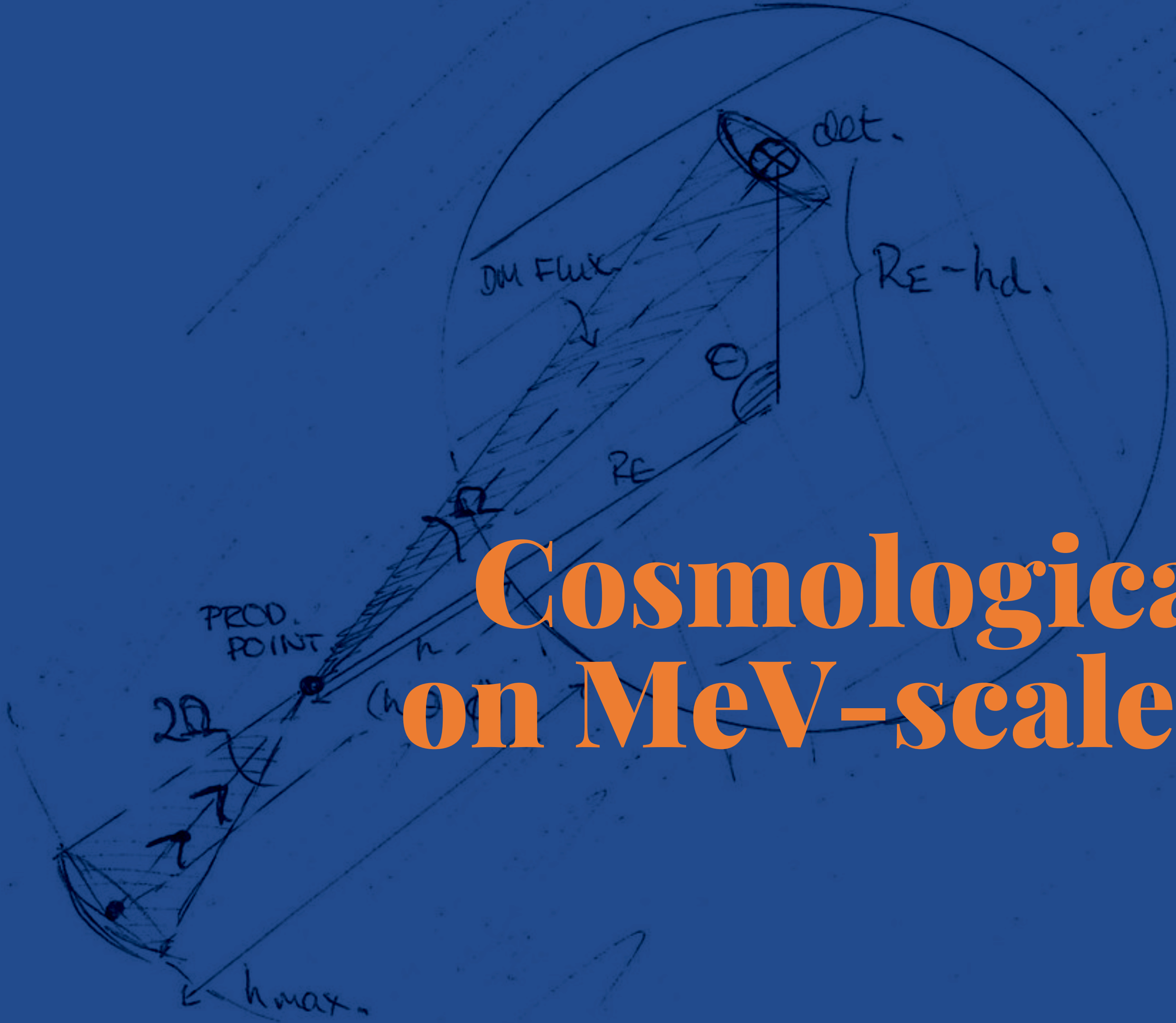


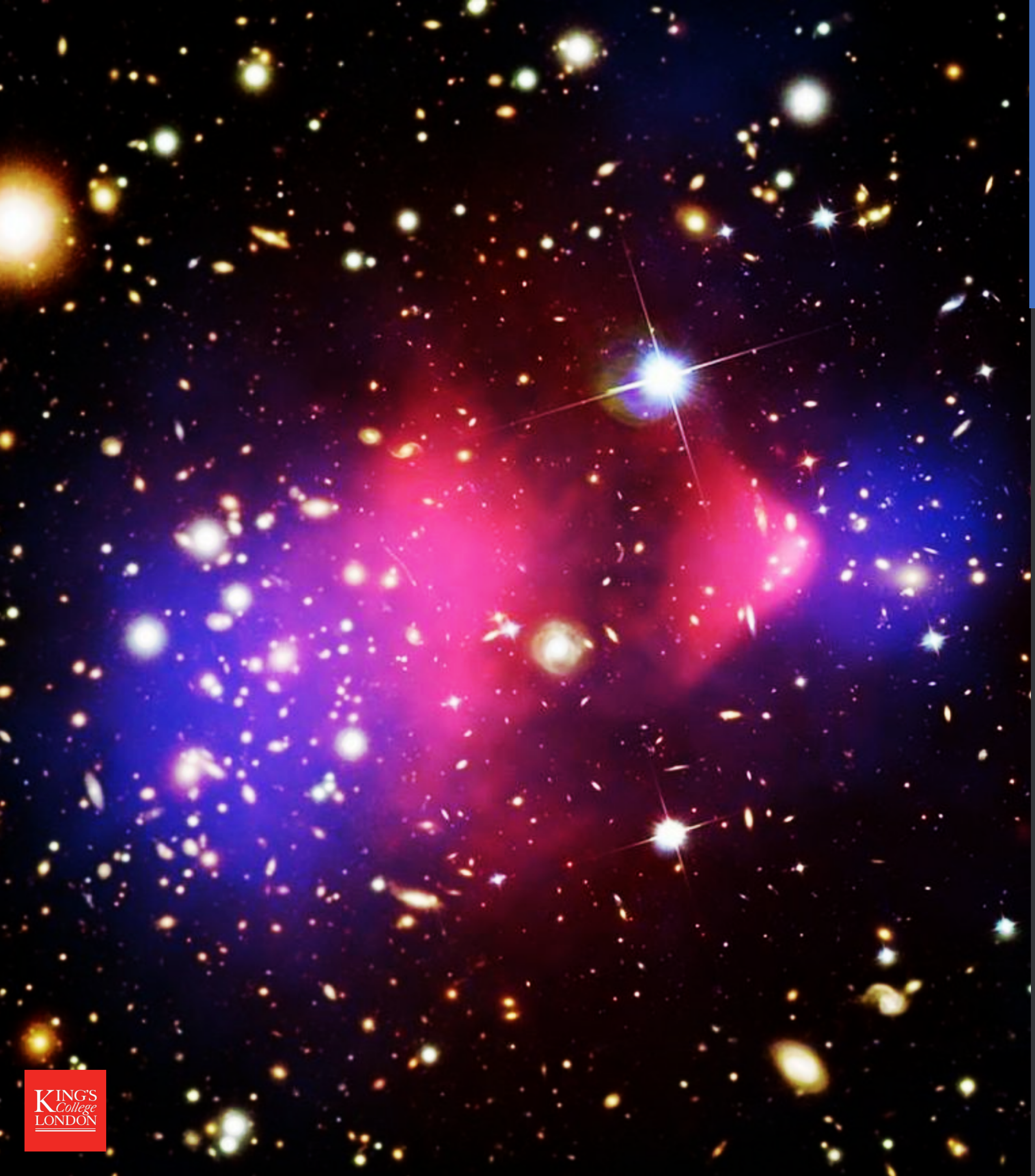
Cosmological Constraints on MeV-scale Dark Sectors

James Alvey
King's College, London

Based on 1910.01649, 1905.05776, and 1902.01450

Outline

1. Introduction
2. Big Bang Nucleosynthesis
3. Cosmic Ray Dark Matter
4. Neutrinos at IceCube
5. Final Thoughts



Indirect Evidence for Dark Matter

- CMB Observations
- Galaxy Rotation Curves
- The Bullet Cluster
- Weak and Strong Gravitational Lensing
- Diffuse X-ray Background
- etc...

