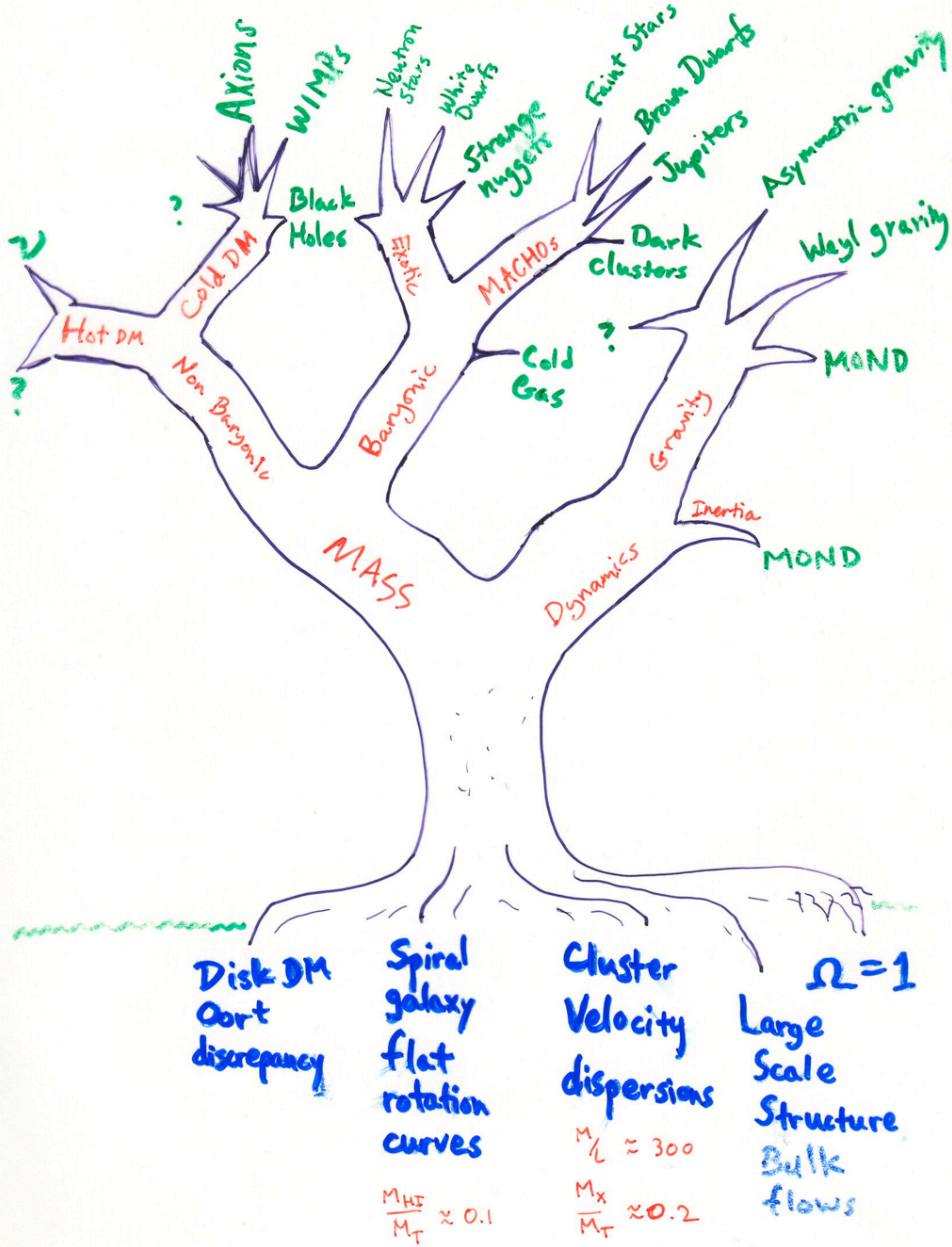
Dark Matter

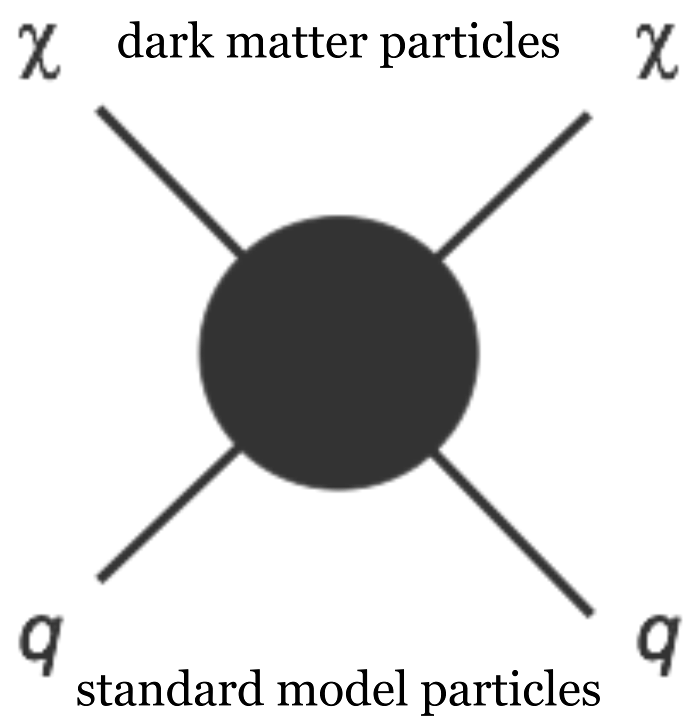
ASTR 333/433



TODAY

WIMP Detection

Efficient annihilation now
(Indirect detection)



Efficient production now
(Particle colliders)

Efficient scattering now
(Direct detection)

