Measuring mediator masses with low-threshold direct detection experiments

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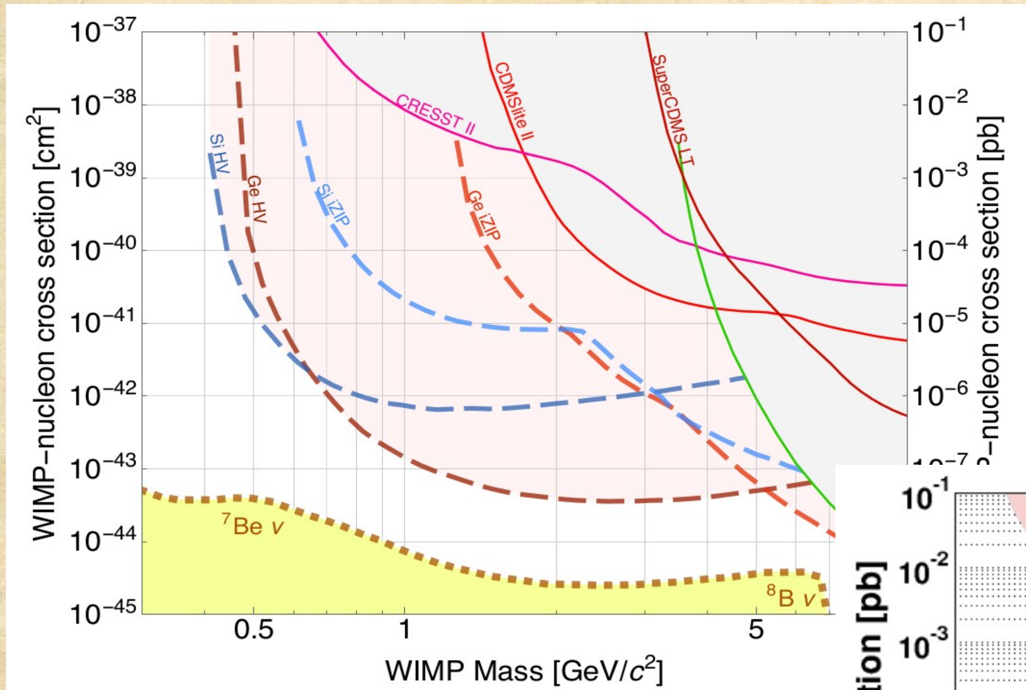
[1707.08571]: Felix Kahlhoefer, Suchita Kulkarni, SW

+ a little bit of [1704.02149]: Felix Kahlhoefer, Kai Schmidt-Hoberg, SW

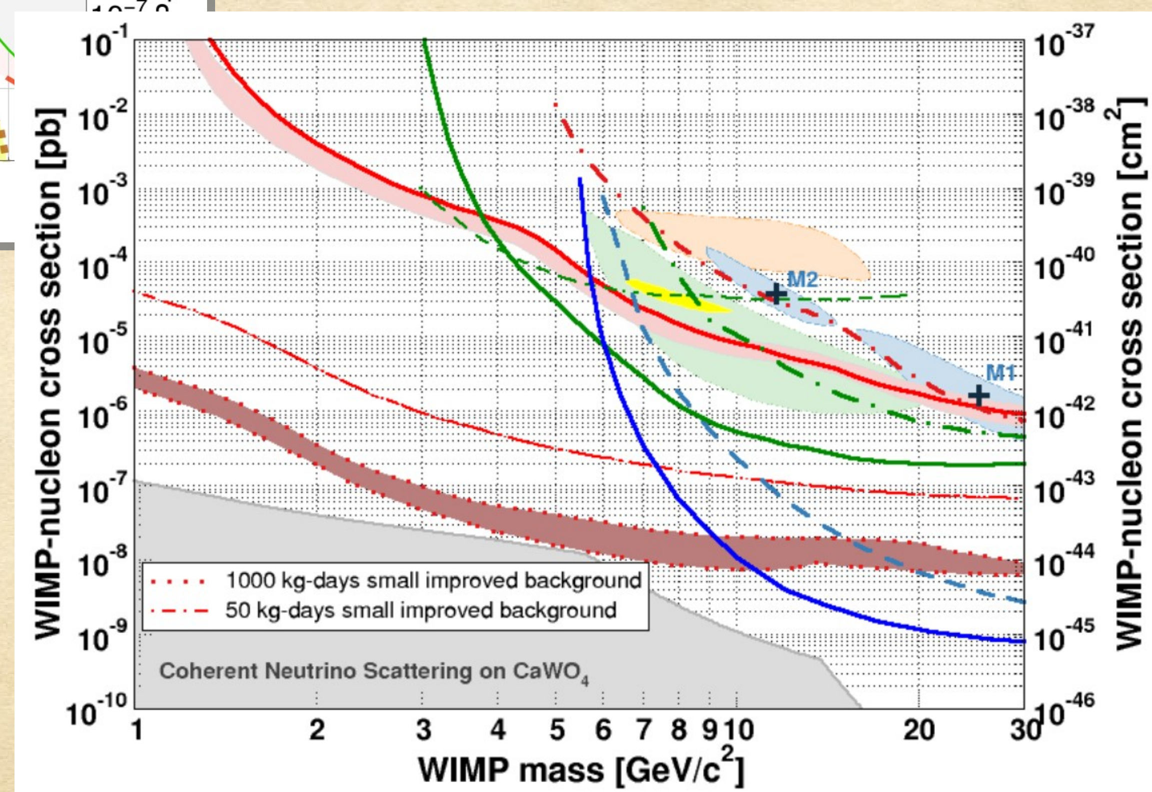
DESY Theory Workshop 2017

Bright future for low-threshold experiments

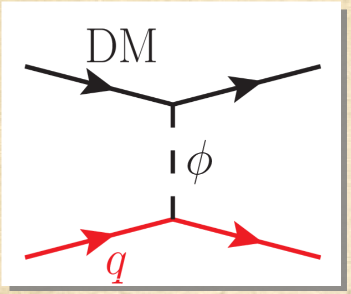
SuperCDMS collaboration [1610.00006]



CRESST collaboration [1503.08065]



Sensitivity of DD to light (MeV) mediators



$$\propto \frac{g}{q^2 + m_\phi^2}$$

→ Low threshold is even more important for light mediators (steeply falling spectrum)

see also DelNobile& [1507.04007]

