DARK MATTER

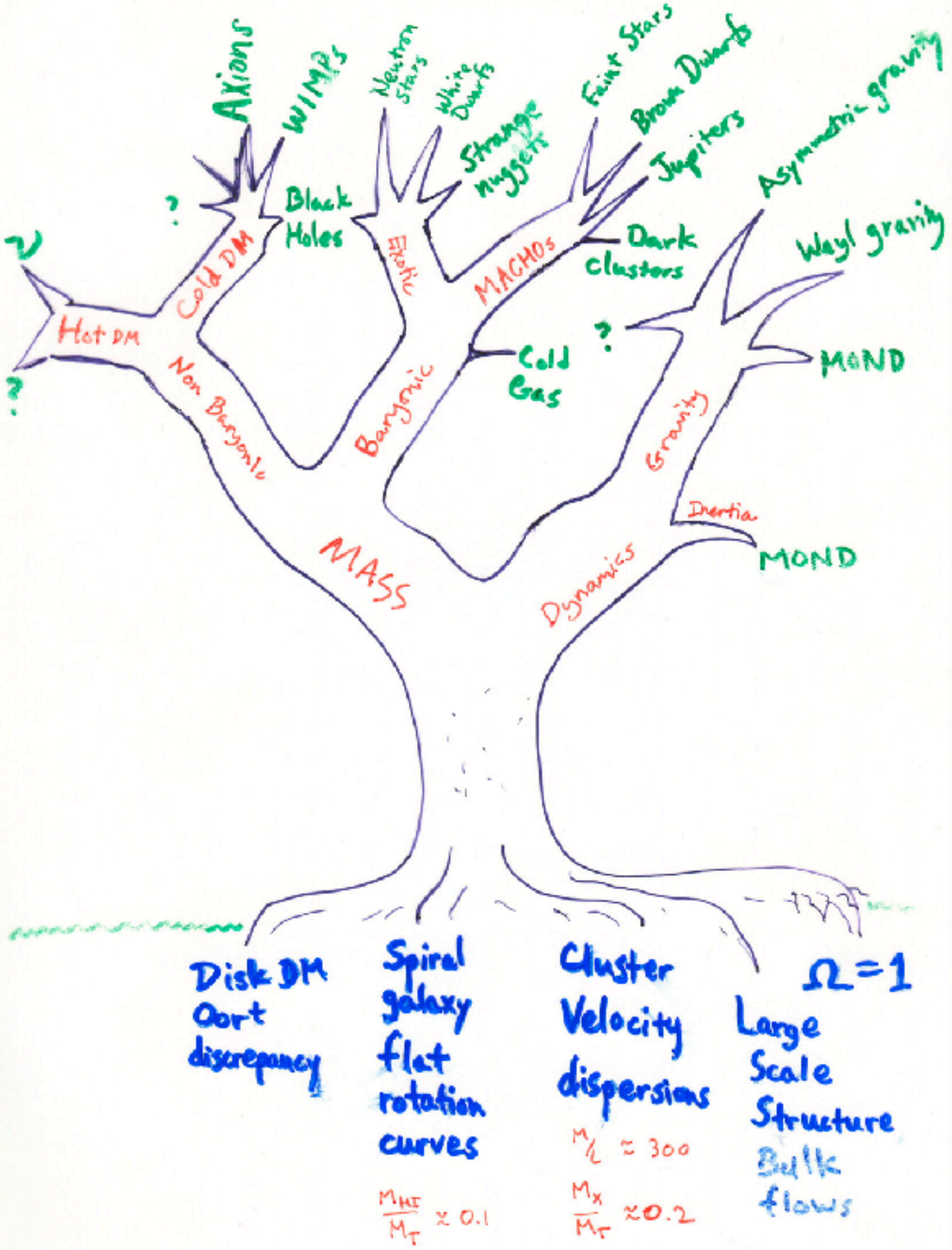
ASTR 333/433

TODAY

WIMPS
WIMP DETECTION

ASTR 433 Projects
4/17: distribute abstracts
4/19: 20 minute talks

4/24: Homework 4 due
4/26: Exam

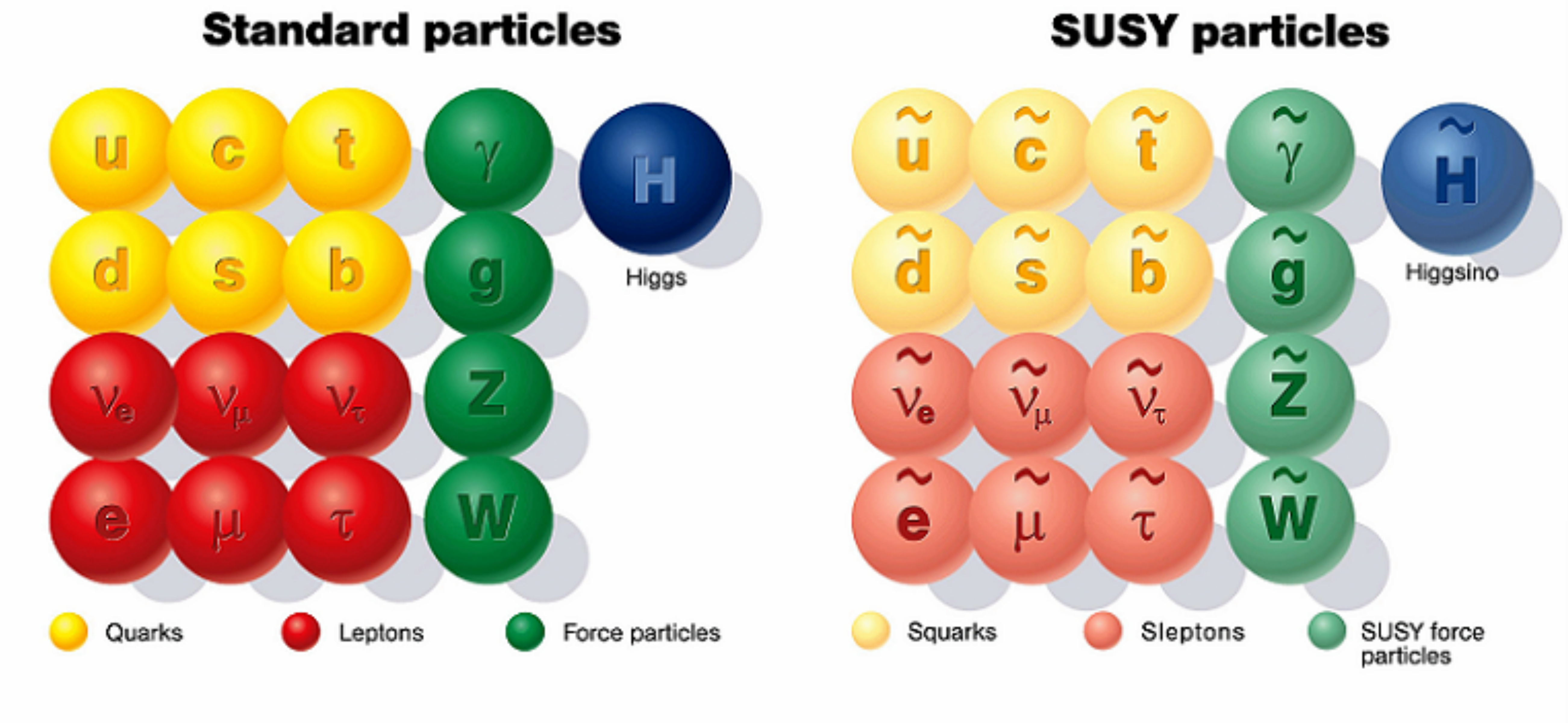


STANDARD MODEL OF ELEMENTARY PARTICLES

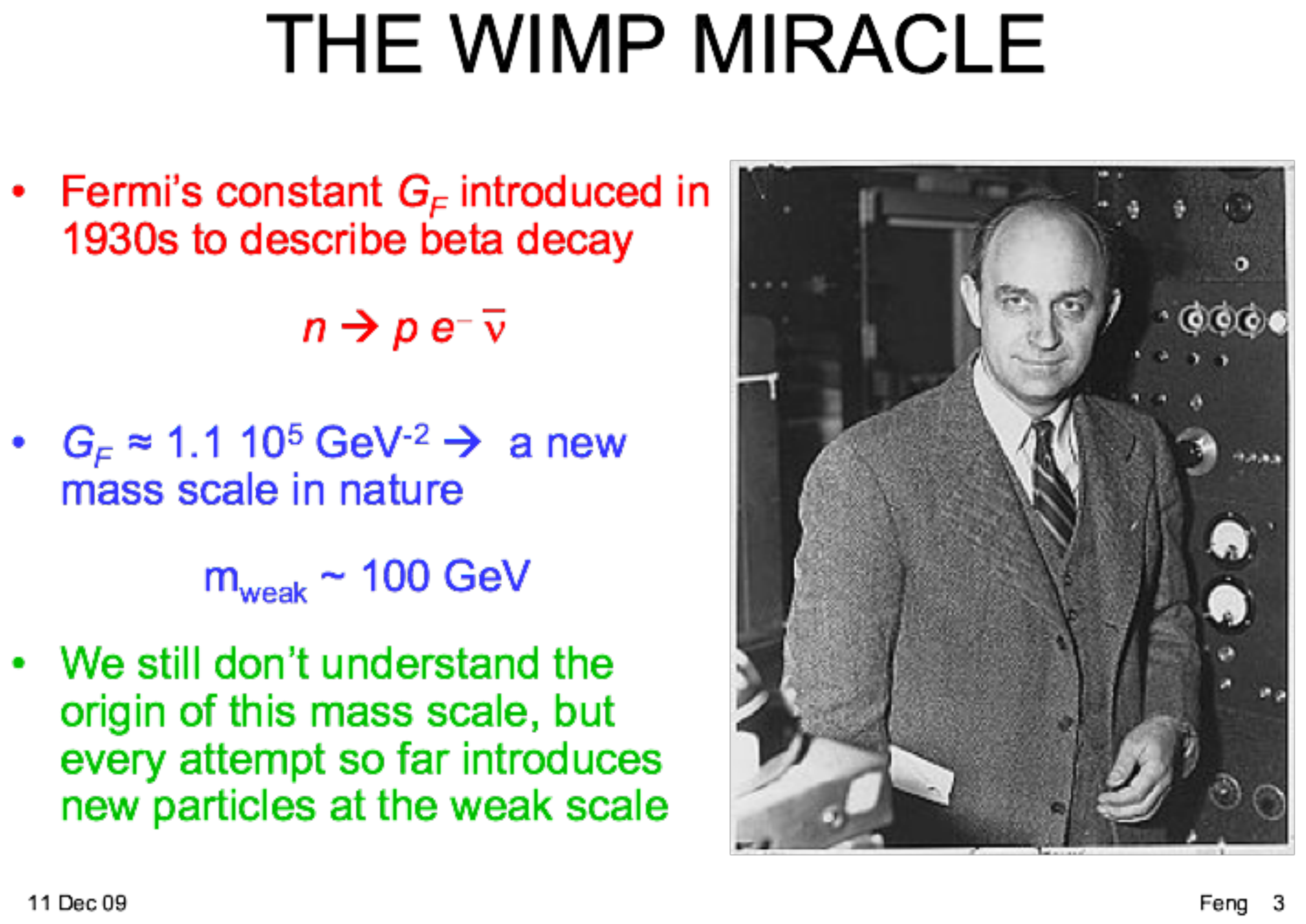
QUARKS	UP mass 2,3 MeV/c^2 charge ⅔ spin ½ u	CHARM 1,275 GeV/c^2 ⅔ ½ c	TOP 173,07 GeV/c^2 ⅔ ½ t	GLUON 0 0 1 g	HIGGS BOSON 126 GeV/c^2 0 0 H
	DOWN 4,8 MeV/c^2 -⅓ ½ d	STRANGE 95 MeV/c^2 -⅓ ½ s	BOTTOM 4,18 GeV/c^2 -⅓ ½ b	PHOTON 0 0 1 γ	
LEPTONS	ELECTRON 0,511 MeV/c^2 -1 ½ e	MUON 105,7 MeV/c^2 -1 ½ μ	TAU 1,777 GeV/c^2 -1 ½ τ	Z BOSON 91,2 GeV/c^2 0 1 Z	