Image Credit: Ethan Seigel (Forbes)

Why the MeV scale?

The WIMP Paradigm

The GeV-scale WIMP paradigm is under pressure from (in)direct detection experiments and experiments at the LHC

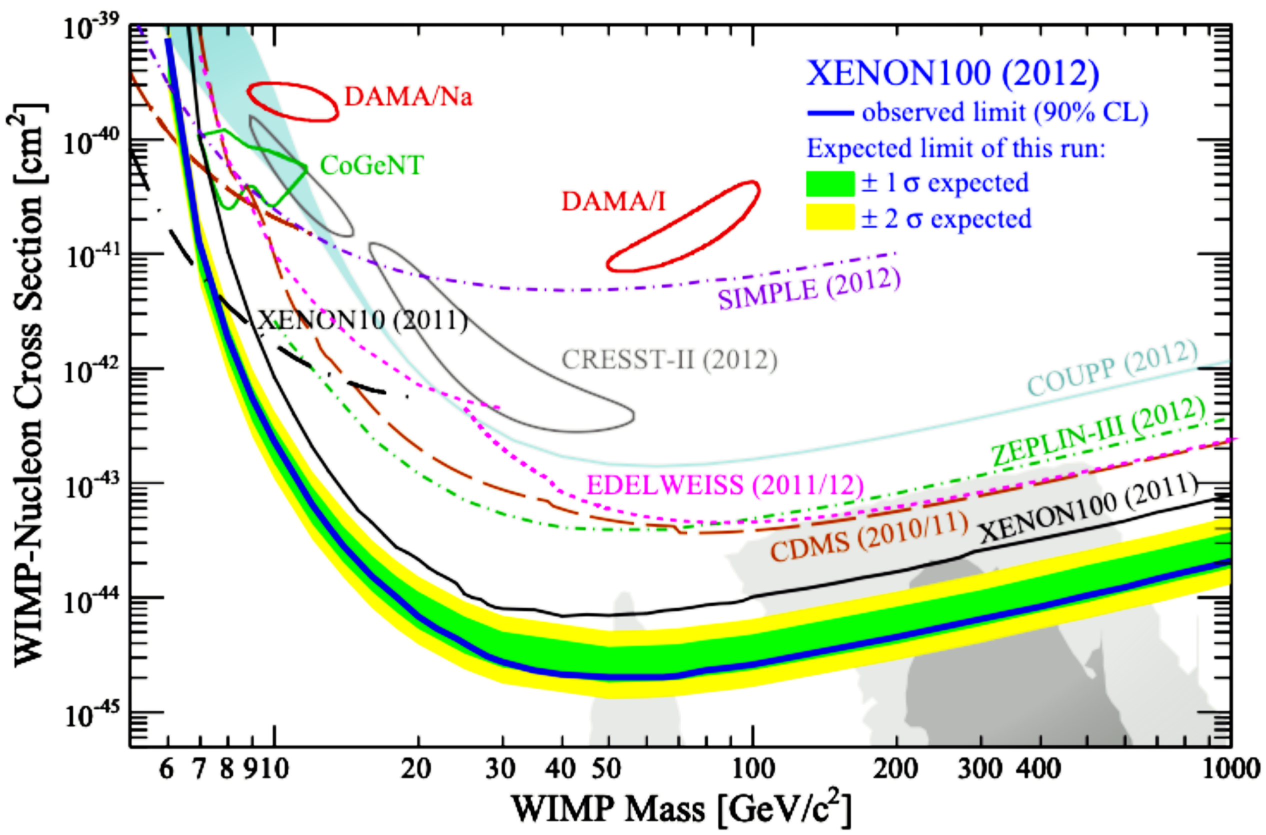
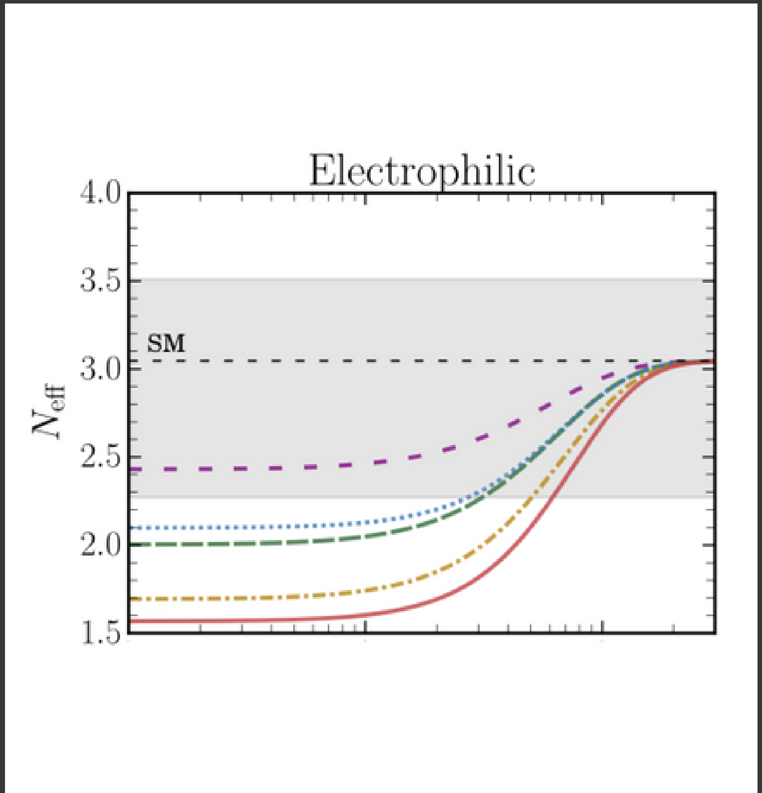


Image: **XENON100** [1207.5988]

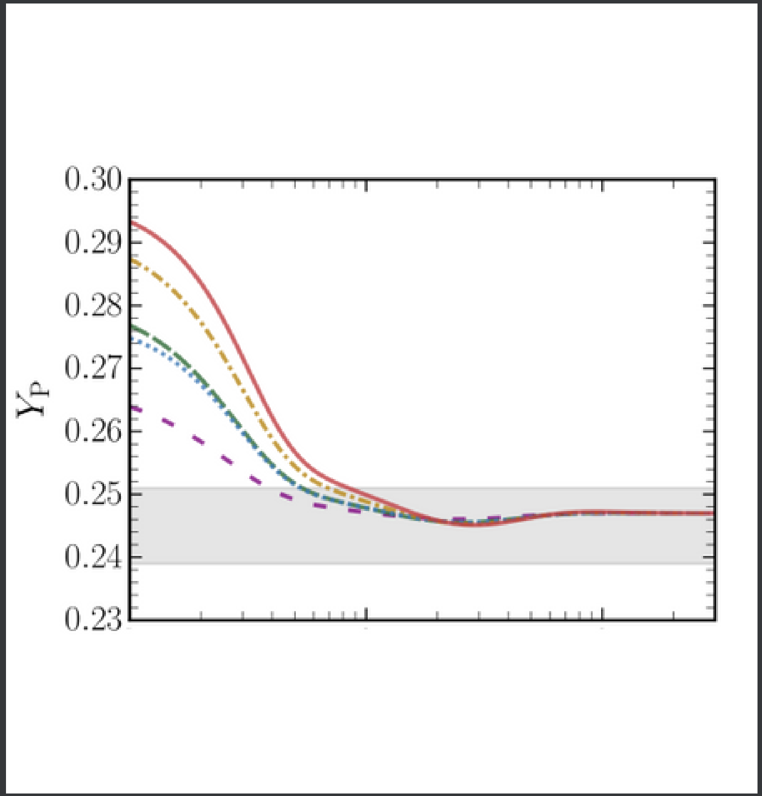
Big Bang Nucleosynthesis

How do light particles affect BBN?

