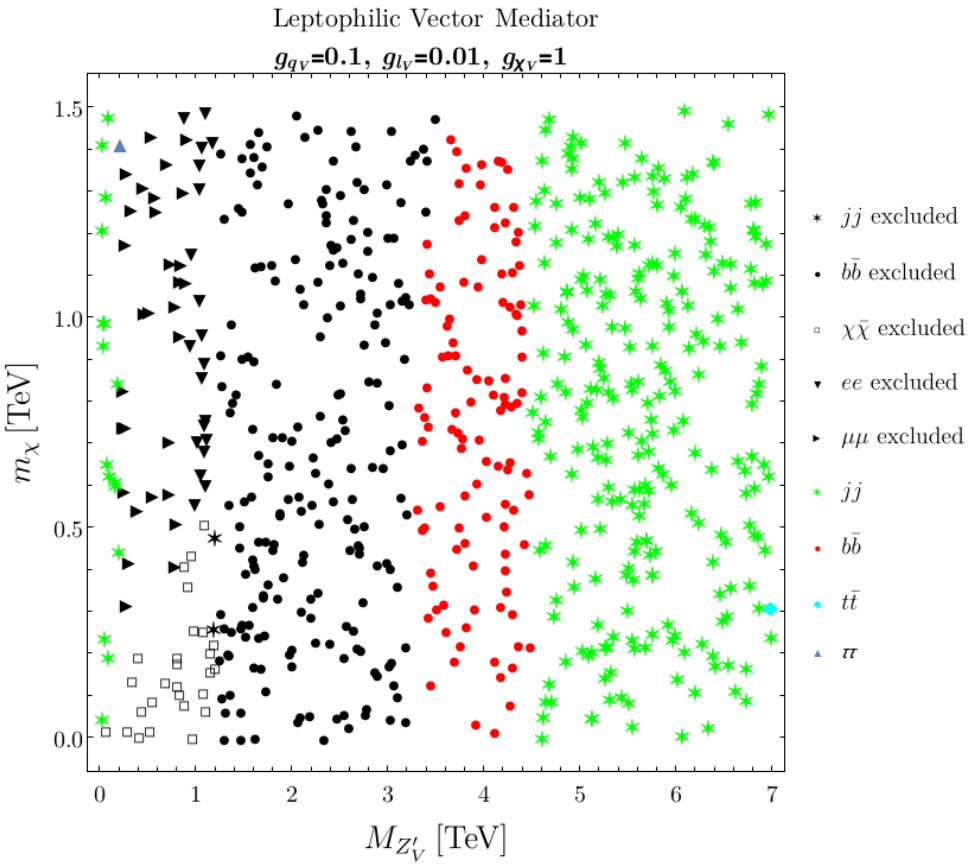
We set $g_l = 0$ so the Z' does not couple to leptons.

