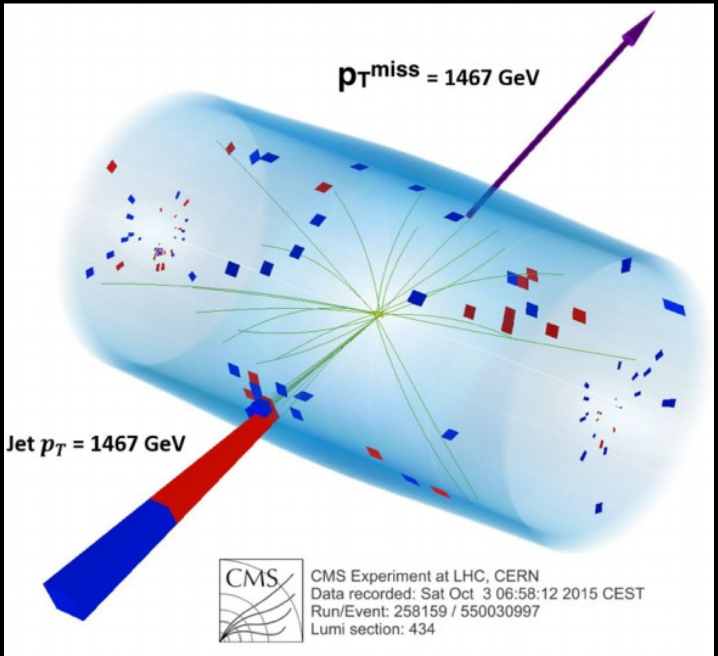
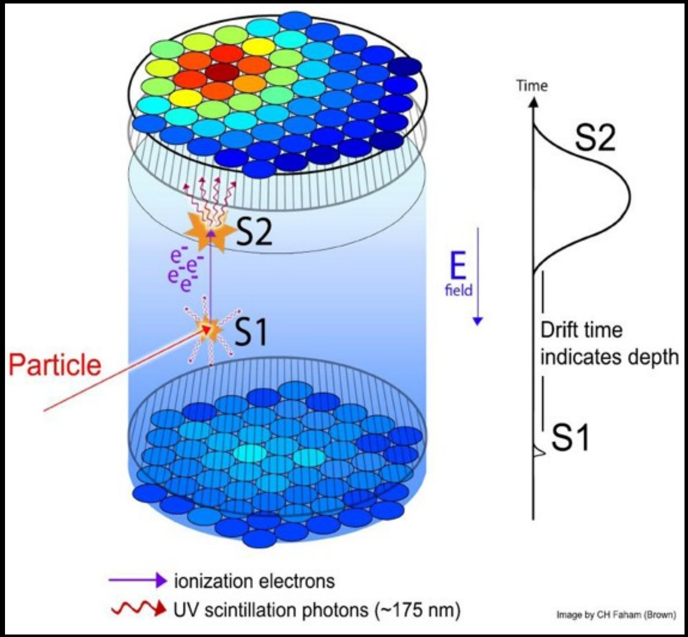
# Dark Matter: A Review



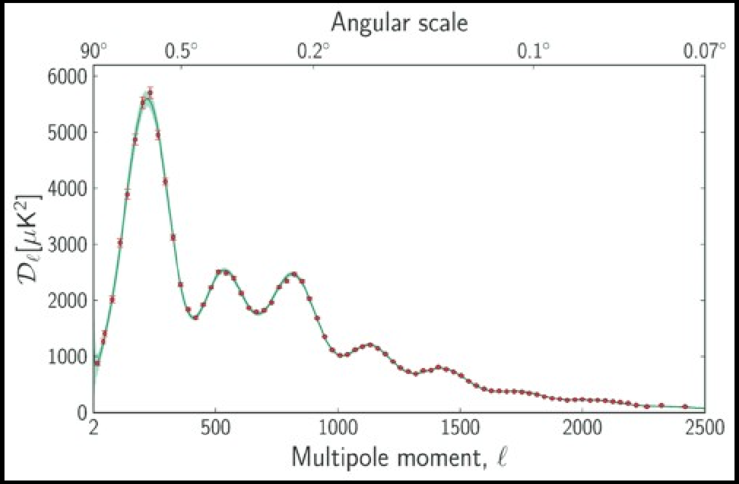


**Carlos E. Yaguna**
**UPTC, Colombia**

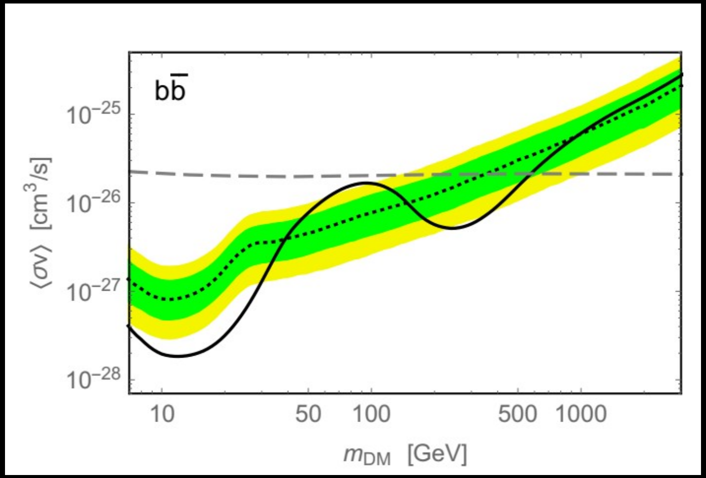
**2018**

# I will present an overview of the current status of dark matter research

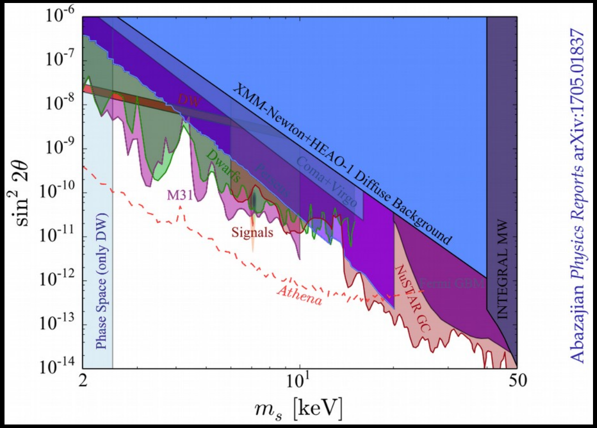
## 1. Motivation




## 2. WIMPs




## 3. Beyond WIMPs

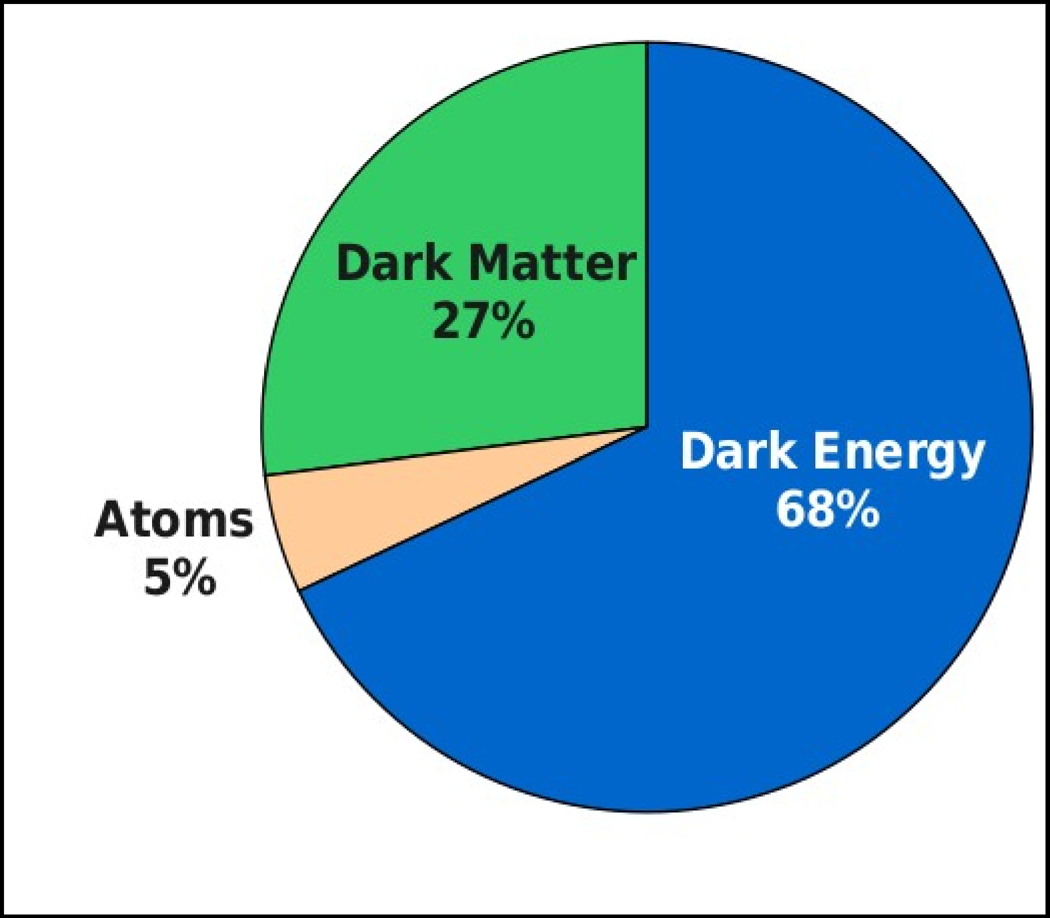


# Dark Matter accounts for about 27% of the energy-density of the Universe

Most of it is dark energy (Λ?)