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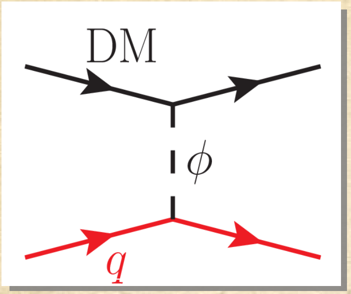

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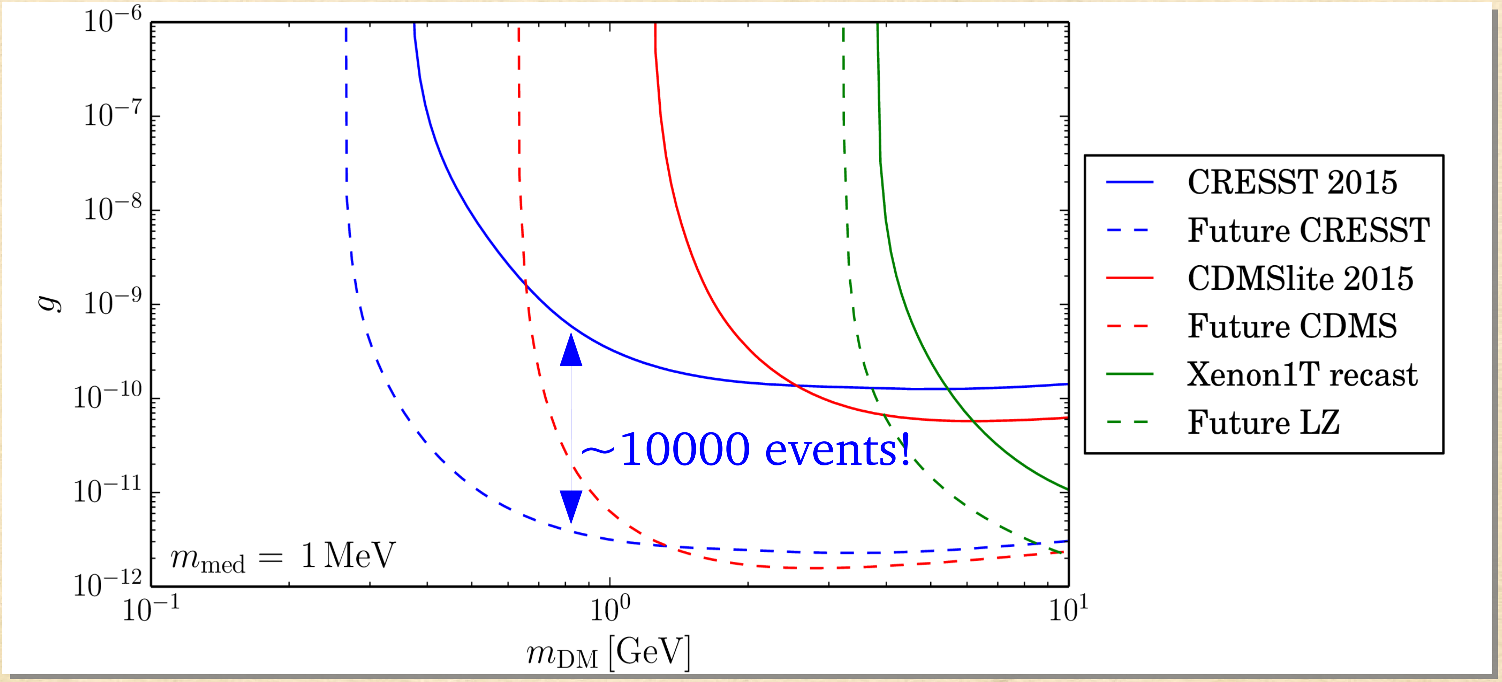


- Spectrum depends sensitively on m_ϕ if $m_\phi \sim q \equiv \sqrt{2 m_T E_T} \sim (1 - 100)\,\mathrm{MeV}$

→ Measuring **mediator masses** with direct detection?

Parameter reconstruction

(1) Choose a benchmark point $(m_{\rm DM}, m_\phi, g)$

→ must be compatible with current exclusion limits

(2) Generate mock data for CRESST-III and SuperCDMS@SNOLAB

→ set of observed events N_i binned in energy (incl. energy resolution)

→ typically between 500 and 8000 events in total

(3) Which combinations of $(m_{\rm DM}, m_\phi)$ provide a good fit to the data?

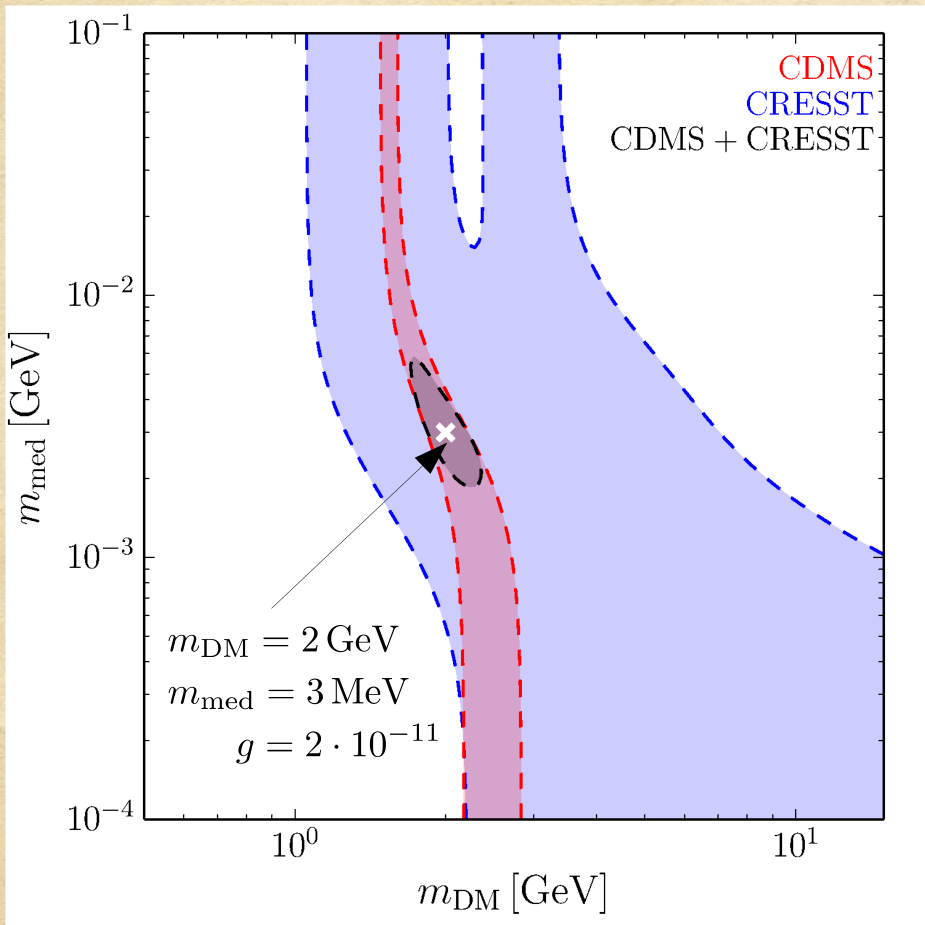
→ we always profile out the coupling strength g