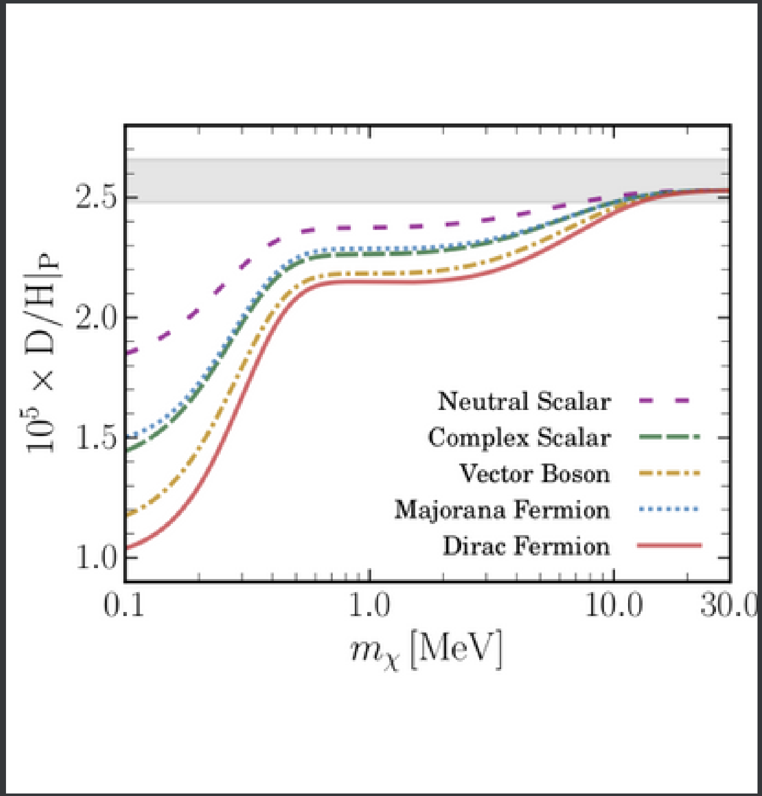
The Electrophilic Case



No. of Effective Neutrino Species



Primordial Helium Abundance



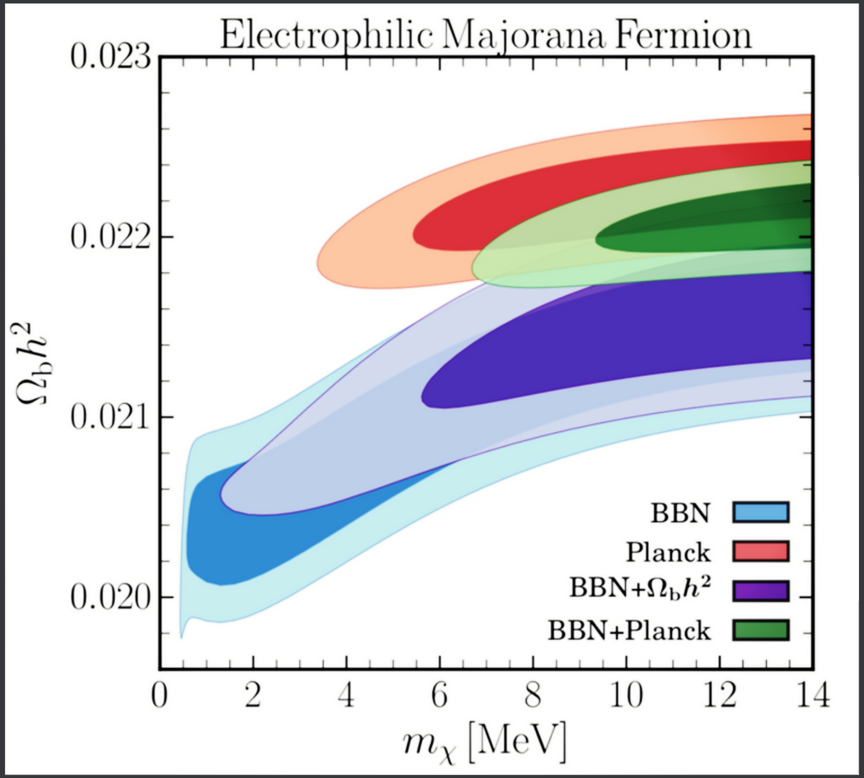
Primordial Deuterium Abundance

How do we constrain new physics?

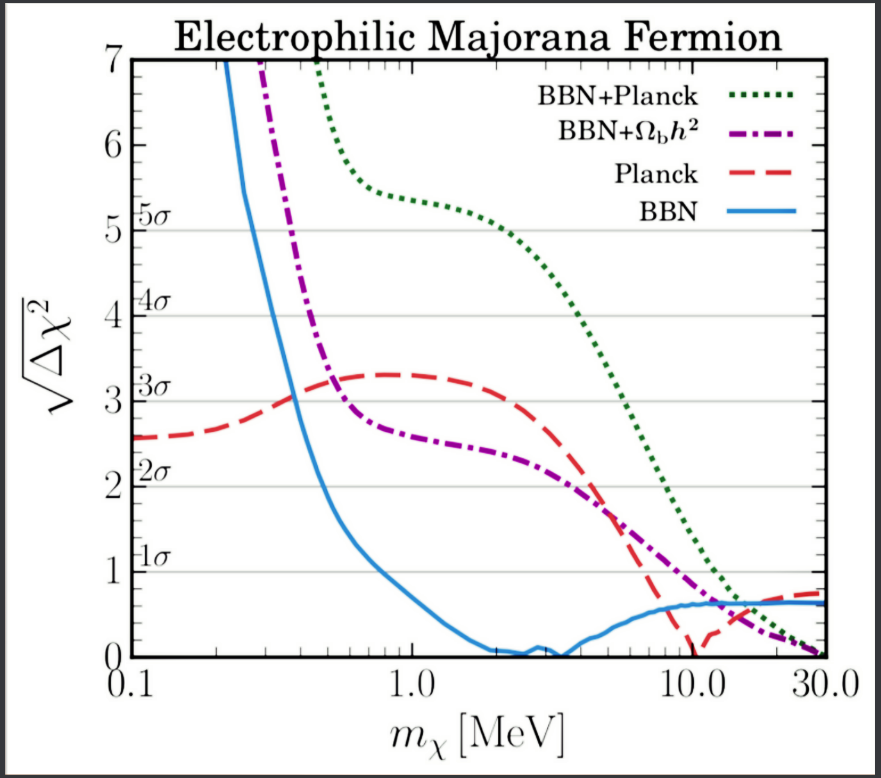
$$\chi^2_{\rm BBN} = \frac{\left[Y_{\rm P} - Y_{\rm P}^{\rm Obs}\right]^2}{\sigma^2_{Y_{\rm P}}|^{\rm Theo} + \sigma^2_{Y_{\rm P}}|^{\rm Obs}} + \frac{\left[{\rm D/H}|_{\rm P} - {\rm D/H}|_{\rm P}^{\rm Obs}\right]^2}{\sigma^2_{\rm D/H|_P}|^{\rm Theo} + \sigma^2_{\rm D/H|_P}|^{\rm Obs}},$$

- We construct a number of data combinations to constrain the predictions from PRIMAT.
- We use abundance measurements, Planck CMB data, and weak priors on the baryon density.

