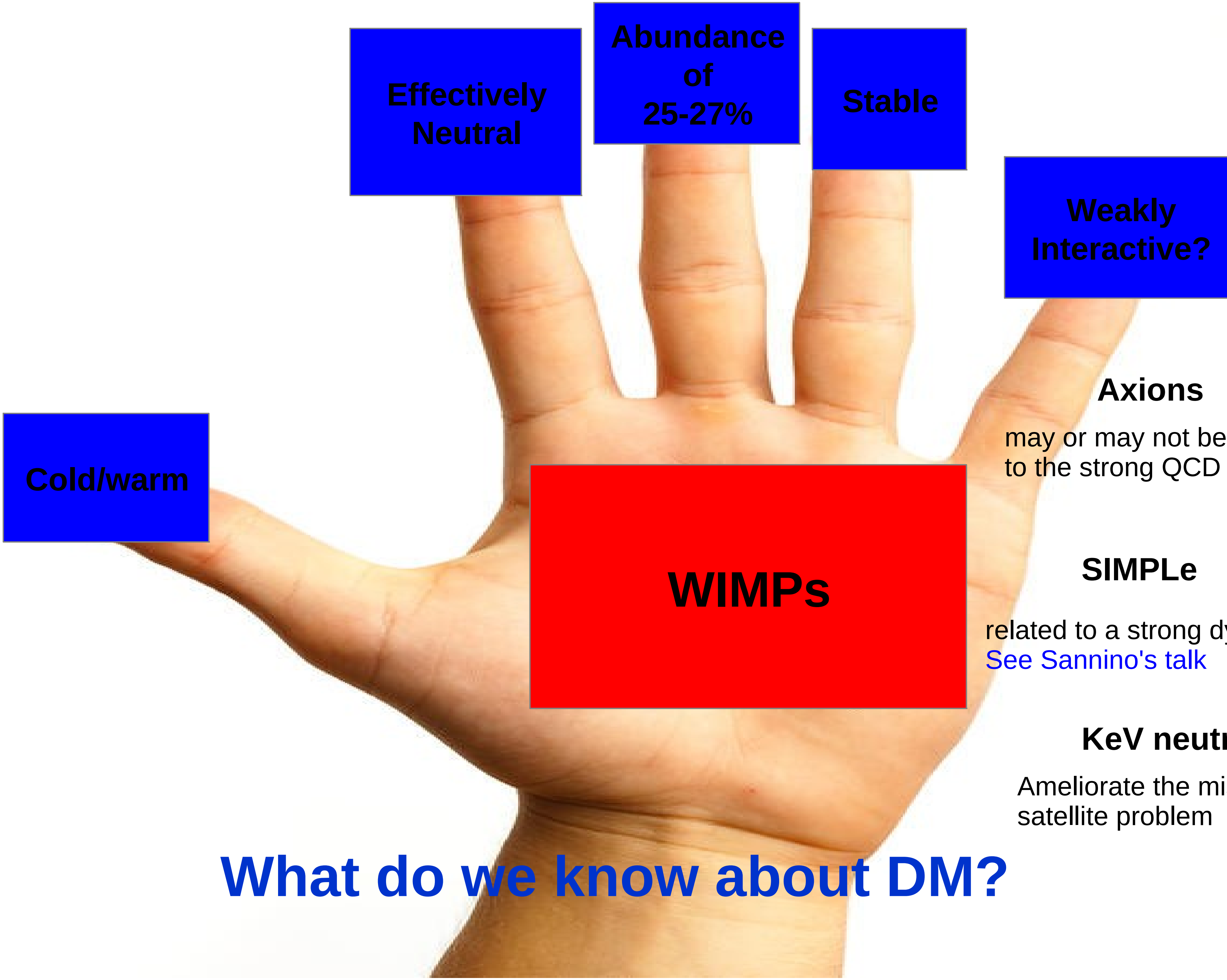
WIMP Theory Review

Farinaldo Queiroz
Max Planck Institut fur Kernphysik

06/07/2017



Axions

may or may not be related to the strong QCD problem

SIMPLe

related to a strong dynamics
See Sannino's talk

KeV neutrinos

Ameliorate the missing satellite problem

What do we know about DM?