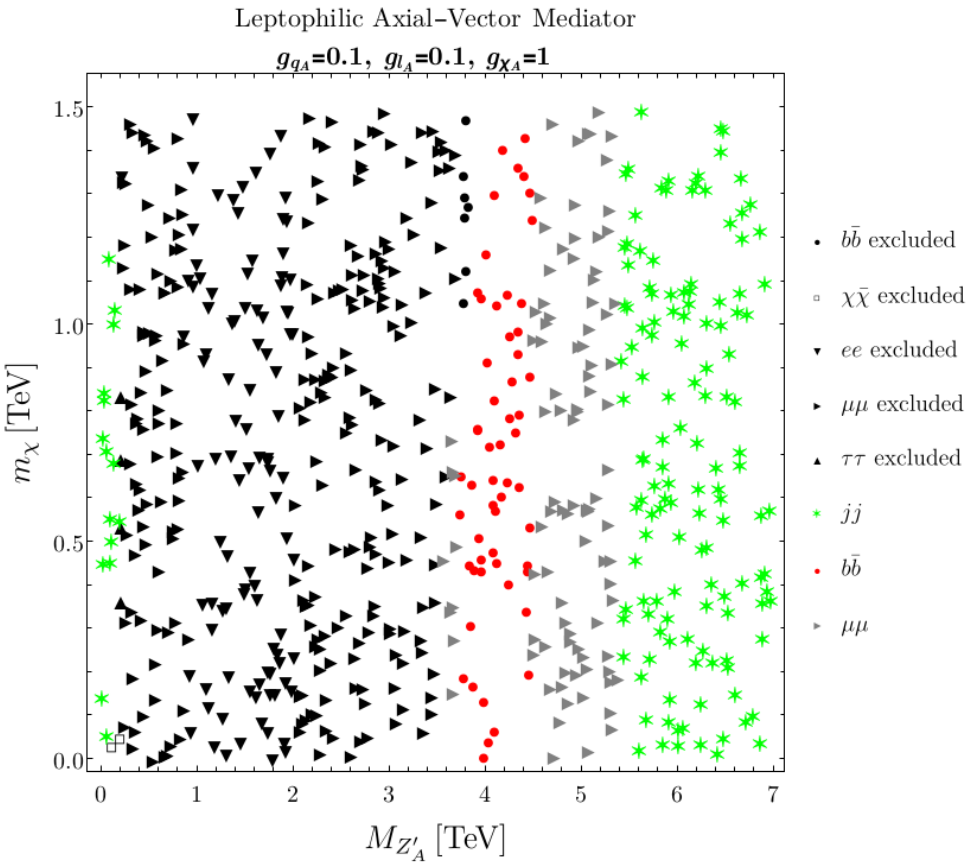




Results.

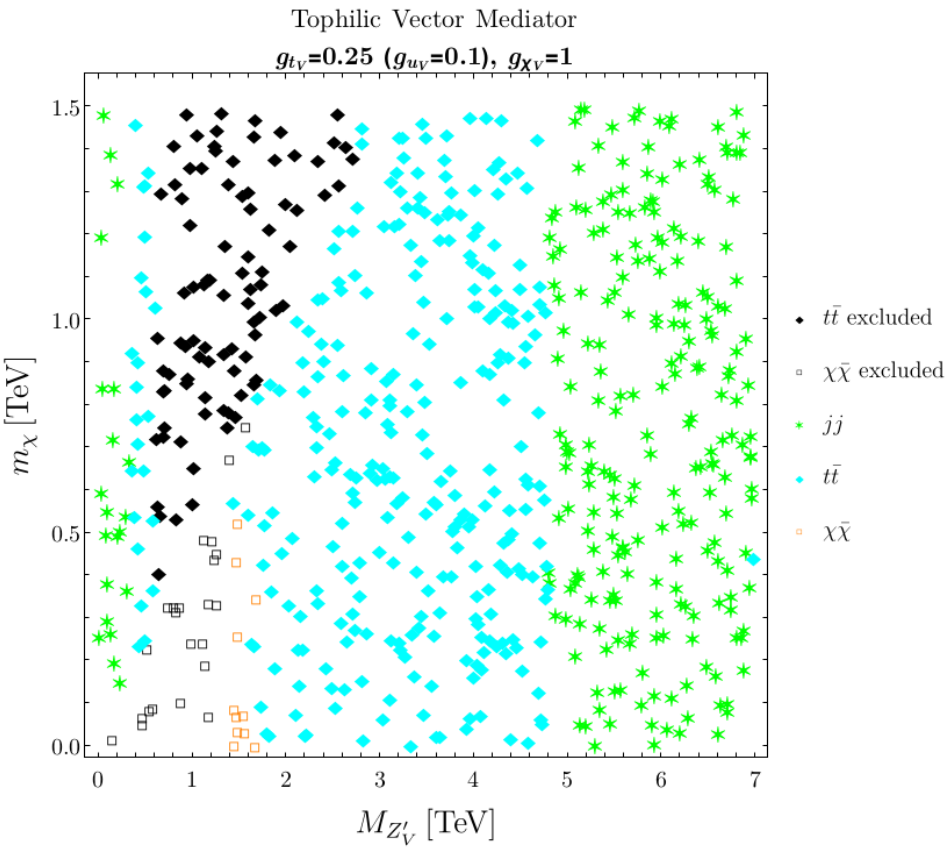
We allow the Z' to couple to both quarks and leptons.