Results and Implications



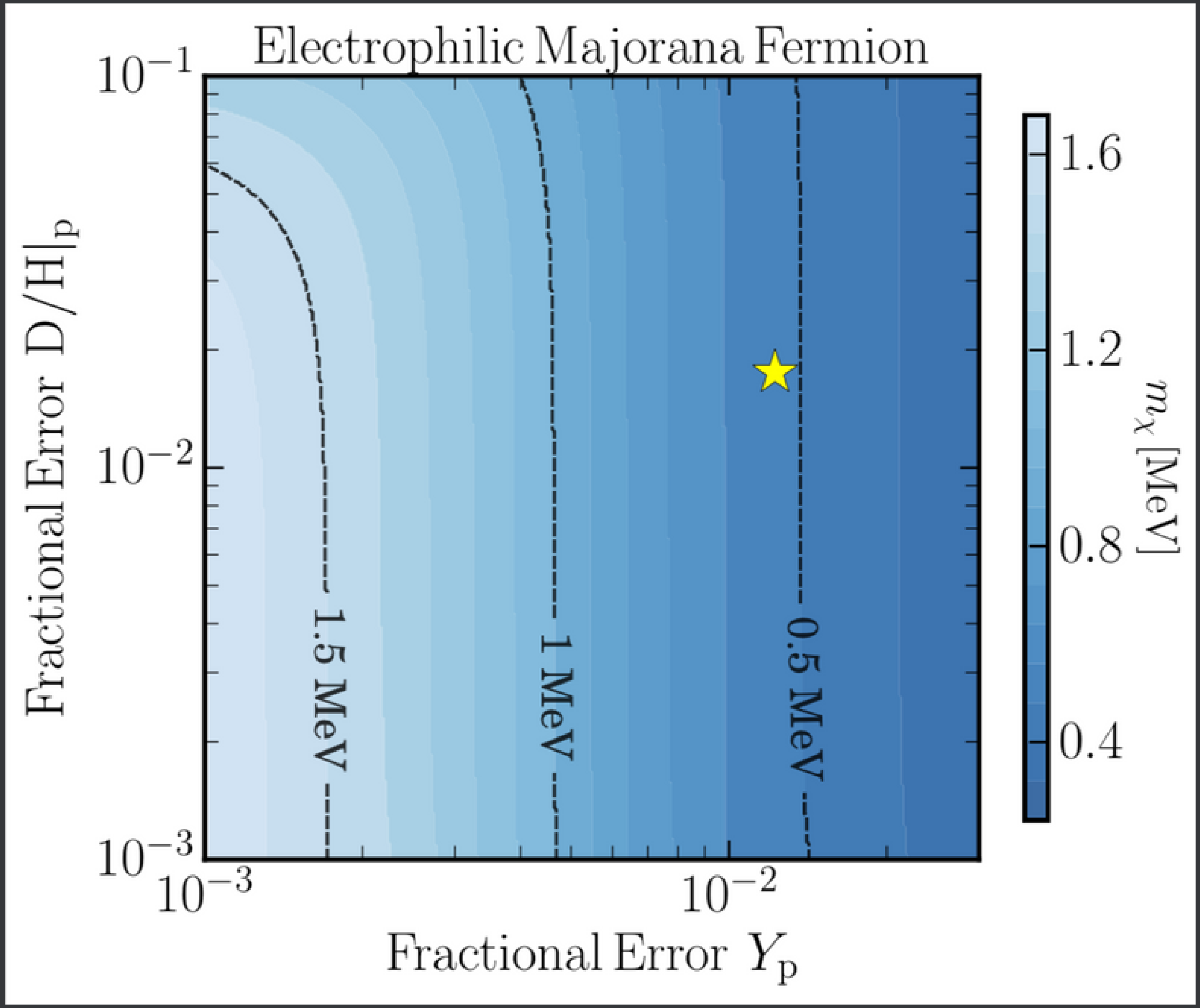
Contour plot of the 1 and 2 sigma confidence intervals for an Electrophilic Majorana Fermion



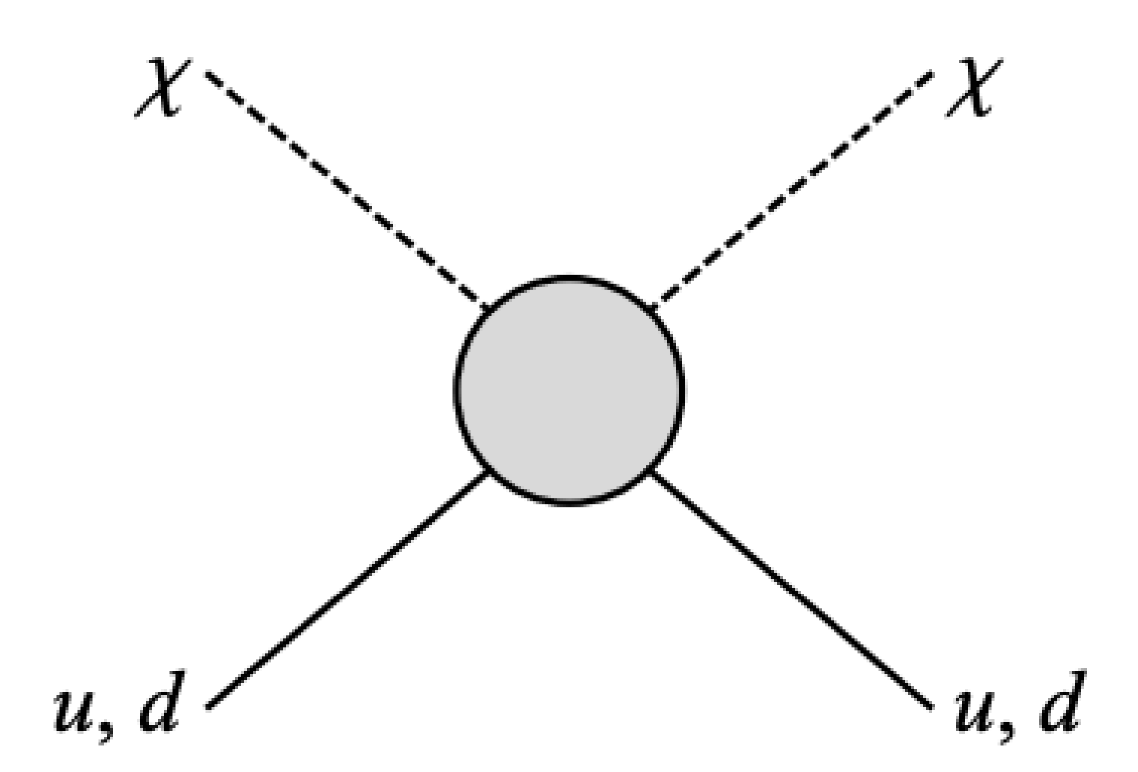
Marginalized chi-squared distribution as a function of the dark matter mass.

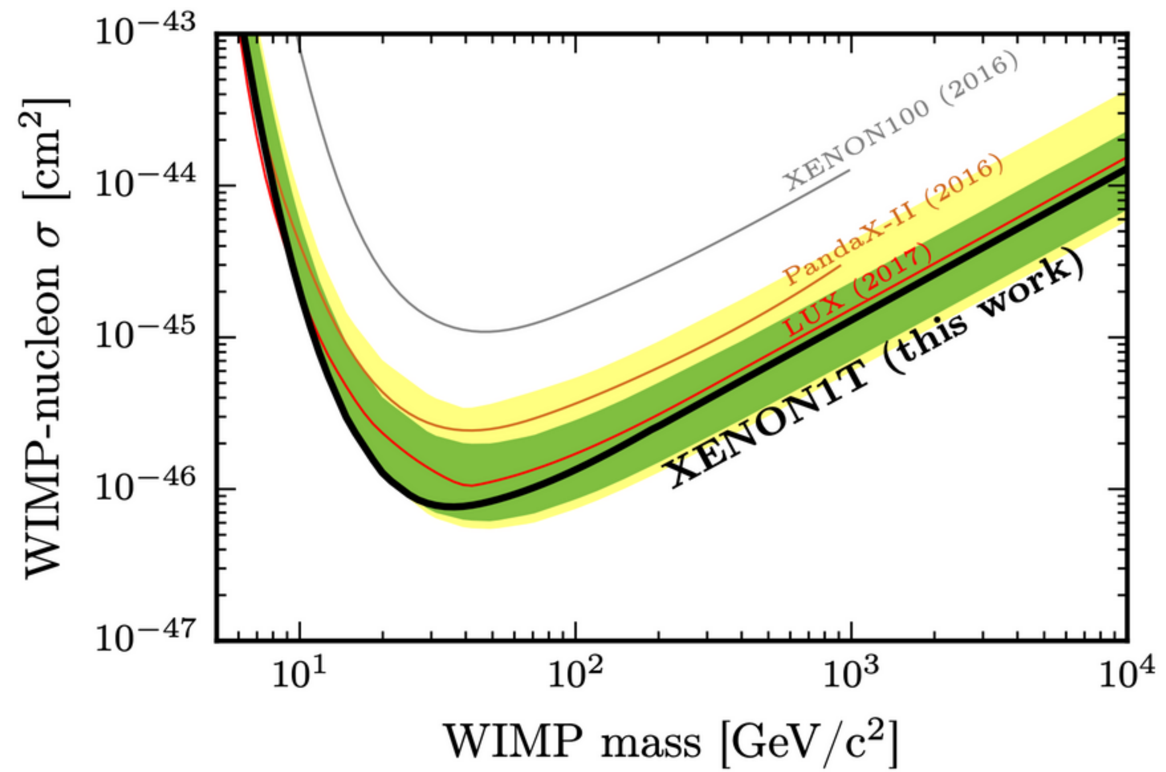
Better Measurements

What if we measure the **primordial abundances** more precisely than today?