Basic Concepts

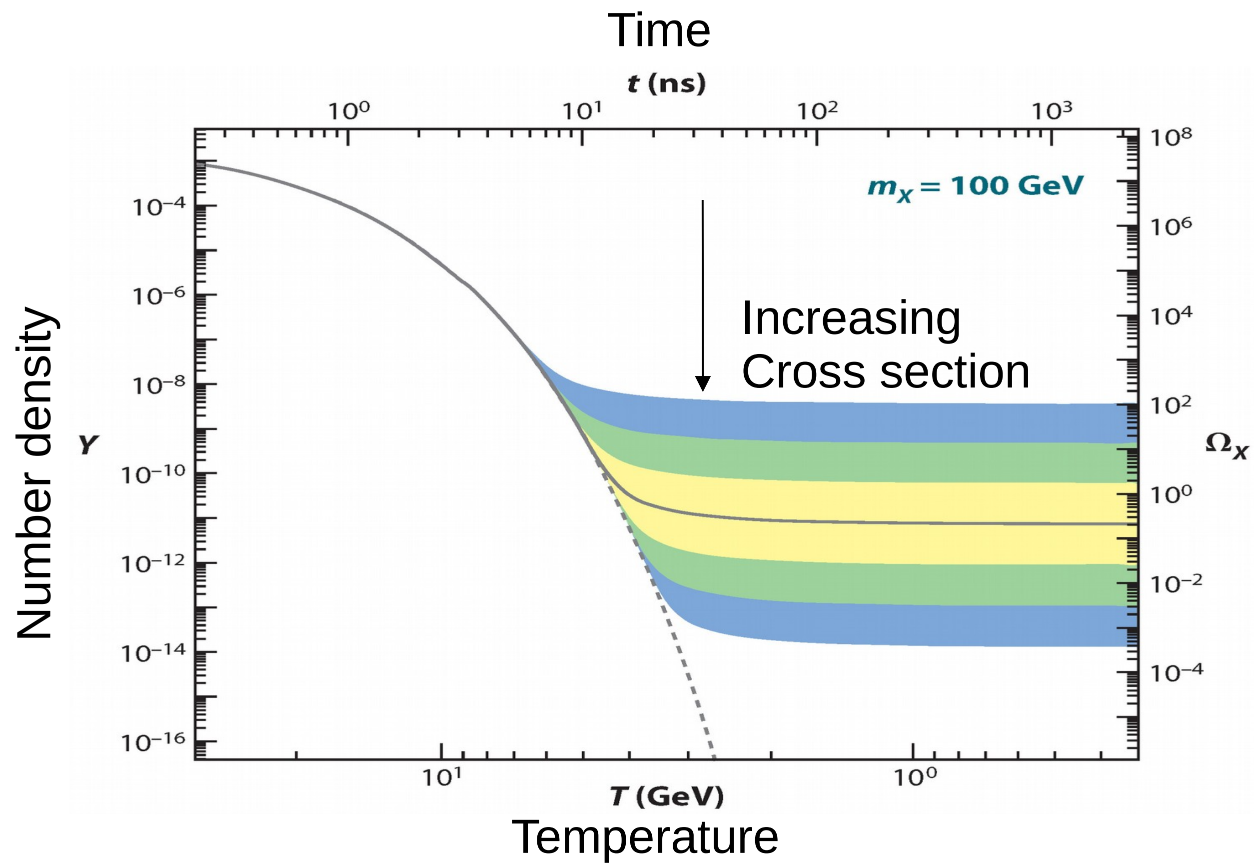
Dark Matter Abundance

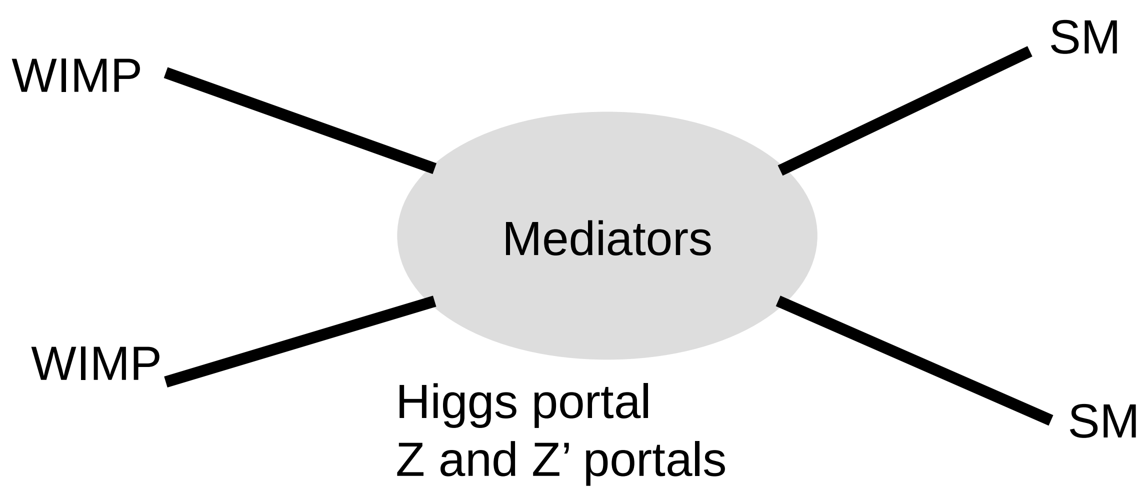
A. dark matter particles could interact with standard model particles and reach thermal equilibrium. Non-thermal processes are also OK.

B. As the universe cools down and expands, eventually the expansion rate equals the interaction rate → freeze-out.

C. After the freeze-out the dark matter particles cluster forming the structures we observe today.

D. In the WIMP paradigm the abundance is straightforwardly connected to the annihilation cross section.





Basic Concepts

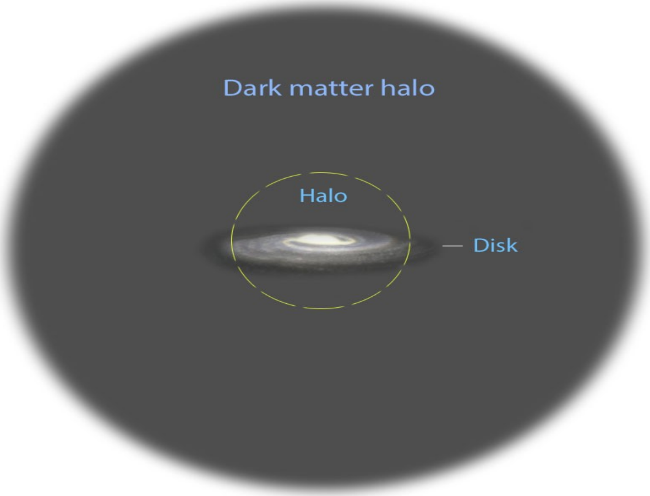
Direct Detection

A. There is a smooth halo of dark matter particles in our galaxy described by a Maxwell velocity distribution.

(Kelso+,1601.04725)

B. Due to the rotation of the Galactic Disk the solar system experiences an effective WIMP wind, which leads to an annual modulation due to Earth's orbital motion.