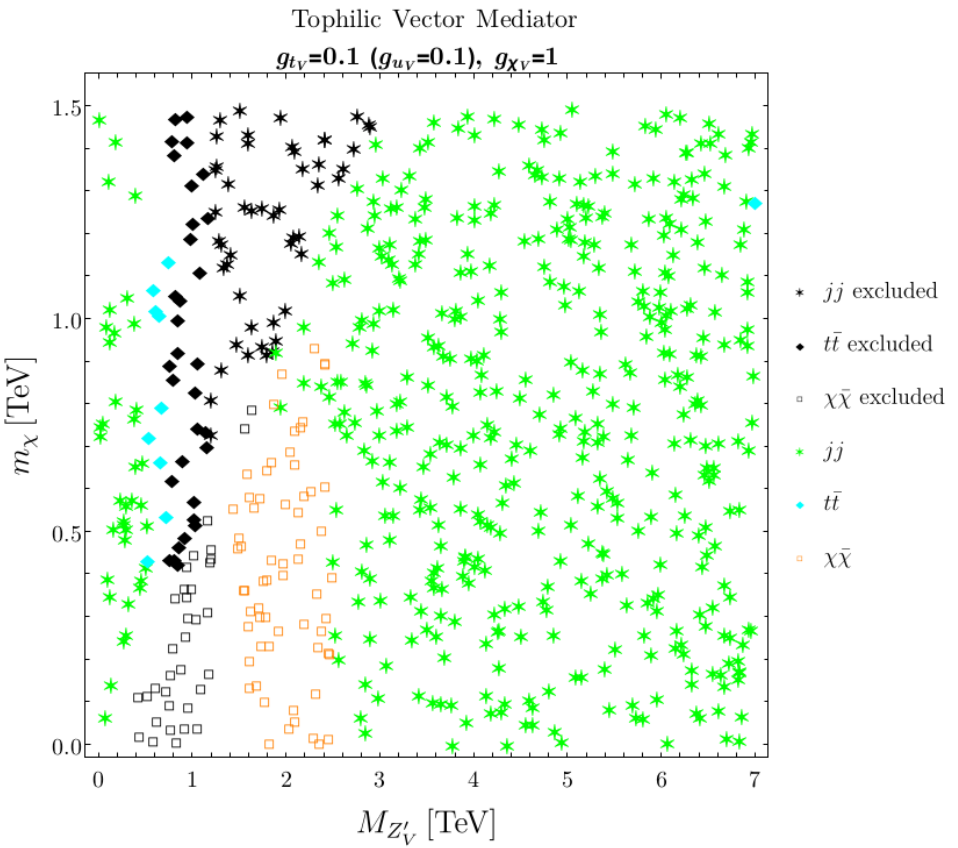




Results.

We set $g_l = 0$ so the Z' does not couple to leptons and we fix the couplings so the the Z' coupling to top quarks dominates.





Results.