Cosmic Ray Dark Matter

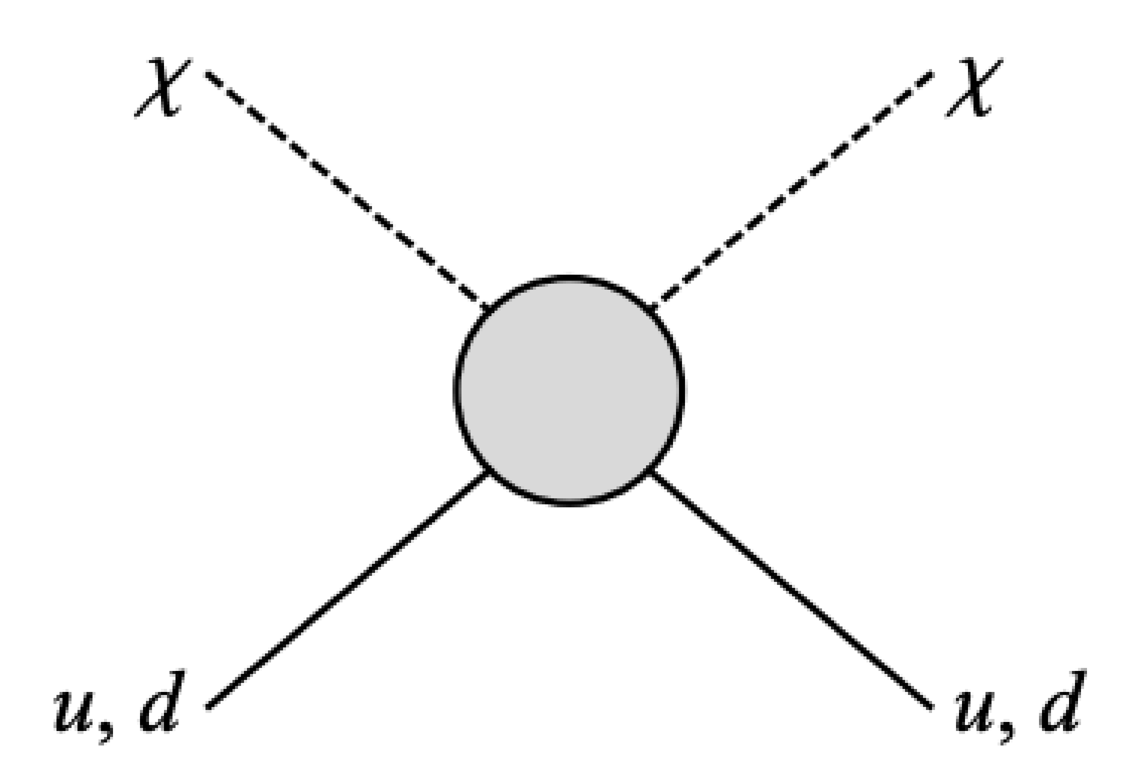


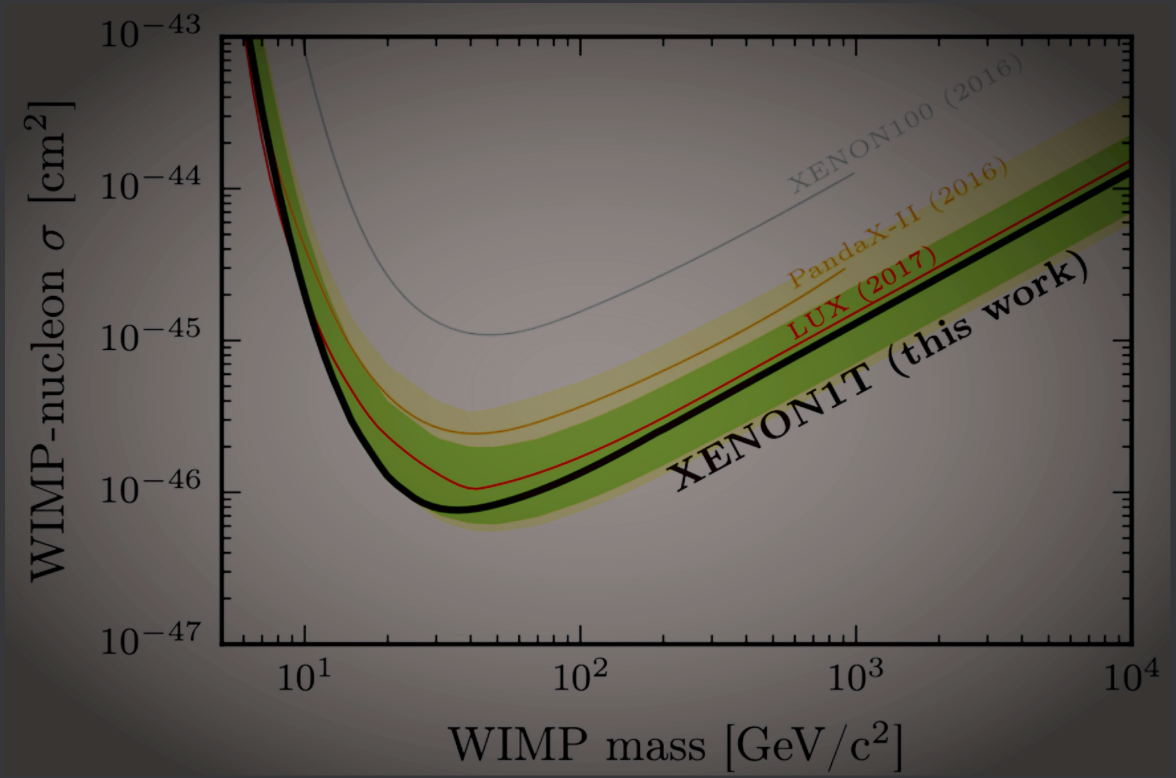


Direct Detection

Experiments **lose sensitivity** at low dark matter masses due to small nuclear recoils

Left: Bateman et al. (2014), **Right:** Xenon Collaboration (2017)





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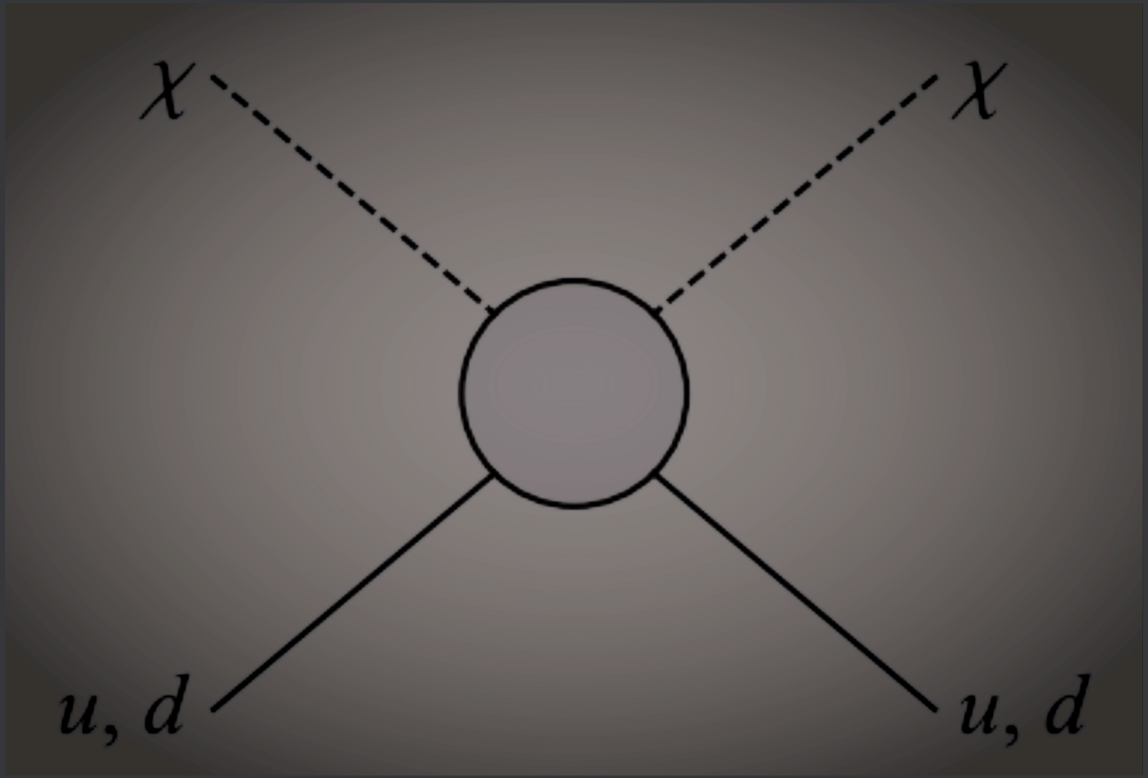