	ELECTRON NEUTRINO <2,2 eV/c^2 0 ½ ν_e	MUON NEUTRINO <0,17 MeV/c^2 0 ½ ν_μ	TAU NEUTRINO <15,5 MeV/c^2 0 ½ ν_τ	W BOSON 80,4 GeV/c^2 ±1 1 W	

GAUGE BOSONS

Supersymmetry: a hypothetical new symmetry of nature



Every Standard Model particle has a superpartner.
The lightest stable massive superparticle is the most favored WIMP candidate. Usually the neutralino (theory dependent).



THE WIMP MIRACLE

- Fermi's constant G_F introduced in 1930s to describe beta decay

$$n \rightarrow p\, e^- \bar{\nu}$$

- $G_F \approx 1.1\ 10^5\ \text{GeV}^{-2} \rightarrow$ a new mass scale in nature

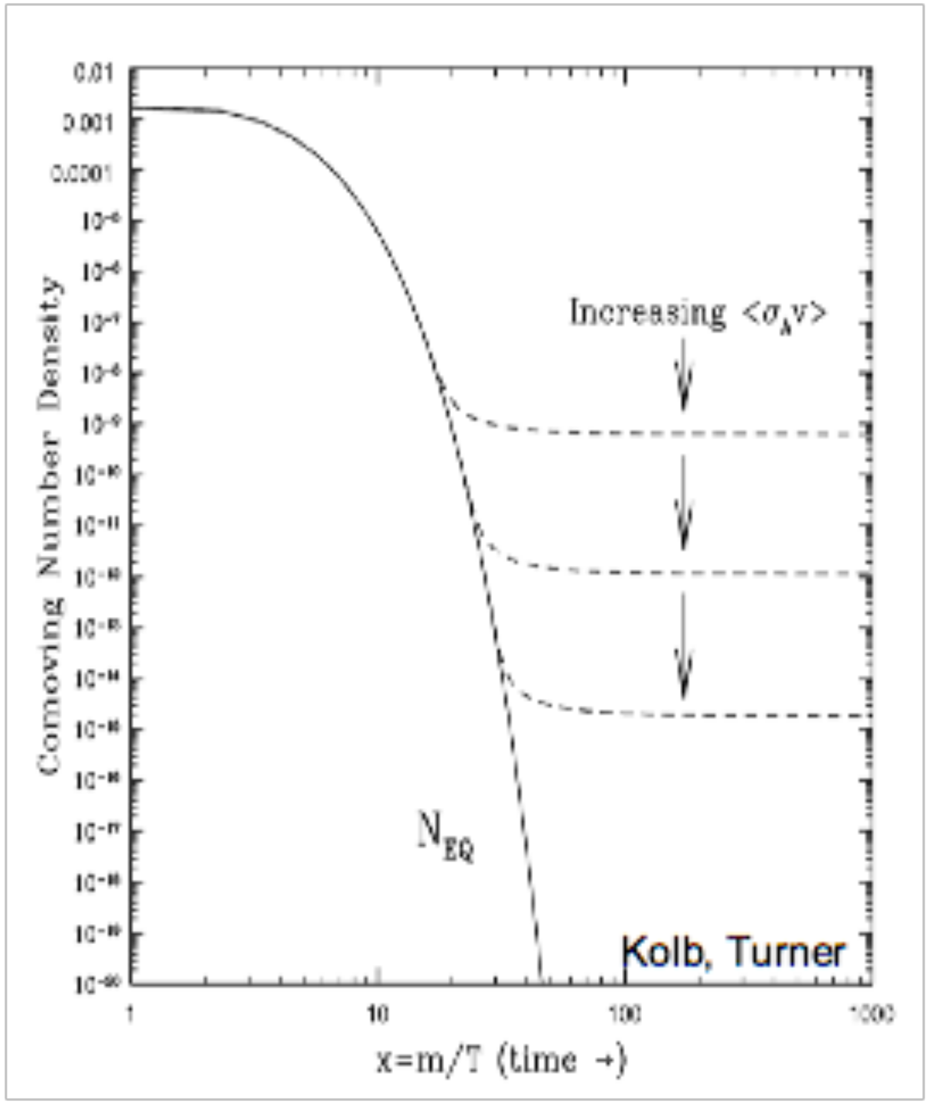
$$m_{\text{weak}} \sim 100\ \text{GeV}$$