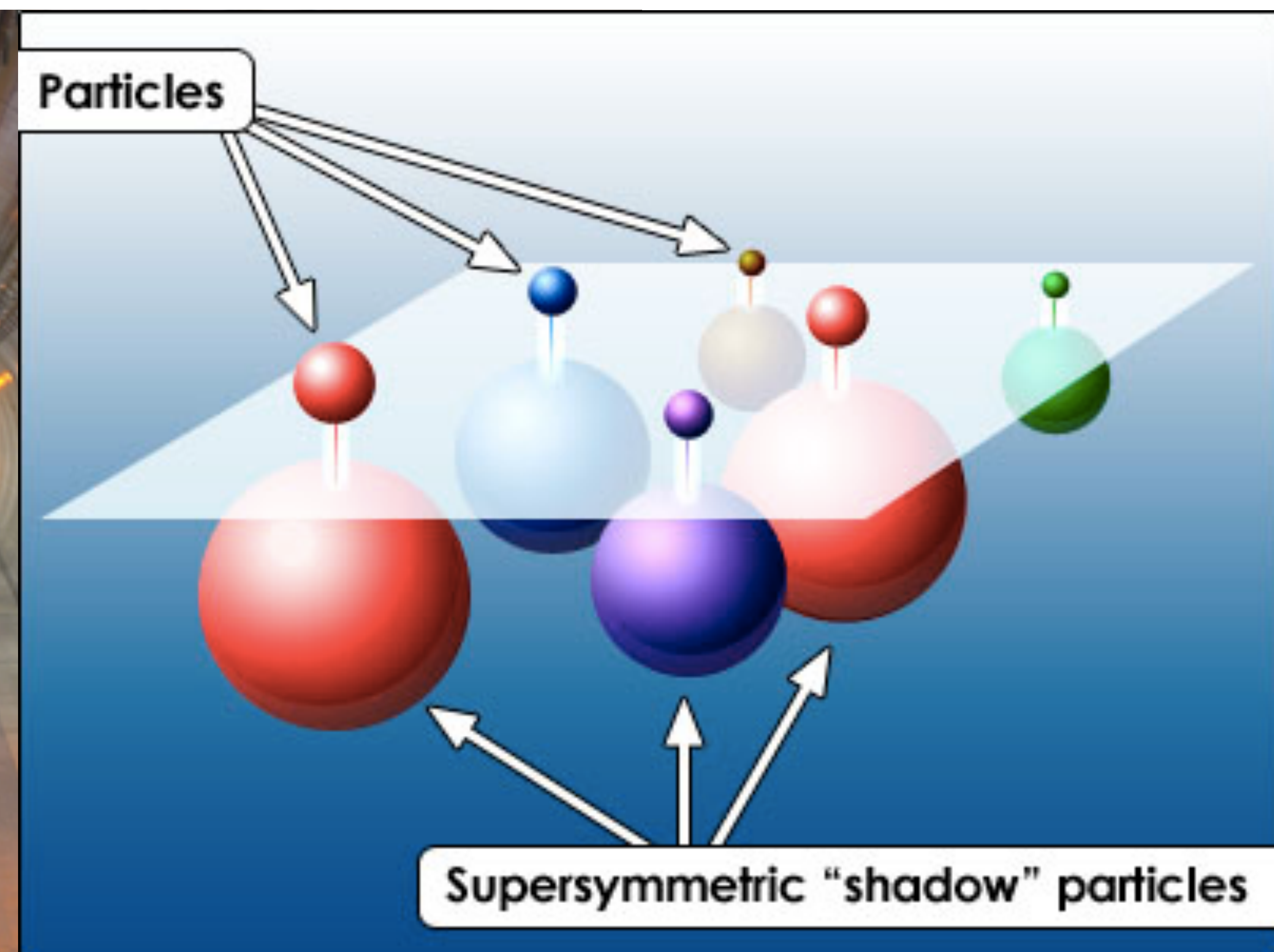
Experimental results to date (2021): nada

Particle production

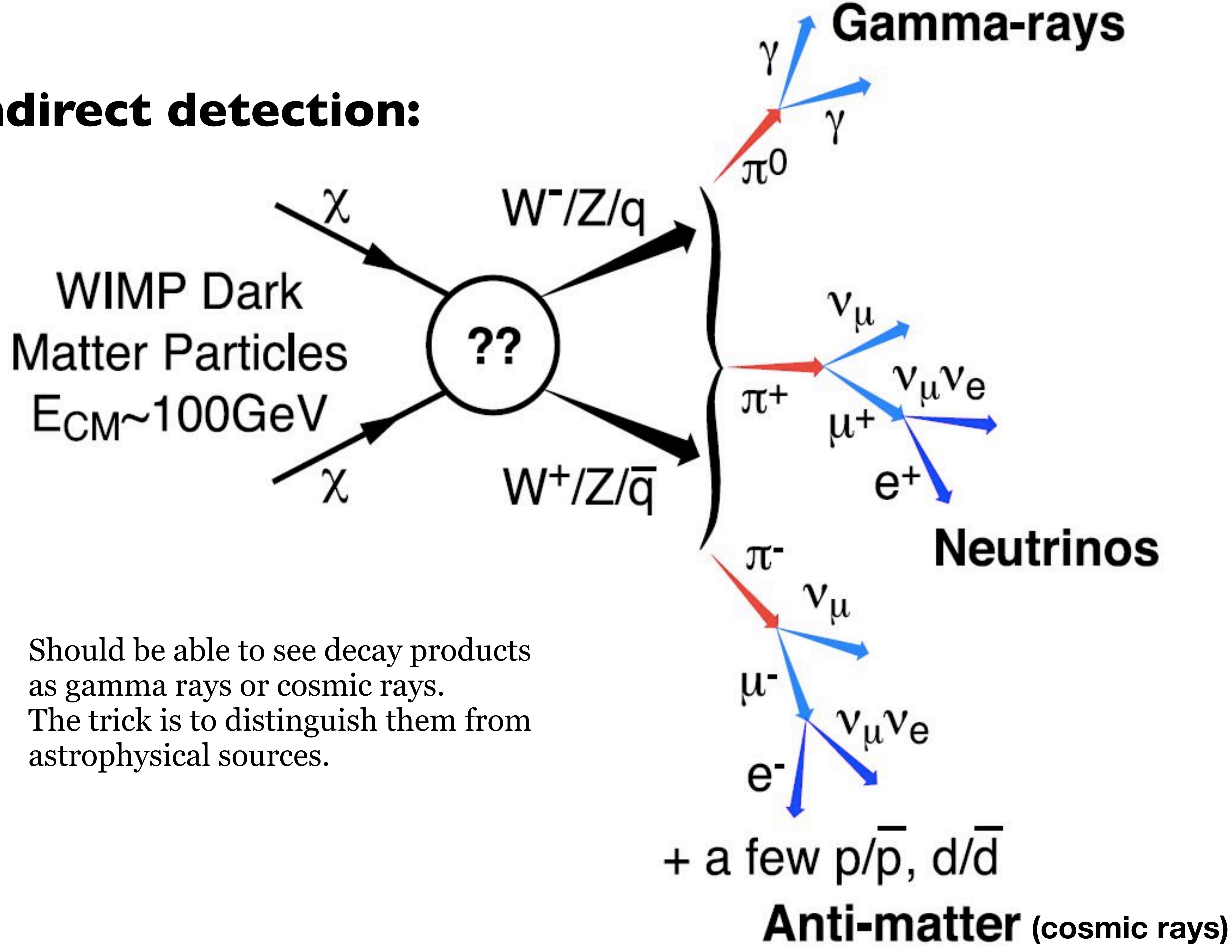
DM created in the LHC would escape like a neutrino; would be noticed by non-conservation of mass-energy

the LHC has discovered the Higgs
- a necessary ingredient for SUSY
- too "normal" for MSSM (minimal SUSY)

the LHC has NOT observed excess B_s meson decay
- the Golden Test for SUSY
- looking grim for MSSM, SUSY in general