We can try now with a more complicated model: a Stückelberg portal from D6 branes.

$$SU(3)_c \times SU(2)_L \times U(1)_V^A \times U(1)_V^B \times U(1)_V^C \times U(1)_V^D \times U(1)_h^m \times G_h$$

Matter field	Q_A	Q_B	Q_C	Q_D	Y
Q_L	1	-1	0	0	1/6
q_L	1	1	0	0	1/6
U_R	-1	0	1	0	-2/3
D_R	-1	0	-1	0	1/3
L	0	-1	0	-1	-1/2
E_R	0	0	-1	1	1
N_R	0	0	1	1	0

$$Q^Y = \frac{1}{6}(Q_A - 3Q_C + 3Q_D).$$

$$g_\alpha^{Z'} = aQ_{\alpha A} + bQ_{\alpha B} + cQ_{\alpha C} + dQ_{\alpha D} + \sum_{i=1}^{m} h_i Q_{\alpha i}^h,$$

JHEP 11 (2001) 002. (hep-th/0105155)
Phys. Rev. Lett. 113 (2014) 061802. (1401.5880)
JHEP 05 (2014) 065. (1401.5890)
JHEP 04 (2015) 175. (1503.01780)

Results.

We have chosen three different scenarios:

Scenario	a	b	c	d	g_χ^L	g_χ^R
1	0.07	0.00058	0.01	0.006	1.0	-1.0
2	-0.025	-0.005	0.005	0.025	1.0	1.0
3	0.1	-0.01	0.01	0.01	1.0	1.0

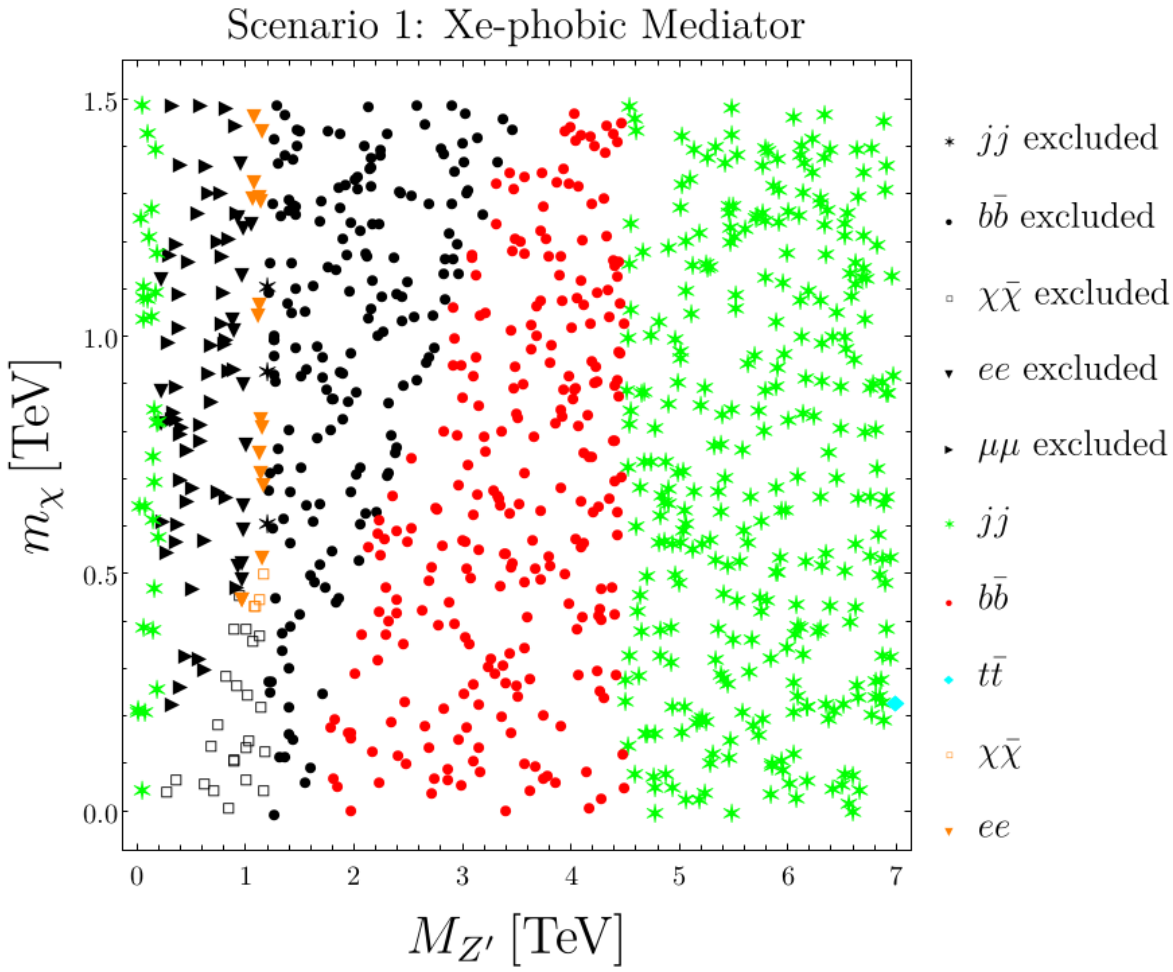
Scenario 1: Xe-phobic case, the amount of isospin violation makes it less sensitive to Xenon based direct detection experiments