(Lee+,1308.1953; Del Nobile+, 1512.03961)



Milky Way model

C. The nucleus is described by the Helm form factor.

(Fitzpatrick+, 1308.6288/1405.6690)

Differential scattering rate **Velocity distribution** **Differential cross section**

$$\frac{dR}{dE}(E,t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(\mathbf{v},t) \cdot \frac{d\sigma}{dE}(E,v)\, \mathrm{d}^3 v$$

Spin-Independent

$$\sigma_0^{\mathrm{SI}} = \sigma_p \cdot \frac{\mu_A^2}{\mu_p^2} \cdot [Z \cdot f^p + (A-Z) \cdot f^n]^2 \xrightarrow{f^p = f^n} A^2$$

Spin-Dependent

$$\sigma_0^{\mathrm{SD}} = \frac{32}{\pi} \mu_A^2 \cdot G_F^2 \cdot [a_p \cdot \langle S^p \rangle + a_n \cdot \langle S^n \rangle]^2 \cdot \frac{J+1}{J}$$

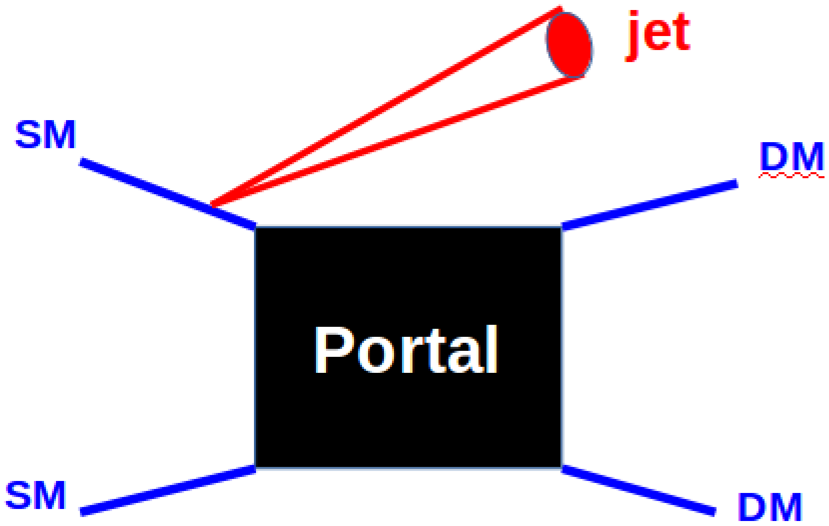
Collider Searches

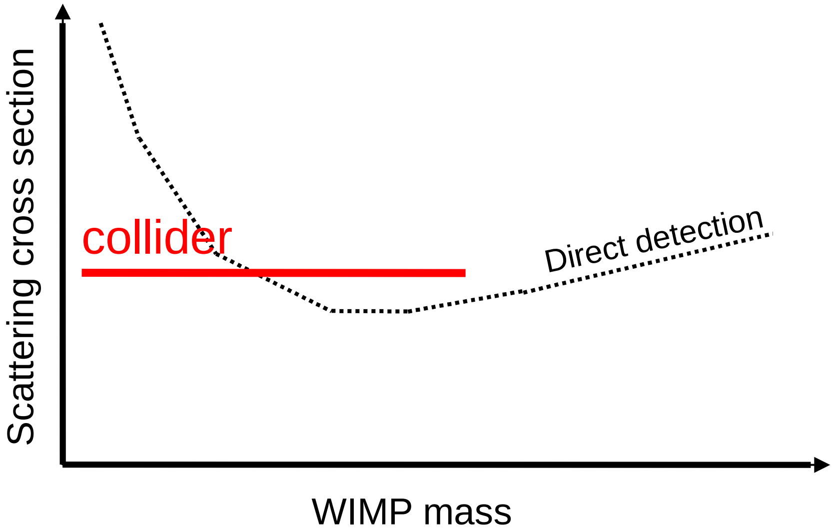
Basic Concepts

A. Dark matter is cosmologically stable, therefore is "seen" as missing energy at colliders, mono-X searches.

B. The observation relies on the detection of the accompanying particles/jets

Note:New resonance searches provide stringent limits on new gauge bosons often used as mediators between the dark and visible sectors.