→ **binned profile likelihood**, allowing us to consider **nuisance parameters**:

- background normalization
- coupling ratio f_n/f_p
- astrophysical uncertainties (varying v_0, $v_{\rm local}, v_{\rm esc}$)

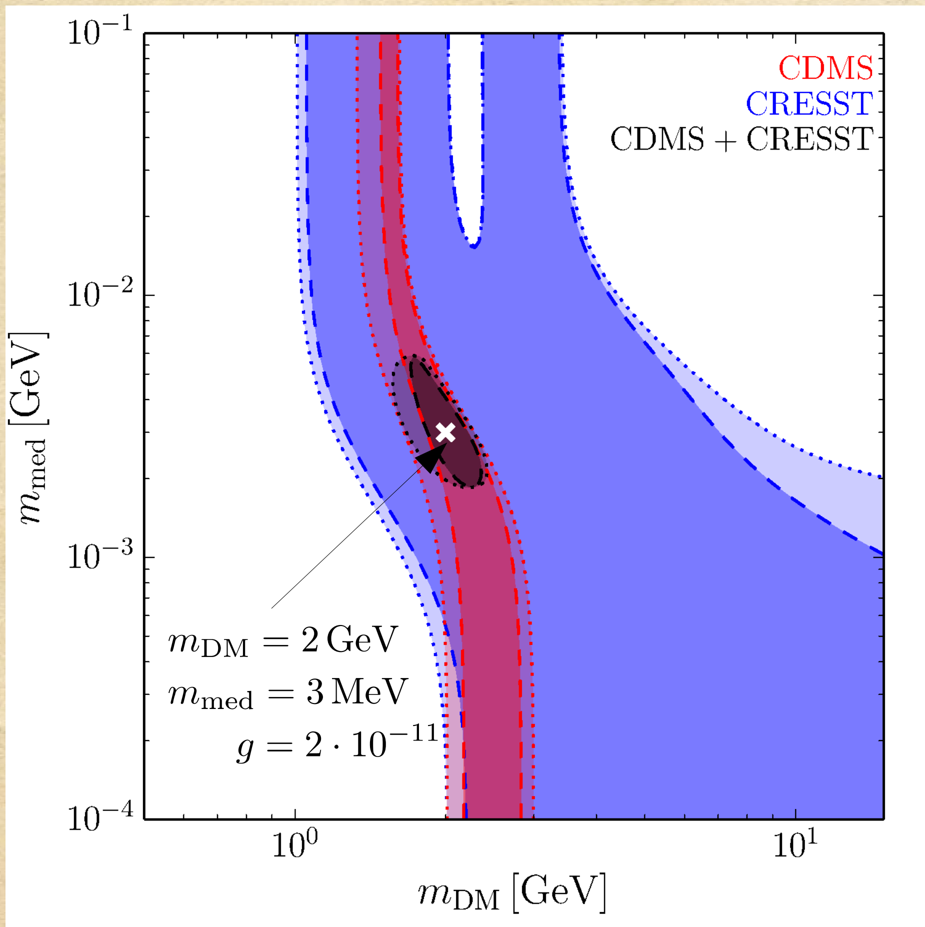
→ Realistic assessment of the potential of future low-threshold experiments!

Parameter reconstruction: an example



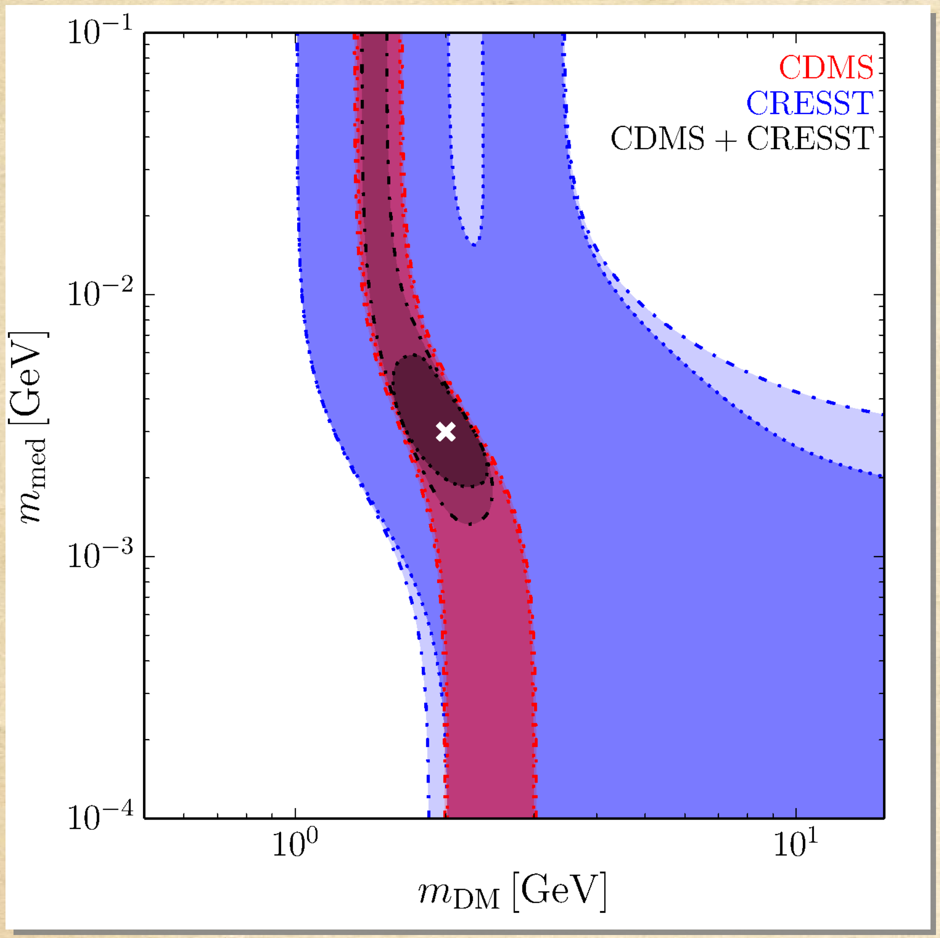
- For this benchmark point:
  $N_{\rm CDMS} \simeq 700,\ N_{\rm CRESST} \simeq 200$
- In this plot:
  no additional nuisance parameters
- Two branches for CRESST:
  scattering of Ca/O vs. W
- Smaller $m_{\rm DM}$ can be (partially) compensated by larger $m_{\rm med}$
- **Strong complementarity** of CDMS and CRESST!

