DARK PORTALS AT DIRECT DETECTION

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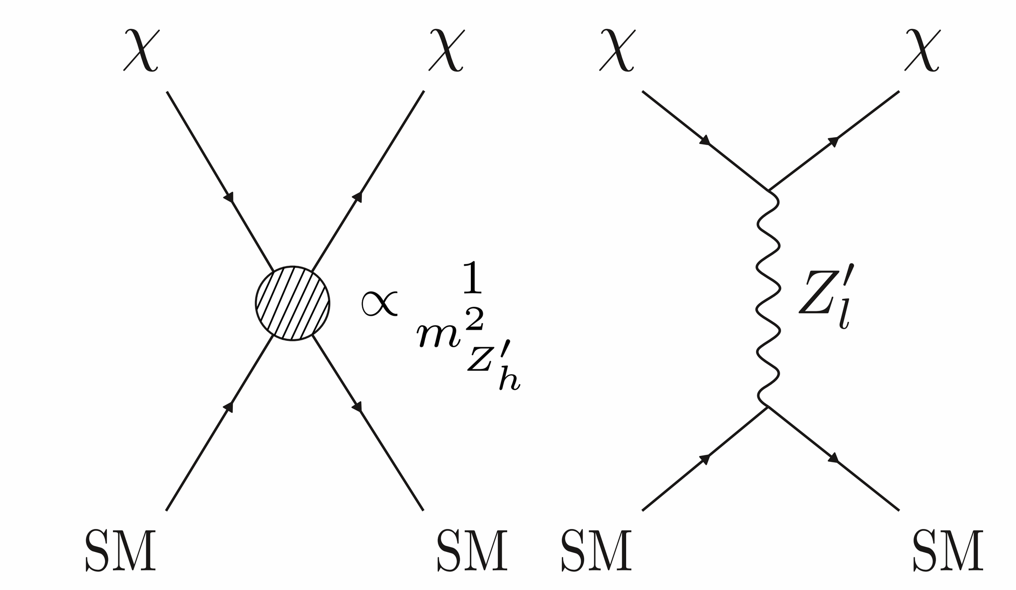
THE BI-PORTAL MODEL



- Direct detection experiments aim to detect dark matter (DM) - Standard Model (SM) interactions directly within the detector material
- Nuclear recoil is the most prominent option for DM-SM interaction with recoil energies of order keV
- Interaction with quarks in nucleus via some mediating particle (usually beyond SM particles) [1] [2]
- New model where DM-SM scattering takes place via two mediators (bi-portal model):

$$\mathcal{L}_{int} = g_{qh} Z'_h \bar{q}\gamma^\mu q + g_{\chi h} Z'_h \bar{\chi}\gamma^\mu \chi + +g_{ql} Z'_l \bar{q}\gamma^\mu q + g_{\chi l} Z'_l \bar{\chi}\gamma^\mu \chi$$

- One heavy vector mediator Z'_h with mass $m^2_{Z'_h} \gg q^2$ and one light vector mediator Z'_l with mass $m^2_{Z'_l} \leq q^2$

- Expected number of recoil events given by nuclear recoil spectrum:

$$\frac{dR}{dE_R} = \frac{\rho_x}{m_N m_\chi} \int_{v_{min}}^{v_{esc}} d^3v\, f(\vec{v}) v \frac{d\sigma(\vec{v}, E_R)}{dE_R} \quad (1)$$

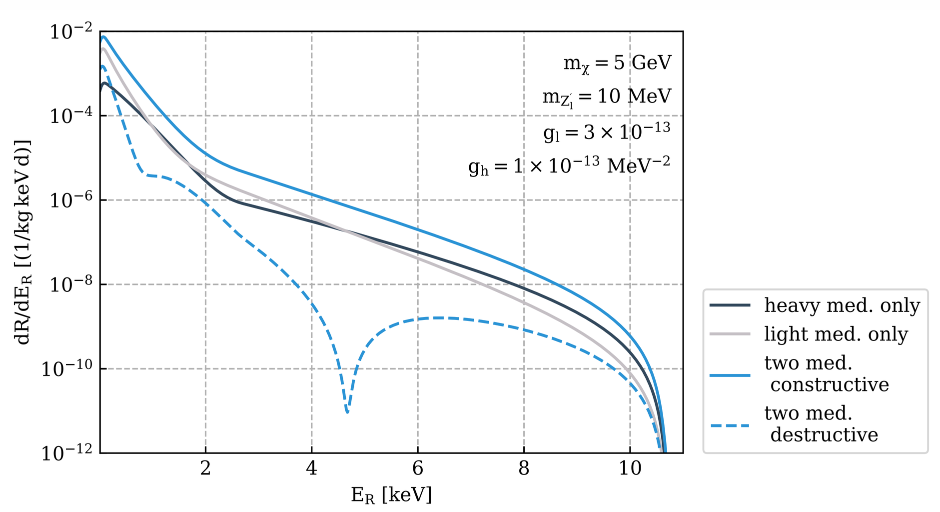
- Spin-independent cross section from Lagrangian (see Feynman diagram) and simplified model approach
- Second mediator in the DM-SM interaction leads to an interference term in the cross section