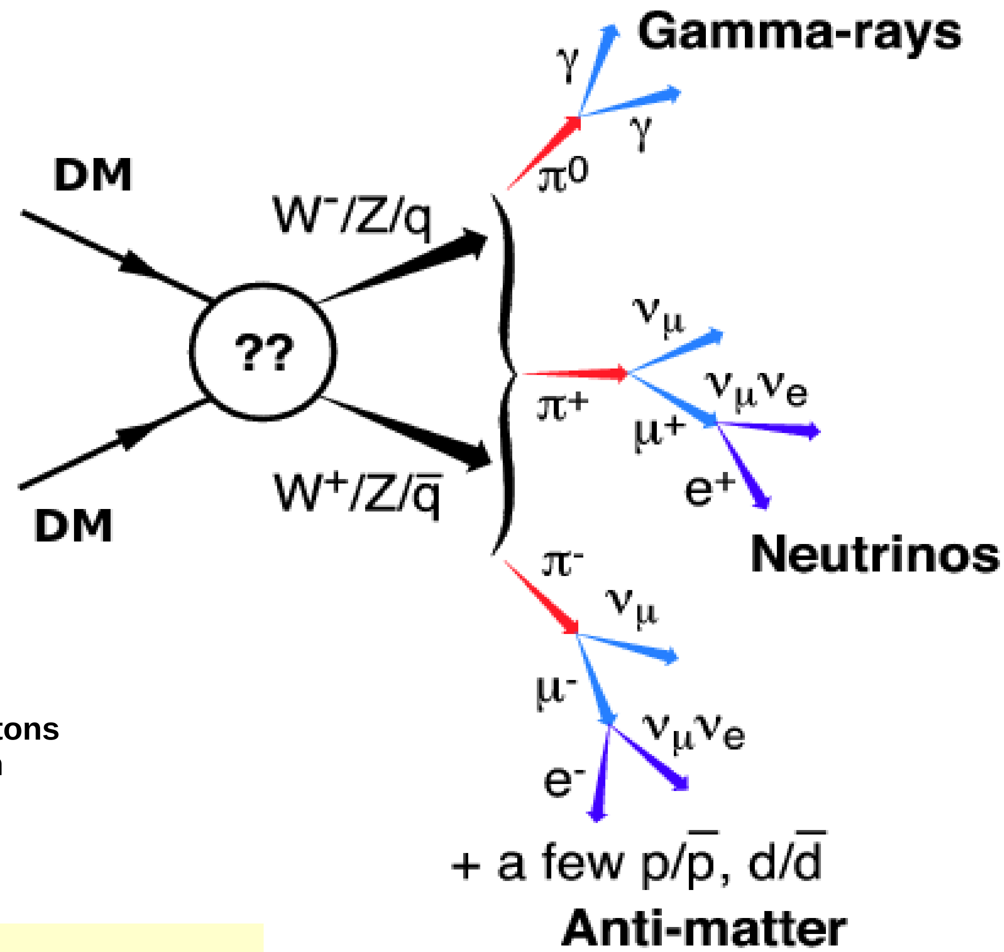


For a scan over several simplified dark matter models see:

The ATLAS/CMS Dark Matter Forum, 1507.00966

Basic Concepts

Dark Matter Indirect Detection



A. The dark matter particles might still be able to interact with standard model particles and produce an observable signal.

B. We know how to account for hadronization and final state radiation well up to the dark matter mass which can be very heavy.

Differential Flux

Annihilation cross section

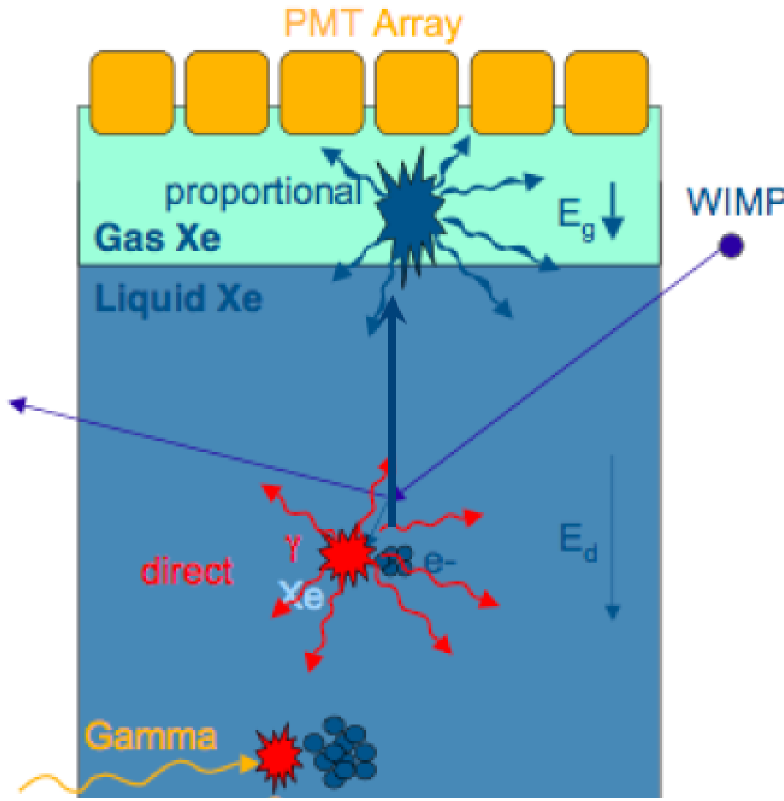
Number of photons per annihilation

$$\frac{d\phi}{d\Omega dE} = \frac{\langle \sigma v_{\rm rel} \rangle}{8\pi m_\chi^2} \frac{dN_\gamma}{dE} \times \int_{\rm l.o.s.} ds \; \rho(\vec{r}[s,\Omega])^2$$

Line of sight integral

Dark matter density

http:www.EPSnews.com



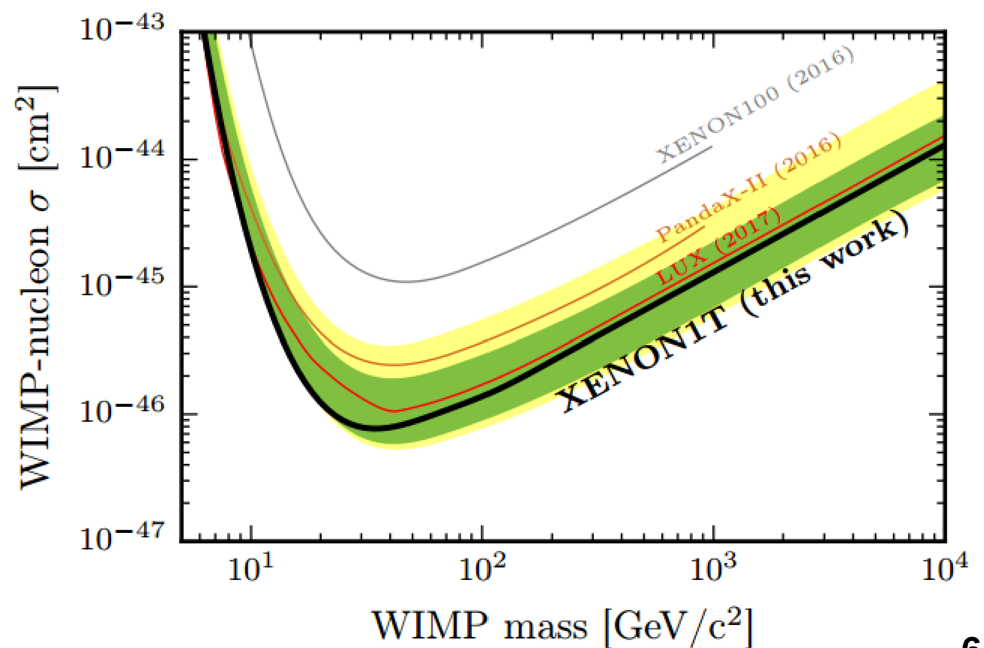
WIMP NEWS

WIMP dies after crossing Liquid XENON

WIMP is in check after meeting with LHC congress

Will WIMP be prosecuted by Indirect Searches?