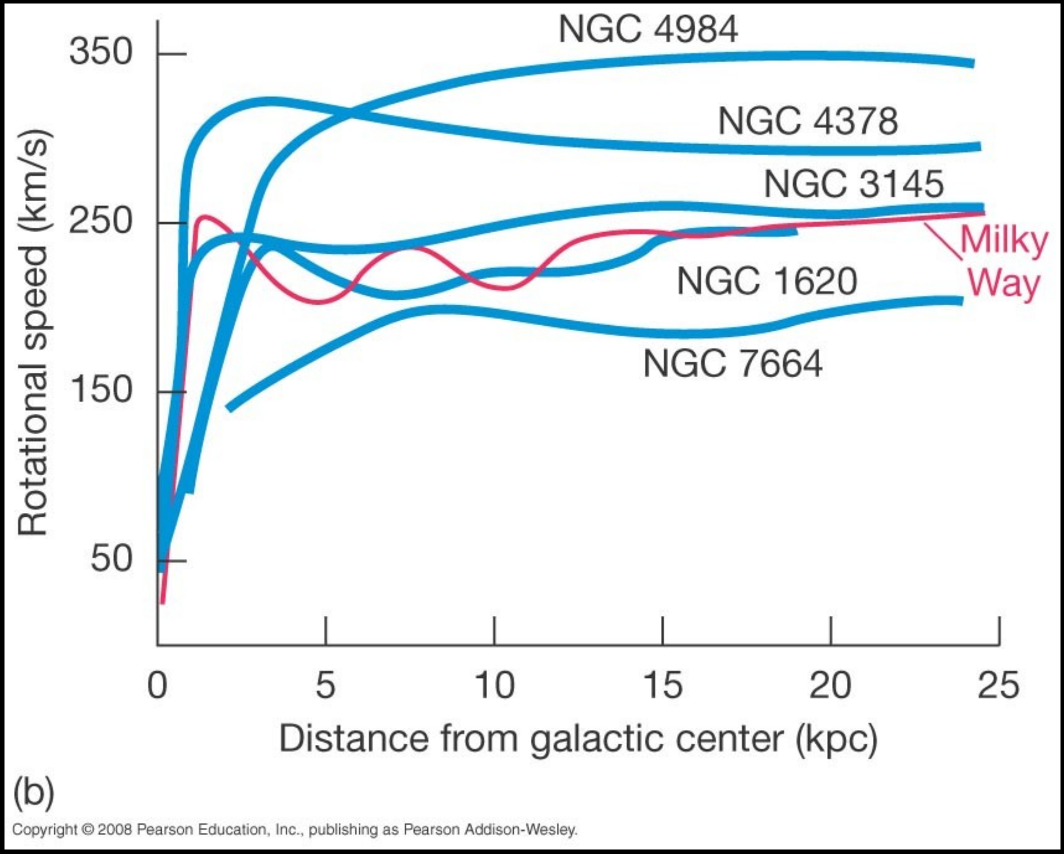
Atoms contribute a small fraction

DM is about 5 times more abundant



# Dark Matter has been detected throughout the Universe

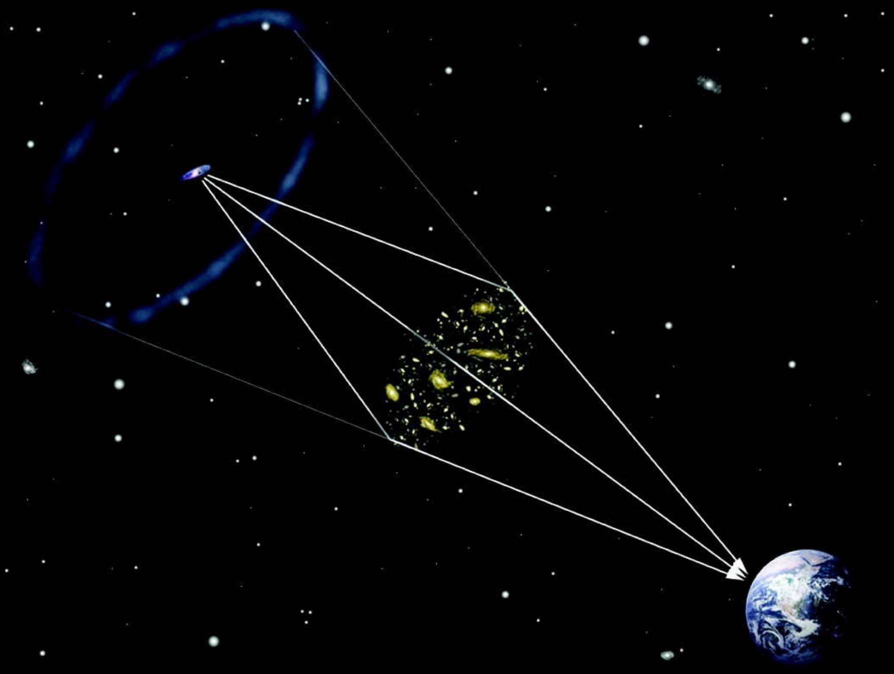
Galaxies



# Dark Matter has been detected throughout the Universe

Galaxies

Galaxy clusters

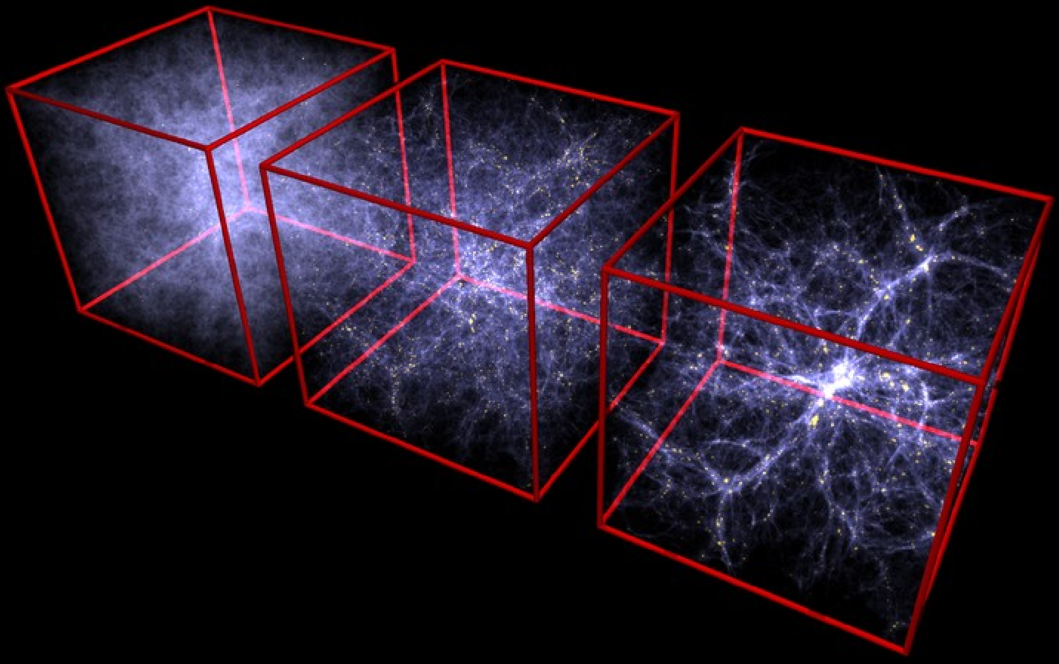


# Dark Matter has been detected throughout the Universe

Galaxies

Galaxy clusters

Large structures



# Dark Matter has been detected throughout the Universe

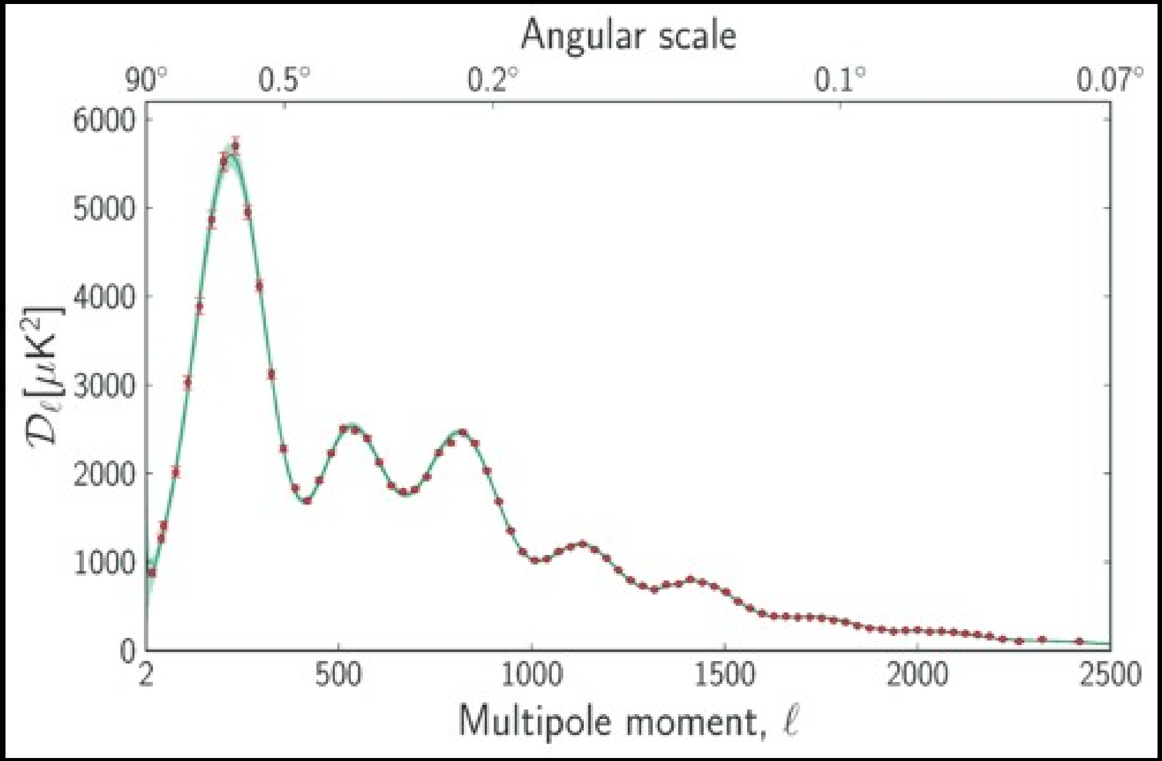
Galaxies

Galaxy clusters

Large structures

CMB

$\Omega_{DM}h^2 = 0.1199 \pm 0.0027$

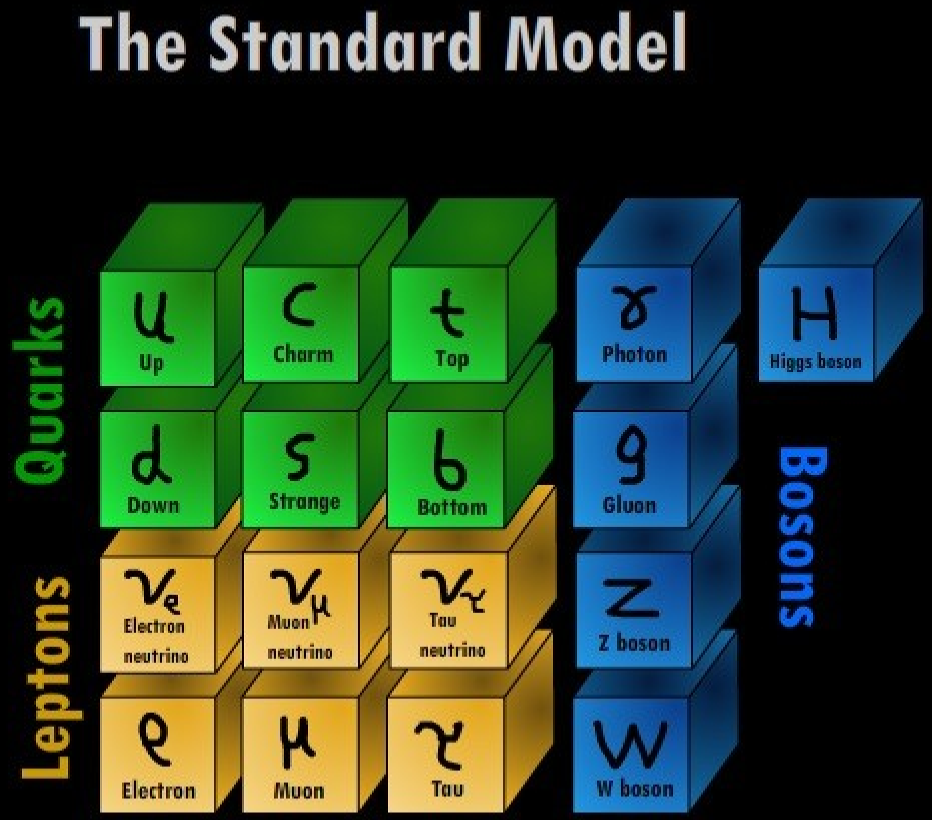


# Dark Matter requires physics beyond the Standard Model

The SM is consistent with all collider data

But it does not include a DM candidate

DM is a signal of new physics



# We don't know much about the dark matter particle

## What we know:

It's stable, neutral and "cold"

It does not interact much

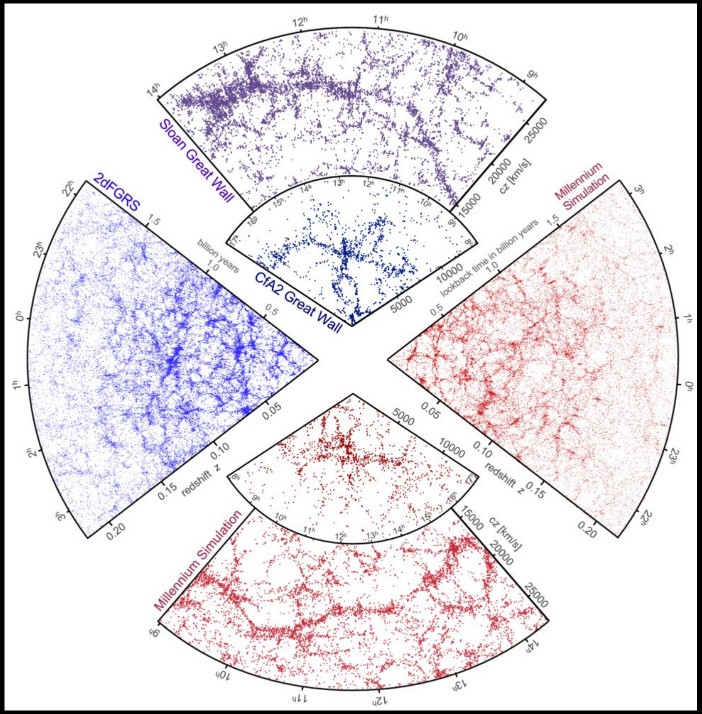
It's a relic from the early Universe

## What we don't know:

Its mass, its spin.
Is it real or complex?
Why is it stable?
Its quantum numbers.
How can it be detected?
Are there several of them?
Is it connected to other problems?
How was it produced?
How is it distributed? ...

# Several approaches are being used to investigate the dark matter

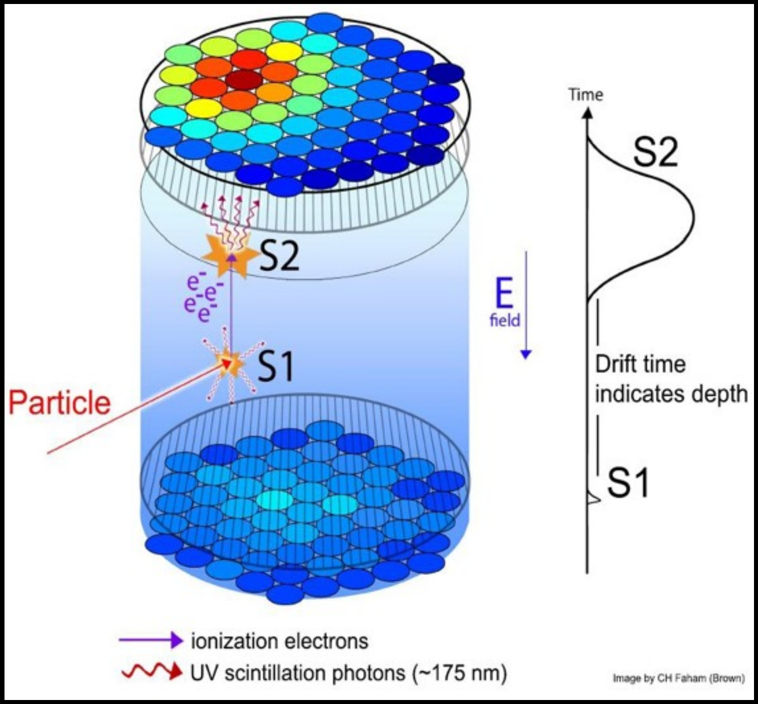
1. Computer simulations



# Several approaches are being used to investigate the dark matter

1. Computer simulations

2. Experimental searches

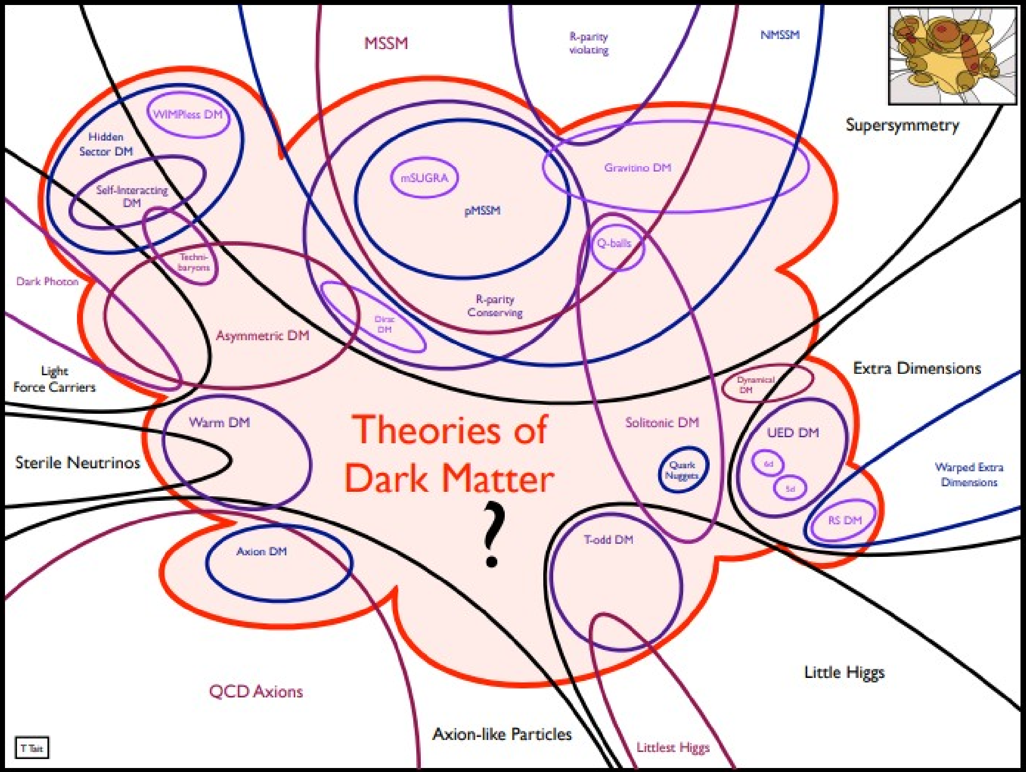


# Several approaches are being used to investigate the nature of dark matter

1. Computer simulations

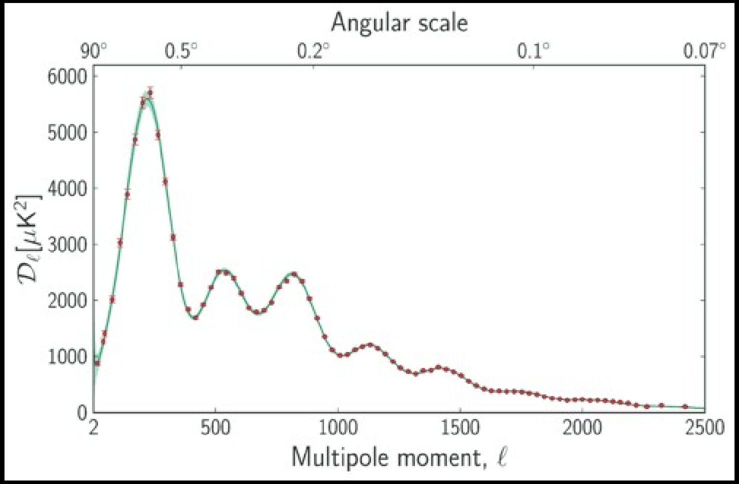
2. Experimental searches

3. Theoretical studies

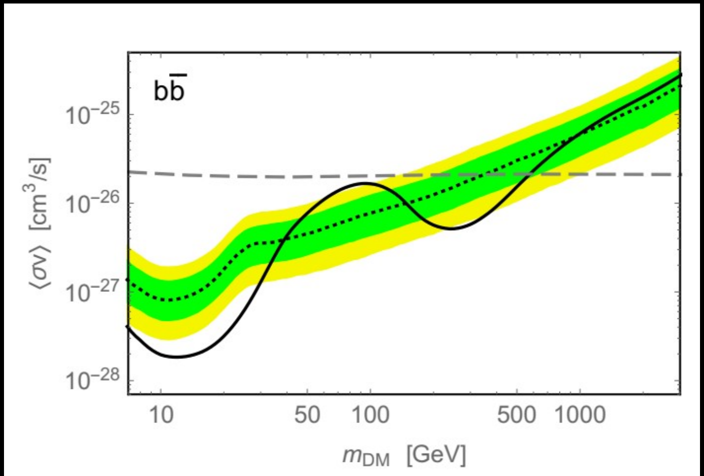


# I will present an overview of the current status of dark matter research

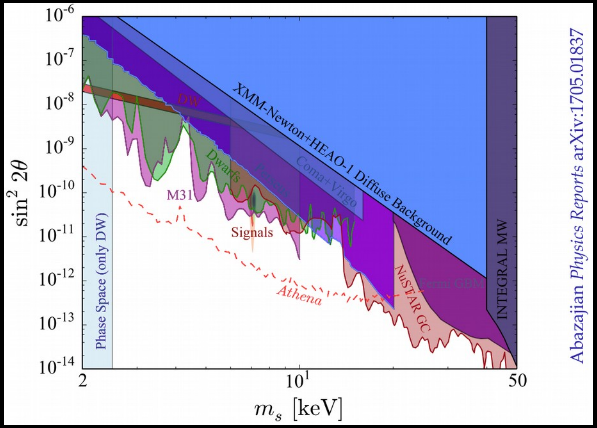
## 1. Motivation




## 2. WIMPs




## 3. Beyond WIMPs



# The WIMP framework can naturally explain the observed dark matter density

**Assumptions:**

A new neutral and stable particle

With a mass in the TeV range

And weak-strength interactions

**Conclusion:**

It is a good DM candidate:

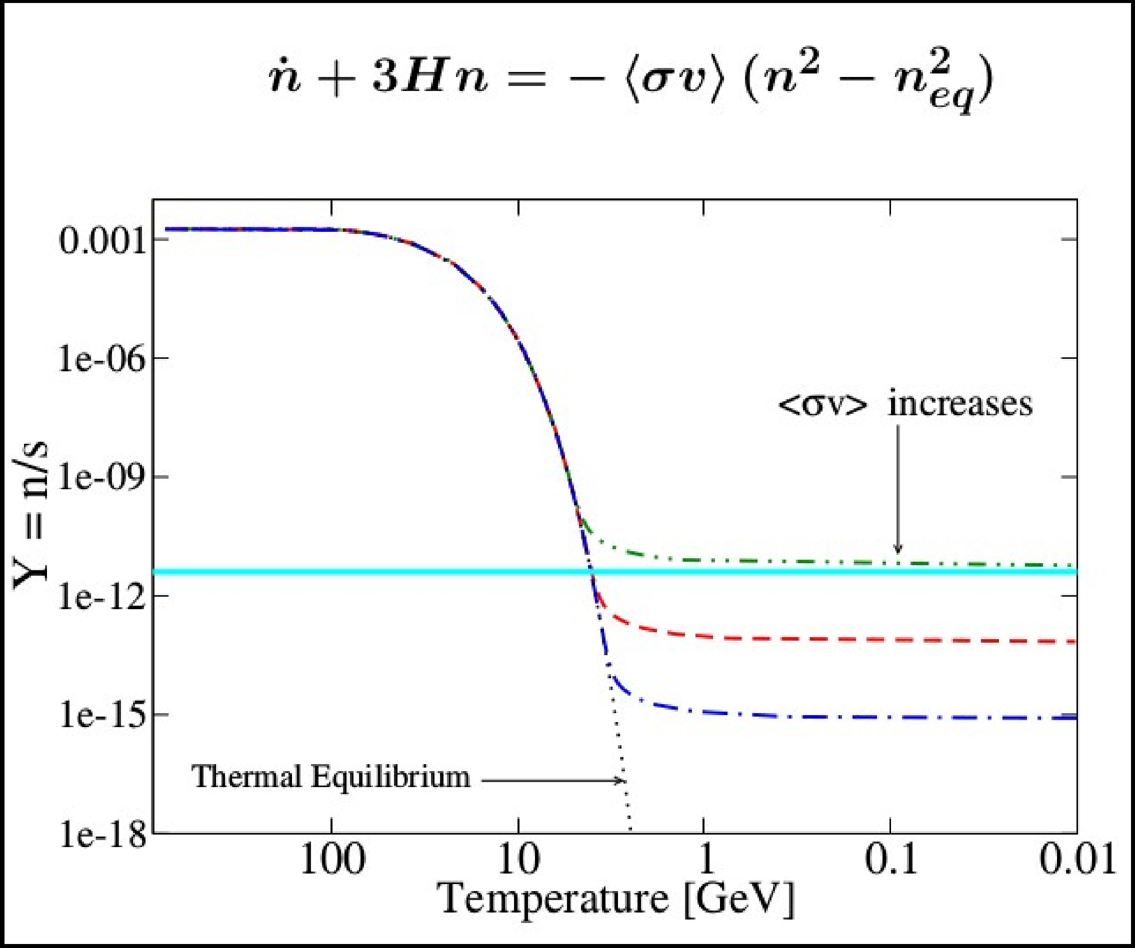
$$\Omega_{WIMP} \sim \Omega_{DM}$$

# WIMPs are created in the early Universe via a process known as freeze-out

They are in equilibrium at high T

They freeze-out at T~ M/25

$\Omega_{WIMP}$ is proportional to 1/<σv>



# WIMPs have additional advantages

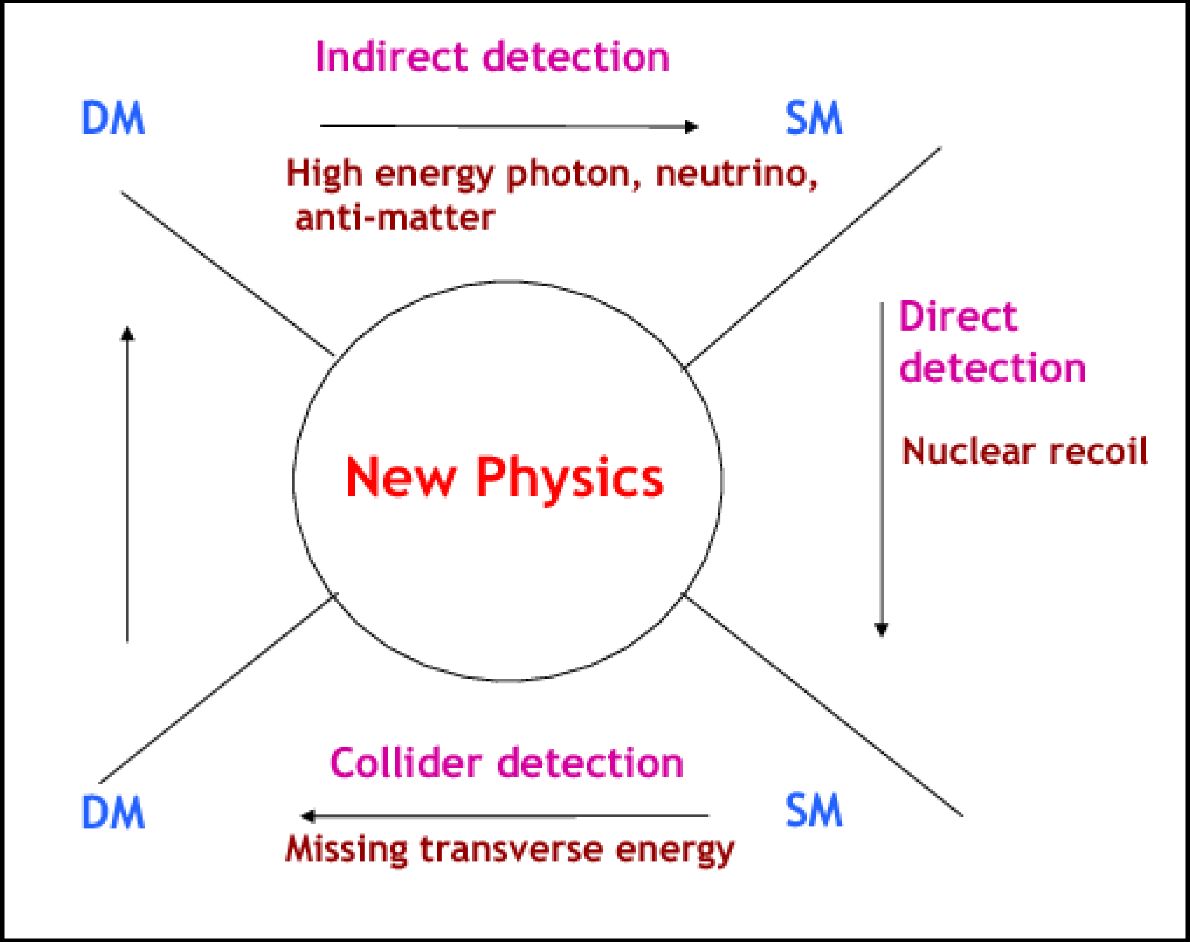
| | |
|---|---|
| They are associated with the TeV scale | New physics, LHC energy |
| They appear in many extensions of the SM | SUSY, UED |
| They give rise to observable signals | Testable! |