- We still don't understand the origin of this mass scale, but every attempt so far introduces new particles at the weak scale

From review by Feng et al. linked off course review literature page.

THE WIMP MIRACLE

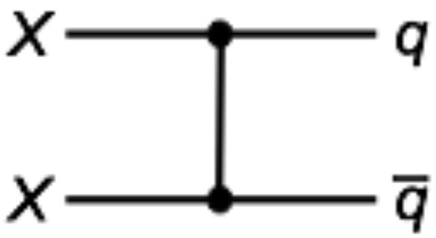
https://www.youtube.com/watch?v=7lbX7VxlrJQ



- Assume a new (heavy) particle X is initially in thermal equilibrium

- Its relic density is

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$



- $m_X \sim 100$ GeV, $g_X \sim 0.6$ → $\Omega_X \sim 0.1$

- Remarkable coincidence: particle physics independently predicts particles with the right density to be dark matter

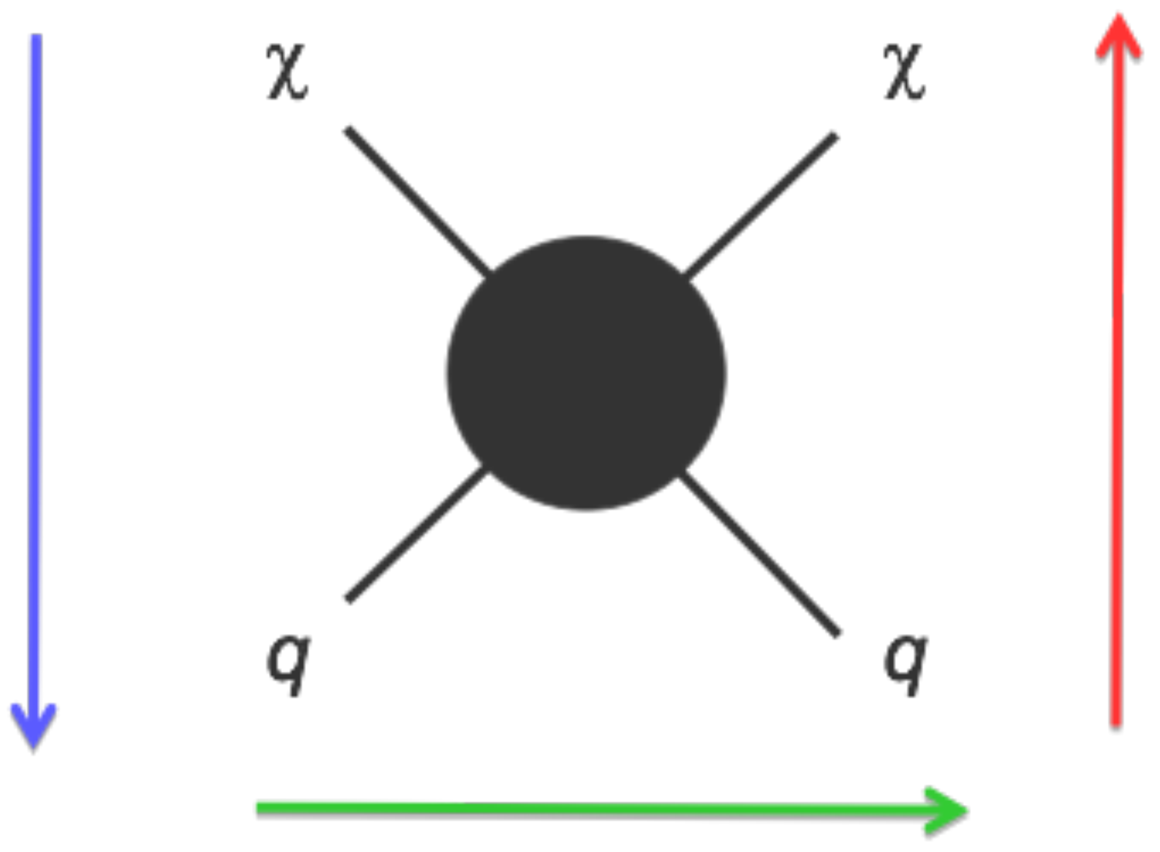
From review by Feng et al. linked off course review literature page.

WIMP DETECTION

Correct relic density → *Lower* bound on DM-SM interaction

WIMPs decay into standard model particles (gamma rays, cosmic rays)

Efficient annihilation now (Indirect detection)



Efficient production now (Particle colliders)

WIMPs created in particle colliders (like the LHC)

Efficient scattering now (Direct detection)