NO, NO and NO! Based on facts!



The Waning of the WIMP? A Review of Models, Searches, and Constraints

arxiv:1703.07364

First Observation: Possible Evidence for Dark Matter Annihilation In The Inner Milky Way

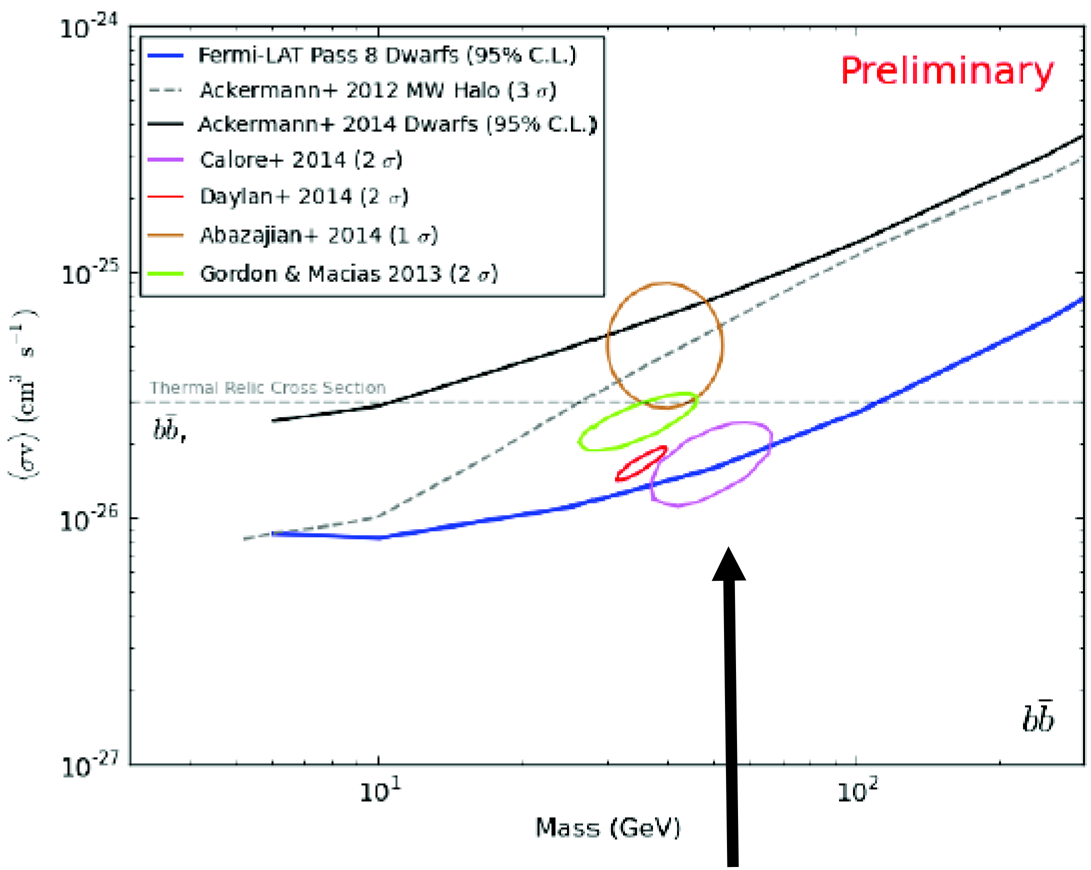
Goodenough, Hooper 0910.2998

Fermi-LAT Observations of High-Energy Gamma-Ray Emission Toward the Galactic Center

"After subtracting the interstellar emission and point-source contributions from the data a residual is found that is a sub-dominant fraction of the total flux".

Fermi-LAT, 1511.02938

Is the GeV gamma-ray excess excluded by Dwarf Galaxies Data?