# WIMPs can be tested in different ways

**1. Direct detection (scattering)**

**2. Indirect detection (annihilation)**

**3. Collider searches (production)**

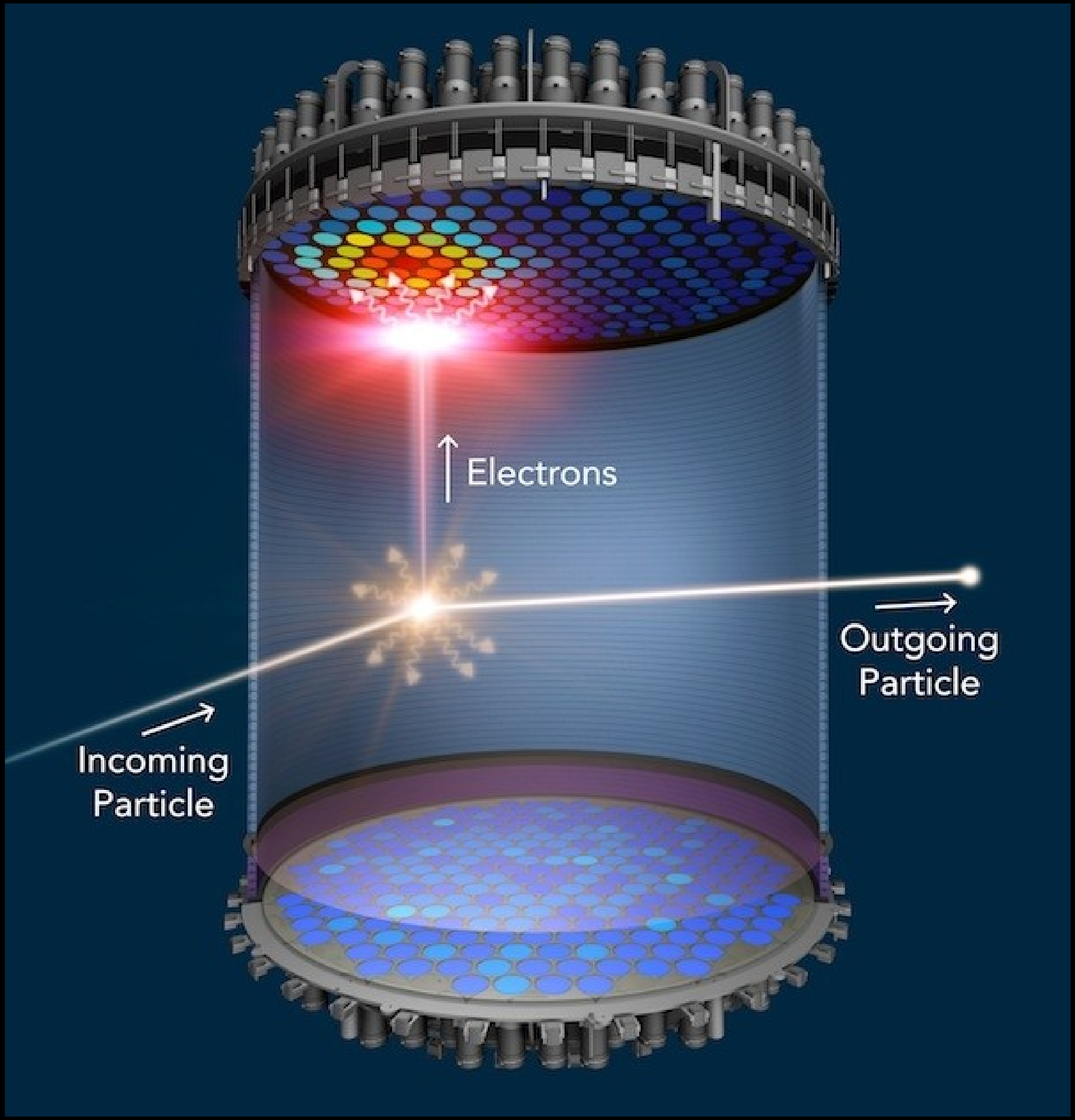


# DD experiments try to detect the nuclear recoil produced by DM scatterings

DM particles are non-relativistic

The recoil energy is of the order of keV

Deep underground experiments

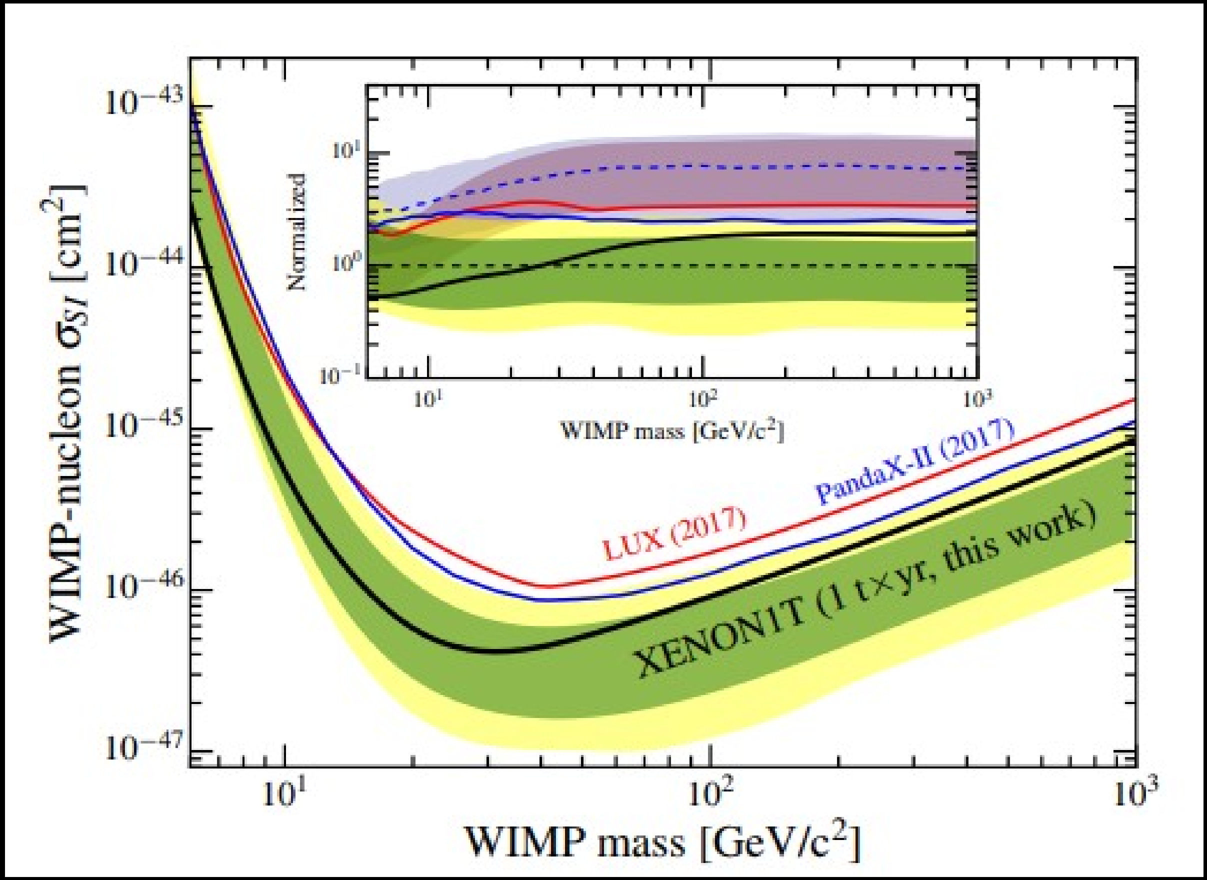


# Xenon targets currently provide the most stringent spin-independent limits

Experiments all over the world

They set similar limits on $\sigma_{SI}$

Ar experiments may become competitive

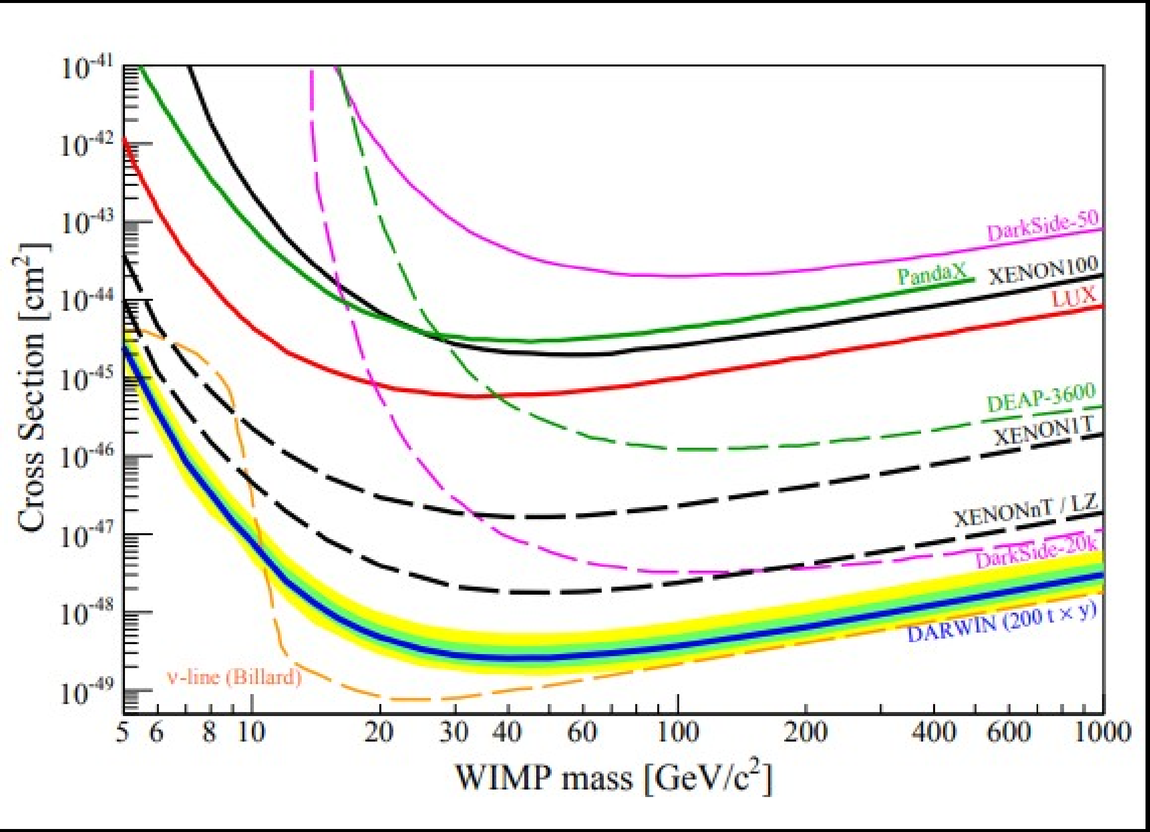


# In the near future more sensitive direct detection experiments will be running

XENONnT and LZ will start running soon

DARWIN will reach the neutrino floor

Ar experiments will also improve

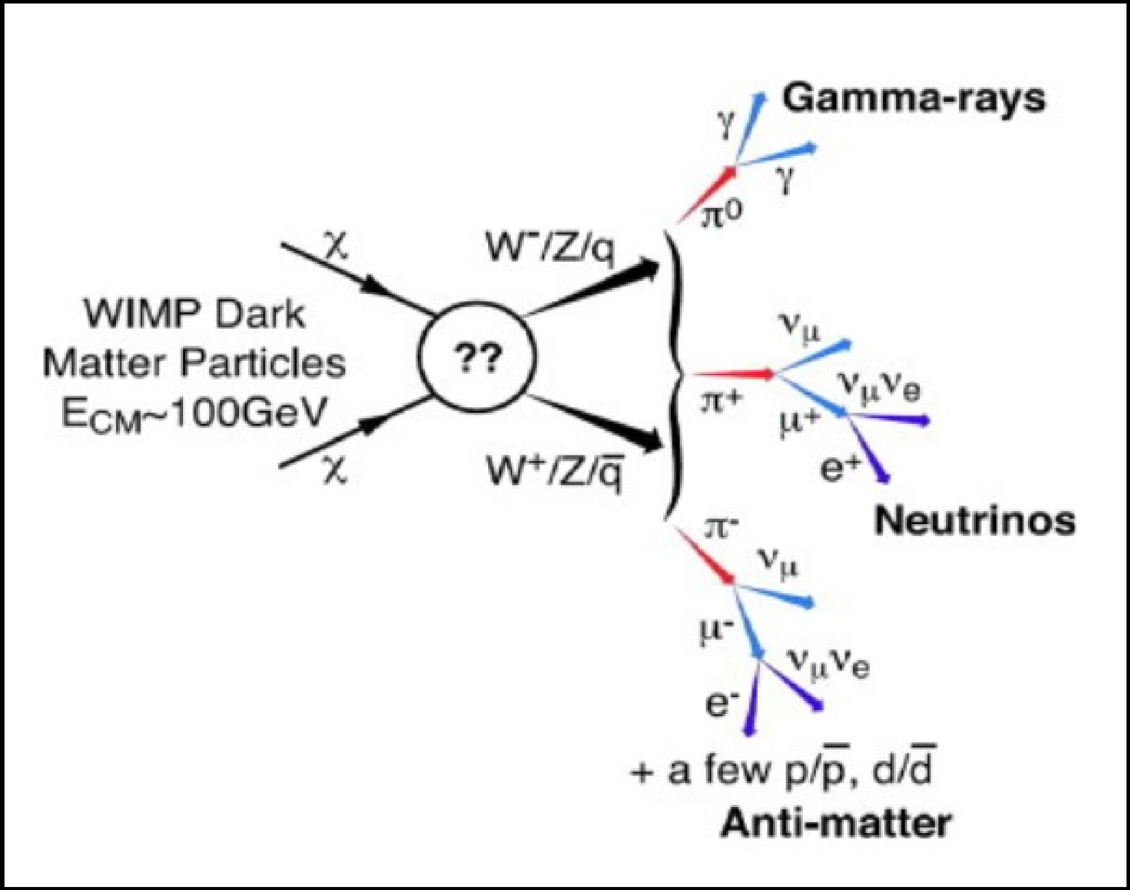


# Indirect detection experiments try to detect the DM annihilation products

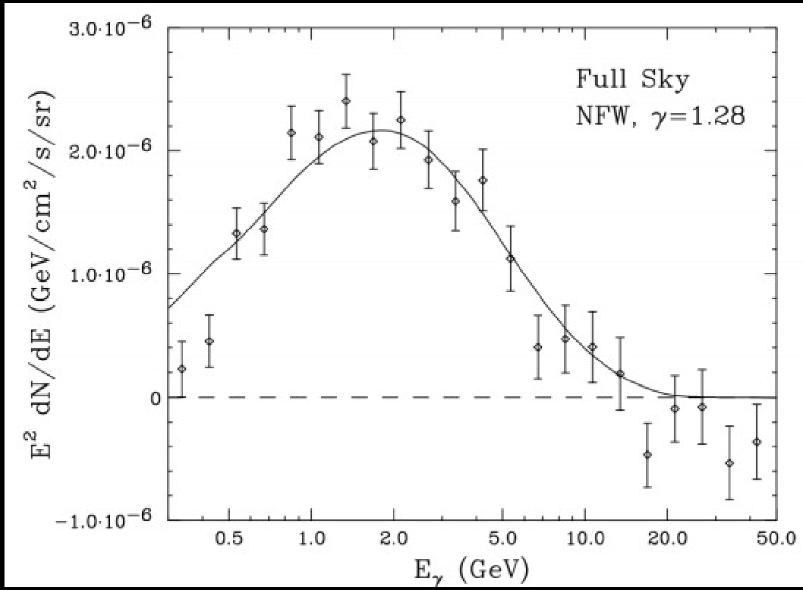
In satellite and ground detectors

Distinguishable from the bkg ?

Different astrophysical environments



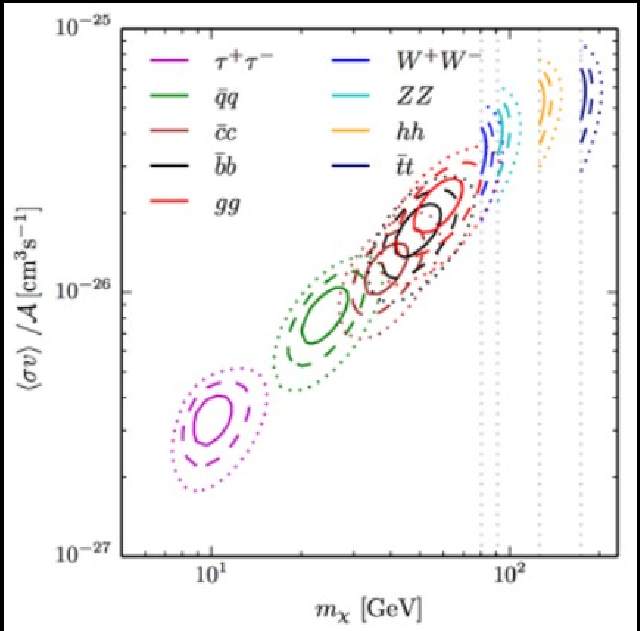
# FERMI-LAT has revealed a gamma-ray excess from the Galactic center