WIMPs scatter off nuclei
in underground
laboratory experiments

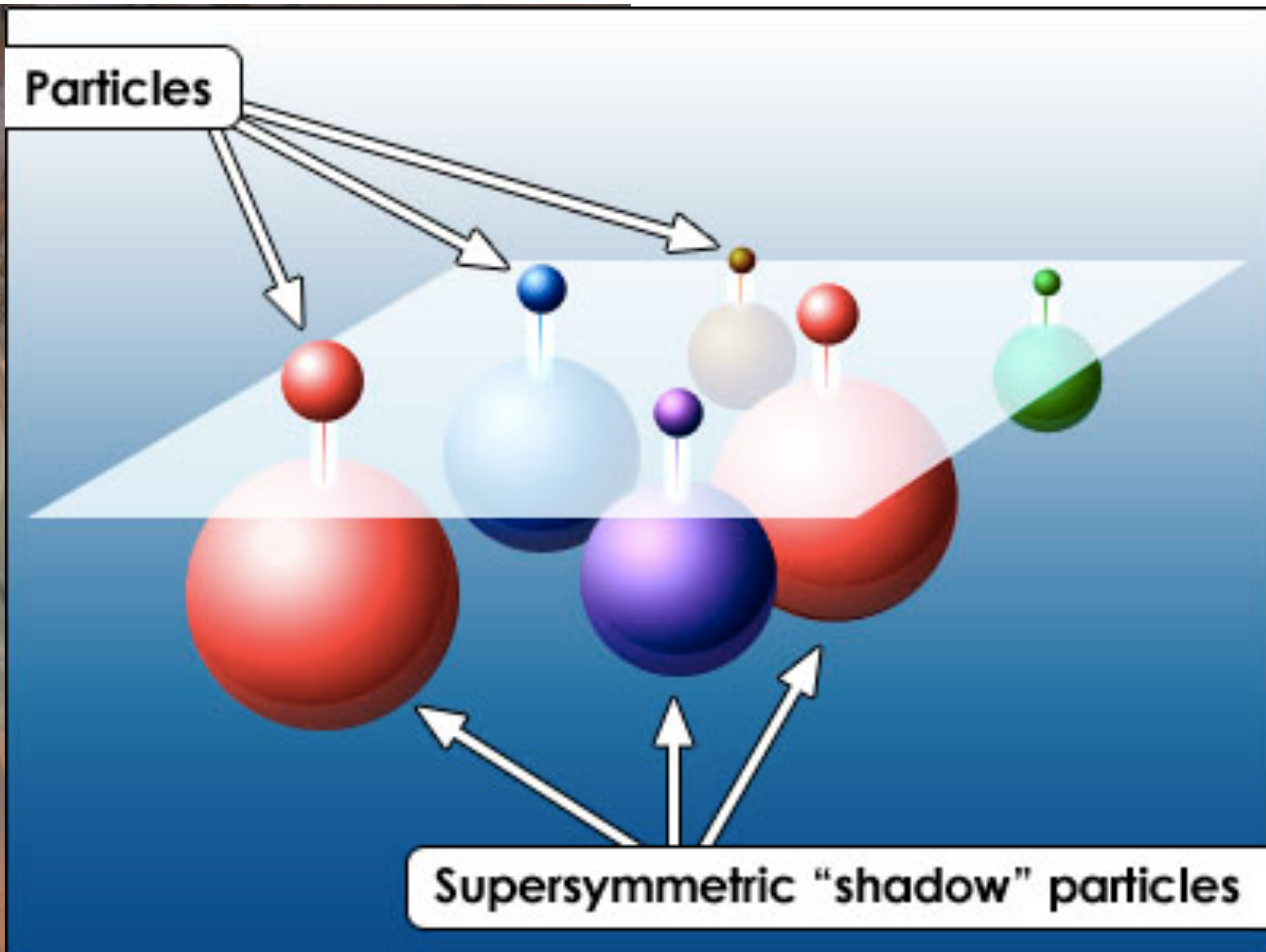
Experimental results to date (early 2018): nada

Particle production

WIMPs 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)

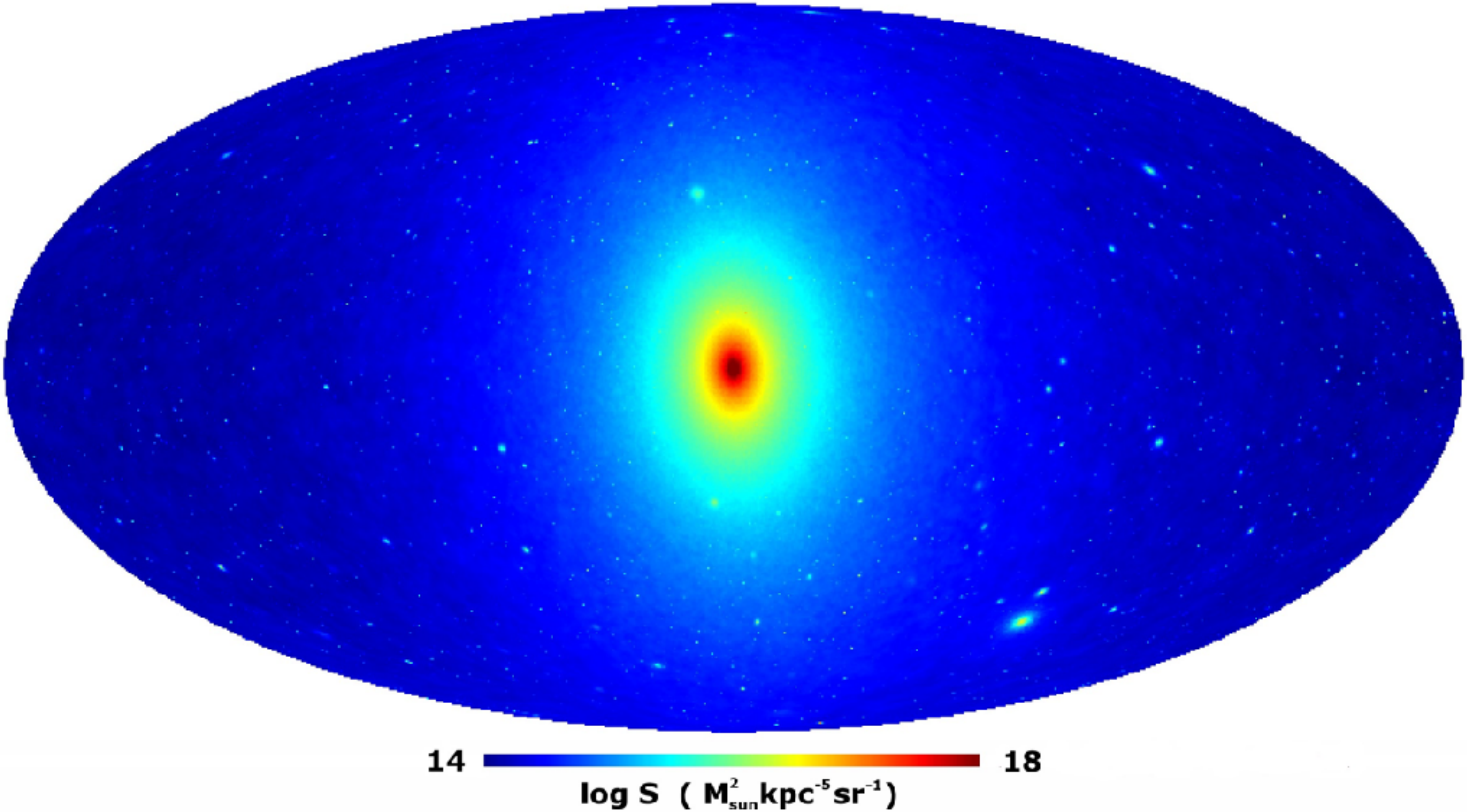
the LHC has NOT observed excess Bs meson decay
  - the Golden Test for SUSY
  - looking grim for MSSM, SUSY in general