The best-fit regions can move downwards by a factor of two-three

With the recent discovery of several dwarf galaxies Fermi-LAT limit improved

The GeV excess probably will not be fully tested in the Fermi's era

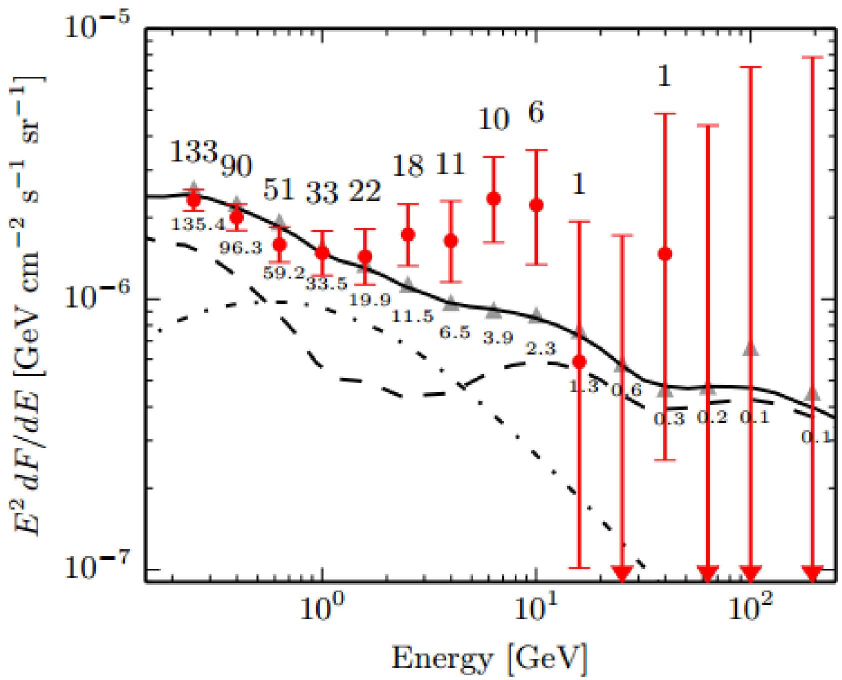
WIMP NEWS

Other potential signals

Reticulum-II Dwarf Galaxy

Fermi-LAT collab. Reported a 2sigma upward fluctuation

A. Geringer-Sameth+, 1503.02320



Subhalo in the Fermi-LAT Catalog

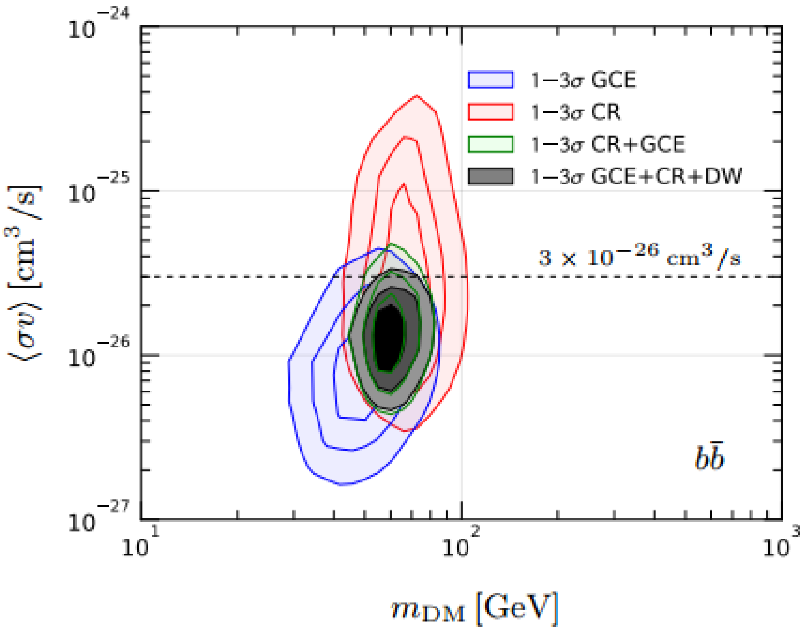
Gamma-ray emission roughly consistent with galactic center excess.

B. Bertoni+, 1602.07303

AMS-02

Excess in anti-protons

A. Cuoco+, 1704.08258
A. Cuoco+,1610.03071



Search for Neutrino Lines with Gamma-rays

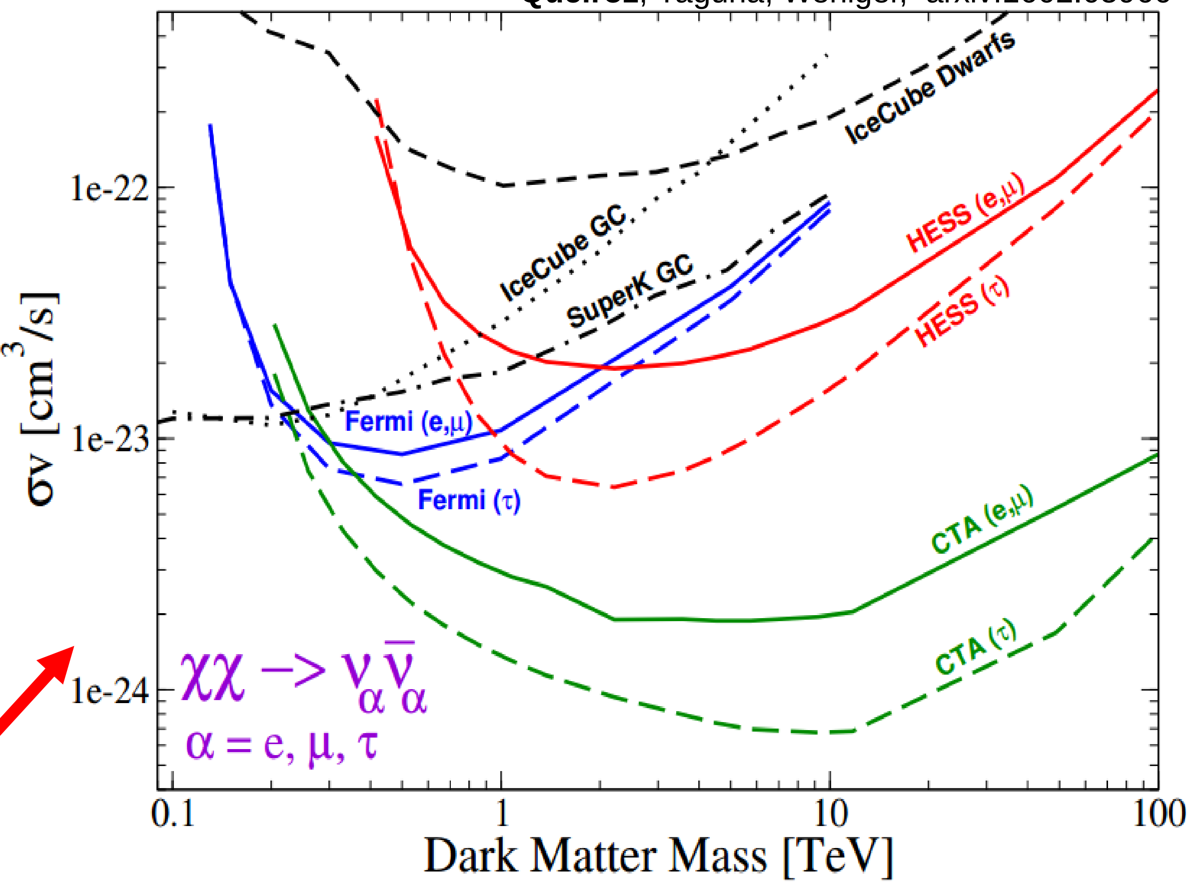
Neutrino telescopes have the advantage of being sensitive to both the WIMP-nucleus scattering and dark matter self-annihilation cross section.