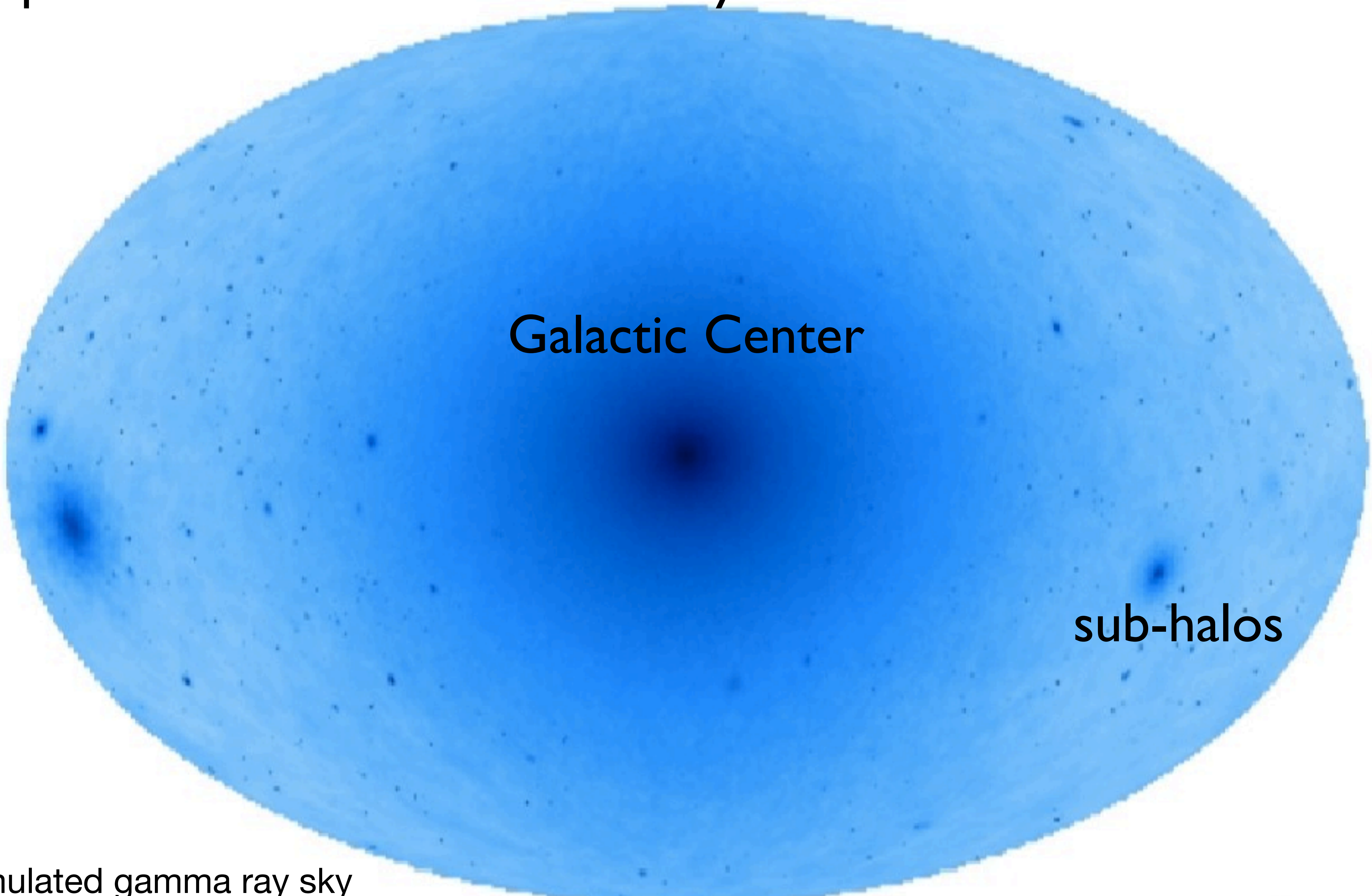
Indirect detection:



Should be able to see decay products as gamma rays or cosmic rays.
The trick is to distinguish them from astrophysical sources.

Experimental results to date (2021): nada

gamma ray flux from WIMP self-annihilation scales as the square of the dark matter density.



simulated gamma ray sky

Working out the expected gamma ray flux

Strigari (2018) Reviews of Modern Physics, 81, e6901

averaged annihilation cross-section

$$\langle \sigma v \rangle = \int d^3 v P(v) \sigma(v)$$

σ here is the interaction cross-section (not velocity dispersion)

σ often assumed to be velocity independent, but doesn't have to be.

Probability of a dark matter particle having velocity v

distribution function

$$P(v) = \frac{f_{DM}(x, v)}{\rho_{DM}(x)}$$

dark matter density

photon flux; photon spectrum

$$\frac{dF}{dE} = \frac{1}{4\pi m^2} \frac{dN}{dE} \int d\Omega \int d\ell \langle \sigma v \rangle [\rho_{DM}(r(\ell, \Omega))]^2$$

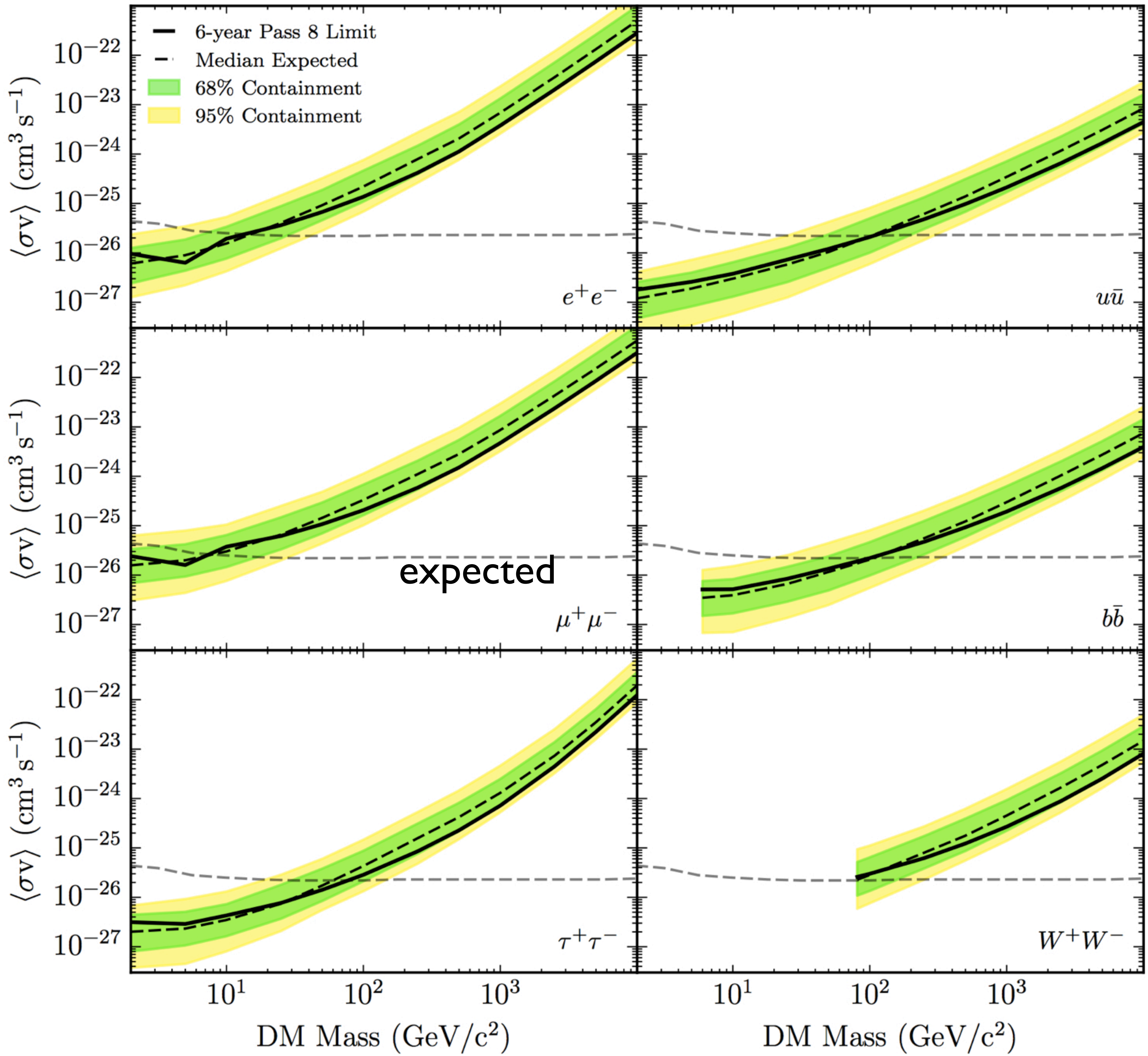
DM particle mass; solid angle; line-of-sight integral; dark matter density squared as projected on the sky