**It is consistent with a DM signal**

**And not inconsistent with other data**

**But could be explained by astrophysics**

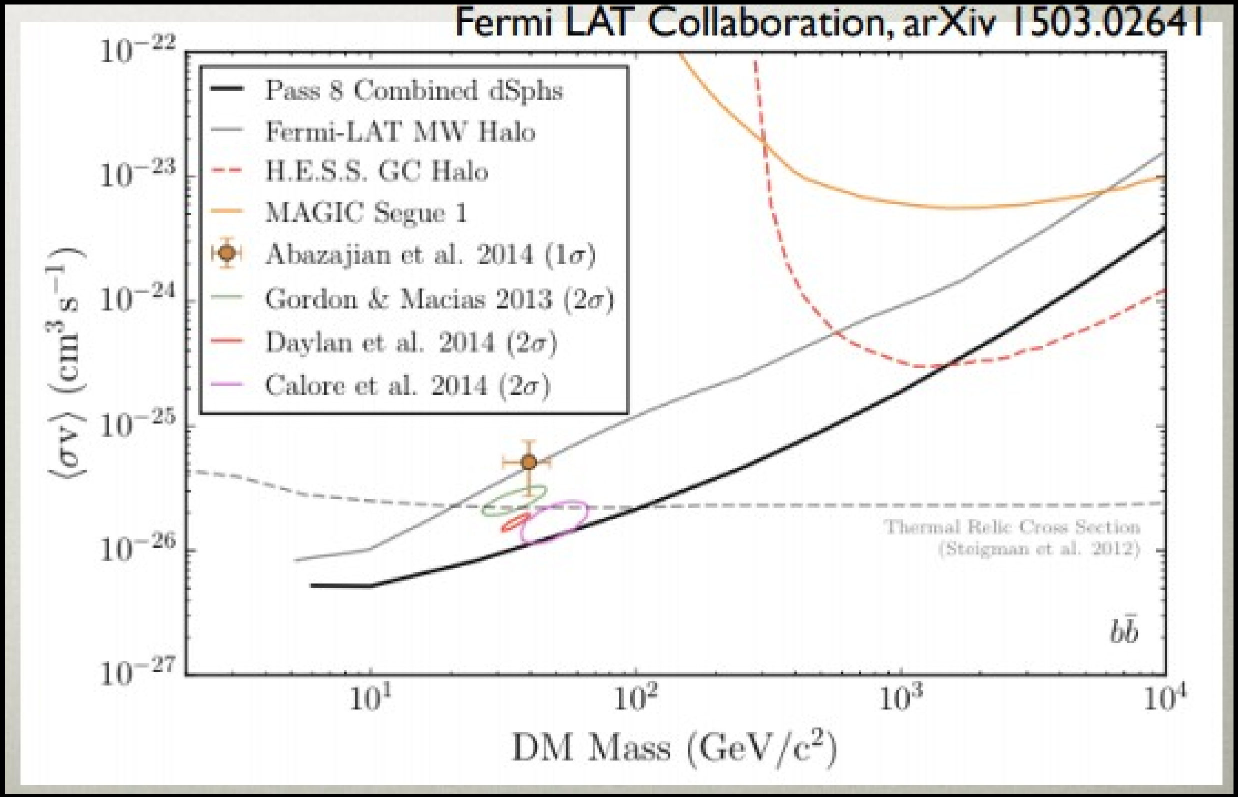


# Dwarf spheroidal satellite galaxies are great targets for gamma-ray searches

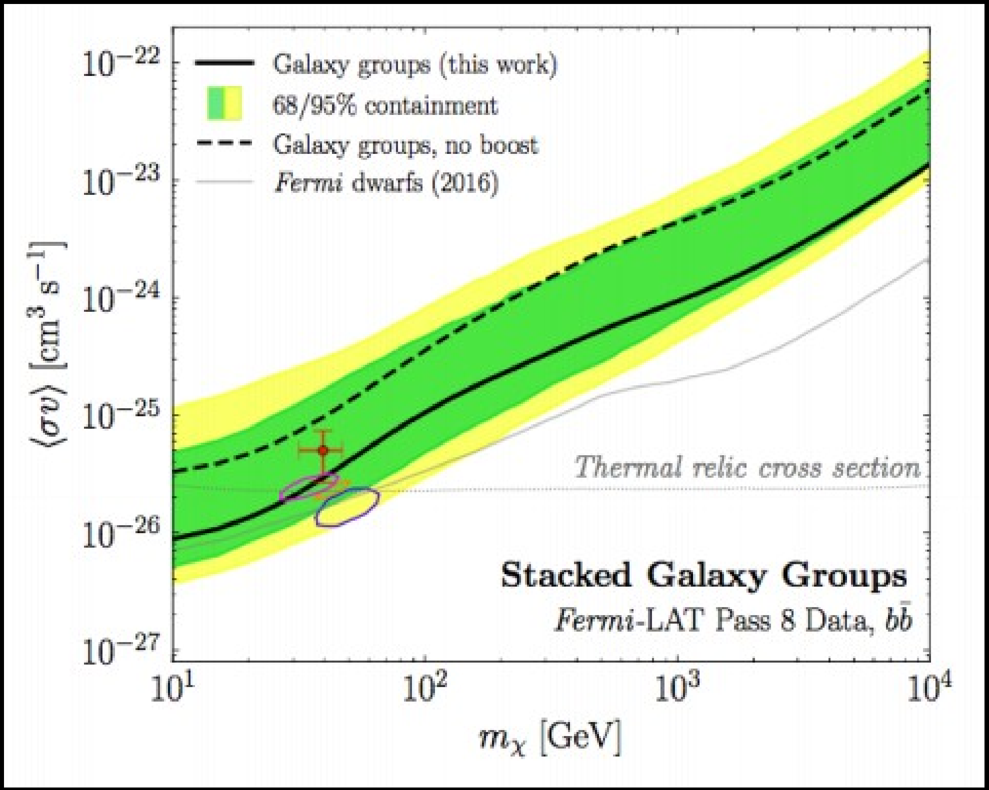
They are nearby and DM dominated

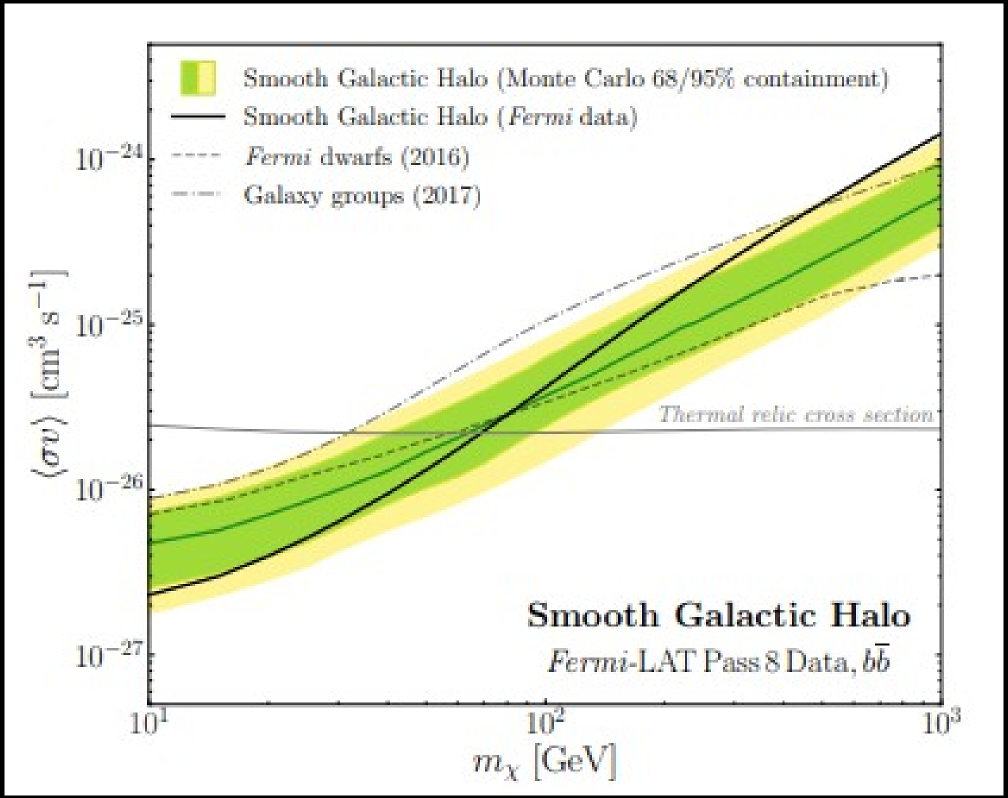
They are “free” of astrophysical bkgs

FERMI has derived strong limits on <σv>



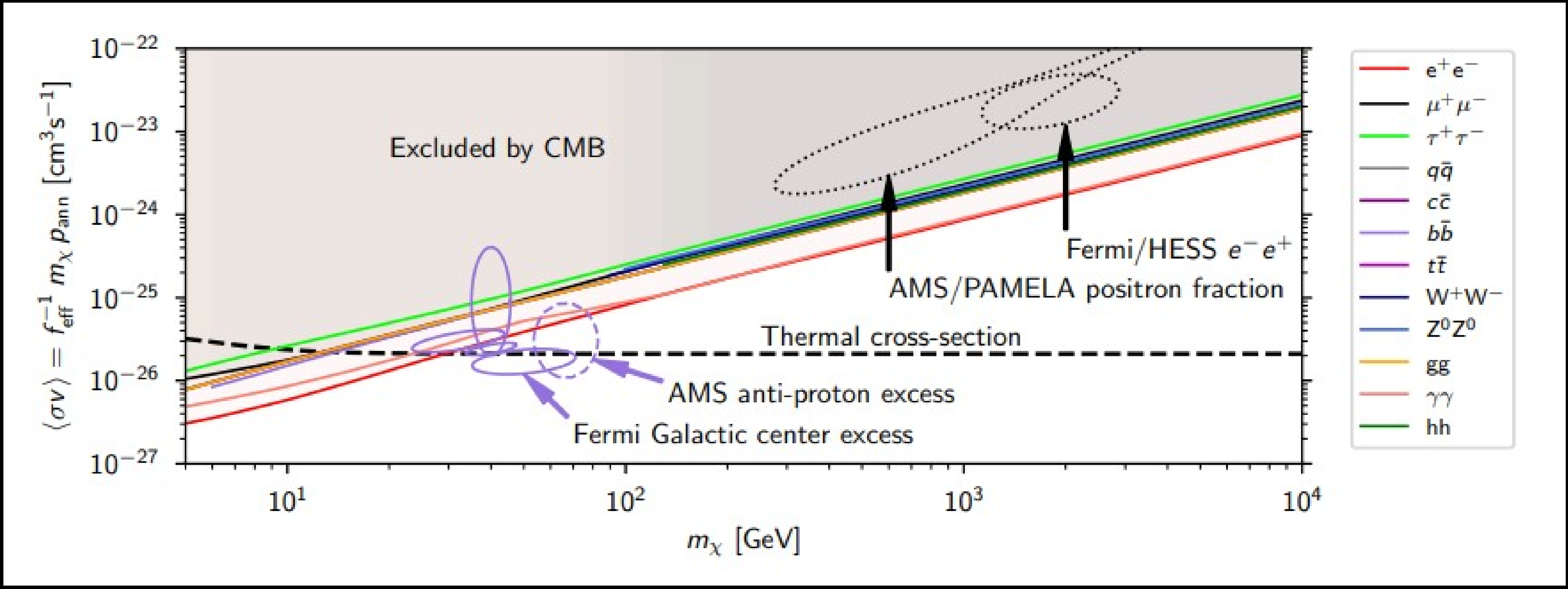
# Recently, comparable limits have been derived from other targets




**Lisanti et al, 2018**

# The CMB also sets stringent bounds on the DM annihilation cross section



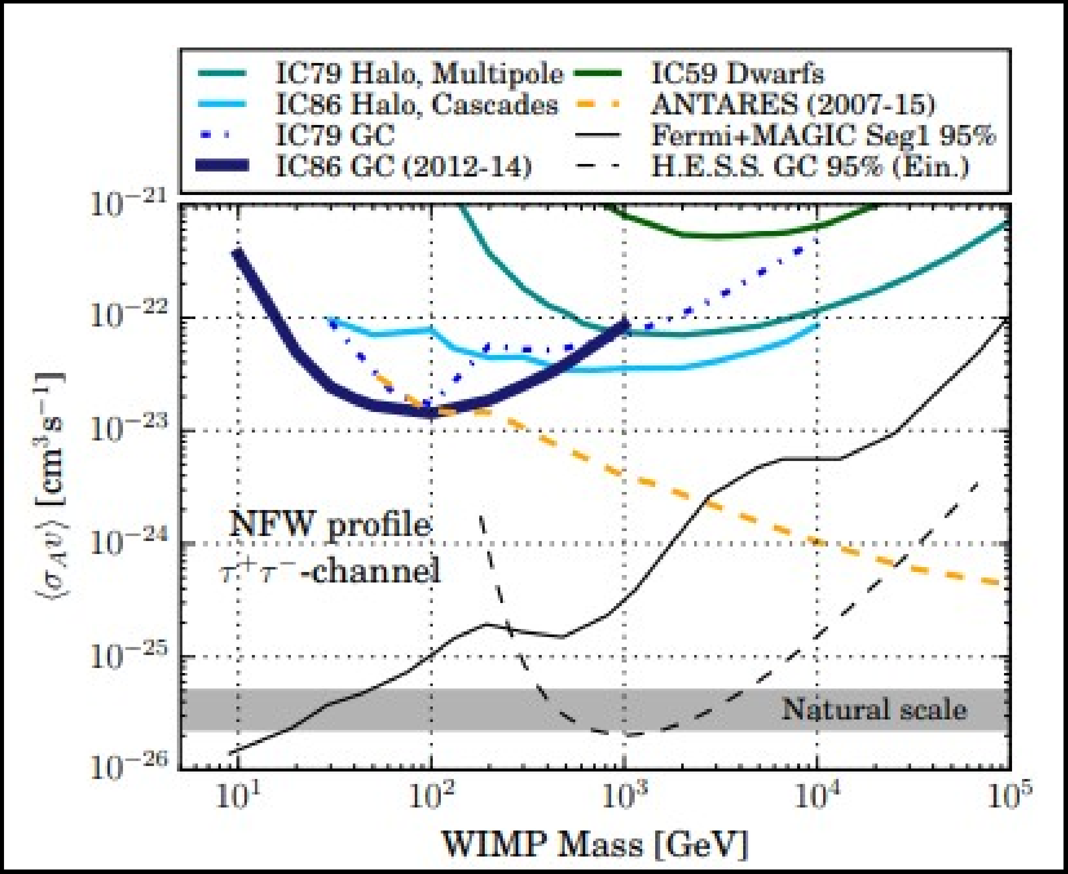

**They are free of astrophysical uncertainties**

# The limits on <σv> from neutrinos are weaker than those from gamma-rays

GC, halo and dwarfs are used as targets

Antares and IceCube complement each other

Current limits do not probe the thermal value



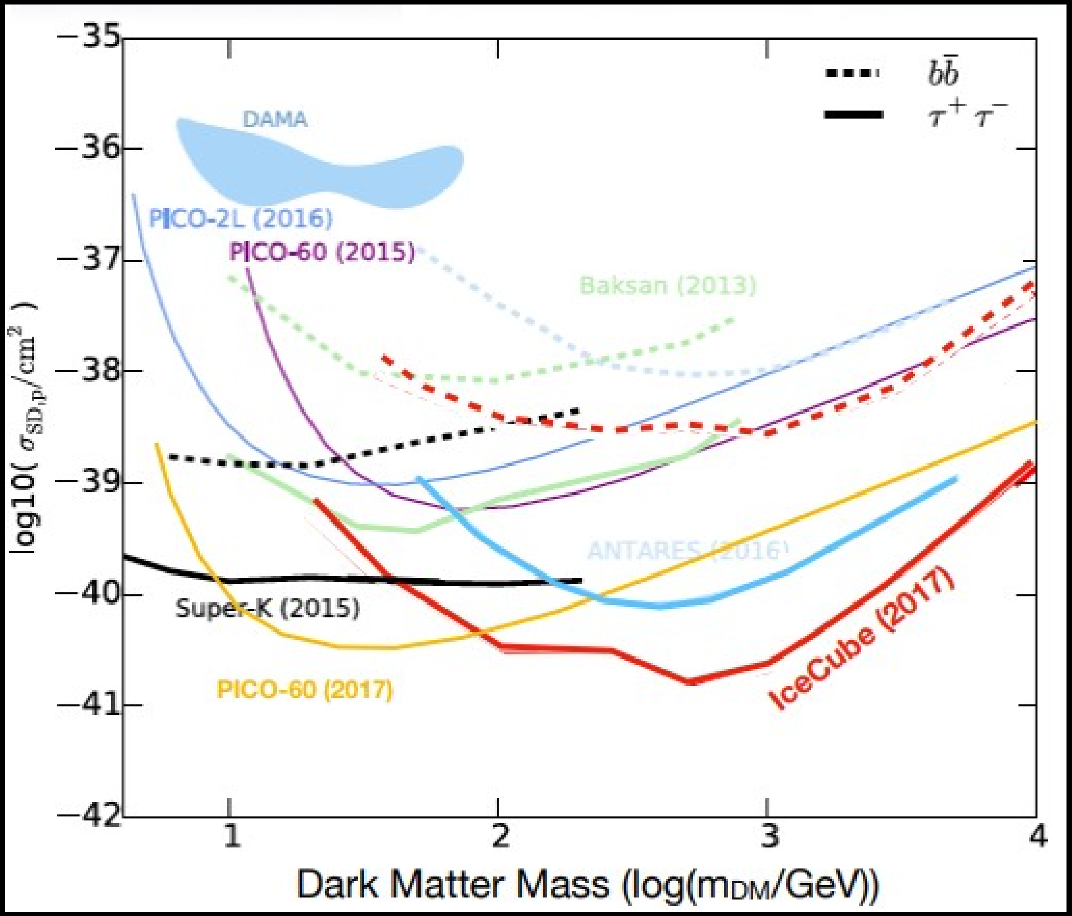

IceCube, 2017

# WIMPs can be captured in the Sun and annihilate producing neutrinos

$\sigma_{SI}$, $\sigma_{SD}$ determine the capture rate

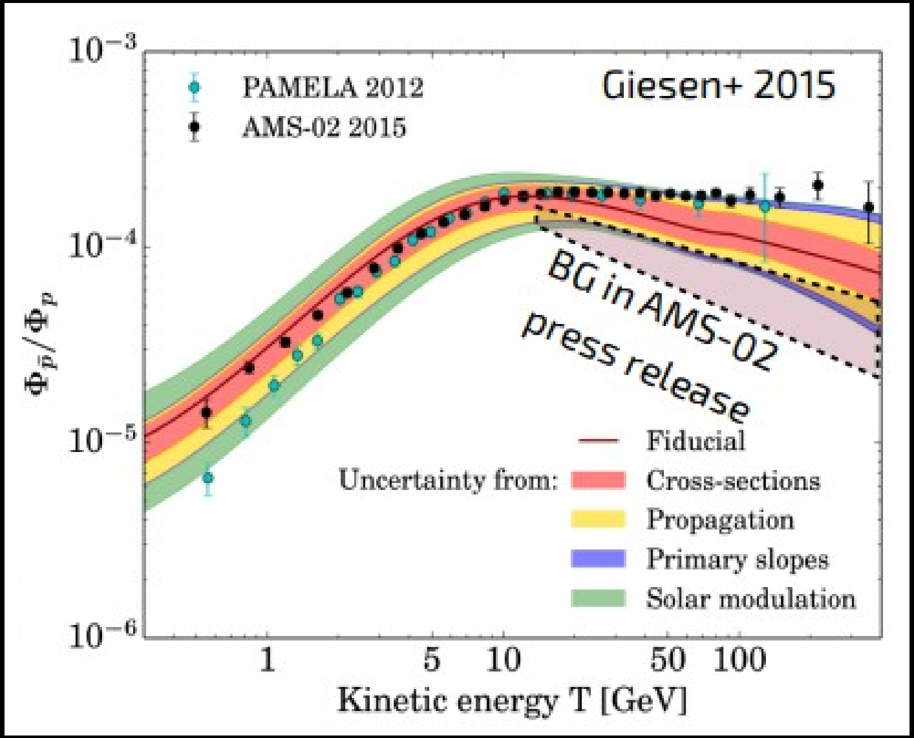
Complementary to direct detection

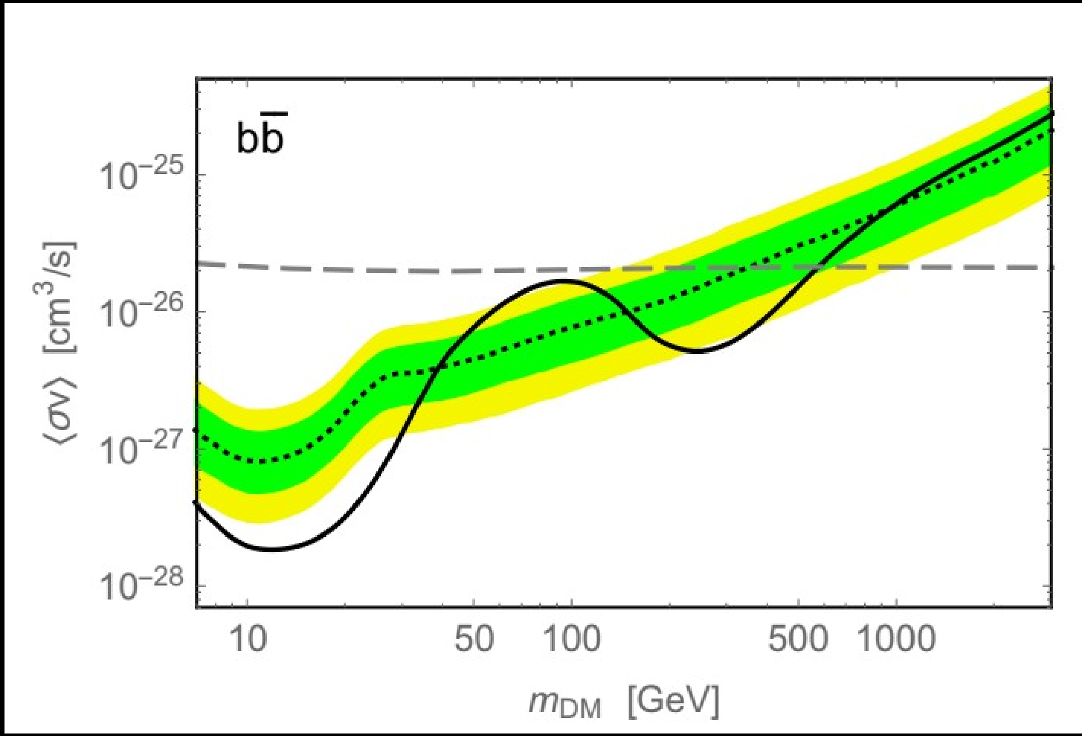
IceCube sets the strongest limits



# DM annihilations would give an additional contribution to the antiproton flux

Reinert and Winkler, 2018




Measurements are consistent with bkg

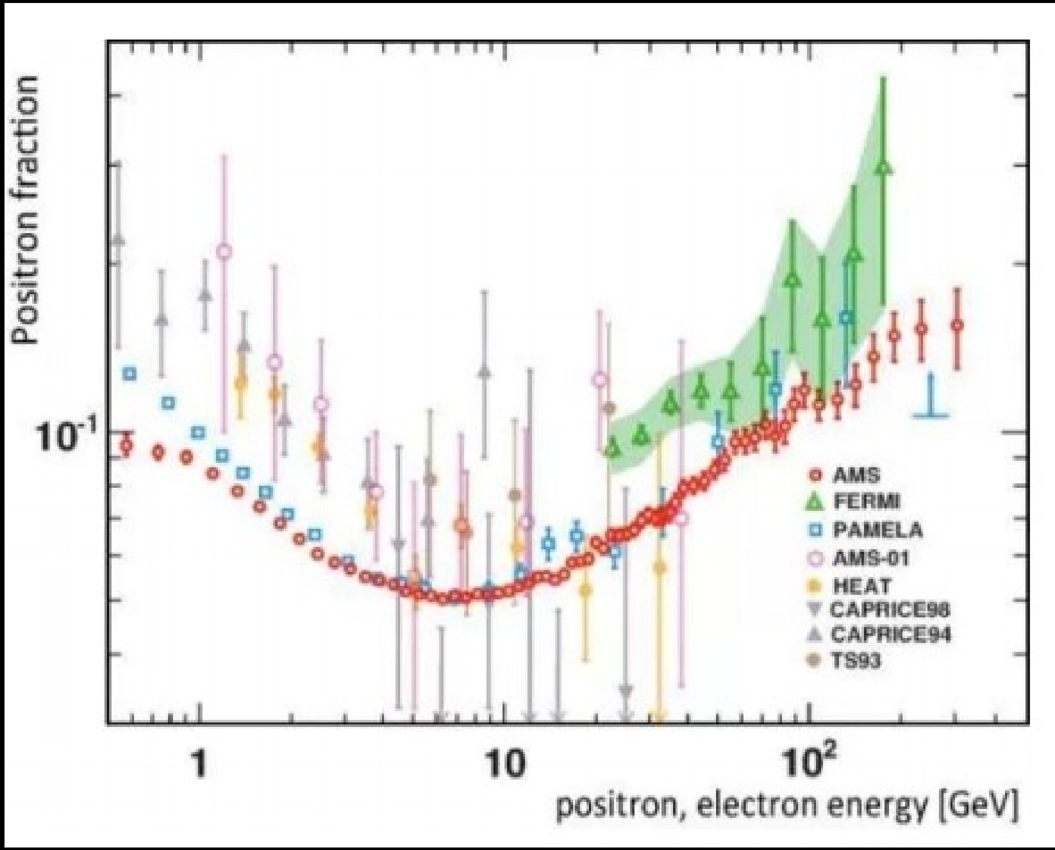
Strong limits can be derived

# An excess over the expectations has been observed in the positron fraction

DM explanation is excluded

Nothing is observed in γ, $p^-$, CMB

Pulsars, microquasars, SNRs ?