Parameter reconstruction: an example



- Treating **background normalizations** as free parameters enlarges the allowed region in parameter space

Parameter reconstruction: an example



- Treating **background normalizations** as free parameters enlarges the allowed region in parameter space
- In this example, allowing f_n/f_p to float freely opens the combined CDMS+CRESST contour to large $m_{\rm med}$

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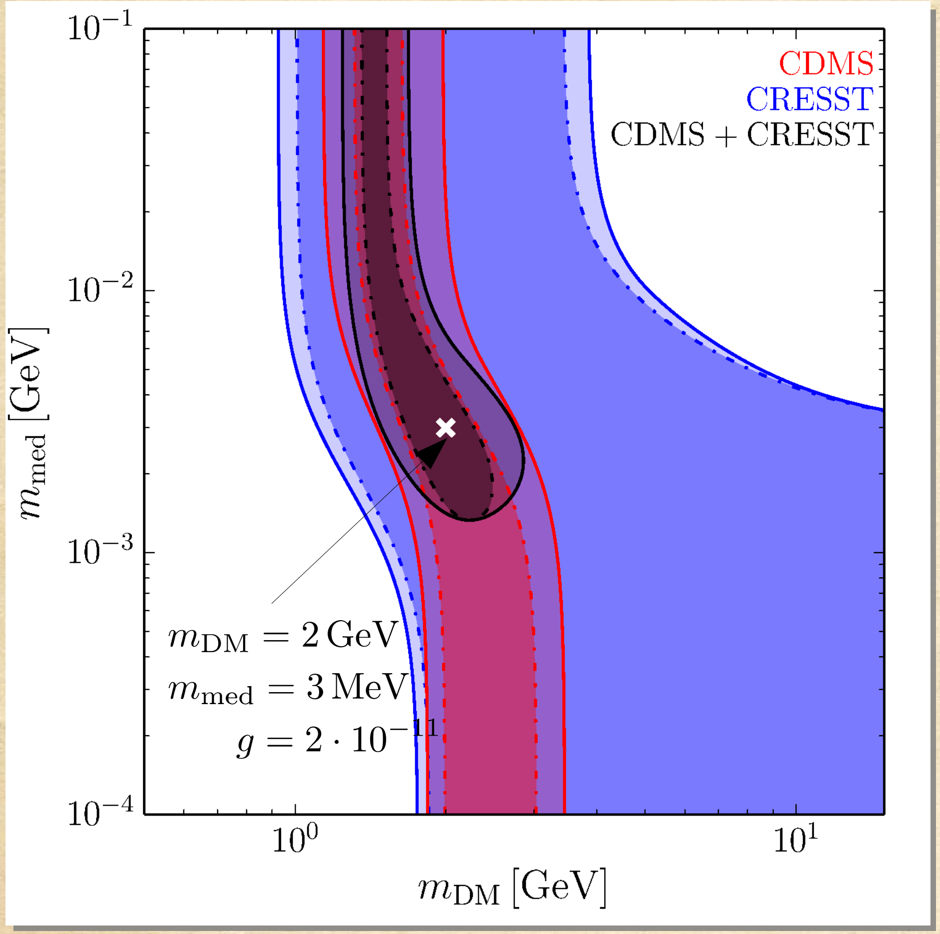
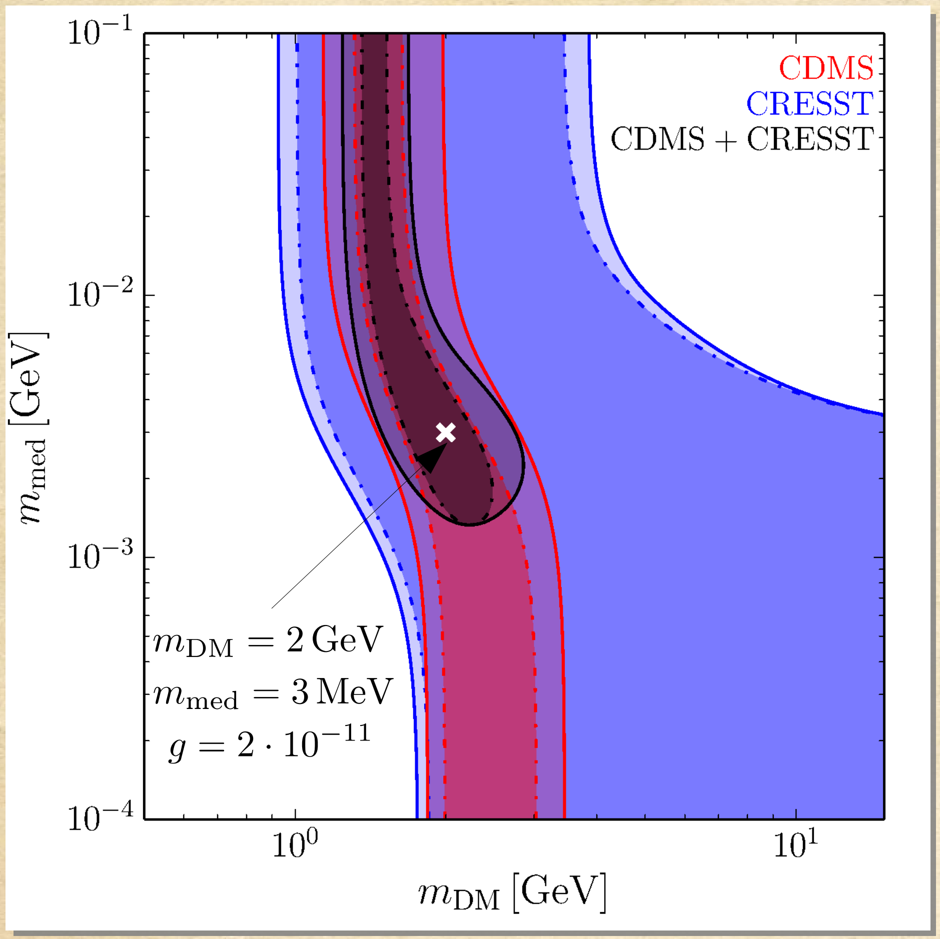
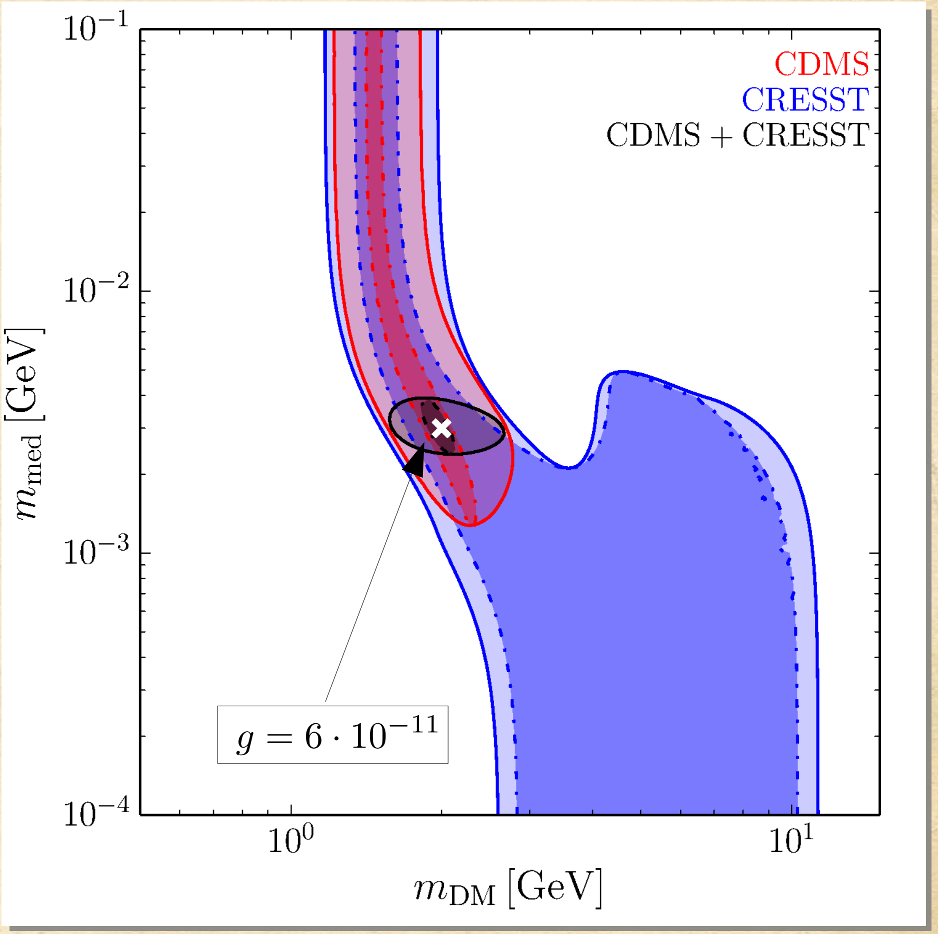