$$\frac{d\sigma}{dE_R} \propto g_h^2 + \frac{2 g_h g_l}{(2E_R m_N + m^2_{Z'_l})} + \frac{g_l^2}{(2E_R m_N + m^2_{Z'_l})^2} \quad (2)$$

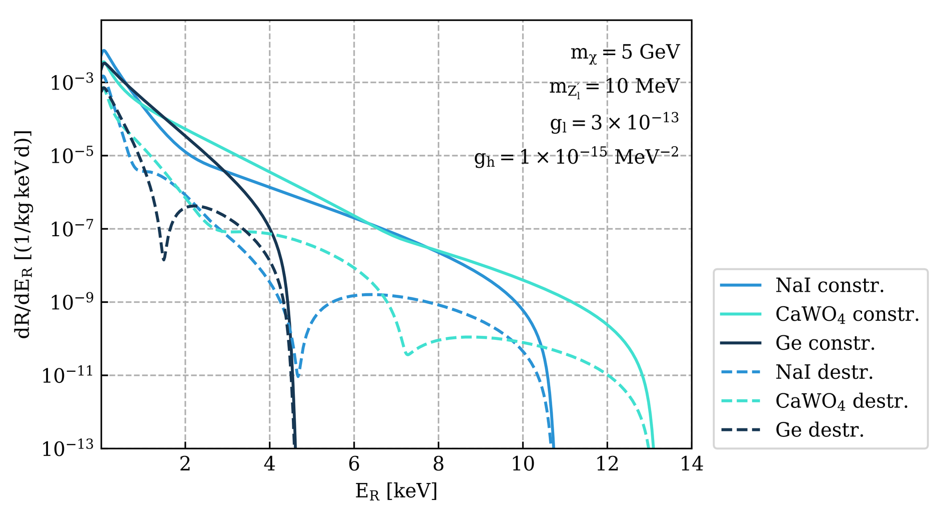
where $g_l = g_{ql} g_{\chi l}$ and $g_h = \frac{g_{qh} g_{\chi h}}{m^2_{Z'_h}}$ an effective coupling

- Differentiate between a constructive and a destructive interference case, depending on the couplings
- Achieve nuclear recoil spectra with shapes distinct from single mediator models
- In the destructive case the interference term leads to prominent dips and kinks in the spectrum
- One destructive feature per element component in the target (i.e. one dip for Ge but three for $CaWO_4$)