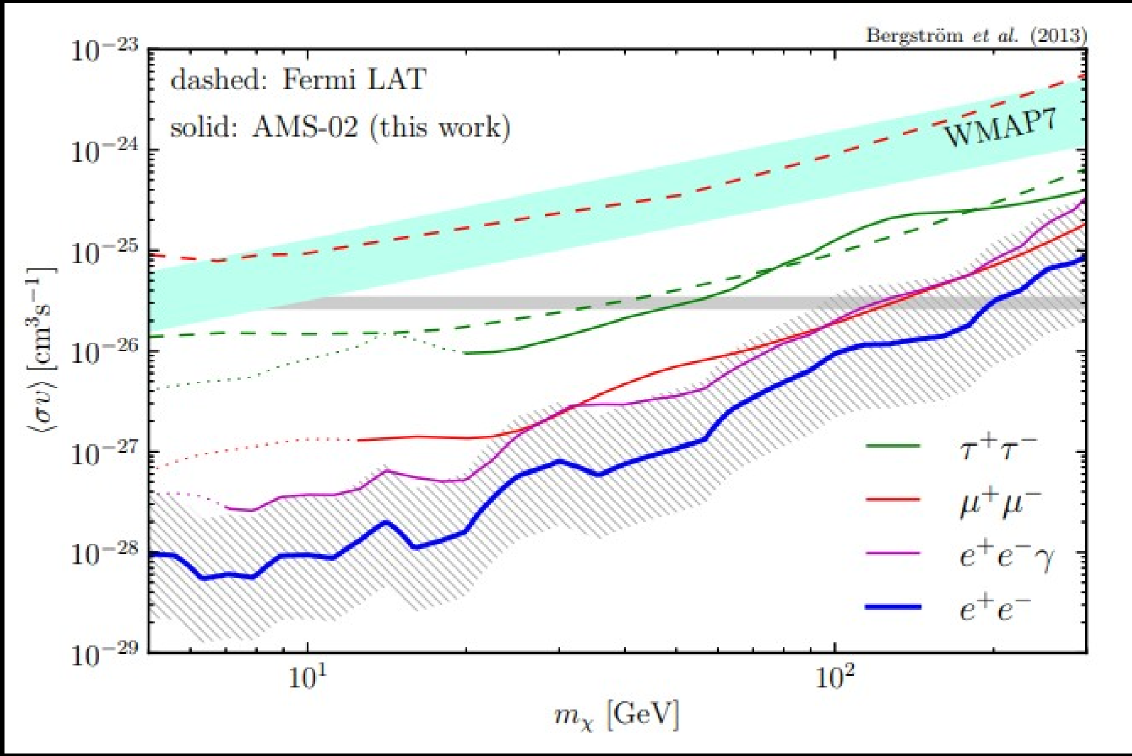


# AMS-02 data can be used to derive strong limits on <σv> for certain final states

The AMS $e^+$ spectrum is smooth

DM should give rise to spectral features

Limits are competitive for $M_{DM}$ < 300 GeV



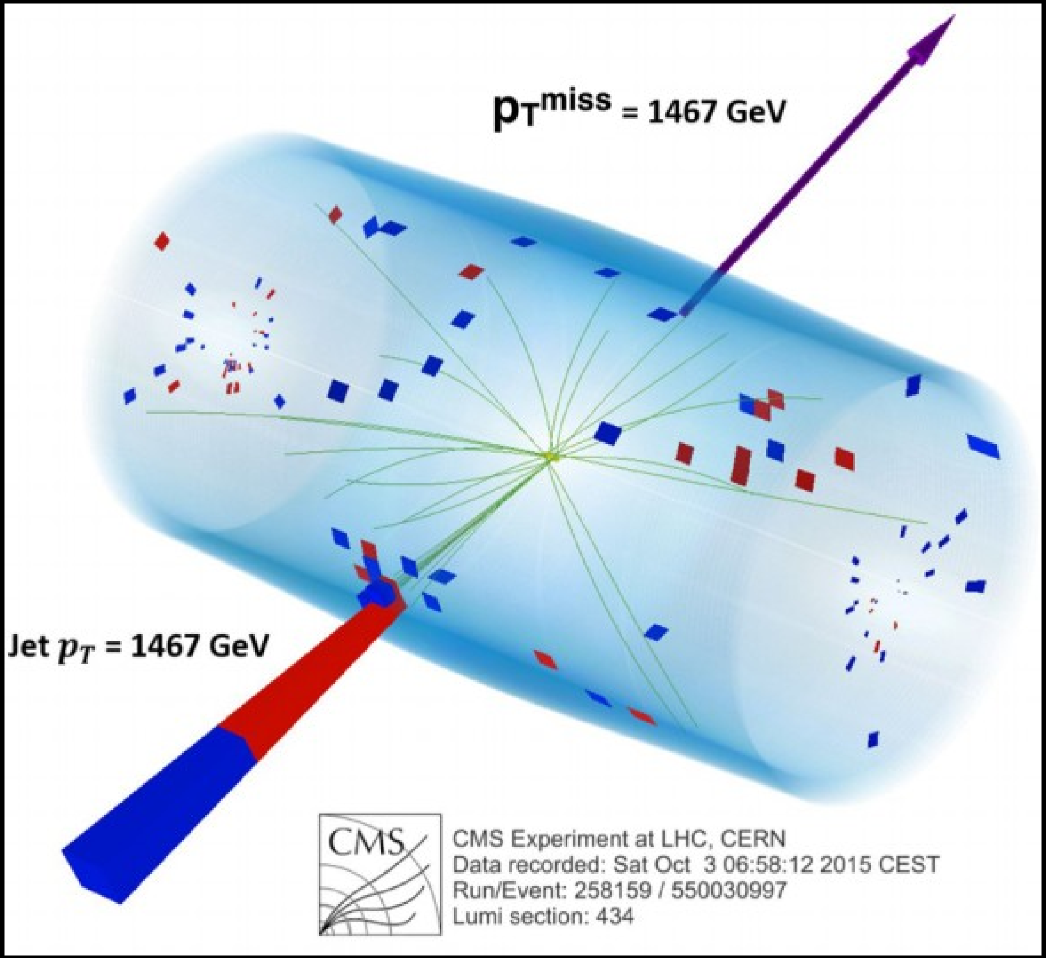
# At the LHC, DM particles may give rise to missing energy signals

**Generic signature:**

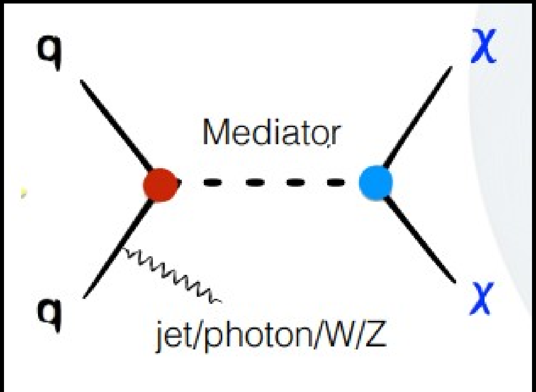
$$pp \to \not{E}_T + X$$

**The X can be g, γ, Z, W. (Mono-X searches)**

**How does DM and p interact?**



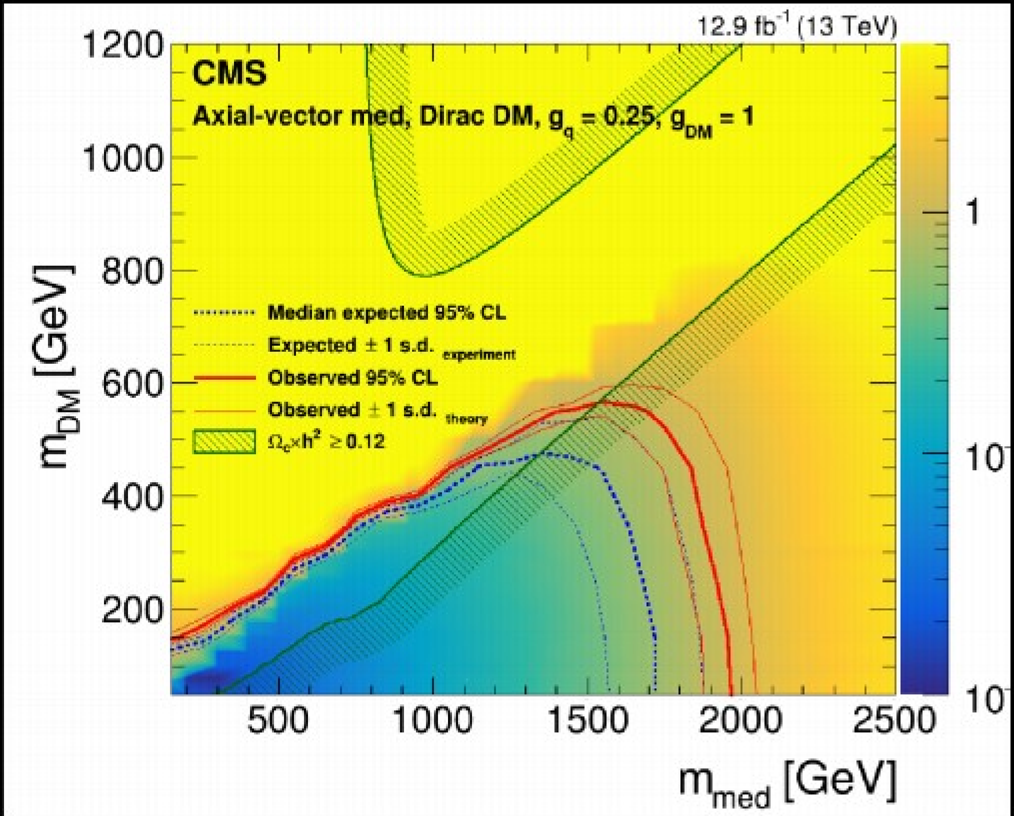
# ATLAS and CMS have set limits on simplified DM models




They contain few free parameters

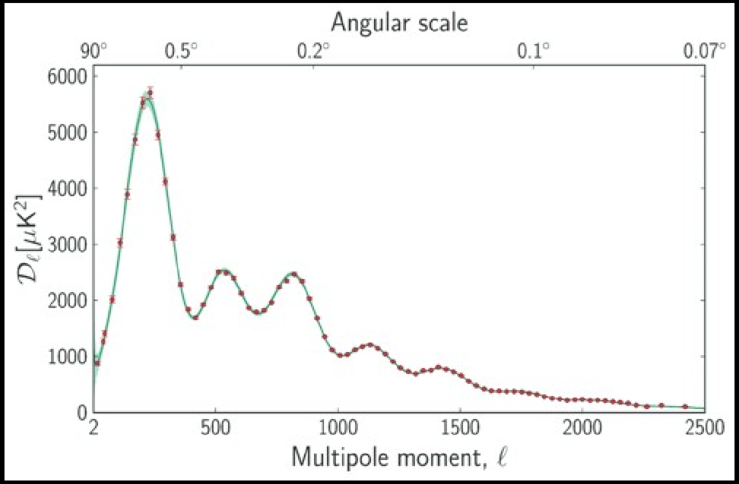
Only a small number of models

Interesting limits can be obtained

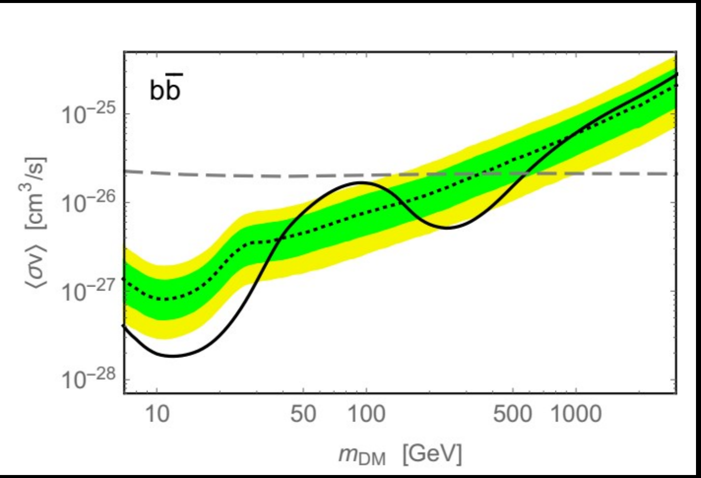


# I will present an overview of the current status of dark matter research

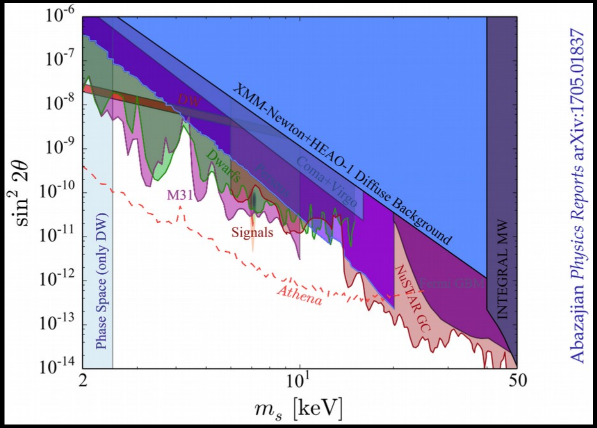
## 1. Motivation




## 2. WIMPs




## 3. Beyond WIMPs



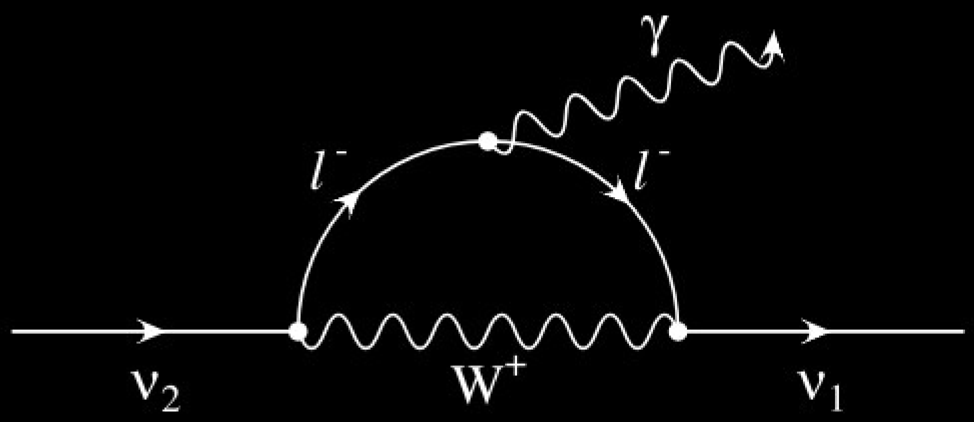
# Sterile neutrinos could be the dark matter if m ~ few keV