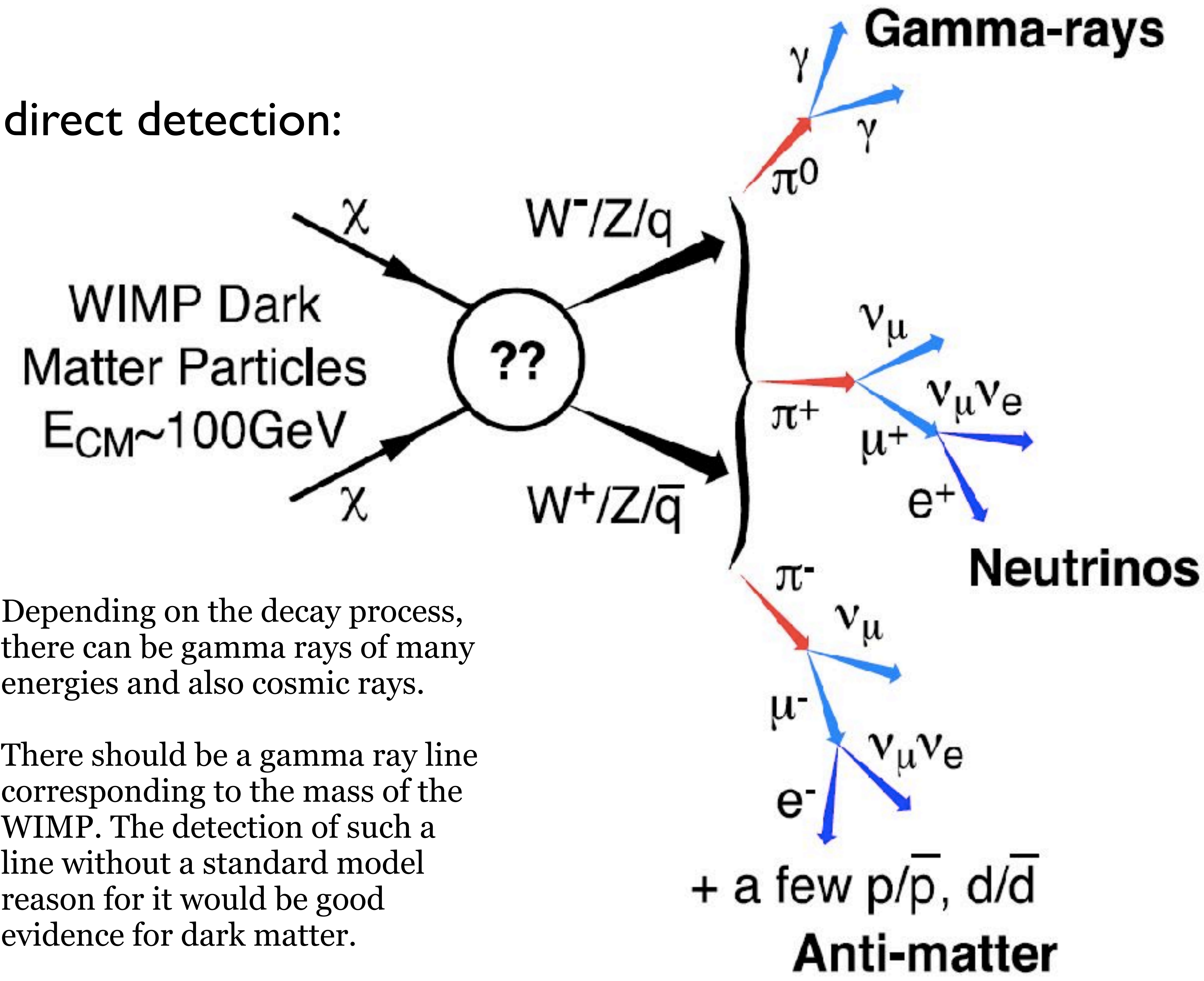
Experimental results to date (early 2018): nada

Indirect detection

predicted gamma ray sky



Indirect detection:

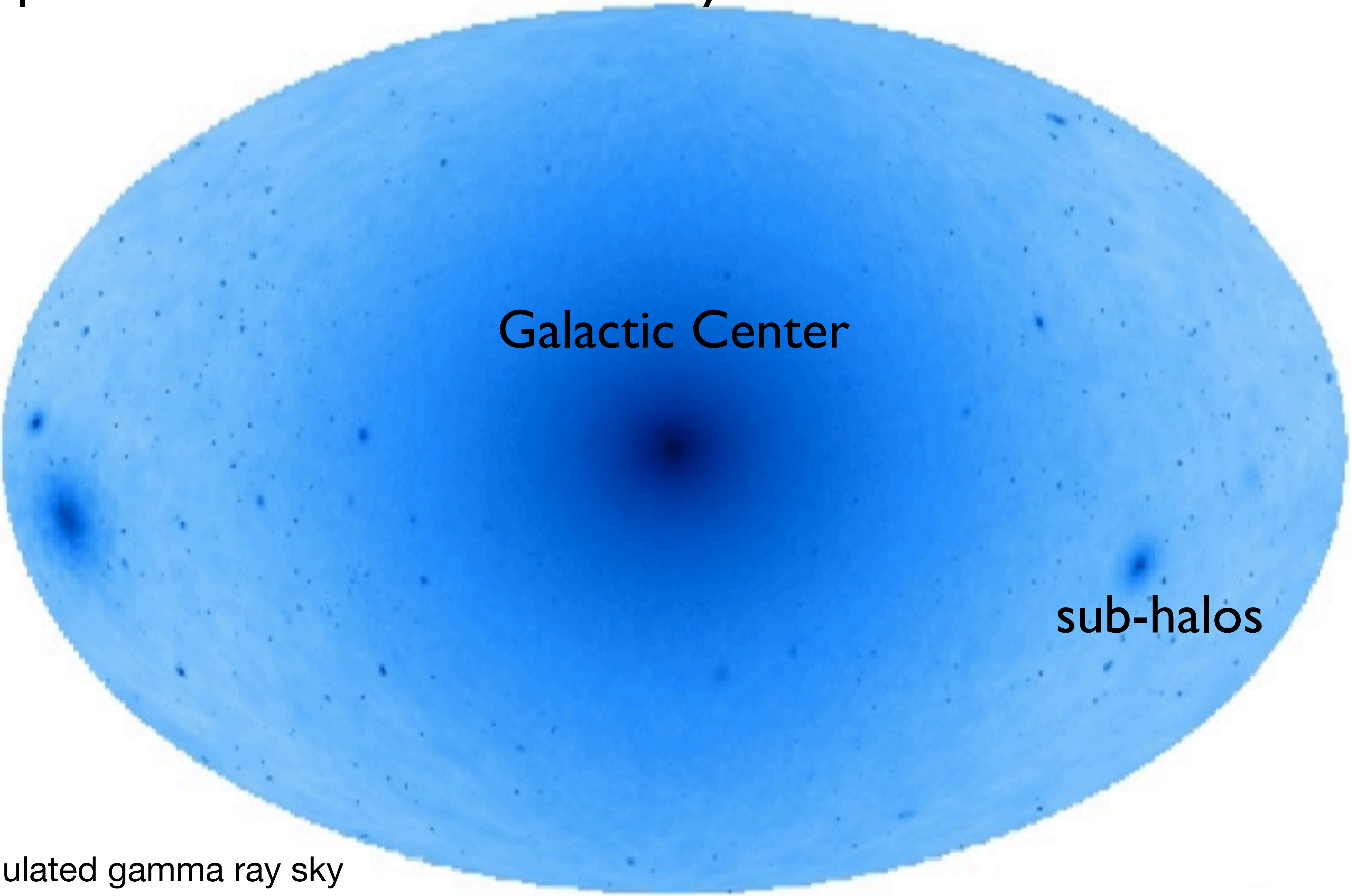


Depending on the decay process, there can be gamma rays of many energies and also cosmic rays.

There should be a gamma ray line corresponding to the mass of the WIMP. The detection of such a line without a standard model reason for it would be good evidence for dark matter.

