Dark Matter Overview

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Take home message 1

Improvements have been made in reducing statistical and systematic errors in direct, indirect and collider searches for dark matter.

Take home message 2

There are two excesses related to indirect dark matter detection:
i) gamma-rays in the GeV range (annihilation) ; ii) in x-rays in the KeV range (decay)

Dark Matter Olympics: GeV gamma-ray excess search

Hooper,Linden,Abazajian et al (US)

Cholis et al (Greece)

Weniger et al (Germany)

Gordon et al (South Africa)

Calore et al (Italy)

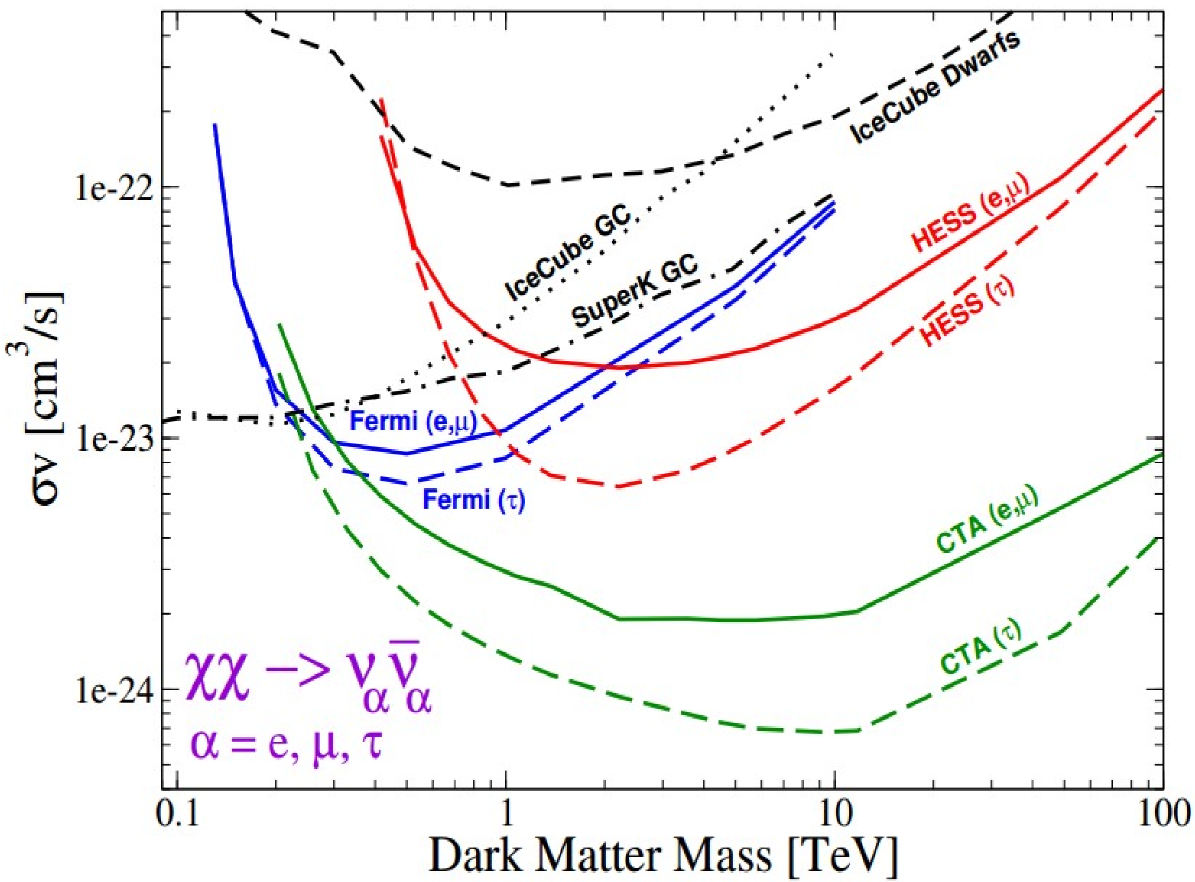
Space available

+49 01737324407

Borrowed from Cirelli

Take home message 3

Gamma-ray Telescopes are more sensitive (comparable to) than neutrino detectors to neutrino lines from dark matter annihilation.



Queiroz, Yaguna, Weniger, arxiv:1602.05966

HIGH FIVE DM!