"J factor"

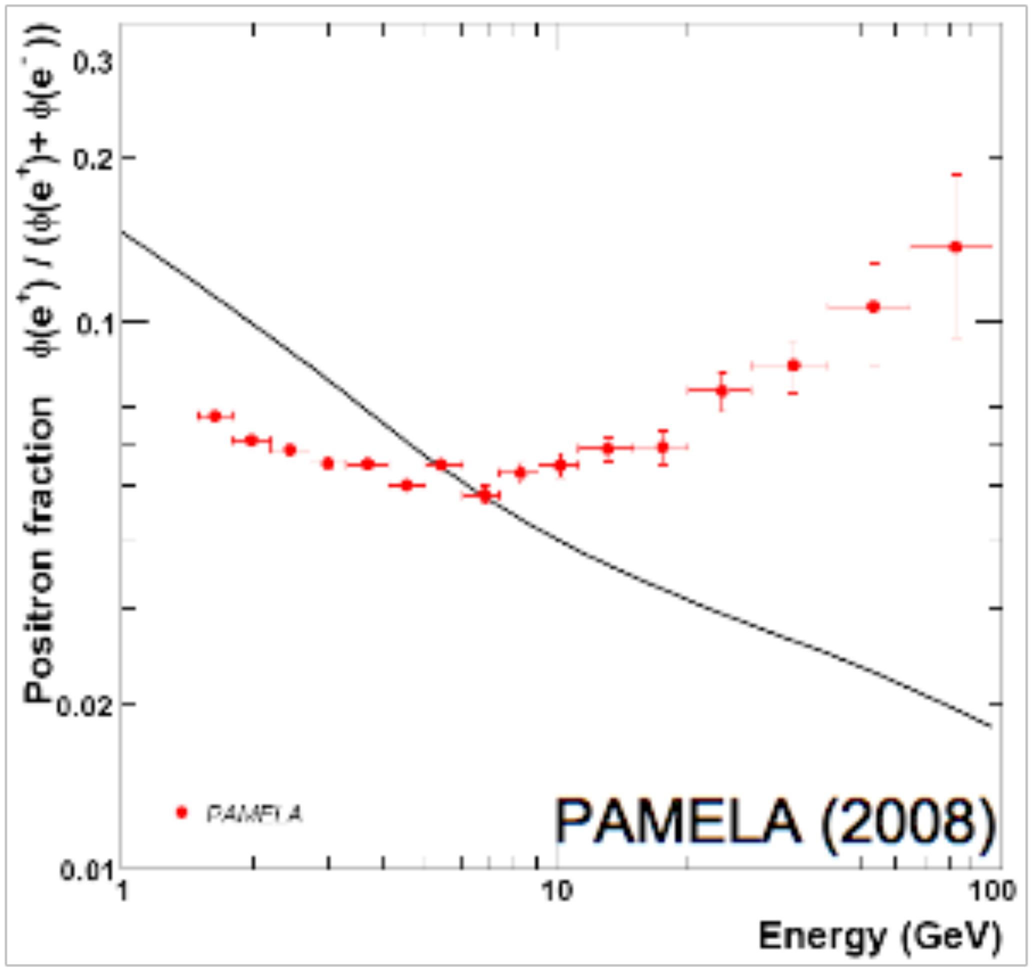
$$J = \int d\Omega \int d\ell [\rho_{DM}(r(\ell, \Omega))]^2$$

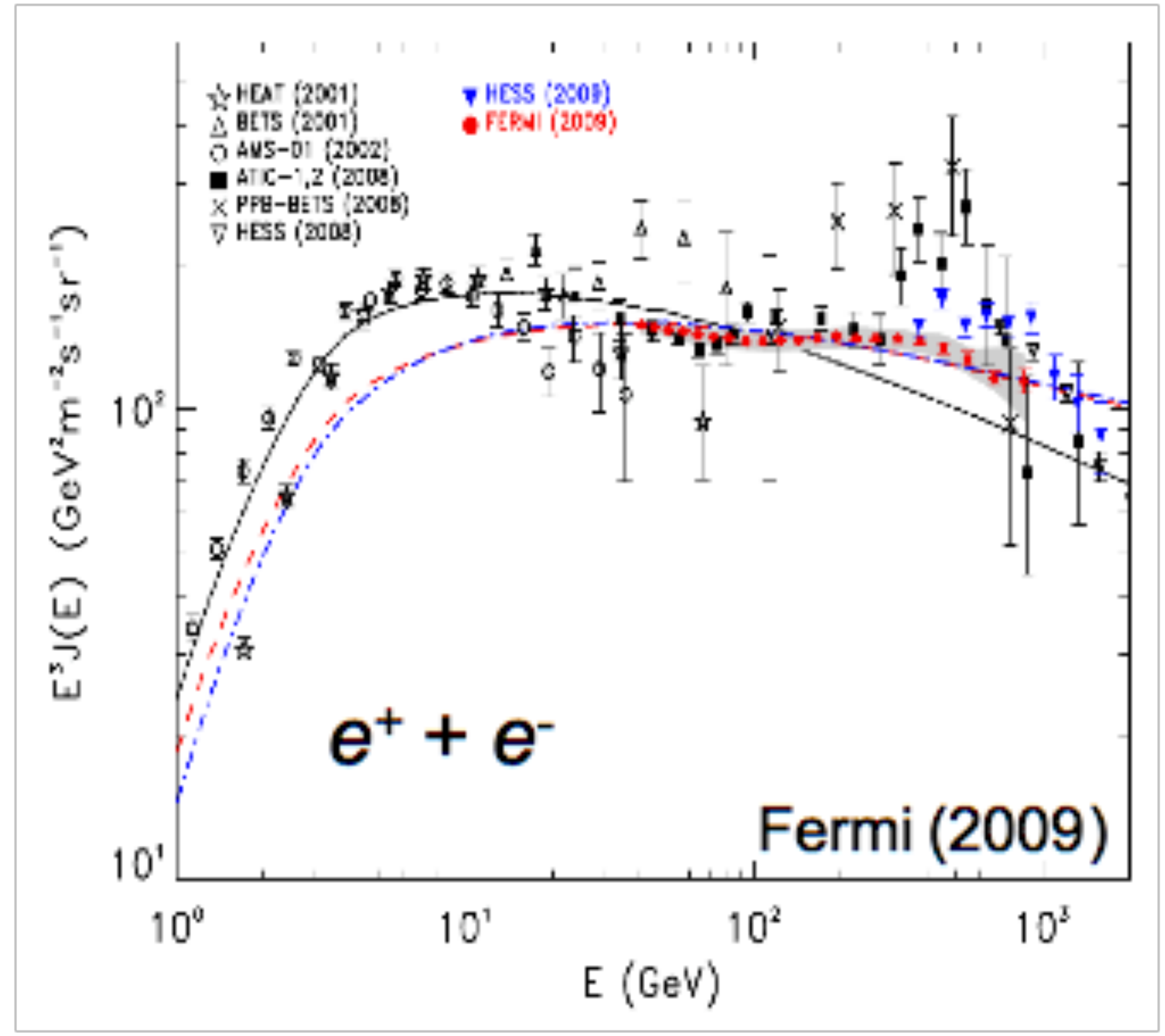
If the interaction cross-section is not velocity-dependent, then the flux depends only on the DM density profile.