Experimental results to date (early 2018): 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

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

dark matter density squared as projected on the sky

DM particle mass

solid angle

line-of-sight integral

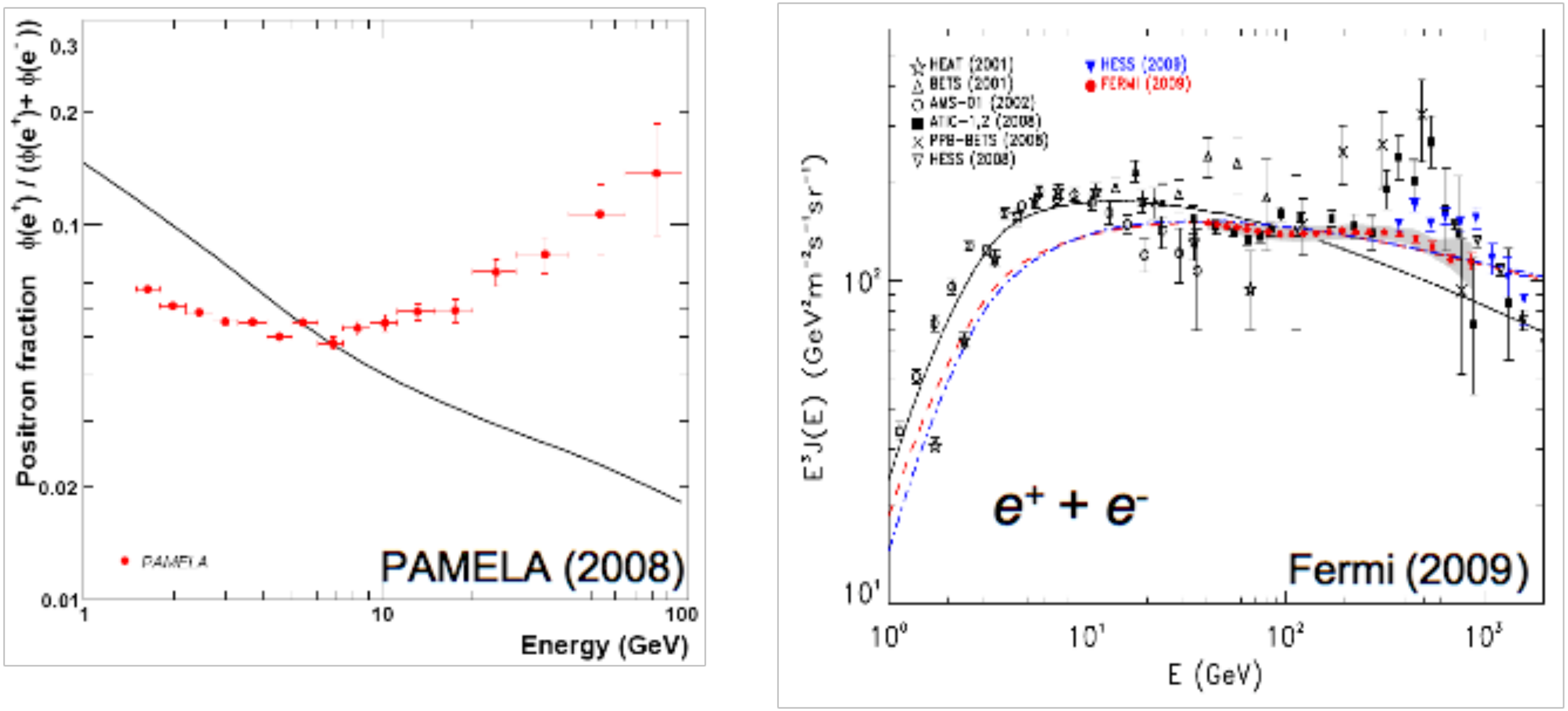
"*J* factor"

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

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

INDIRECT DETECTION

cosmic rays as DM decay products



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

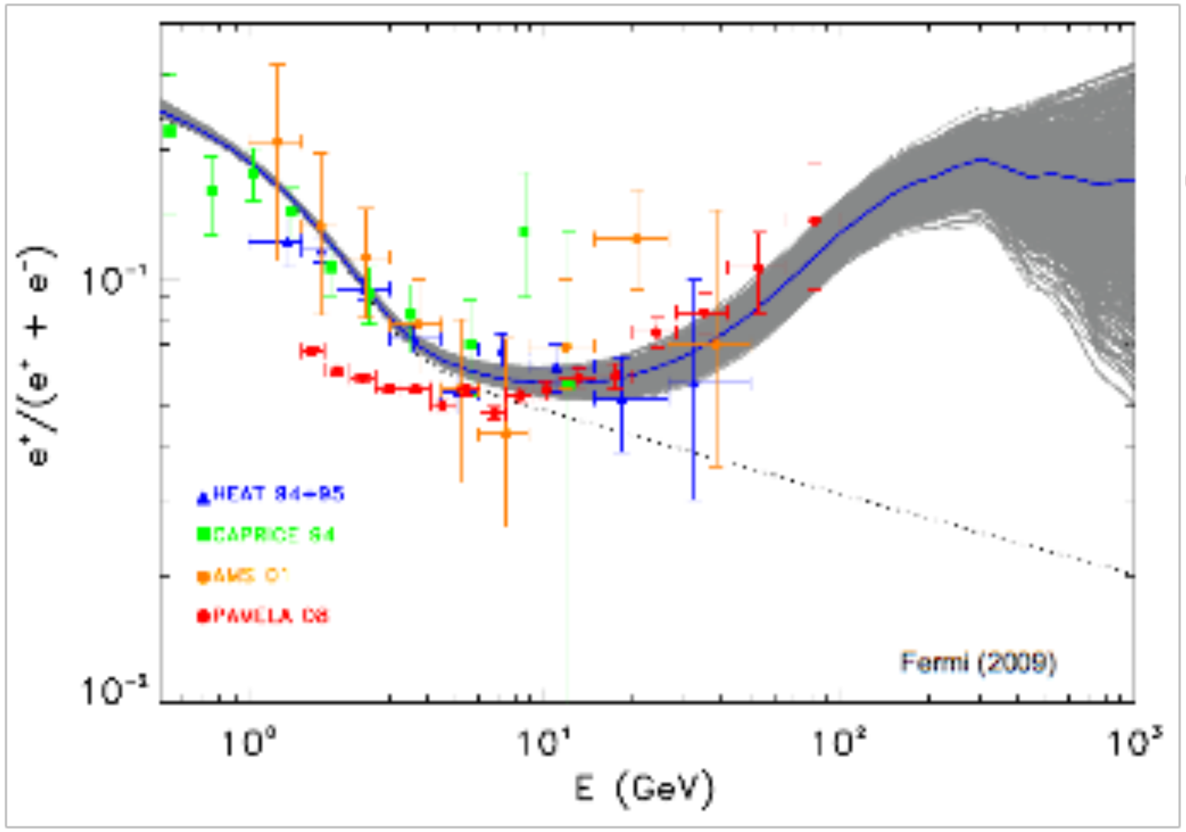
One must exclude astrophysical sources before claiming a detection of dark matter.

From review by Feng et al. linked off course review literature page.