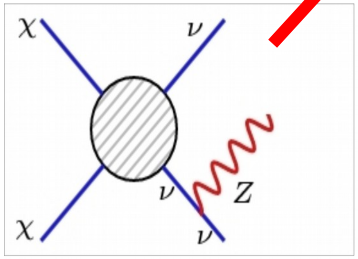
Several searches for neutrinos flavors from dark matter annihilations have been Conducted by Super-K, IceCube and ANTARES collab. as well as by independent groups.

Please notice that weak corrections are important and a neutrino final state also gives rise to a gamma-ray emission which can be probed by Fermi-LAT/H.E.S.S. instruments.

NEW ERA

Queiroz, Yaguna, Weniger, arxiv:1602.05966





Kachelriess+, 0707.0209
Bell+, 0805.3423
Cirelli+,1012.4515

As for dark matter decays, neutrino telescopes remain the most promising instruments
El Aisati et al,151005008

A New Test Toward the Nature of WIMP Dark Matter

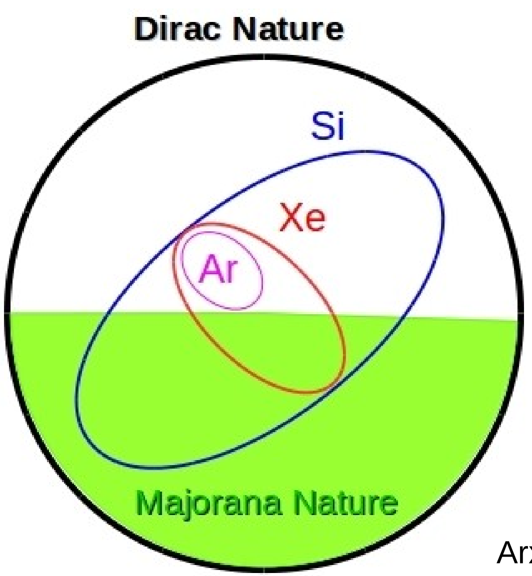
$$\sigma_{SI}^{M} = \frac{4\mu_\chi^2}{\pi}\left[\lambda_p^M Z + \lambda_n^M (A - Z)\right]^2 \quad \begin{cases} \left[\lambda_p^M Z_X + \lambda_n^M (A_X - Z_X)\right]^2 = \dfrac{\pi\tilde{\sigma}_X}{4\mu_\chi^2}, \\ \left[\lambda_p^M Z_Y + \lambda_n^M (A_Y - Z_Y)\right]^2 = \dfrac{\pi\tilde{\sigma}_Y}{4\mu_\chi^2}. \end{cases}$$

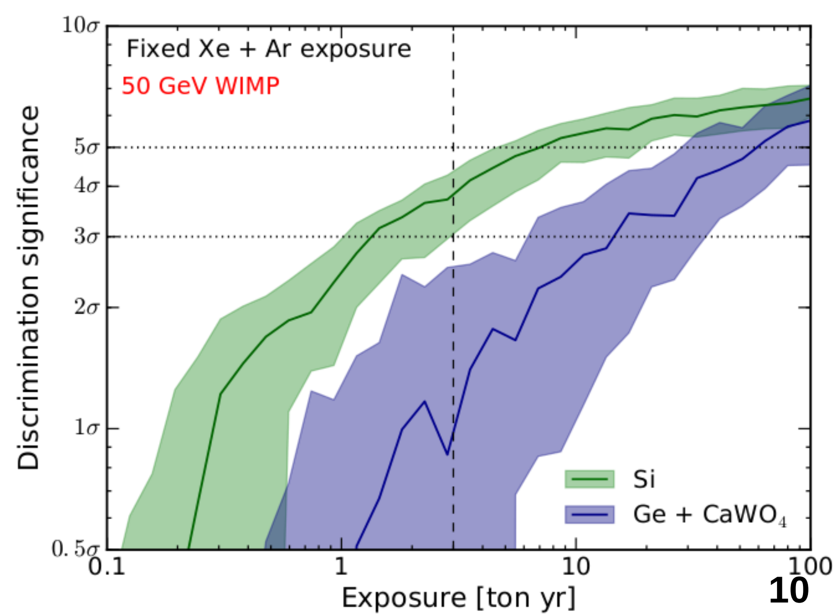
A + B = 10

2A + B = 15 **find A and B**

Nucleus	$Z/(A-Z)$
$^{132}_{54}Xe$	0.69
$^{72}_{32}Ge$	0.76
$^{28}_{14}Si$	1.00
$^{40}_{20}Ca$	1.00
$^{127}_{53}I$	0.72
$^{16}_{8}O$	1.00
$^{23}_{11}Na$	0.92
$^{40}_{18}Ar$	0.82
$^{19}_{9}F$	0.90
$^{184}_{74}W$	0.67