Low mass WIMPs excluded for various decay channels



INDIRECT DETECTION





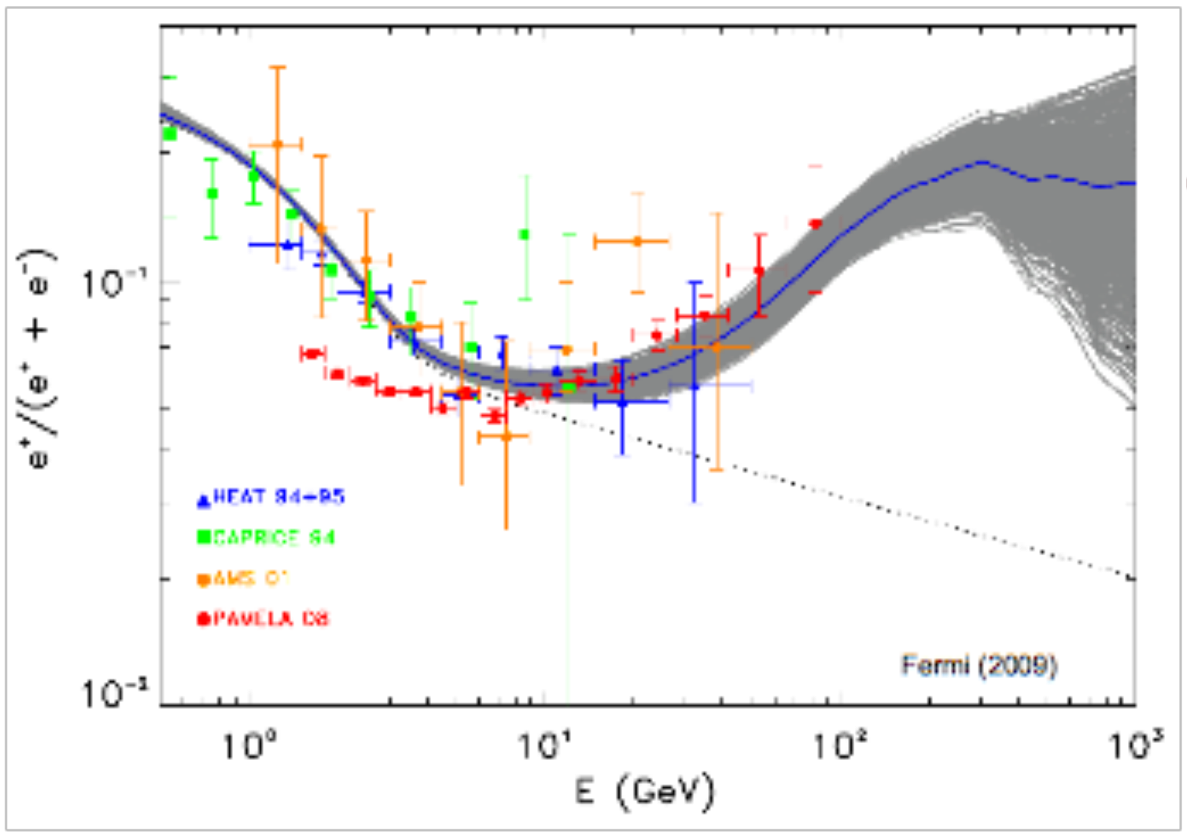
Solid lines are the predicted spectra from GALPROP (Moskalenko, Strong)

One must exclude astrophysical sources before claiming a detection of dark matter.

ARE THESE DARK MATTER?

- Pulsars can explain PAMELA

Zhang, Cheng (2001); Hooper, Blasi, Serpico (2008)
Yuksel, Kistler, Stanev (2008)
Profumo (2008) ; Fermi (2009)



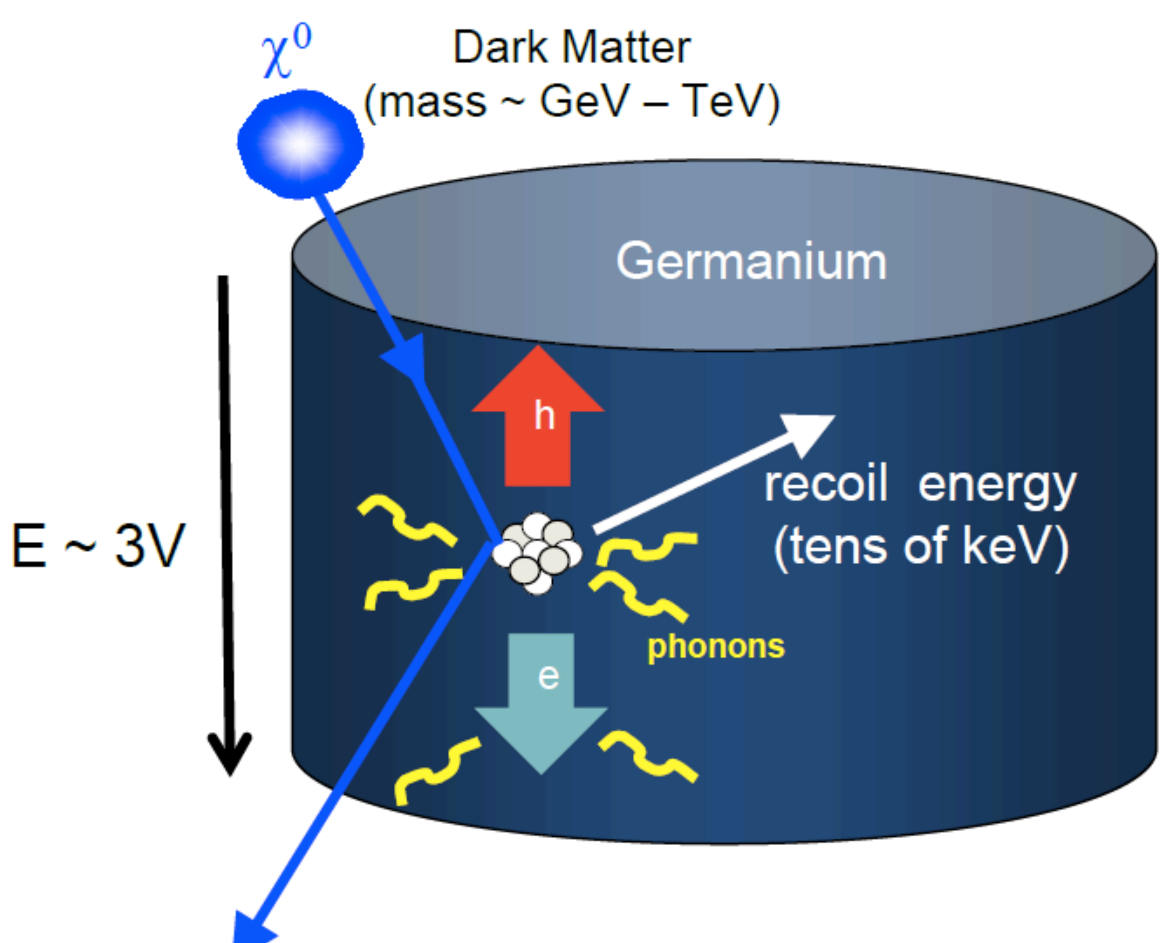
- For dark matter, there is both good and bad news
- Good: the WIMP miracle motivates excesses at ~100 GeV – TeV
- Bad: the WIMP miracle also tells us that the annihilation cross section should be a factor of 100-1000 too small to explain these excesses. Need enhancement from
  - astrophysics (very unlikely)
  - particle physics