They mix with the active ν's

Via a Dirac mass term

They are long-lived but unstable

And decay producing an X-ray photon

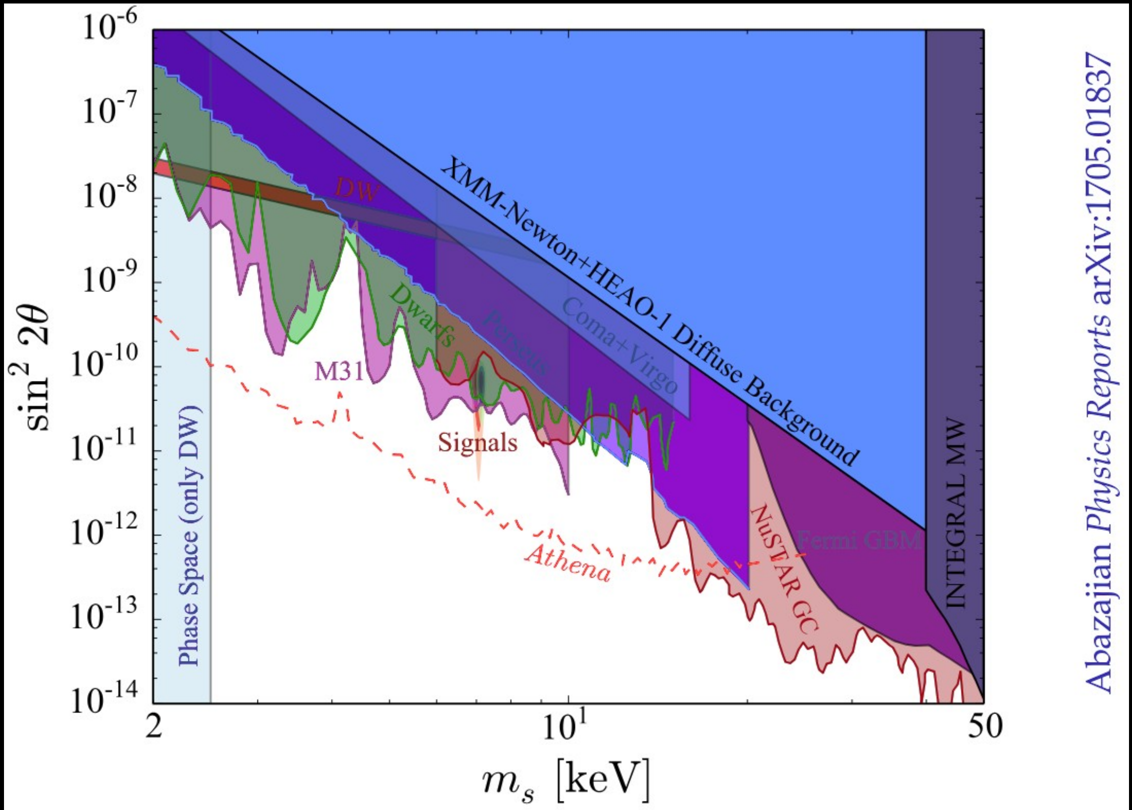


# Currently sterile neutrinos as dark matter are very constrained

Just two parameters: m, θ

No X-ray photon has been observed

It is not easy to produce them



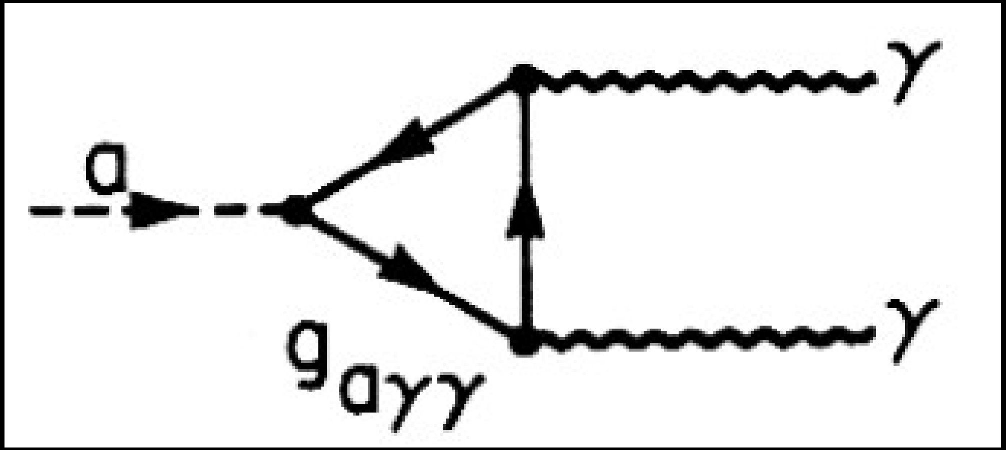
# Axions have a long history as DM candidates

They solve the strong CP problem

Via the PQ mechanism

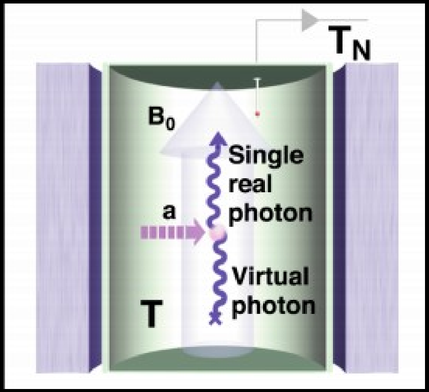
They are very light, $m_a \sim 10^{-5}$ eV

And couple to the photons



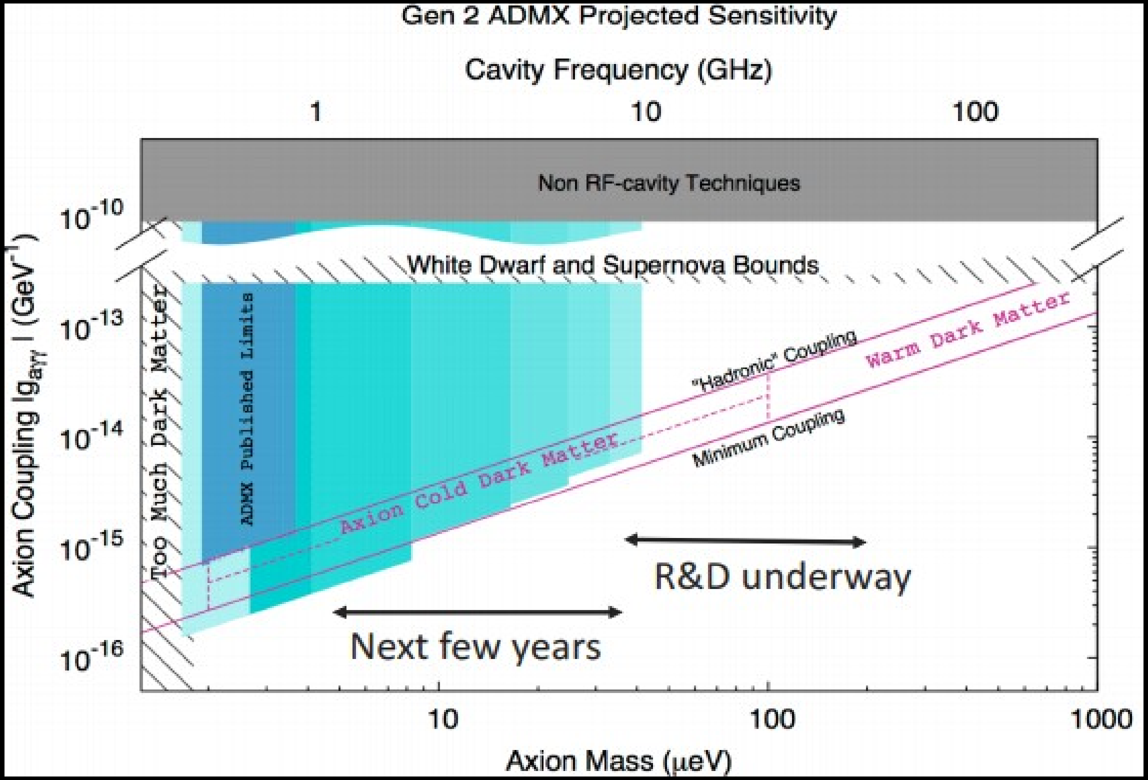
# Over the next few years, the DM axion will be experimentally probed

Via the Primakoff effect




ADMX has already started

And it has a good chance of discovery

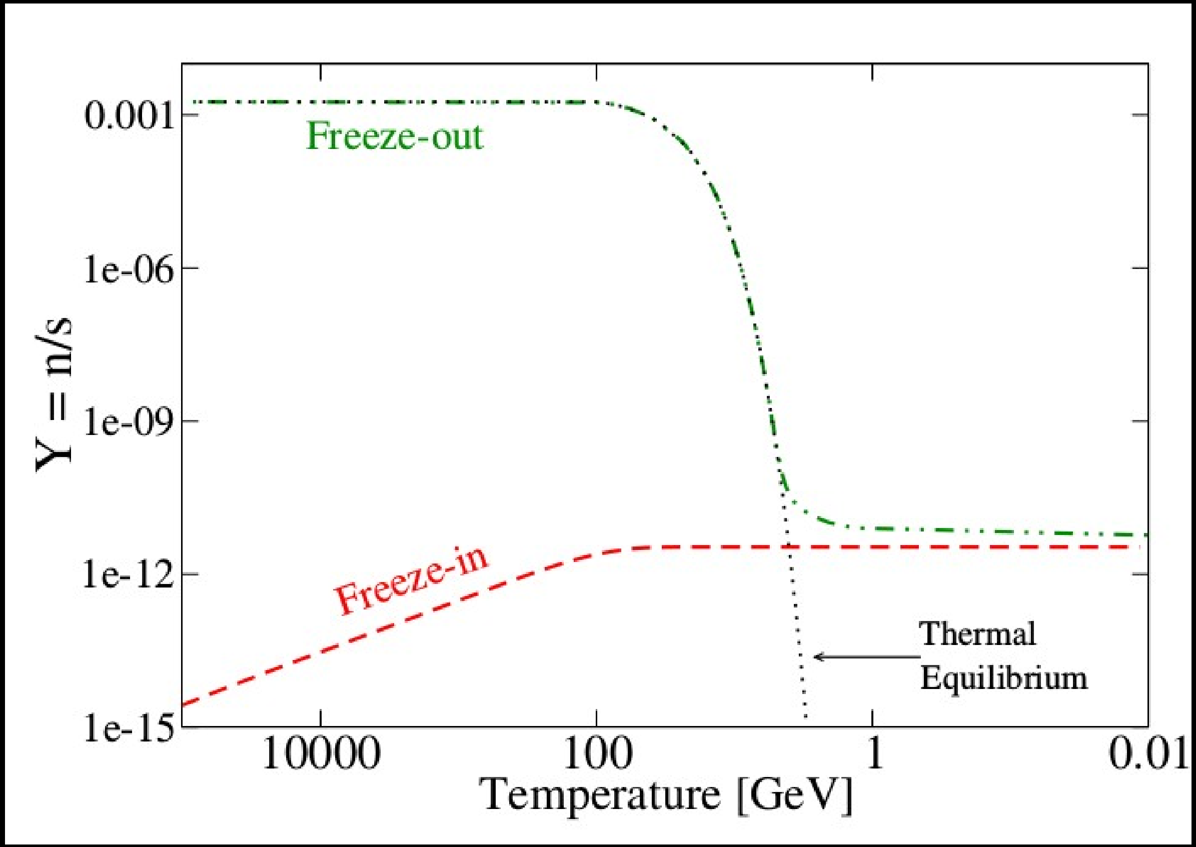


# FIMPs (Feebly Interacting Massive Particles) are an alternative to WIMPs

They have weaker interactions

They are produced via freeze-in

Many possible realizations

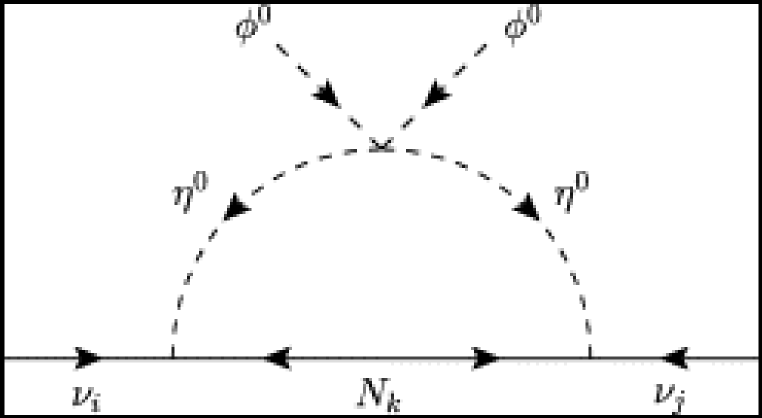


# DM and ν-masses could be explained by the same physics at the TeV scale

Both require new particles

Observable at the LHC?