Exploit the fact that different isotopes lead to different solutions





Arxiv:1706.07819

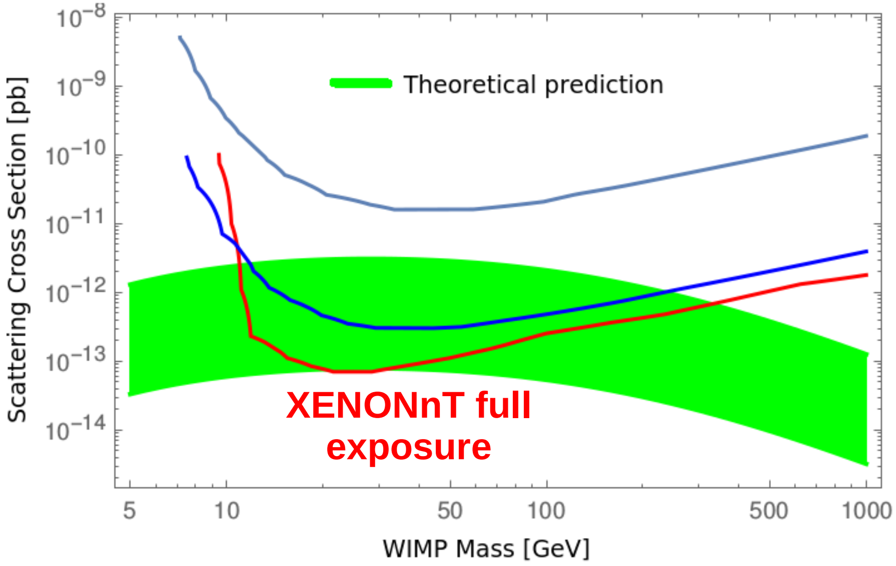
Conclusions

WIMP paradigm remains strong

There is a possible way (not easy) to determine the fundamental nature of WIMP dark matter

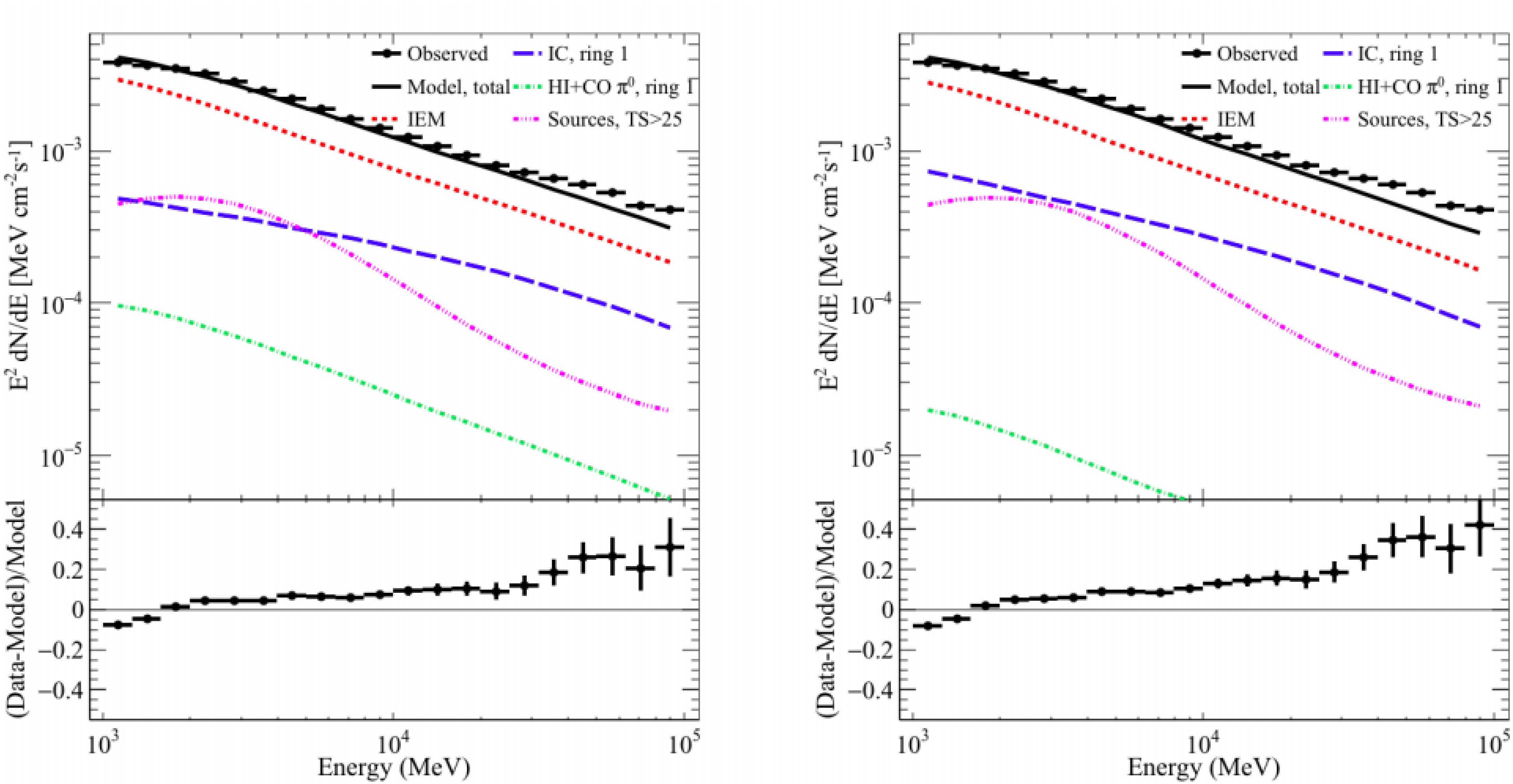
Let's be Optimistic

A WIMP Model at the Neutrino Floor



couplings of order one
mediator of ~10GeV

On the residual see by Fermi-LAT. Interestingly the trend is evident: each model over-predicts the data below ~ 2 GeV and underpredicts above ~ 2 GeV



Back-up slide 1