Experimental results to date (2021): nada

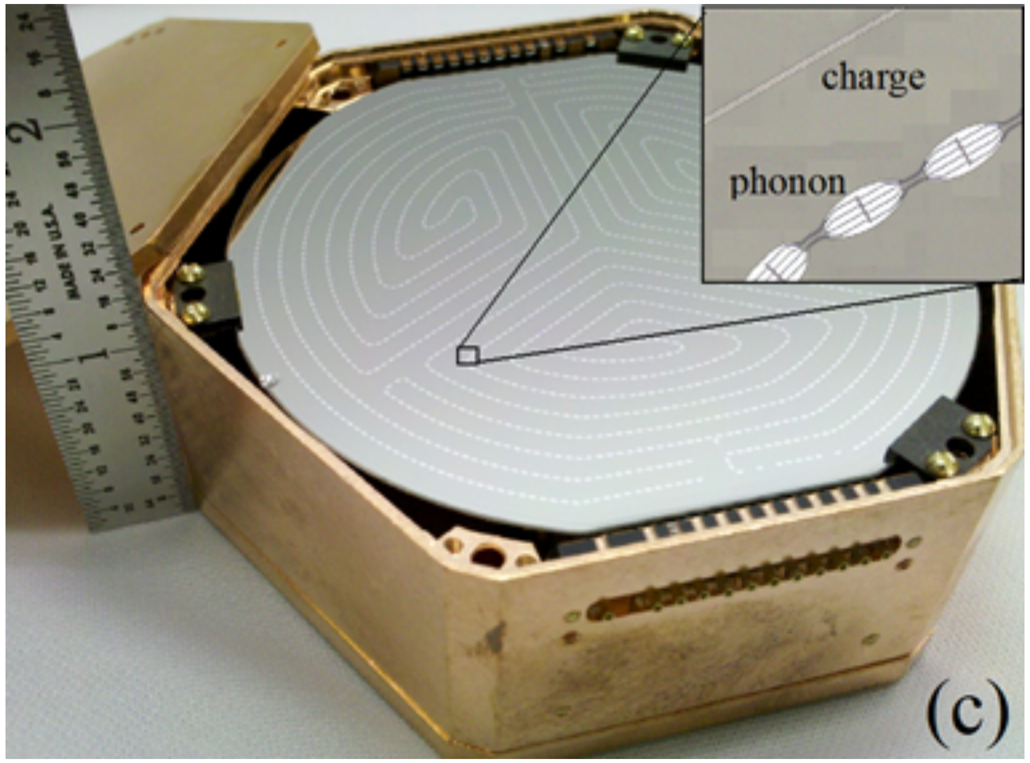
Direct detection

Many, *many* experiments
CDMS, LUX, XENON, DAMA, etc., etc.

Basic idea: WIMP passing through detector interacts via weak force; scatters off nucleus. Detect deposited energy of recoil. (analogous to neutrino detection).