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

11 Dec 09

Feng 11

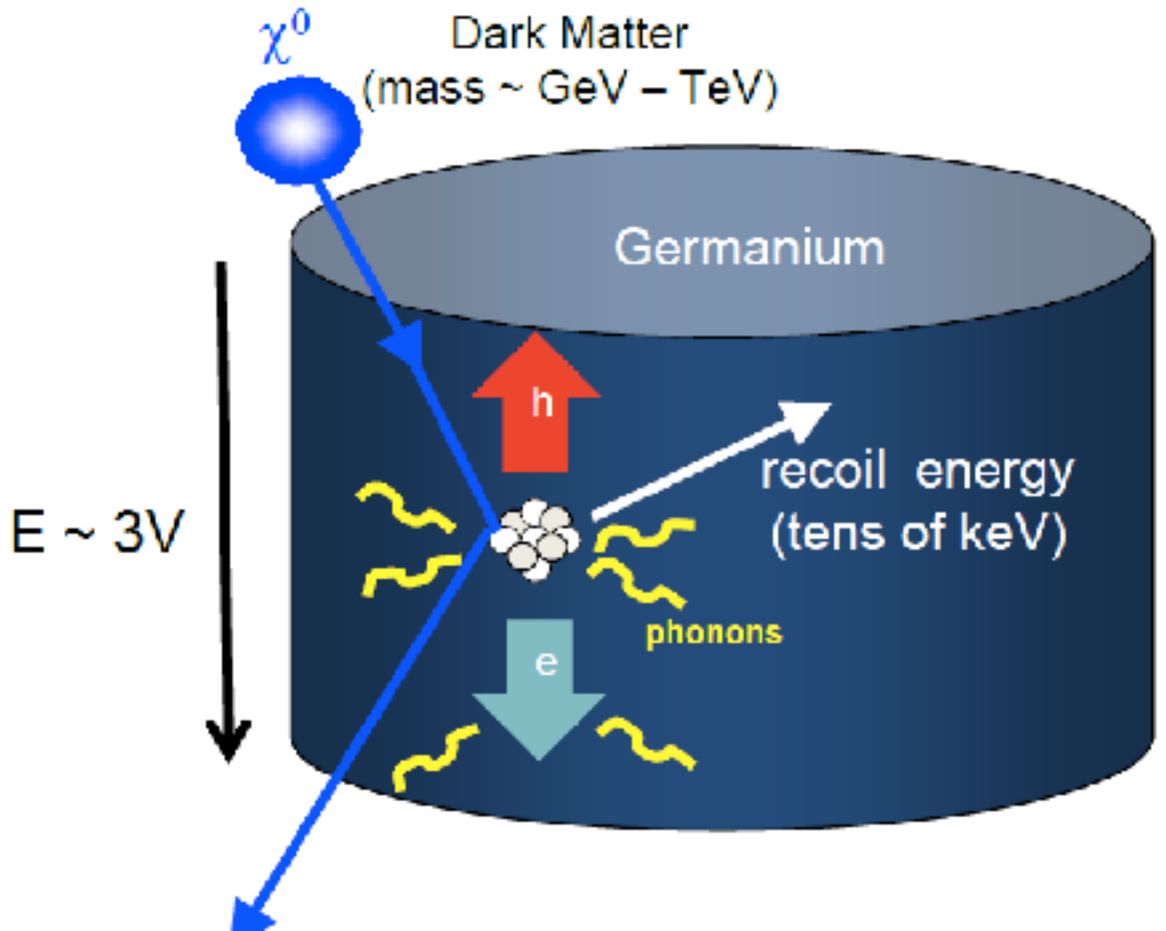
From review by Feng et al. linked off course review literature page.