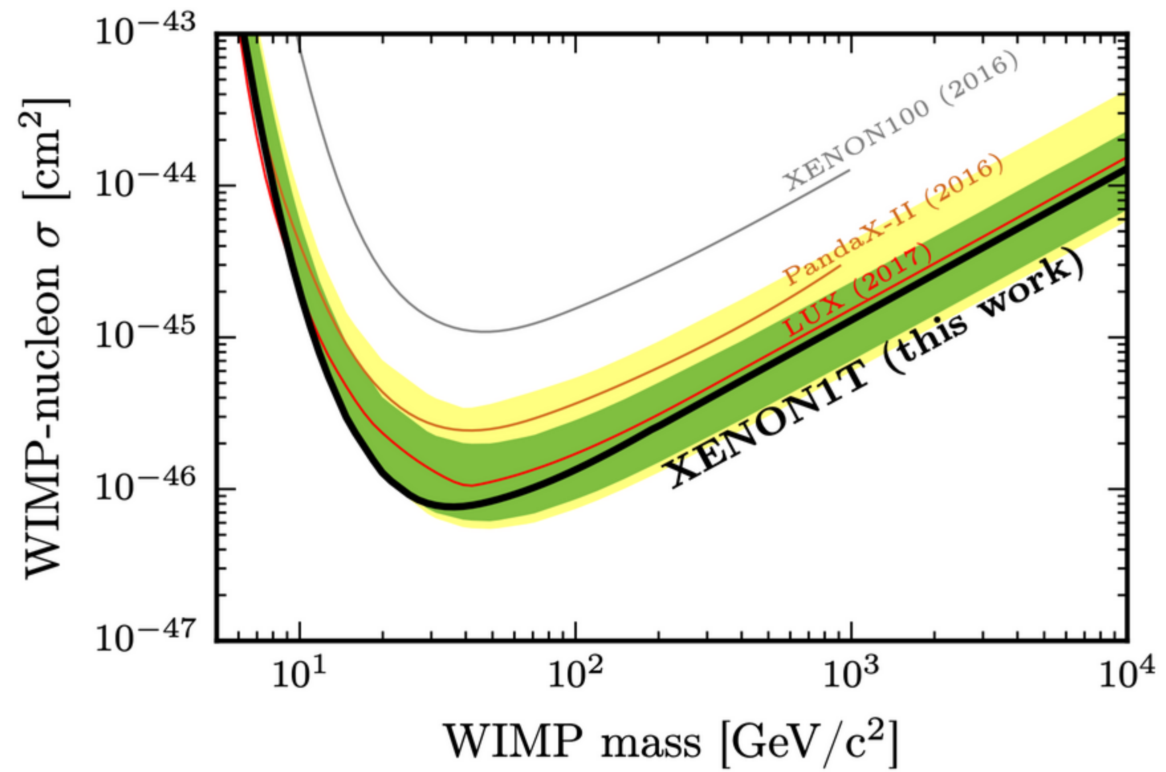

Direct Detection

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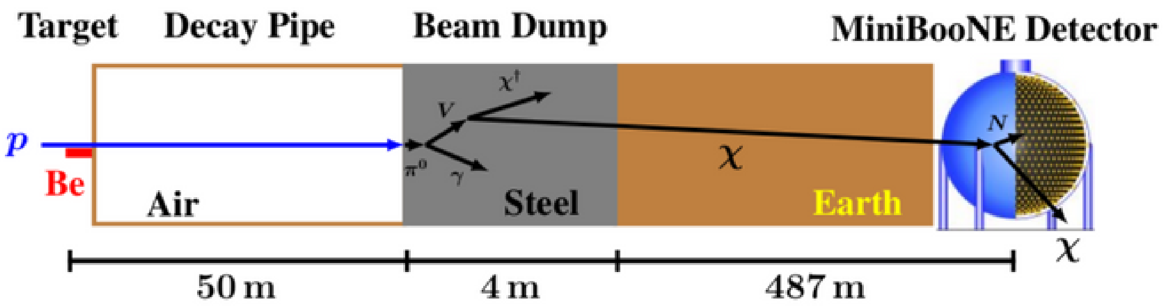
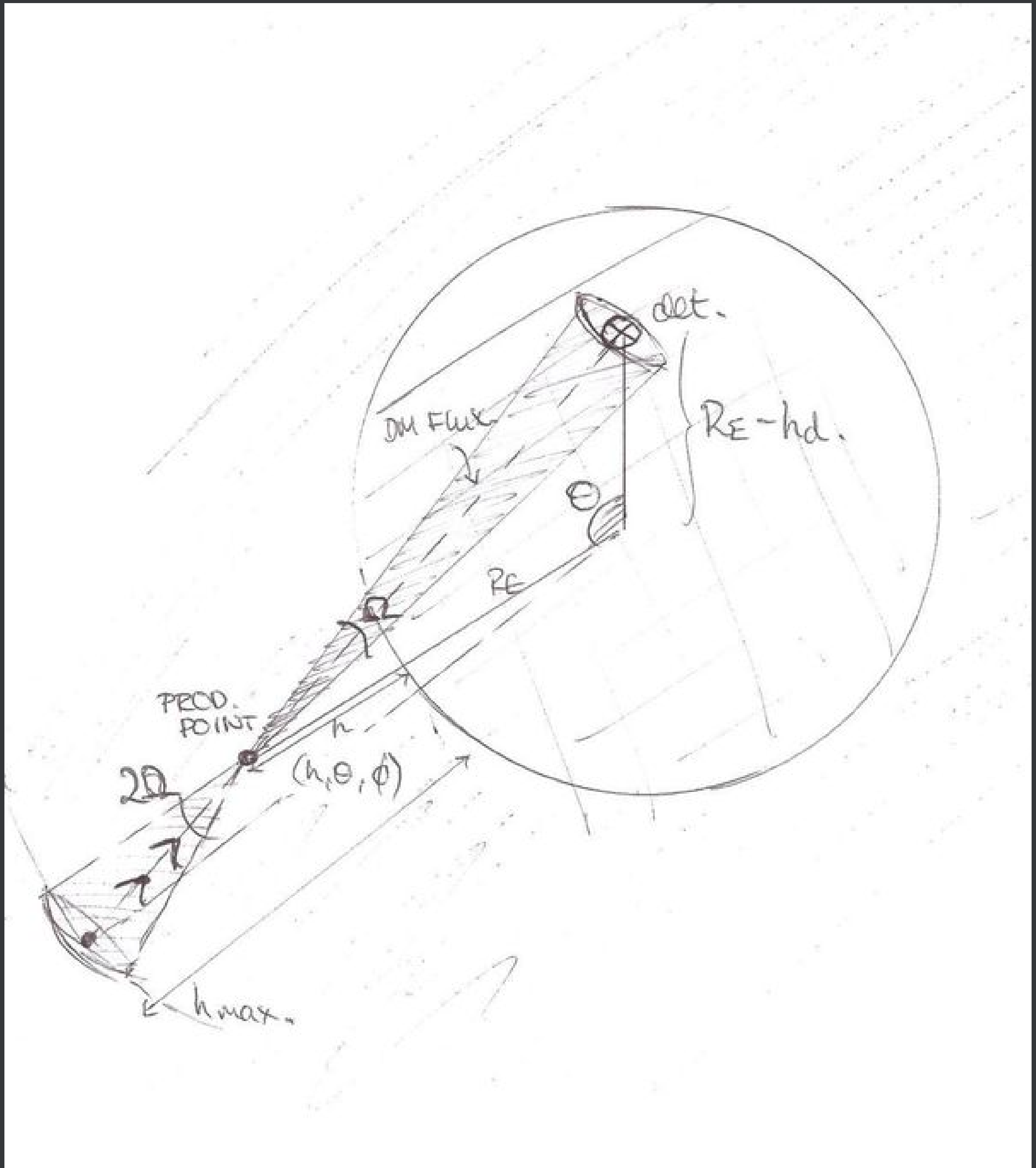
Collider Experiments