Supercooled germanium wafer

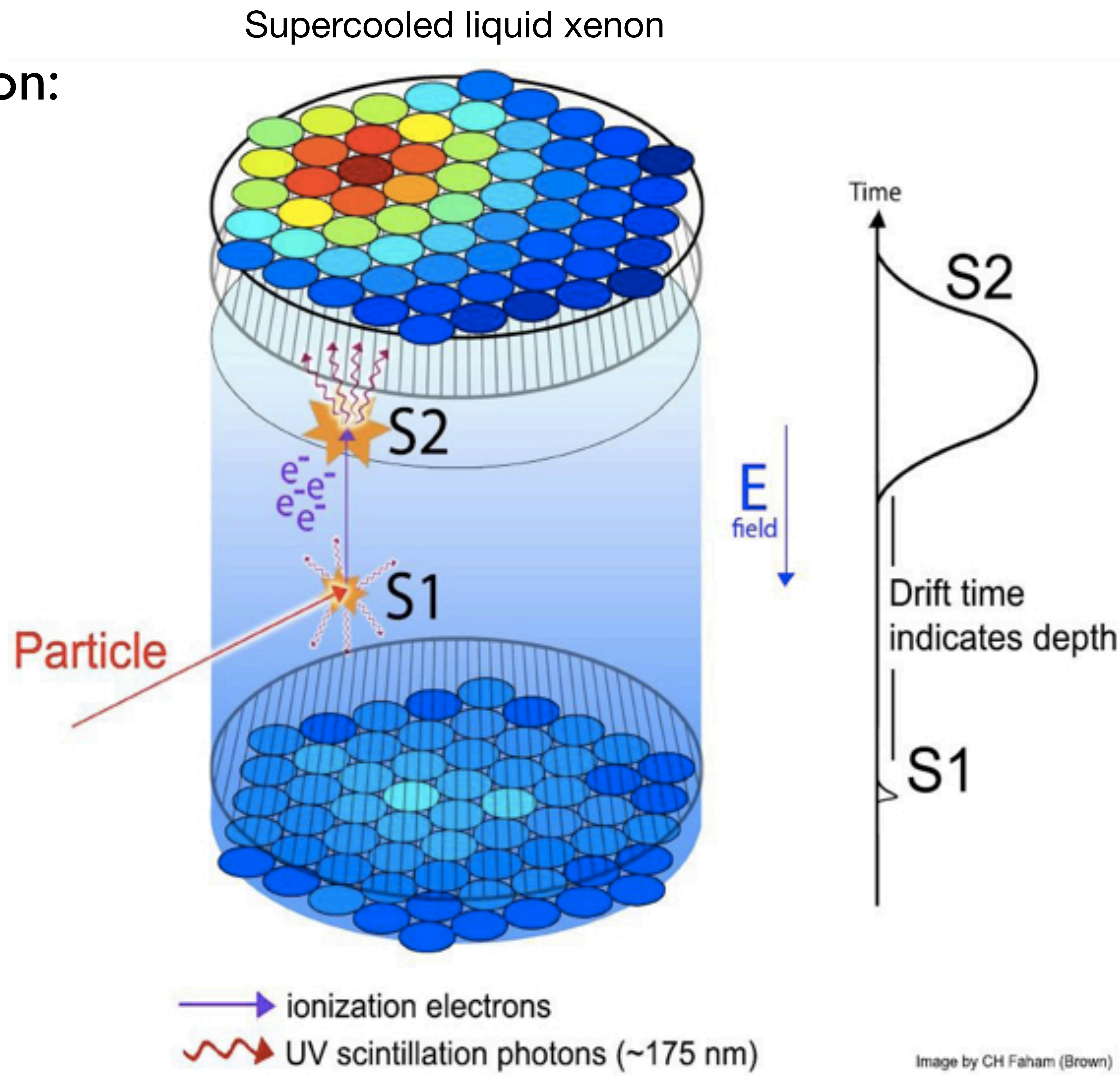


XENON type detectors

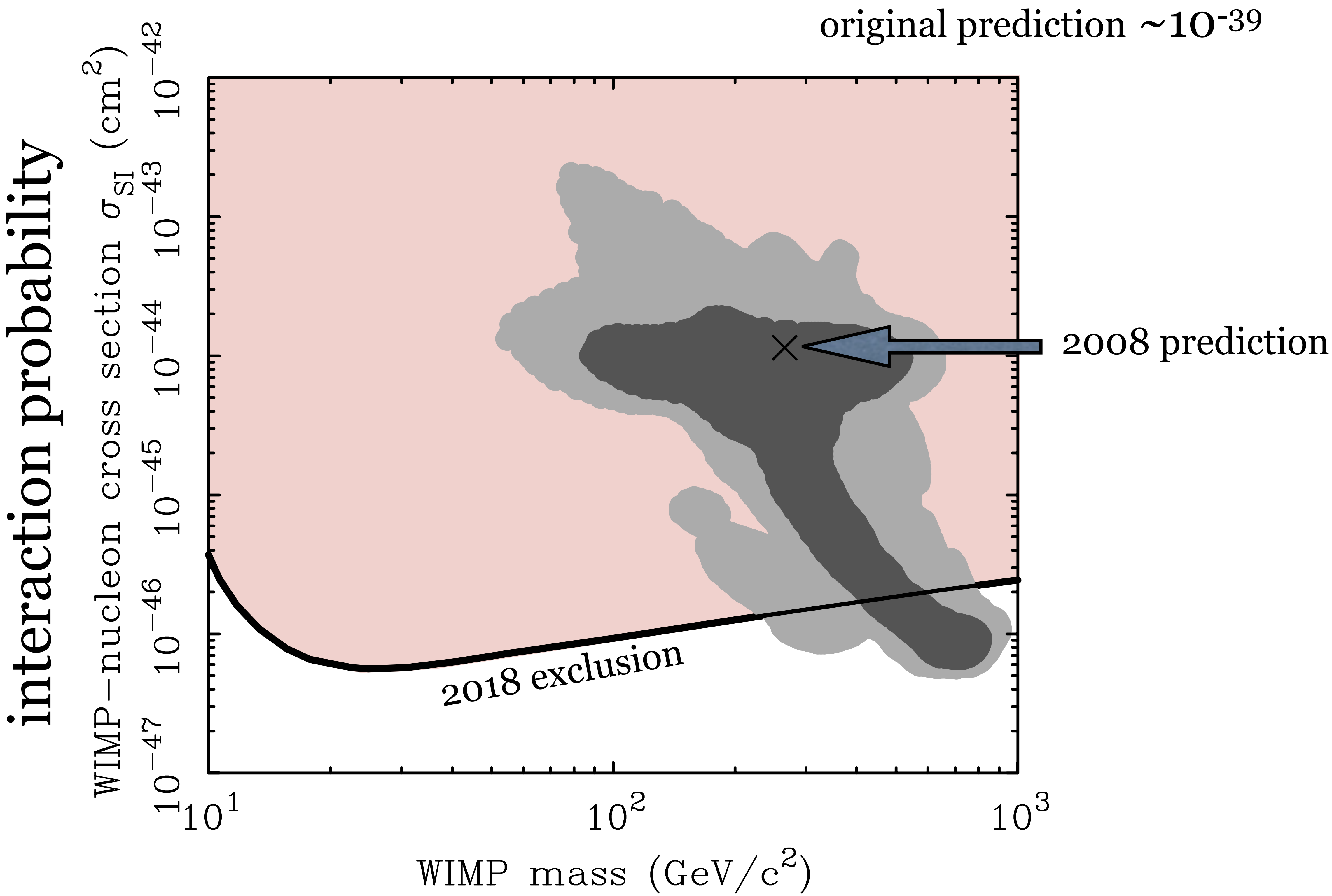
Direct detection:

Must protect experiments from cosmic rays, natural radioactivity, self-radioactivity, etc., etc.

Bury them deep in mines.