- Treating **background normalizations** as free parameters enlarges the allowed region in parameter space
- In this example, allowing f_n/f_p to float freely opens the combined CDMS+CRESST contour to large $m_{\rm med}$
- We take into account **astrophysical uncertainties** by varying v_0, $v_{\rm local}$, $v_{\rm esc}$ within their 95% C.L. allowed ranges
  → this essentially corresponds to a smearing of $m_{\rm DM}$

Parameter reconstruction: an example





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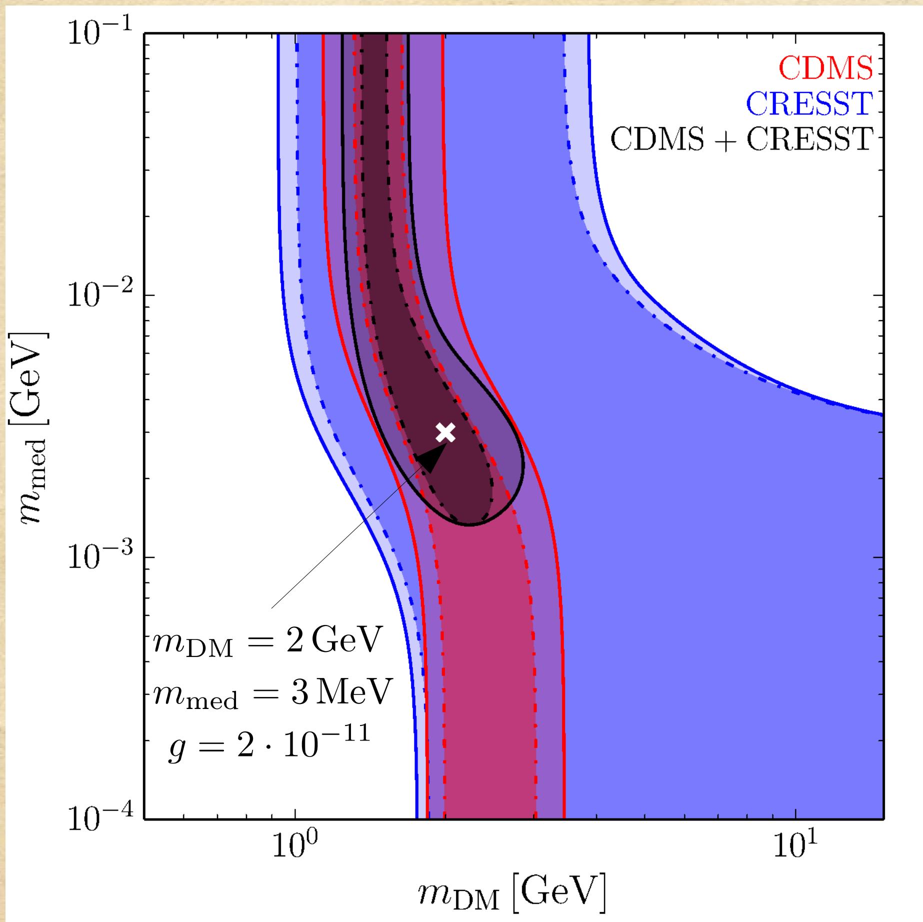
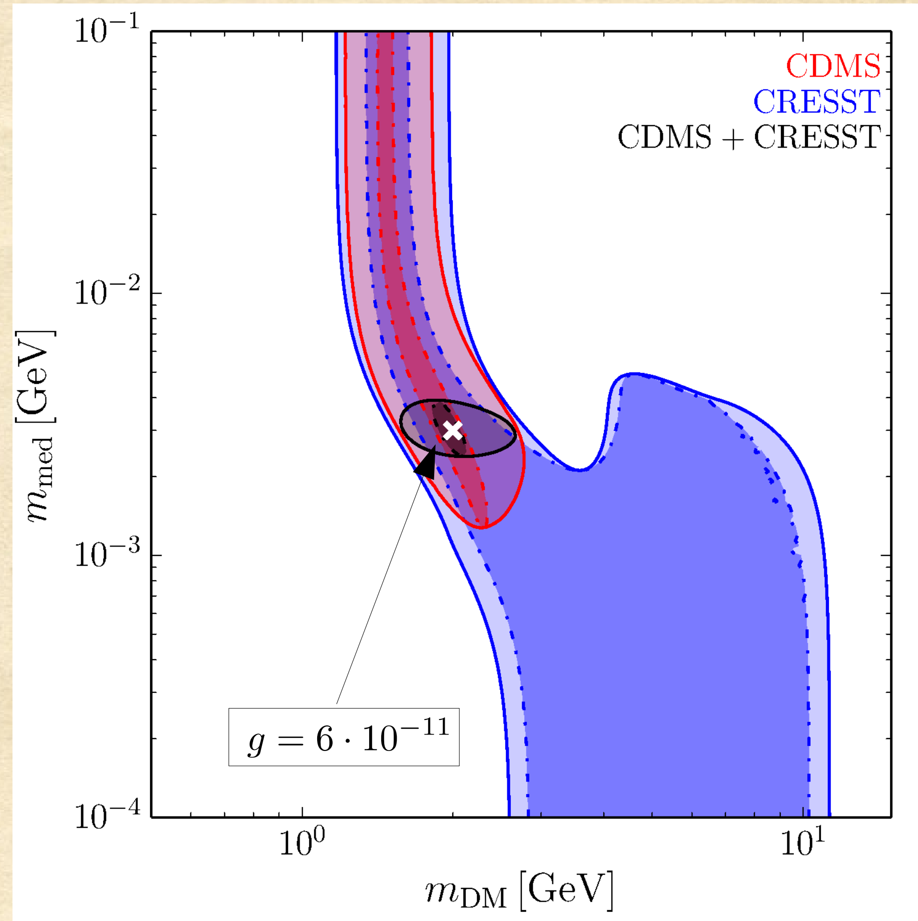


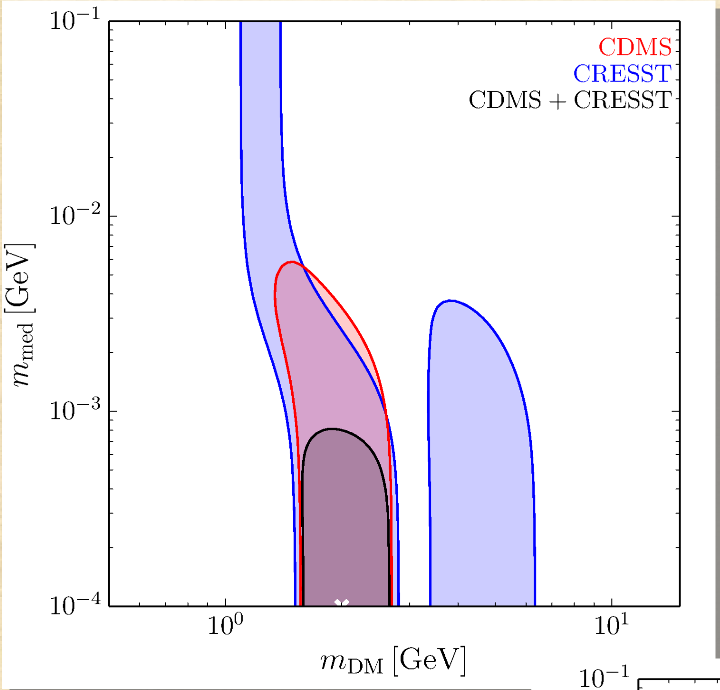


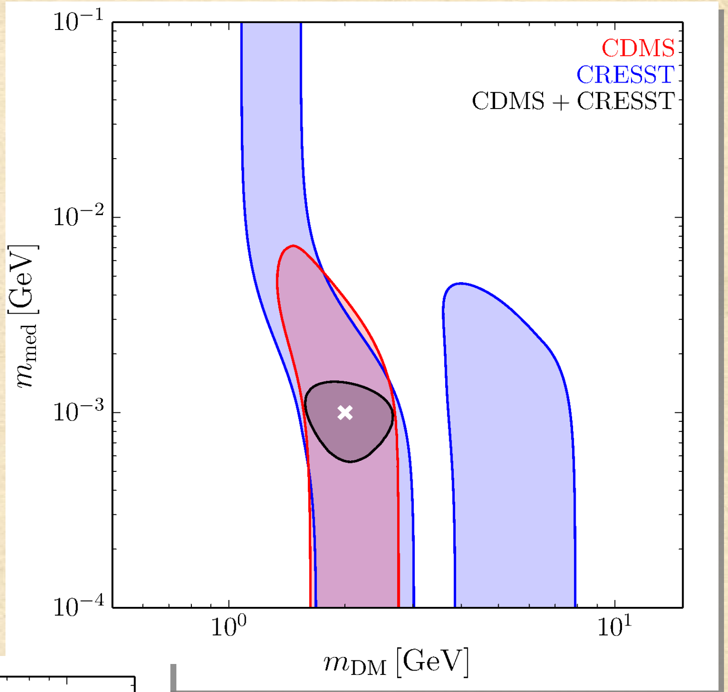
Using the combined information from two experiments, it is feasible to **measure simultaneously** $m_{\rm DM}$ and $m_{\rm med}$!