Effectively Neutral

Abundance of 25-27%

Stable

Weakly Interactive?

Cold/warm

WIMPs

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

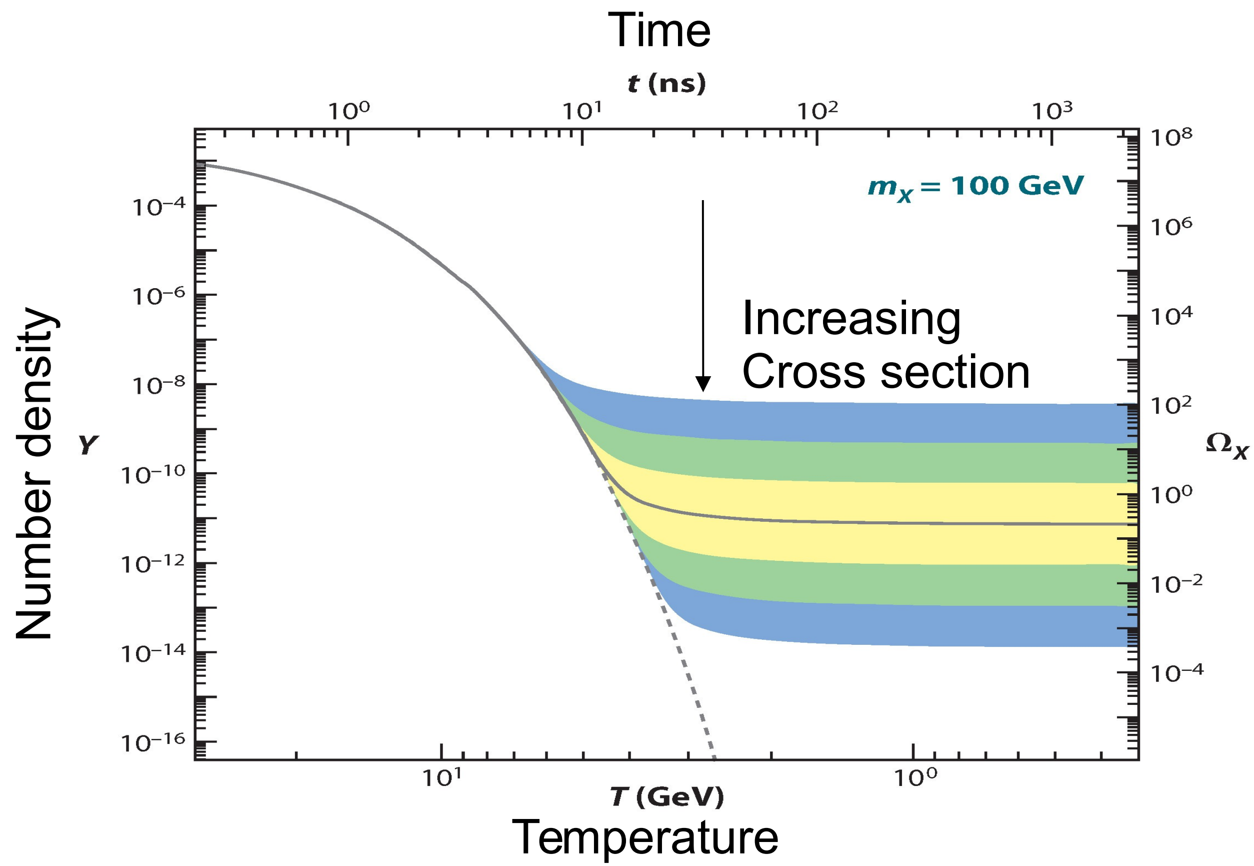
Dark Matter Abundance

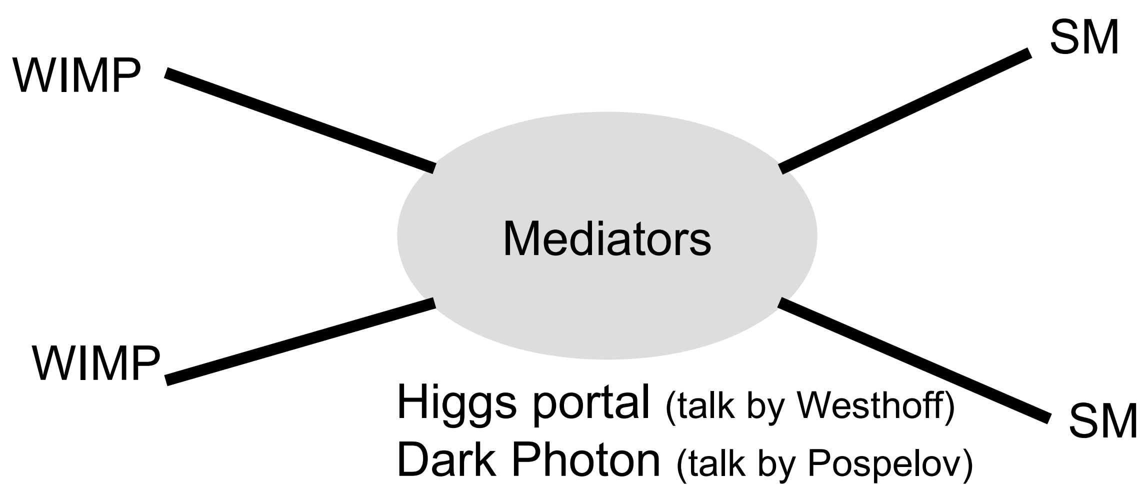
A. dark matter particles could interact with standard model particles and reach thermal equilibrium. Non-thermal processes are also OK.

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

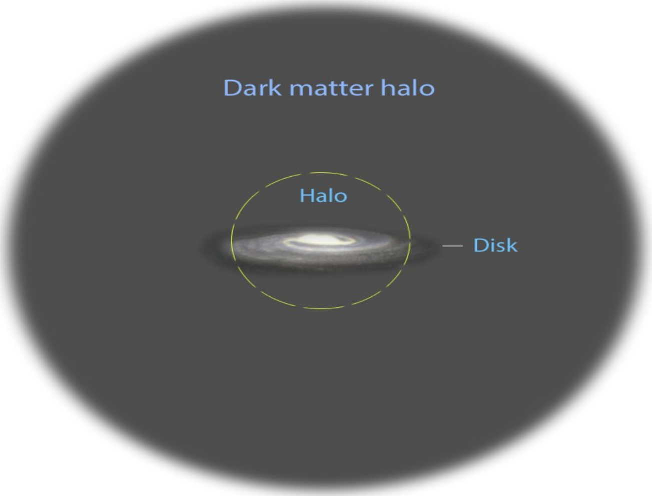
Direct Detection

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

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

Spin-Dependent

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

Basic Concepts

Direct Detection

Why do the limits look the way they do?