Scenario 2: b-quark couplings are reduced so we have an enhancement in the leptonic channels.

Scenario 3: Vector and axial couplings of the leptons are chosen in such a way that they cancel giving rise to a leptophobic scenario.

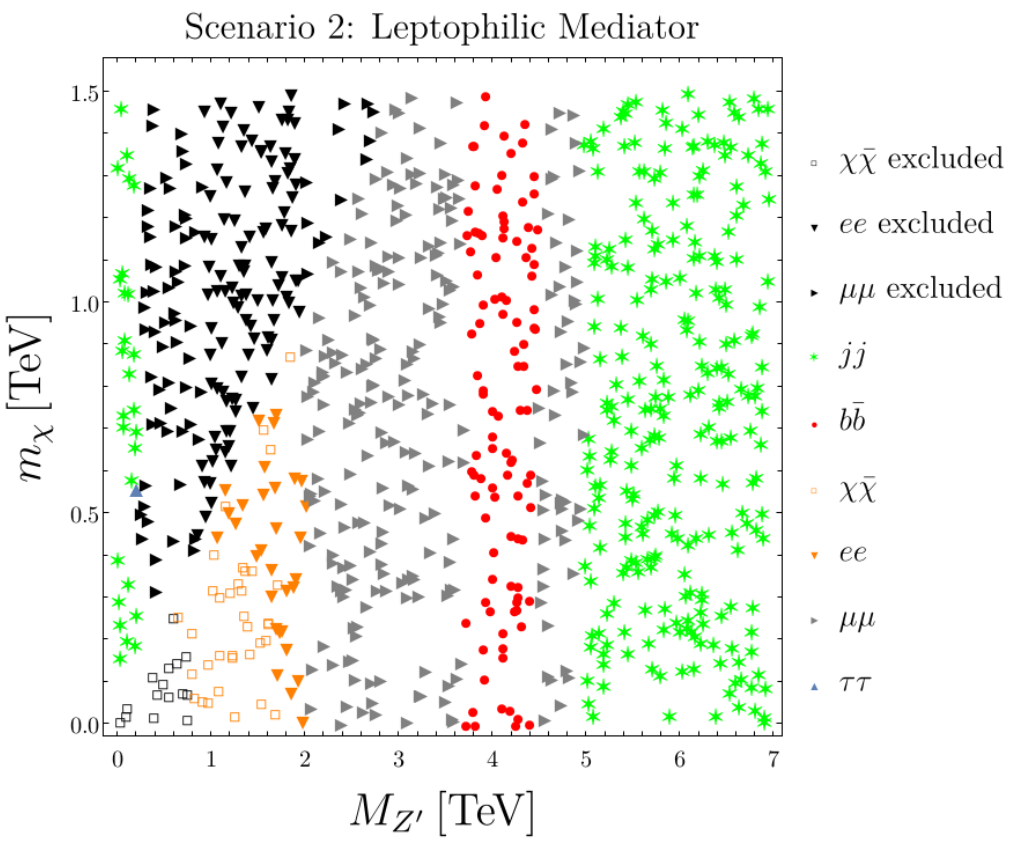
Results.