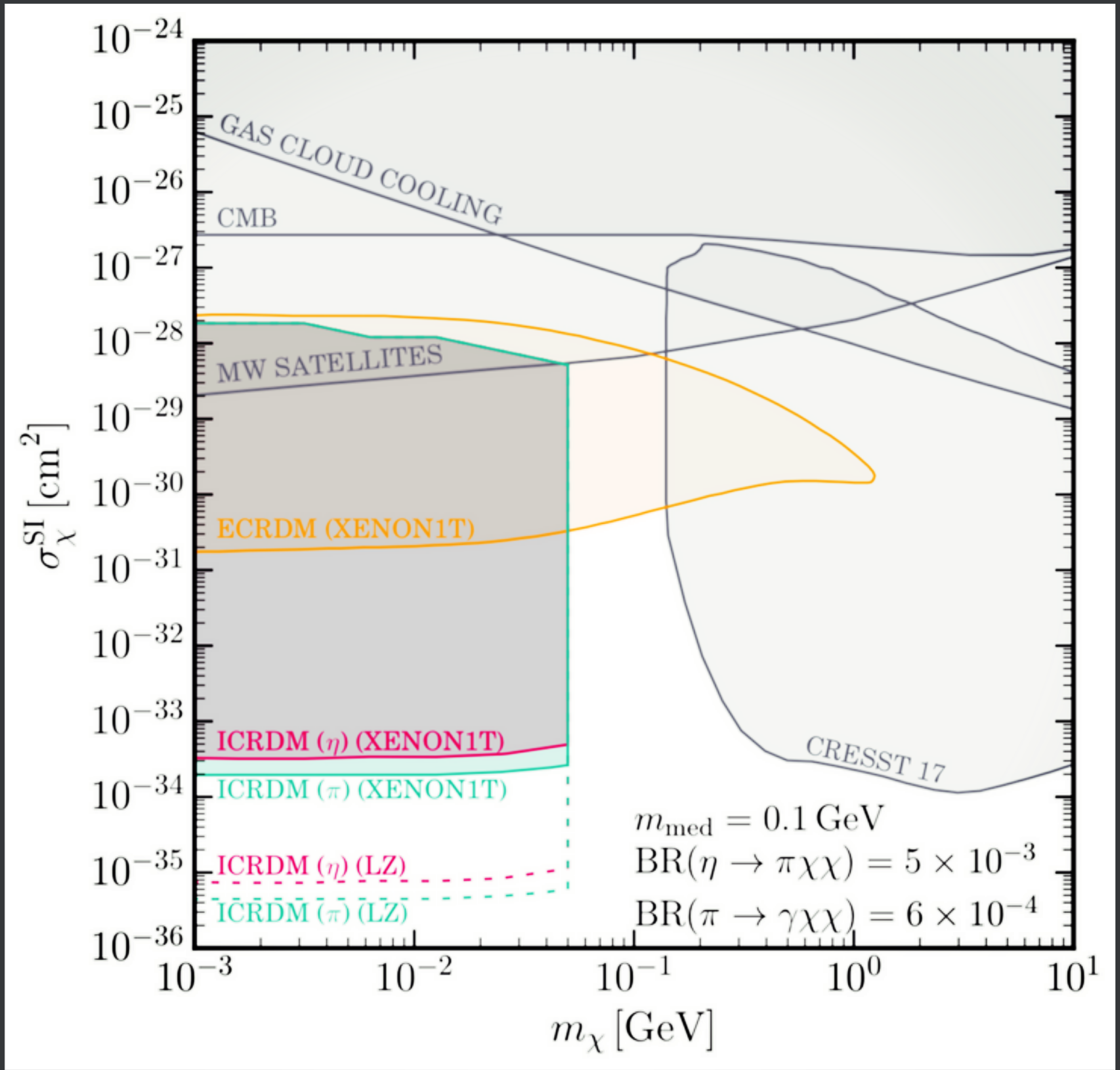
In traditional beam dump experiments like **MiniBooNe**, the accelerated protons are directed at a fixed target with a detector collinear with the beam.



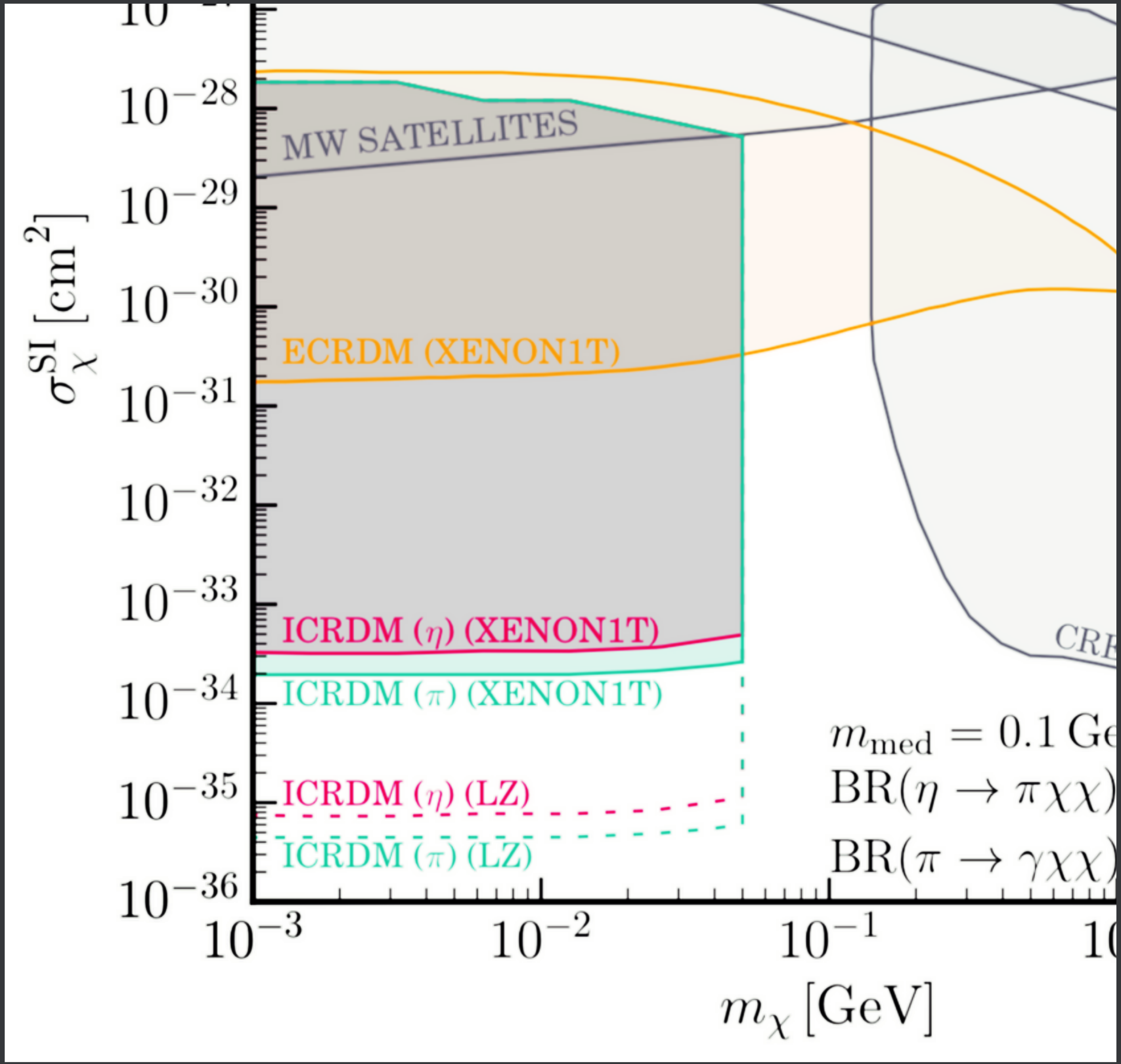
Using the Atmosphere

In our scenario, the protons come from **cosmic rays**, the flux of which is measured by balloon experiments like AMS