TWO MEDIATORS ON NaI



TWO MEDIATORS ON VARIOUS MATERIALS



EXCLUSION LIMITS

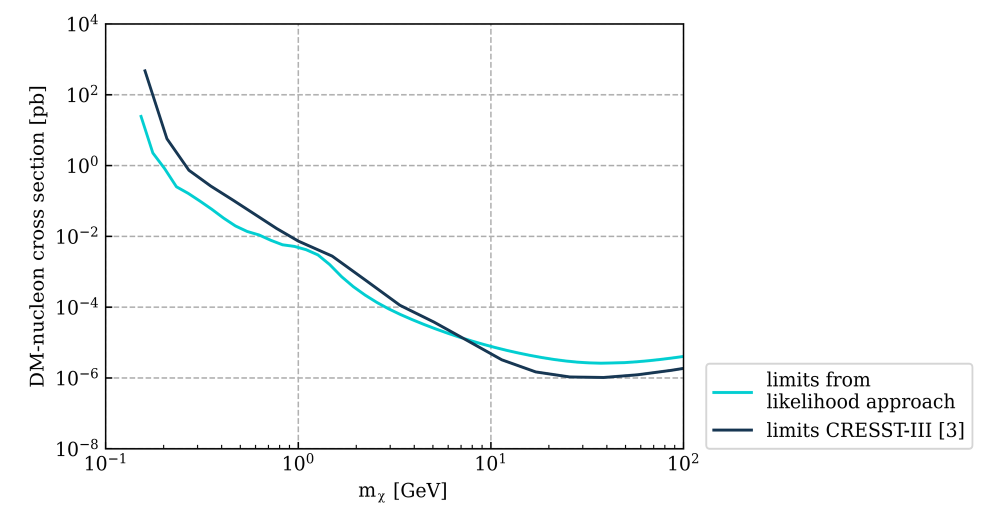
- Calculate 90 % confidence level exclusion limits from data published for the CRESST-III experiment ($CaWO_4$ target) [3] and mock background data based on the projections for the COSINUS experiment (NaI target) [4]
- Choice of experiments due to high resolution and composite target materials containing elements with strong variation in their atomic weights
- We use a profile likelihood ratio approach, which takes the unique shape of spectra in the bi-portal model into account
- Using binned as well as unbinned likelihood functions depending on the counts N_s in the background mock sample $[E_1, \ldots, E_{N_s}]$ (subject to target and exposure)
- Unbinned extended likelihood function reads

$$L(\theta) = \frac{N(\theta)^{N_s}}{N_s!} e^{-N(\theta)} \prod_{i=1}^{N_s} \underbrace{\frac{\frac{dR}{dE}(E_i, \theta)}{N(\theta)}}_{pdf} \quad (3)$$

where $N(\theta) = \int_{E_{thr}}^{E_{max}} dE' \frac{dE}{dR}(E', \theta)$

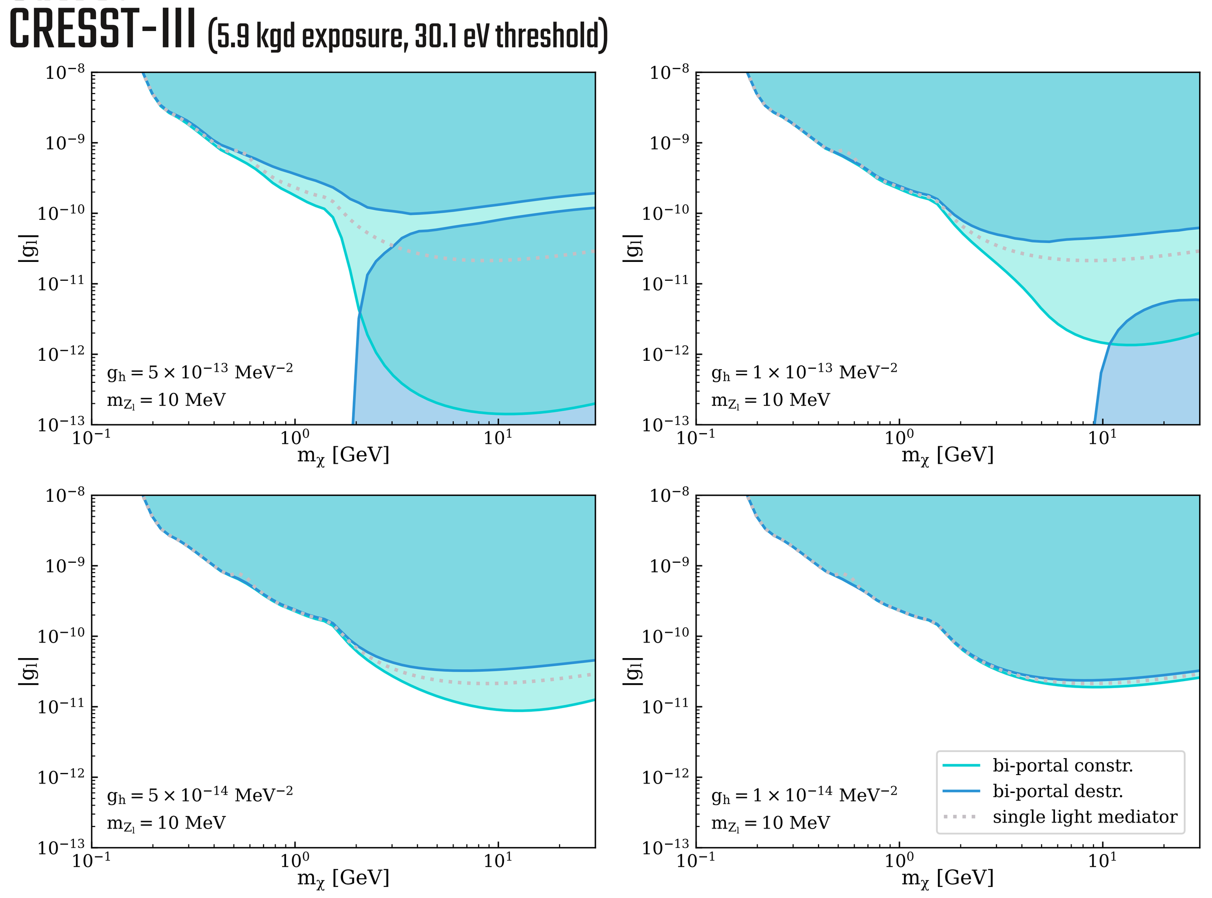
- Validated likelihood approach by reproducing official CRESST limits for the CRESST-III dataset [3]. Used exponential distribution to model the background