Experimental results to date (early 2016): nada

Direct detection

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

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

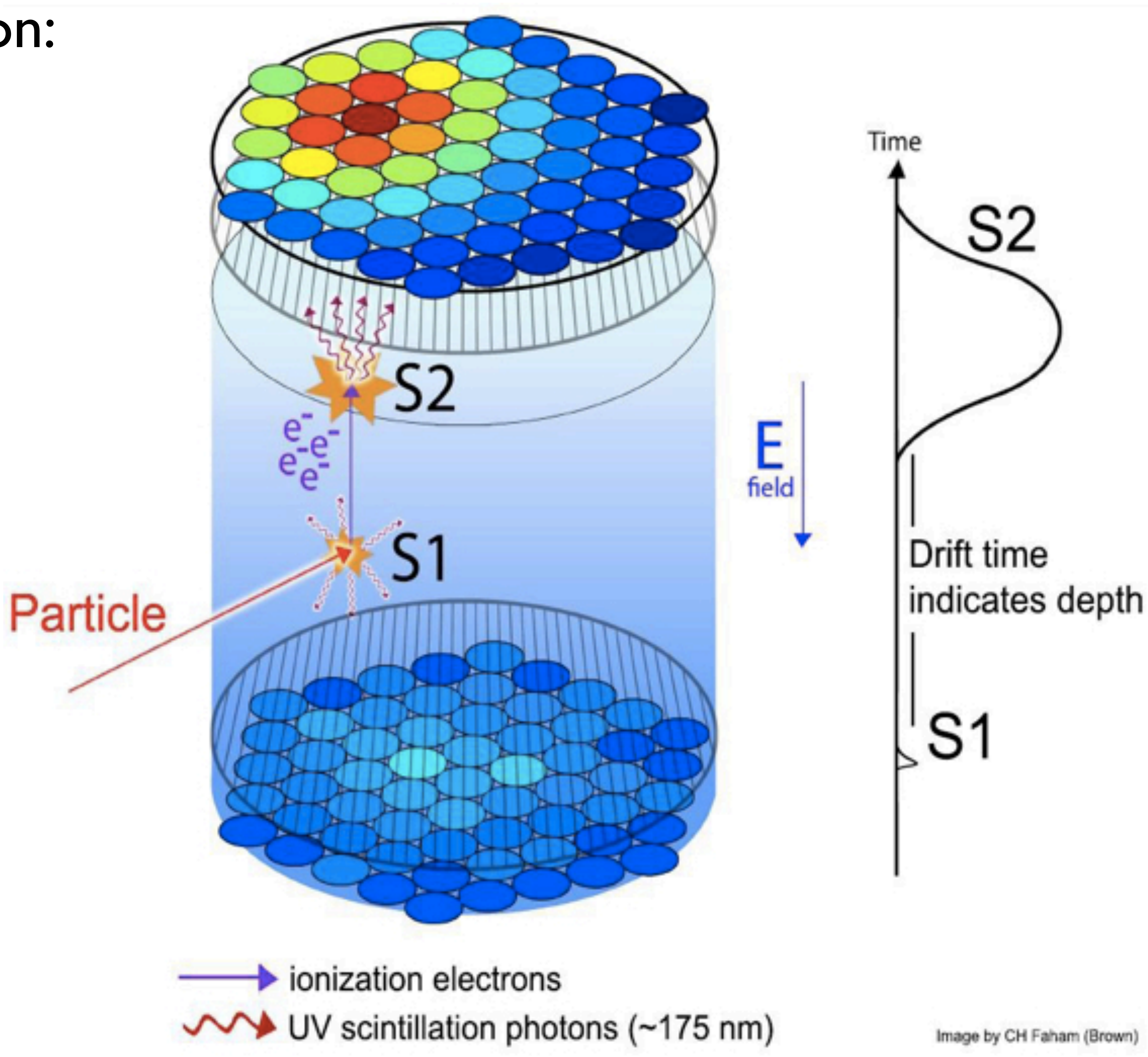


Experimental results to date (early 2018): nada

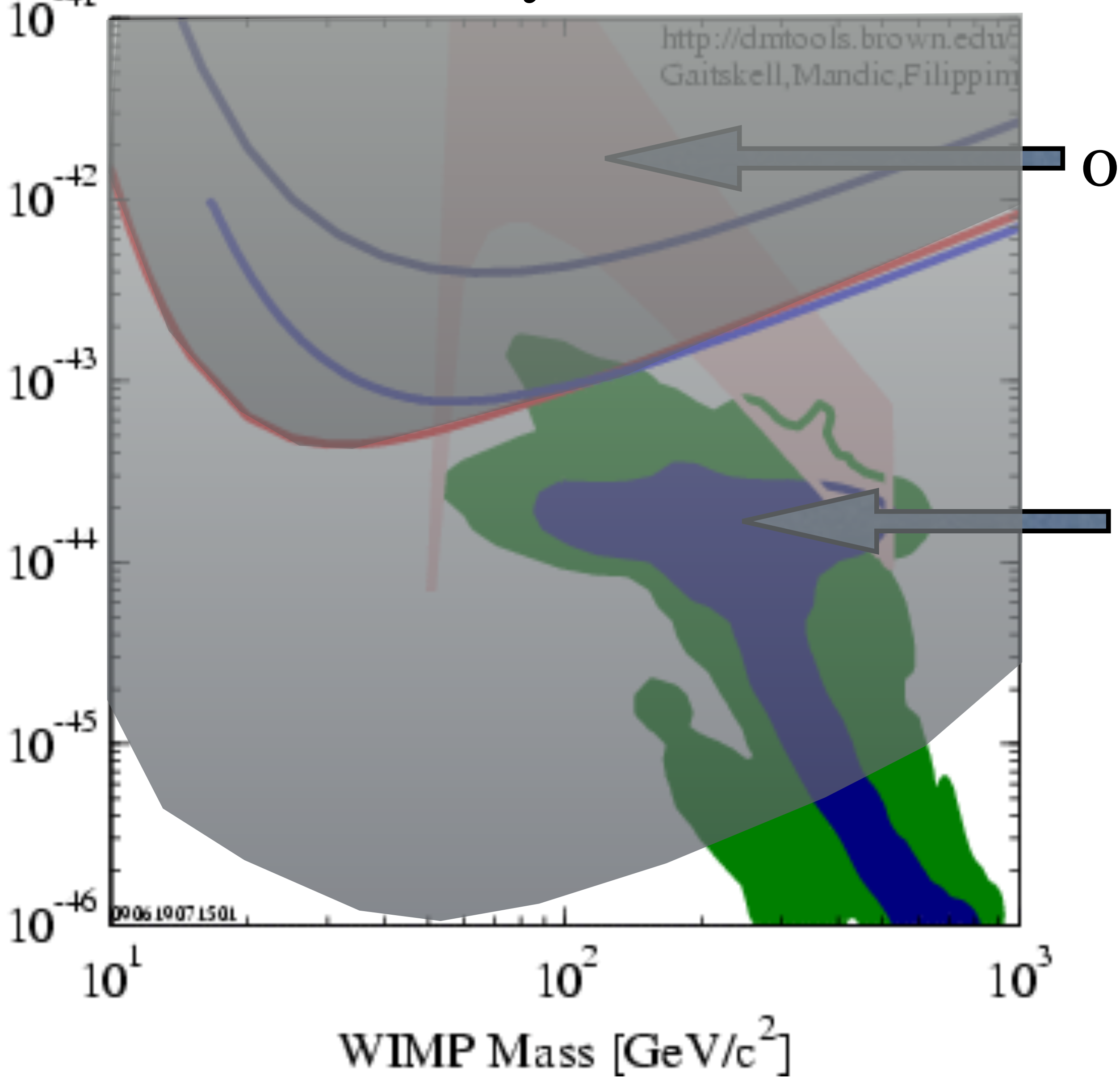
Direct detection:

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

Bury them deep in mines.



WIMPs are hiding



Excluded by 2008

2017

original prediction

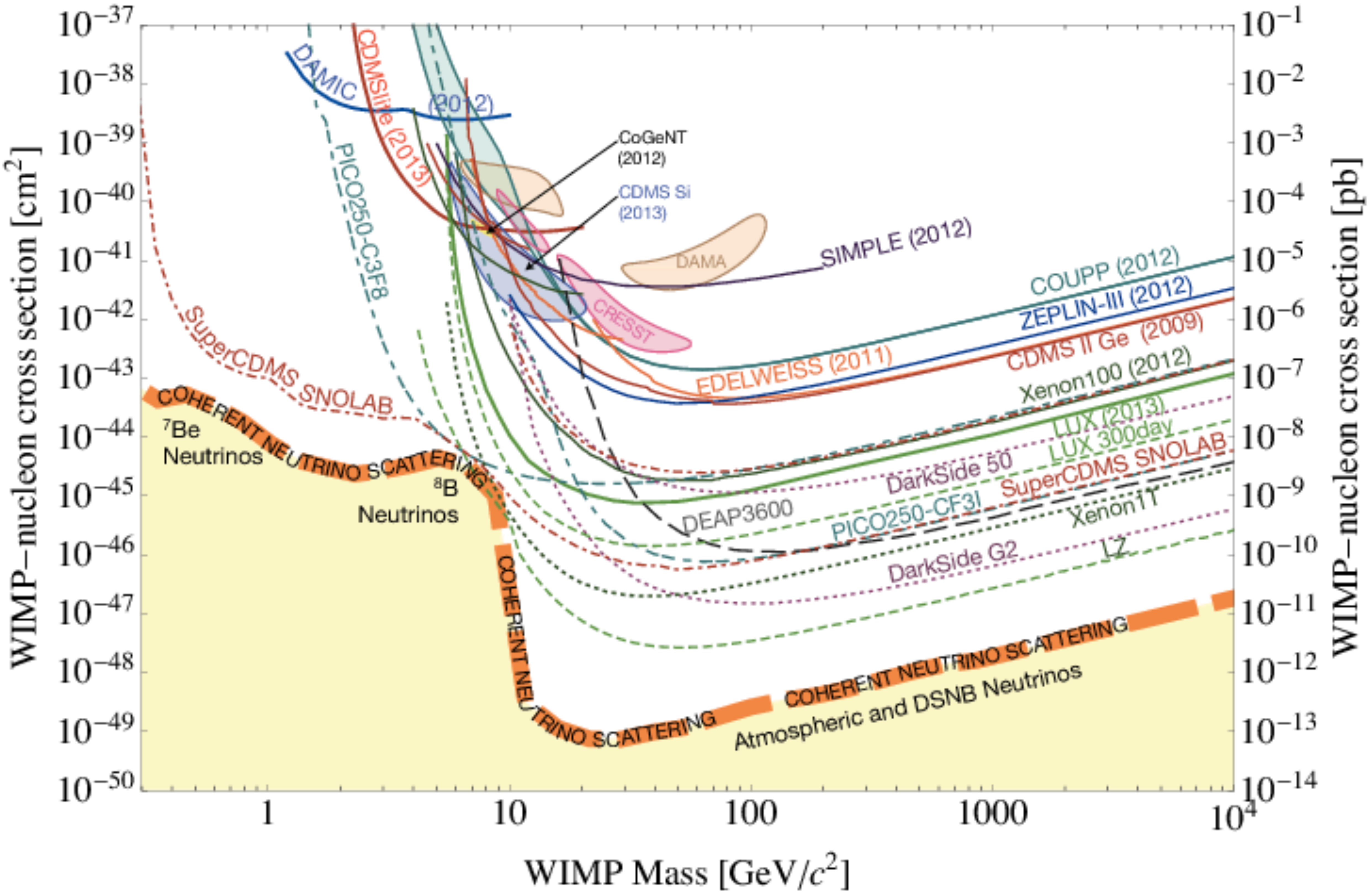
2008 prediction

interaction probability

Mass of WIMP

WIMP detection experiments

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



WIMP mass (~100 GeV natural)

Experimental results to date (early 2018): nada

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

Direct Detection: Nothing so far
well, DAMA

Indirect Detection: Various claims

- gamma ray excess near Galactic Center
- cosmic ray excess
- unidentified X-ray lines

As yet: nothing credible.

MSSM

R-parity violating

NMSSM

WIMPless DM

Hidden Sector DM

Supersymmetry

Gravitino DM

mSUGRA

Self-Interacting DM

pMSSM

Q-balls

Techni-baryons

Dark Photon

R-parity Conserving

Dirac DM

Asymmetric DM

Light Force Carriers

Extra Dimensions

Dynamical DM

Warm DM

Solitonic DM

UED DM

One can always make up other stuff

Sterile Neutrinos

Quark Nuggets

6d

5d

Warped Extra Dimensions

?

RS DM

Axion DM

T-odd DM

Little Higgs

QCD Axions

Axion-like Particles

Littlest Higgs

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