- Consider production of the dark matter from pions and eta mesons
- Opens new low mass window for direct detection experiments



- Consider production of the dark matter from pions and eta mesons

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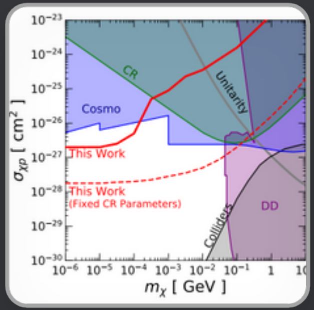
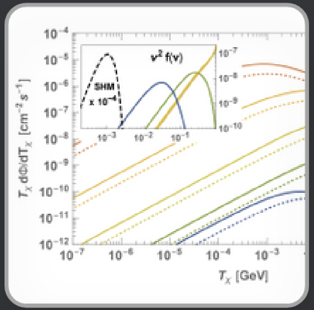
Cosmic Ray Dark Matter (CRDM)

Recently a small sub field has developed exploring these ideas



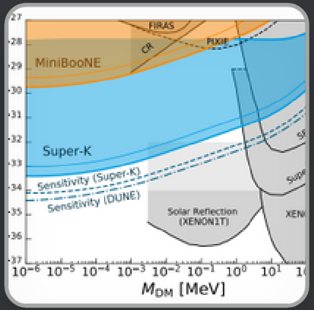
Cappiello et al.

Effect of elastic collisions on CR spectrum



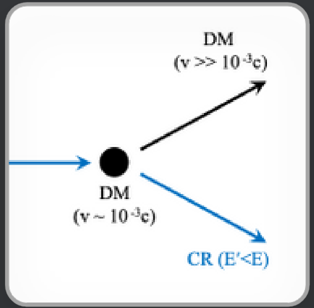
Bringmann et al.

Elastic Proton-DM Collisions



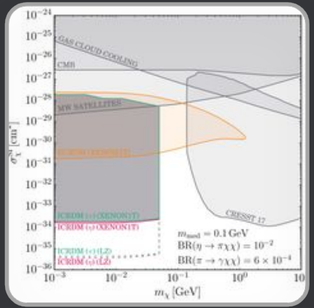
Ema et al.

Elastic collisions of electrons with DM



Cappiello et al.

Elastic CRDM at neutrino experiments



Alvey et al.

Inelastic CRDM production

Neutrinos at IceCube

IceCube

A **neutrino observatory** at the South Pole.

It acts as a **Cherenkov detector** for muons traveling through the ice.

On 22nd Sep. 2017, it measured a **290 TeV** neutrino, likely coming from a **blazar** 1.3 Gpc away.

Particle Physics Model

- We consider an effective theory beyond the Standard Model that radiatively generates neutrino masses.

- There are two new particles in the spectrum: a light scalar dark matter candidate and a heavier right-handed neutrino.

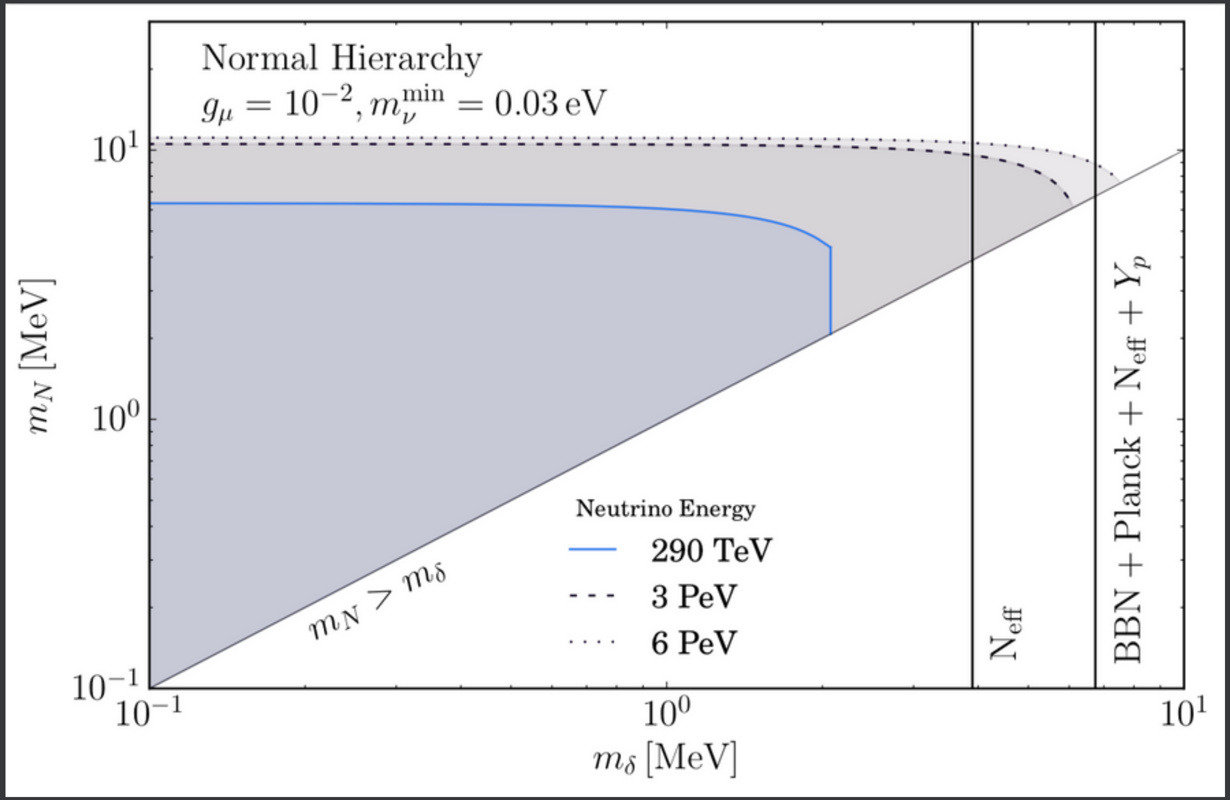
$$\mathcal{L}_{int} = \sum_{\ell} g_{i\ell}\,\delta\,\bar{N}^{i}_{R}\nu^{\ell}_{L} + \text{h.c.}$$

How do we place constraints?

$$\ell^{-1} = \sum_i n_{X_i} \sigma(\nu_\mu X_i \to Y_i)$$

- New physics in the neutrino sector can alter the mean free path for high energy neutrinos.
- We compute the cross section for scattering of the 290 TeV neutrino off the Cosmic Neutrino Background.
- We reject parameter sets for which the mean free path is below that of the distance to the blazar.

Results and Outlook



Constraints on the masses of the new particles along with an outlook for how **future events** impact the bounds.

Final Thoughts

1 New physics at the MeV-scale is motivated but constrained by Cosmology and Particle Physics.

2 Big Bang Nucleosynthesis places stringent constraints on light particles thermally coupled to the SM plasma.

3 Local high momenta sources of dark matter requires reinterpretation of direct detection results.

4 IceCube is an effective probe of new physics and the propagation of species across the Universe.

Thank you, **questions?**

KING'S College LONDON