ν-masses at 1-loop and LFV




Several possibilities for the DM

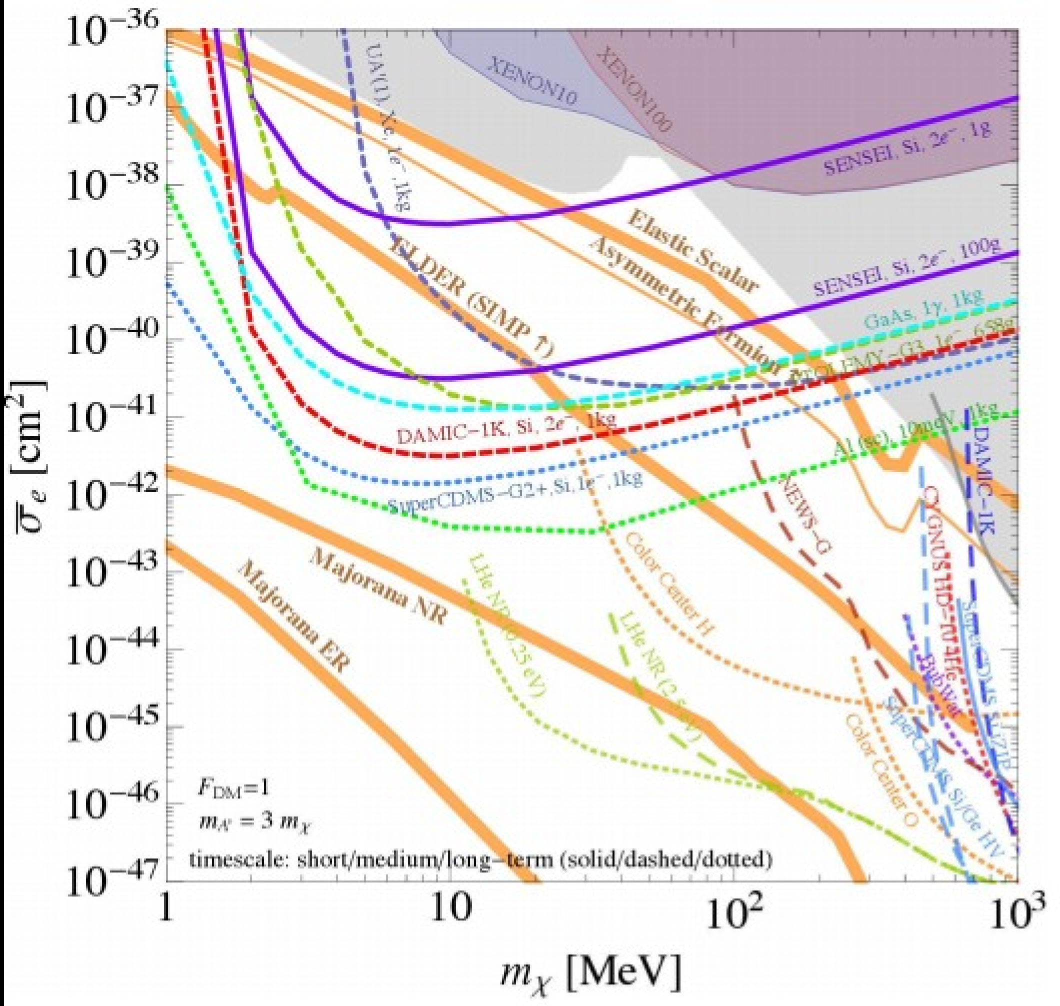
Scalar or fermion, FIMP or WIMP

# DM at the MeV scale has attracted a lot of attention lately

The nuclear recoil energy is very low

Use DM-electron scattering instead

Different techniques are being explored

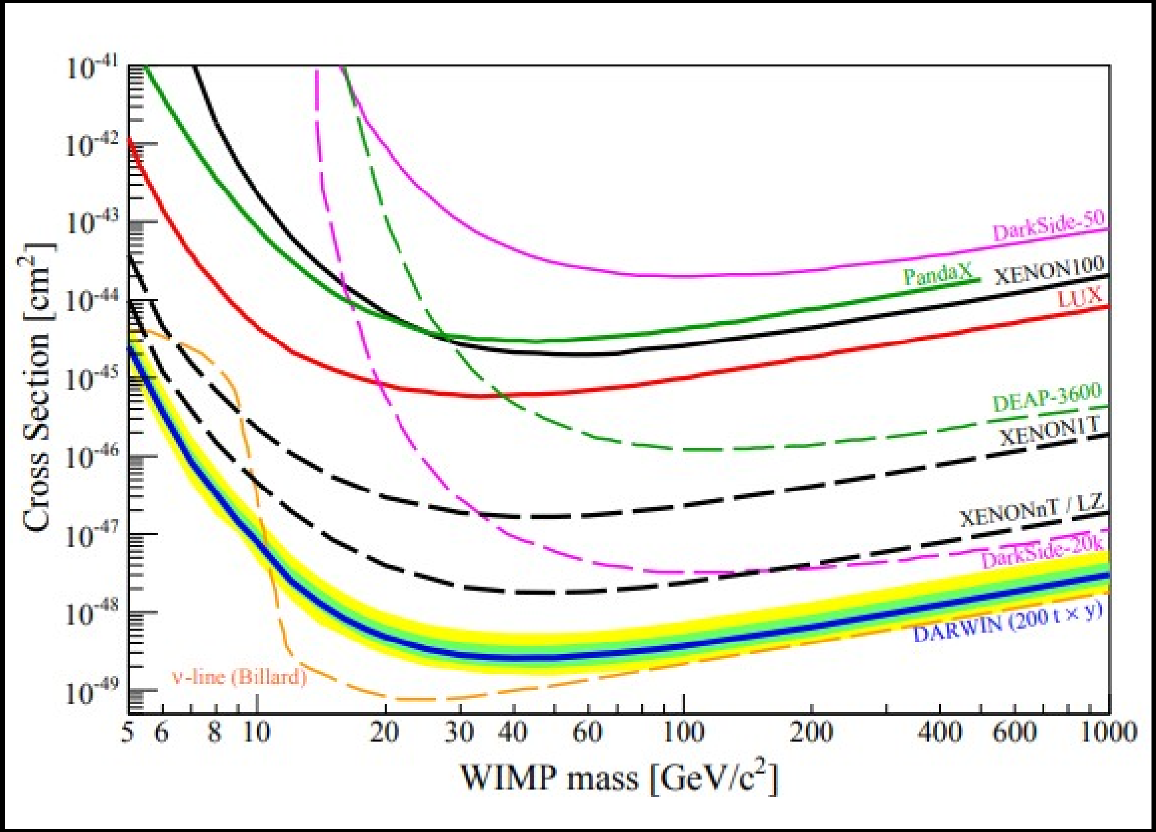


# Dark matter is an active and exciting research field

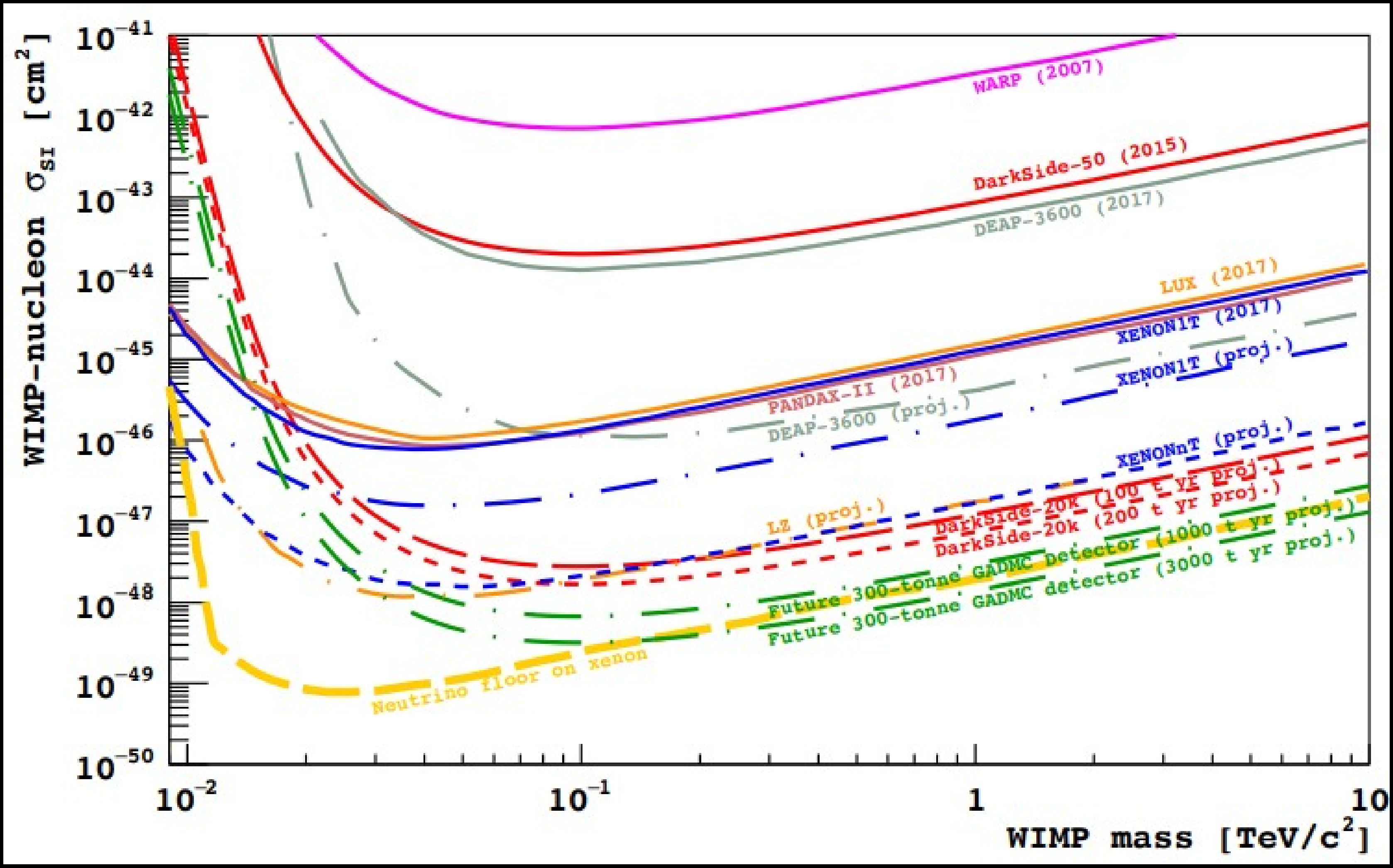
Plenty of open questions

A lot of models and ideas

A strong experimental program

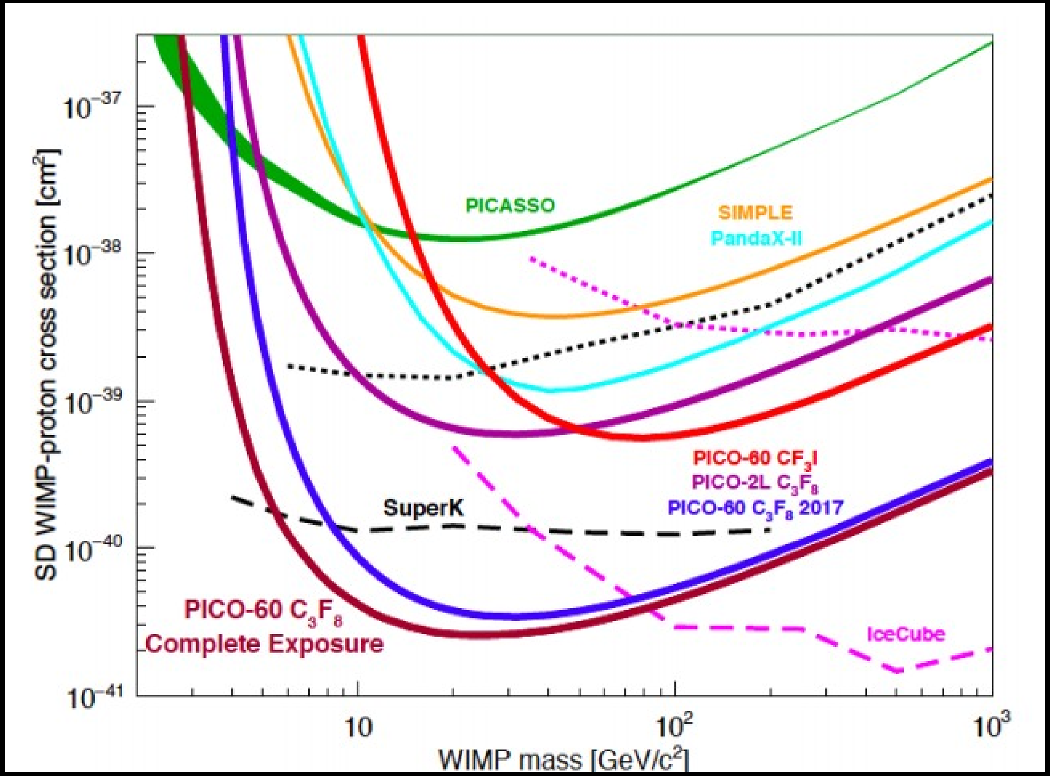


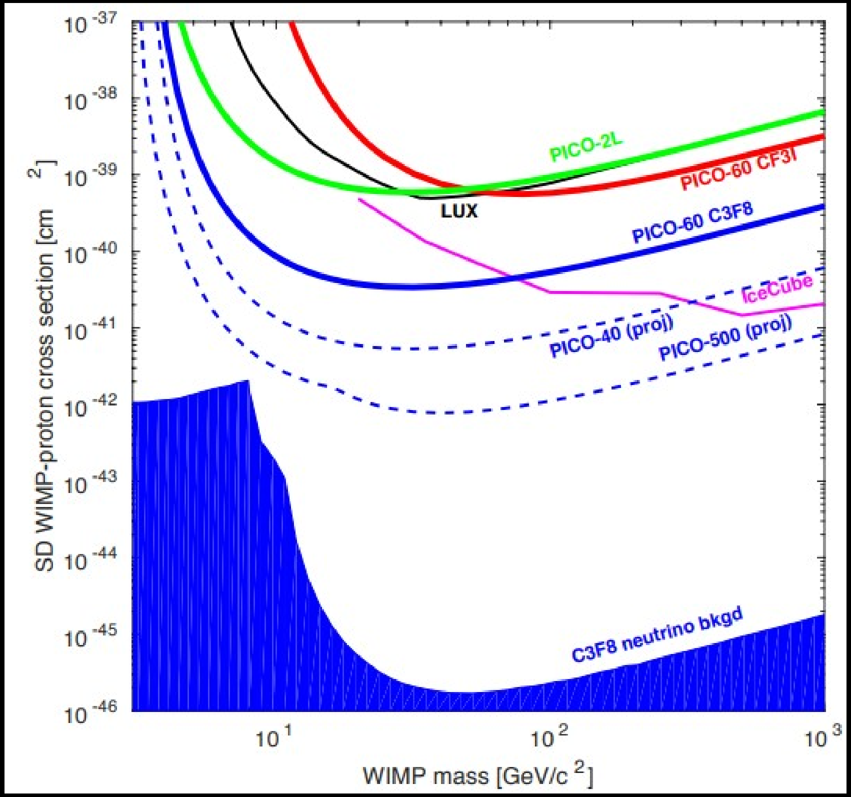
# Ar Spin-independent limits




Phys.Rev. D95 (2017) no.9, 095010
JHEP 1710 (2017) 059

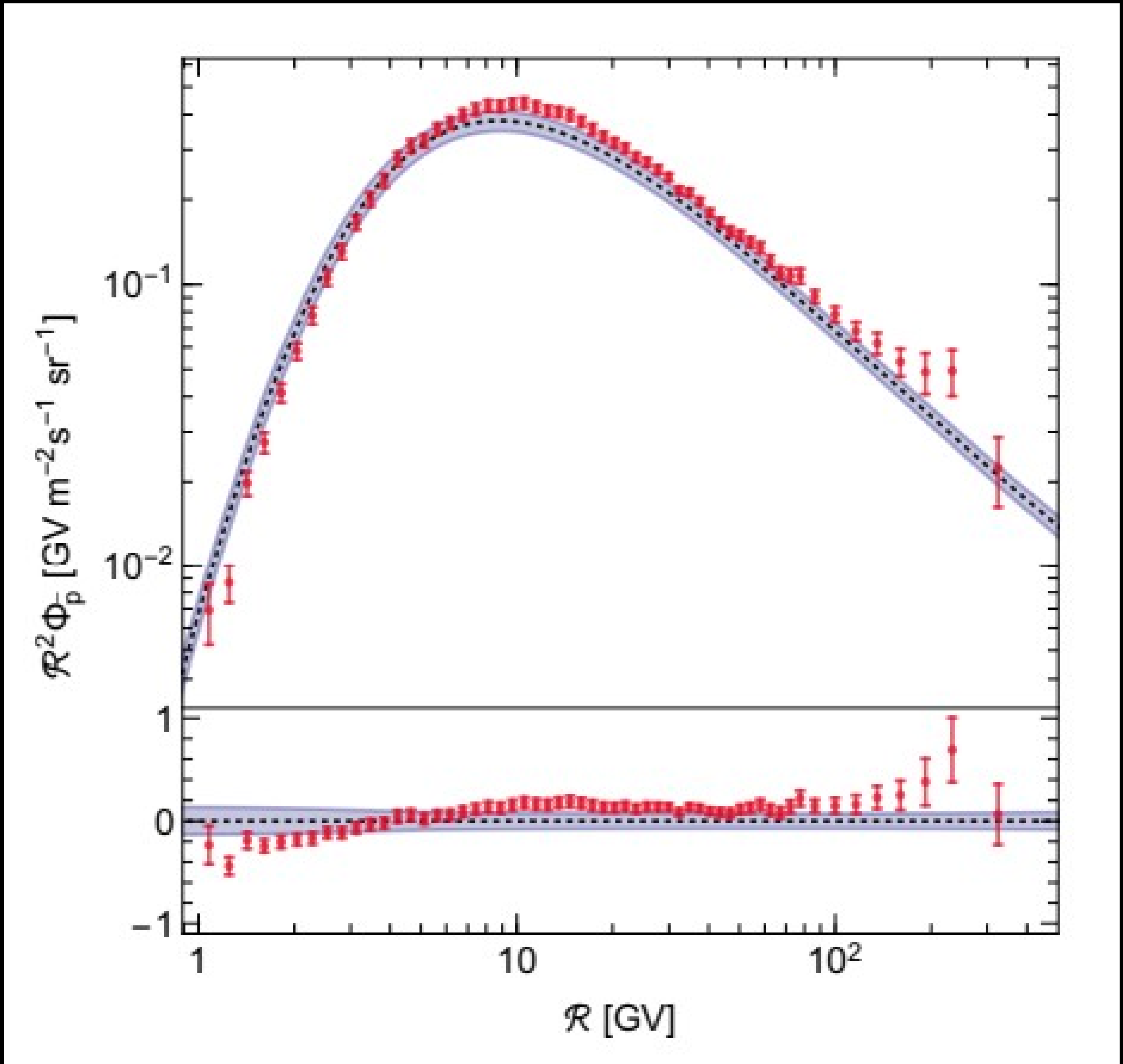
# Spin-dependent limits and prospects




Phys.Rev. D95 (2017) no.9, 095010
JHEP 1710 (2017) 059

# A small excess is observed in the antiproton spectra at R ~ 10




**Reinert and Winkler, 2018**

# DAMPE has confirmed the spectral break in the $e^+ + e^-$ flux