$CaWO_4$ CRESST-III (5.9 kgd exposure, 30.1 eV threshold)



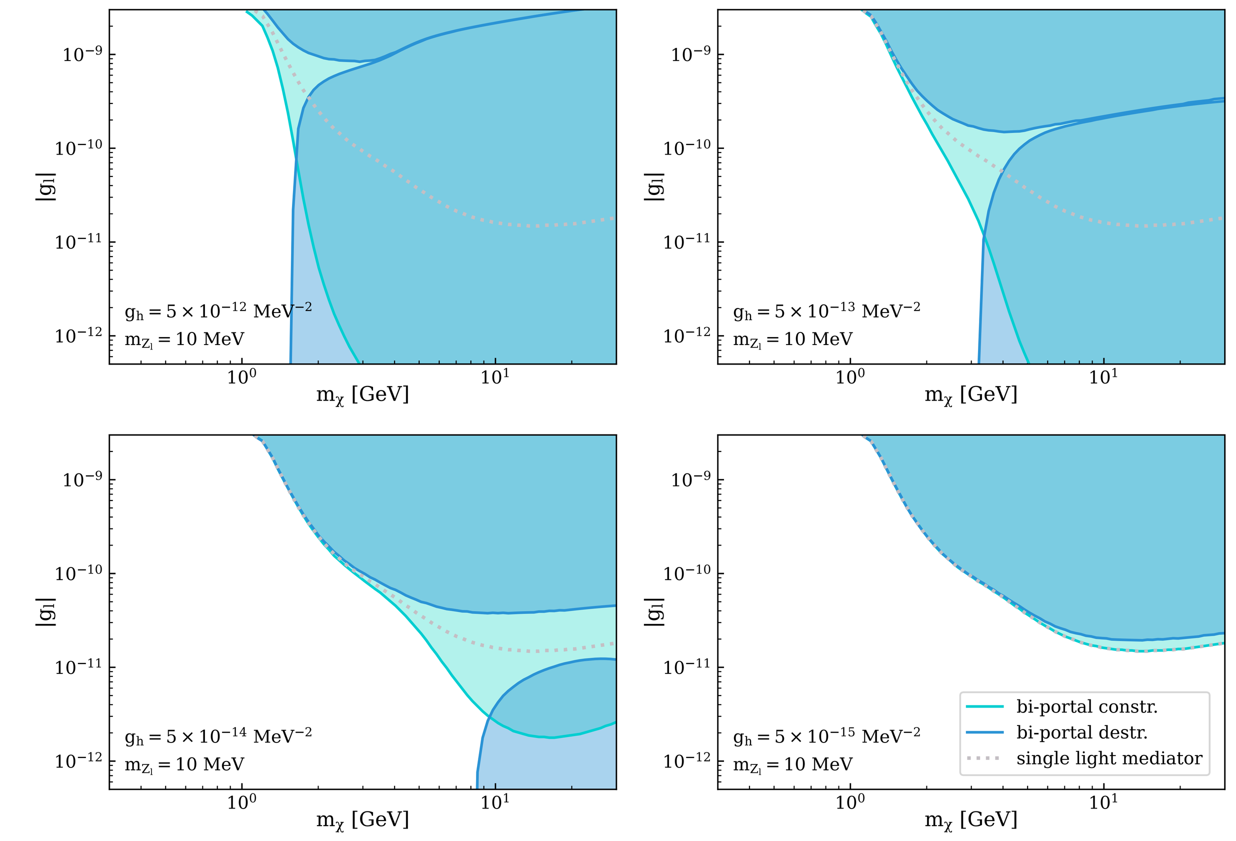
- Exclusion limits on the free parameters of the bi-portal model from CRESST-III data using the likelihood approach and an exponential background model
- Limits in the bi-portal model are shown together with a single light mediator case in comparison (grey line):