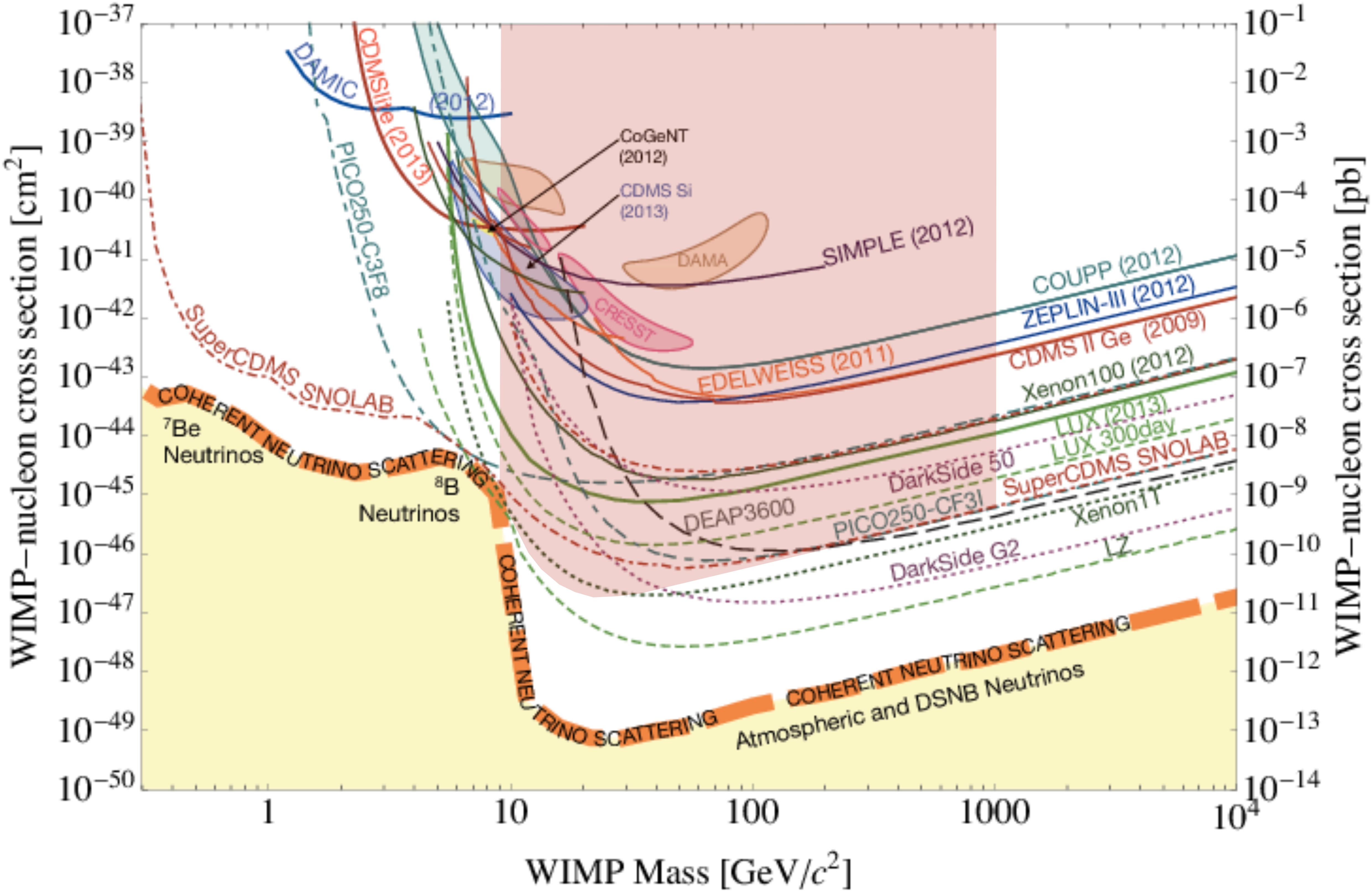
WIMPs are hiding



Mass of WIMP

WIMP detection experiments

Will eventually hit the neutrino background (yellow) then game over (?)



cross section (10^{-39} then 10^{-44} natural)

WIMP mass (~100 GeV natural)

Experimental results to date (2021): nada

LHC: the LHC sees no indication of dark matter
or even supersymmetry

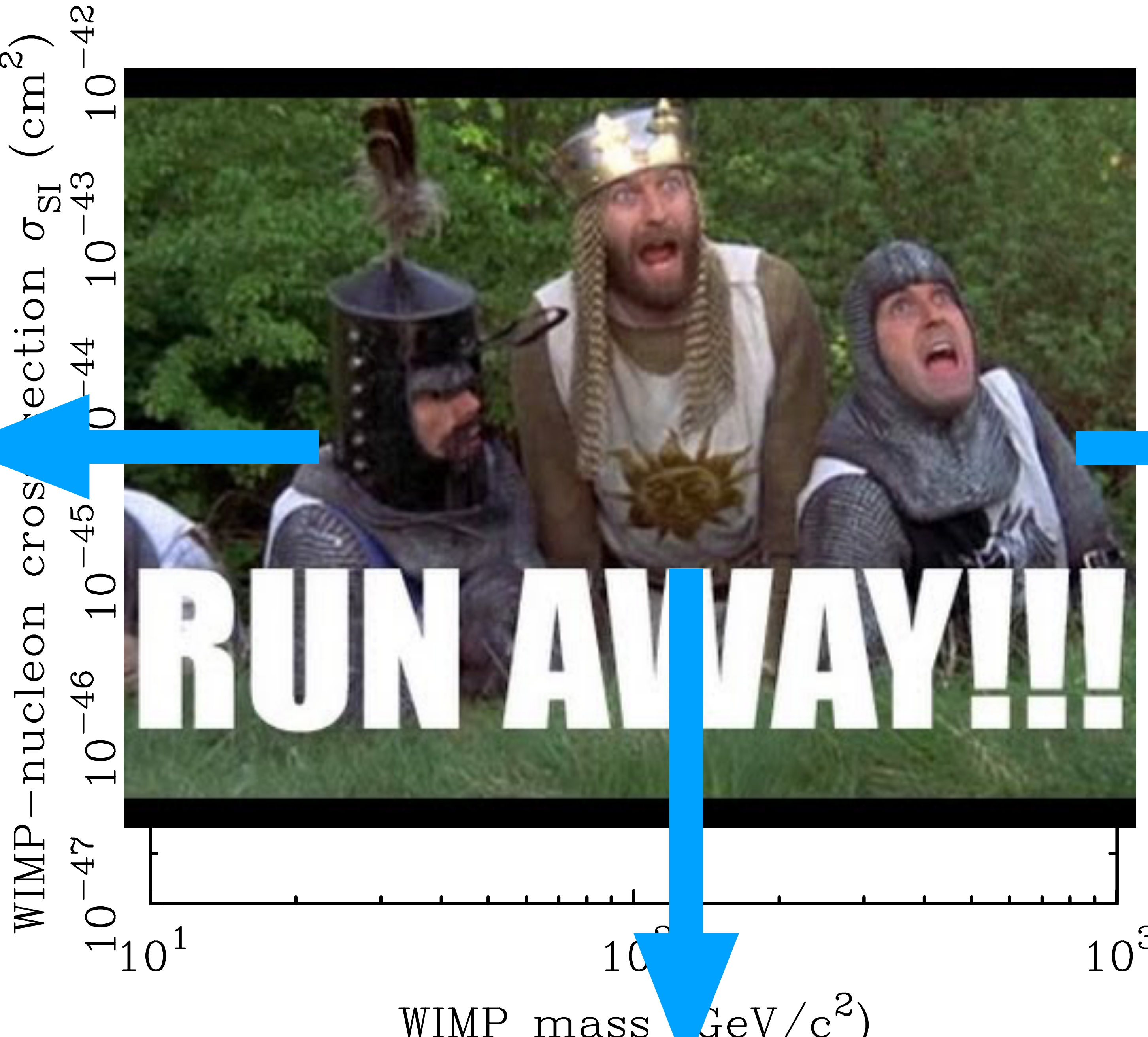
Direct Detection: Nothing so far
(DAMA claims a detection that no one can reproduce)

Indirect Detection: Various claims
gamma ray excess near Galactic Center
cosmic ray excess
unidentified X-ray lines

As yet: nothing credible.

WIMPs, *as originally expected*,
have been thoroughly falsified

- where are the WIMPs?



Light DM
(need to find a clever way to violate the Lee-Weinberg bound: m > 2 GeV)

TeV DM
(WIMPzillas)
(because why not? Unitarity bound not till 100 TeV)

Low cross-section
(weak scale, strongly suppressed)

How do we decide when we've looked hard enough?