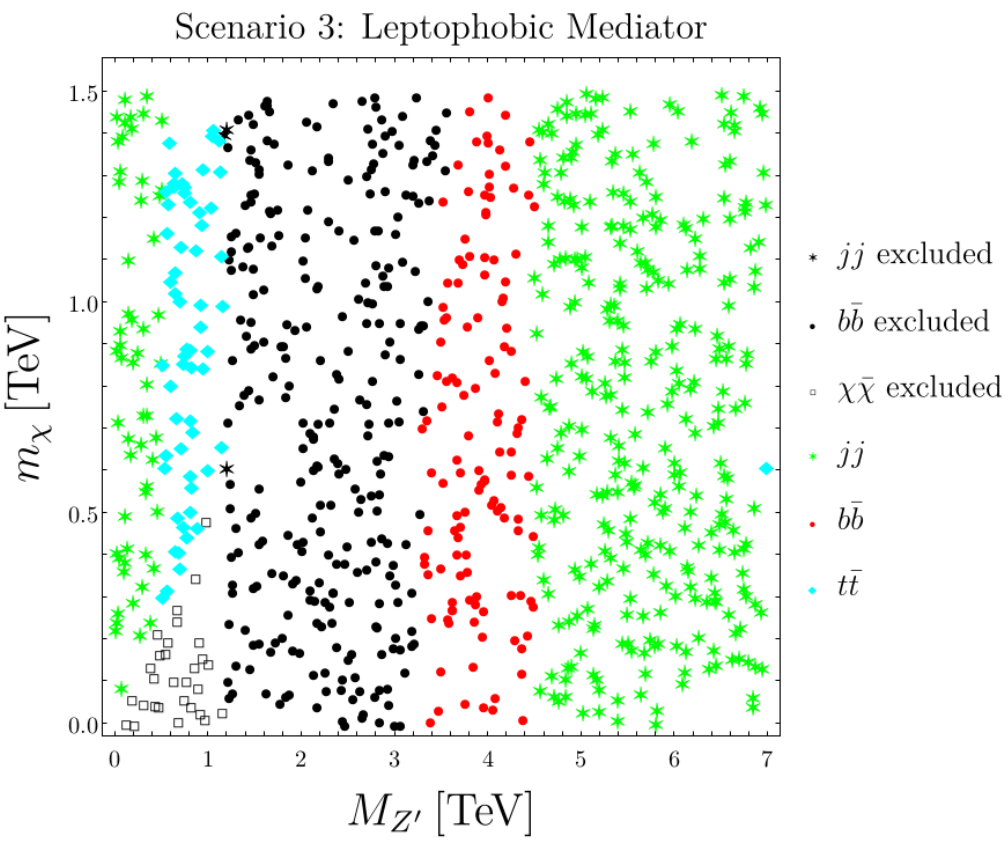
Scenario 1: Xe-phobic mediator.



Results.

Scenarios 2 and 3: Leptophilic and leptophobic mediator.





Conclusions.

-Z'-explorer is able to set bounds on models with an extra U(1).

-It determines the most sensitive channel according to LHC searches.

-It includes all the dijet, dilepton and different Z' searches from ATLAS and CMS experiments.

-It also includes ATLAS mono-jet search at 139 fb^{-1} (first one) and it is validated with ATLAS results.

-Future: other mono-X searches, include computation of DM observables, finite width effects, low Z' masses...

-All the information about Z'-explorer can be found here:
`https://github.com/ro-sanda/Z-explorer-2.0`
`https://gitlab.com/v.martin.lozano/Z-explorer-2.0`

Thank you!

감사합니다