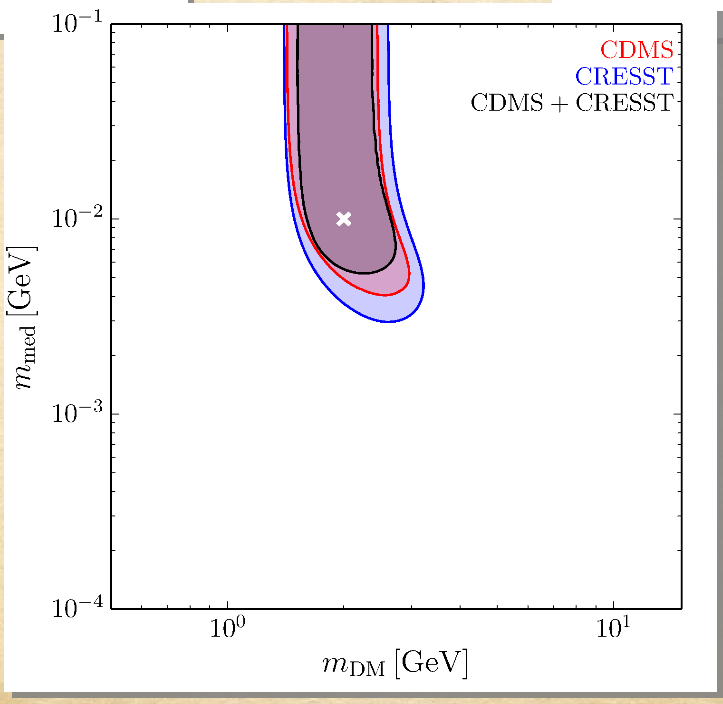
→ for realistic exposures and not-yet-excluded scenarios

→ even after taking into account various nuisance parameters

Some more examples

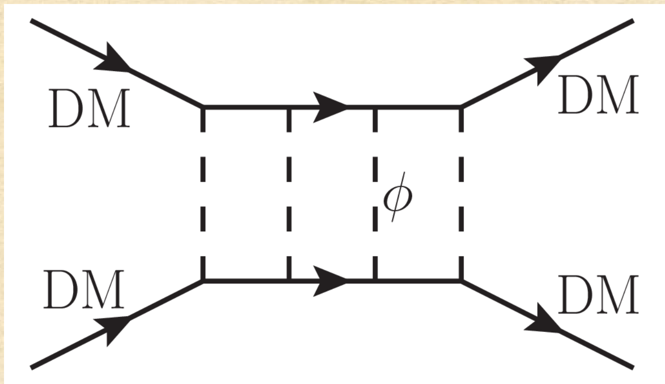






Connection to self-interacting dark matter

Kahlhoefer,Schmidt-Hoberg,SW [1704.02149]

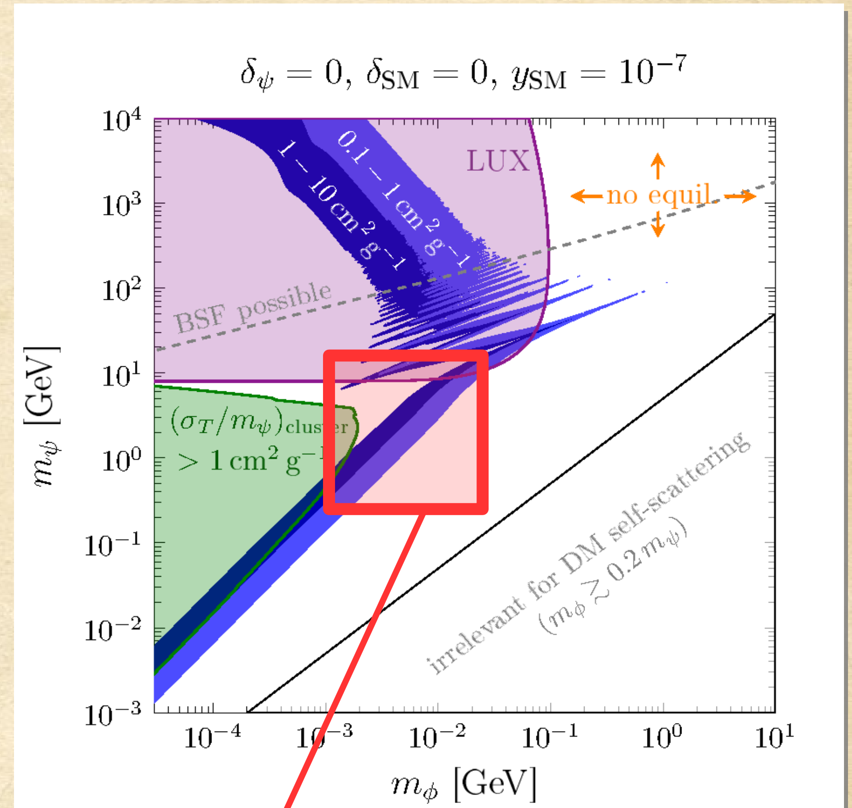


Dark matter coupled to a MeV mediator: potential solution to **small-scale problems** via **strong self-interactions**!