$CaWO_4$ CRESST-III (5.9 kgd exposure, 30.1 eV threshold)



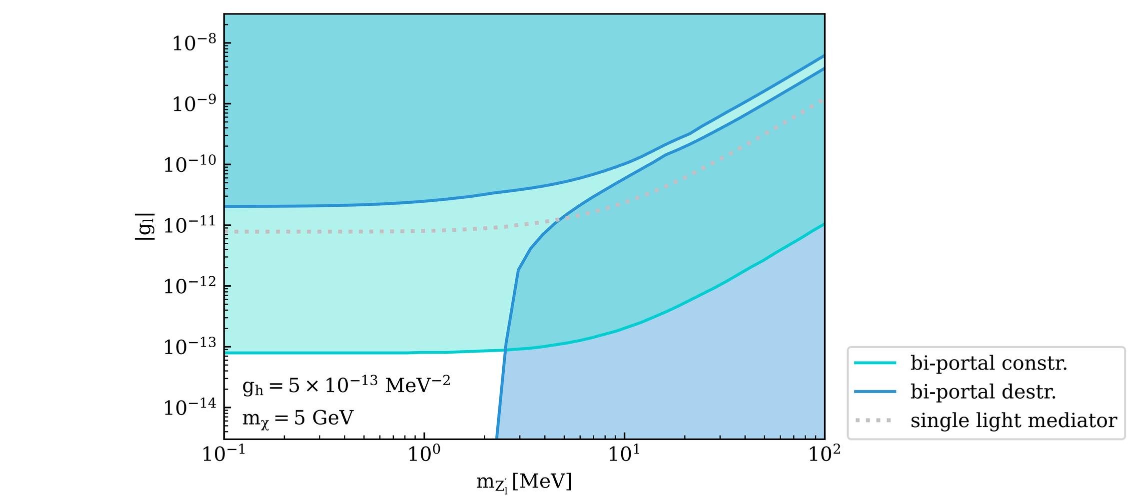
- Compared to a single light mediator the constructive bi-portal model gives stronger limits and the destructive case leads to additional allowed regions of parameter space
- For small values of g_h exclusion limits for the bi-portal model start to represent a single light mediator limit
- Limits calculated from mock data based on a flat background for COSINUS lead to similar results:

NaI COSINUS-LIKE (100 kgd exposure, 1 keV threshold)



- In the $m_{Z'_l}$ - g_l exclusion plane the constructive case gives stronger limits than a single light mediator while the destructive case results in band-like limits

$CaWO_4$ CRESST-III (5.9 kgd exposure, 30.1 eV threshold)



CONCLUSION

- Introducing a second mediator to the DM-SM interaction leads to interference effects, which in turn result in nuclear recoil spectra distinct from a single mediator case
- Analysis of biportal models is most interesting for composite targets with strong variation is atomic weights. Analysis from existing and mock background data opens up new regions of viable parameter space and possibilities to compare with results from collider and indirect DM searches

REFERENCES

[1]: Prateek Agrawal et al. "A Classification of Dark Matter Candidates with Primarily Spin-Dependent Interactions with Matter". 2010. arXiv: 1003.1912.
[2]: Tai Li, Sen Miao, and Yu-Feng Zhou. "Light mediators in dark matter direct detections". DOI 10.1088/1475-7516/2015/03/032.
[3]: CRESST Collaboration. "Description of CRESST-III Data". 2020. arXiv: 1905.07335
[4]: G. Angloher et al. "The COSINUS project: perspectives of a NaI scintillating calorimeter for dark matter search". DOI: 10.1140/epjc/s10052-016-4278-3.