Buckley/Fox [0911.3898]

Feng/Kaplinghat/Tu/Yu [0905.3039]

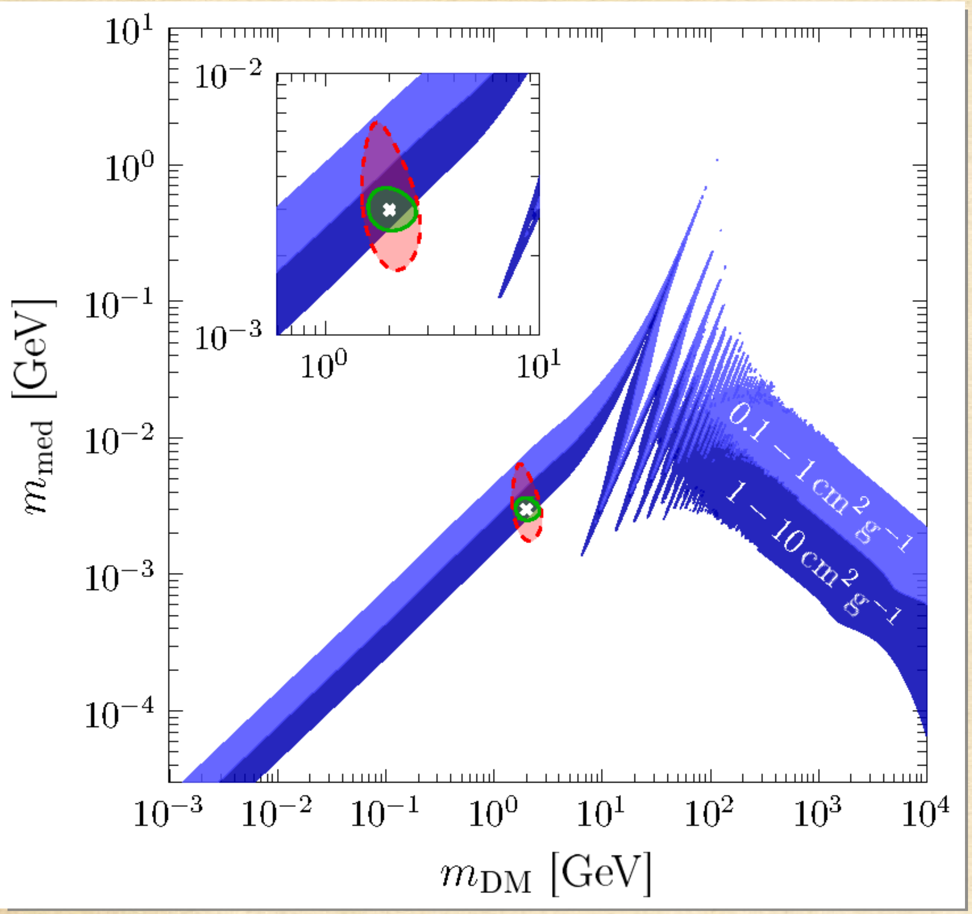
Tulin/Yu/Zurek [1302.3898]

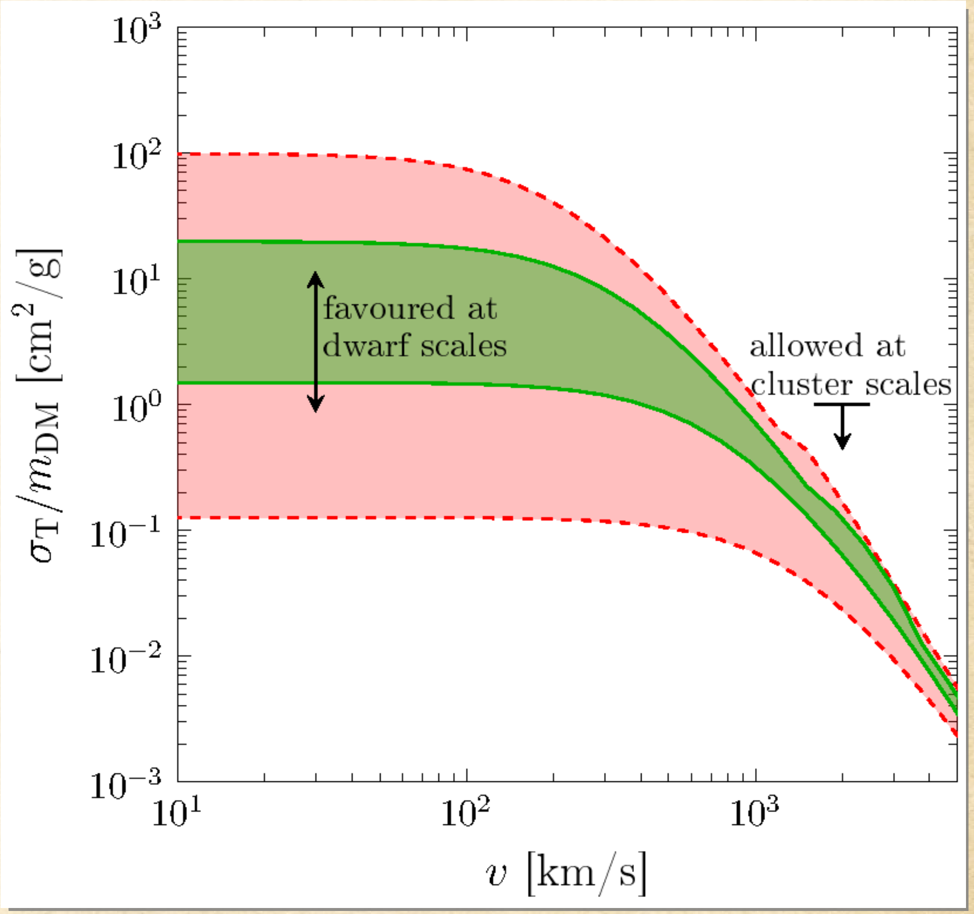


Potentially remaining parameter space: $m_{\rm DM} \sim$ GeV , $m_\phi \sim 1 - 10$ MeV

→ **perfect spot** for low-threshold direct detection experiments!

Interplay: SIDM ←→ direct detection





Future low-threshold DD experiments can potentially probe the behaviour of DM on astrophysical scales!

Conclusions

- In the next years, low-threshold direct detection experiments are expected to improve in sensitivity by **orders of magnitude**

- If the mediator of the DM-nucleon interaction has a mass of $m_\phi \sim (1 - 100)\,\mathrm{MeV}$, the recoil spectrum depends non-trivially on m_ϕ

- Taking into account experimental & astrophysical uncertainties, we showed that future low-threshold experiments could **simultaneously probe** m_{DM} and m_ϕ

  → in the best case scenario, both masses can be determined within to a factor of ~ 2

- Self-interacting DM requires precisely masses in the range where the low-threshold experiments are sensitive

  → probing astrophysical behaviour of DM with laboratory experiments?