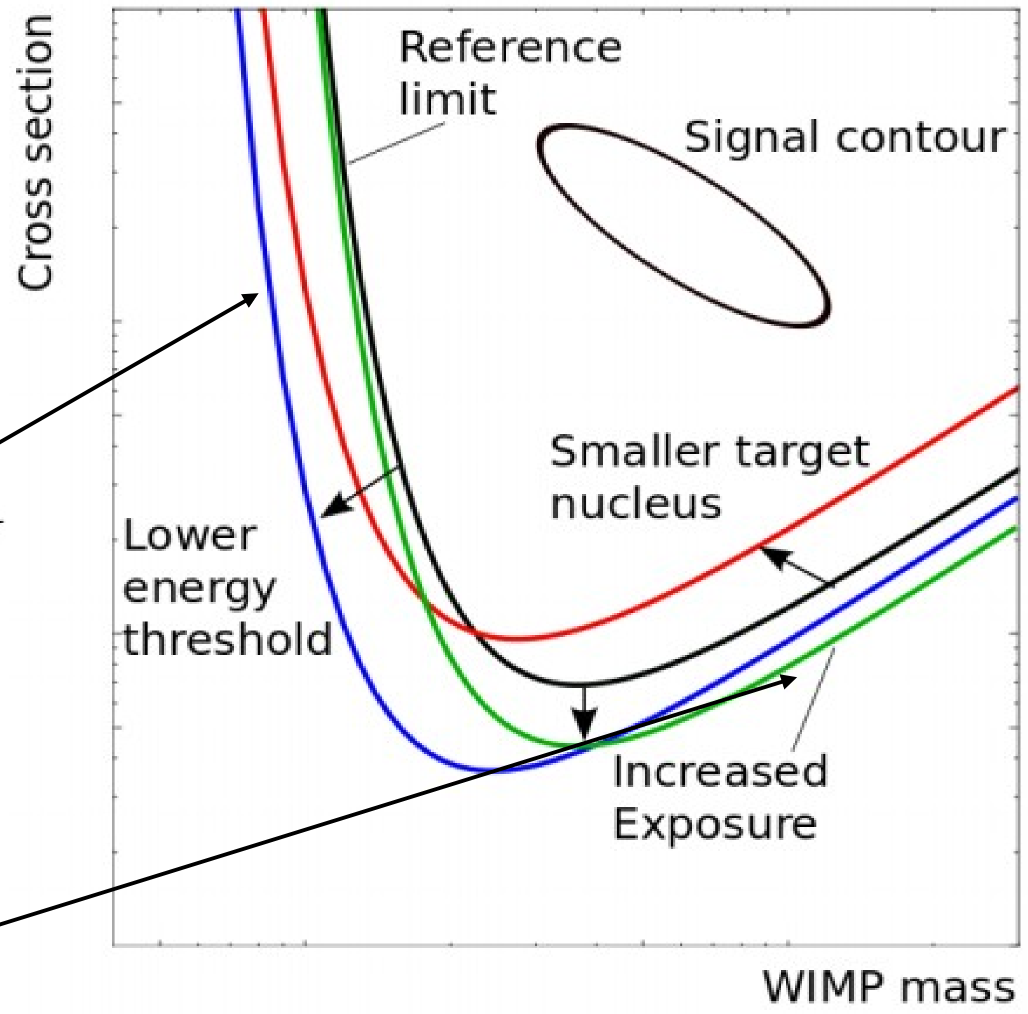
Recoil Energy

$$E_r \propto \left(\frac{M_{DM} M_N}{M_{DM} + M_N}\right)^2 \frac{1}{M_N}$$

10 GeV WIMP

$M_N = 10 GeV \longrightarrow E_r = 5 KeV$

$M_N = 100 GeV \longrightarrow E_r = 1.6 KeV$



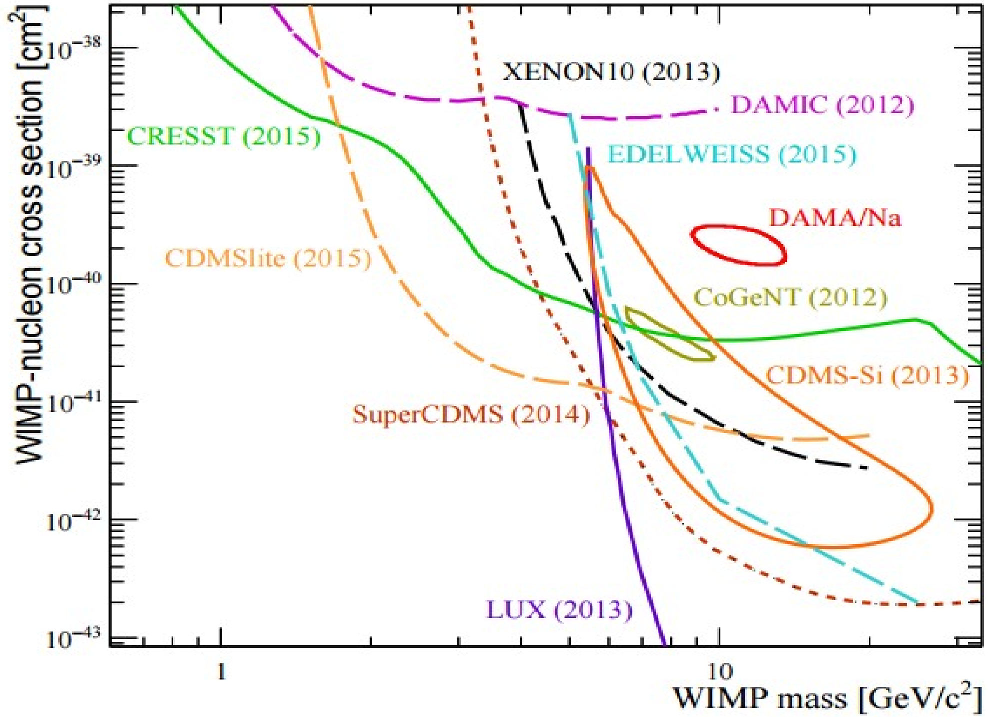
WIMPs number density

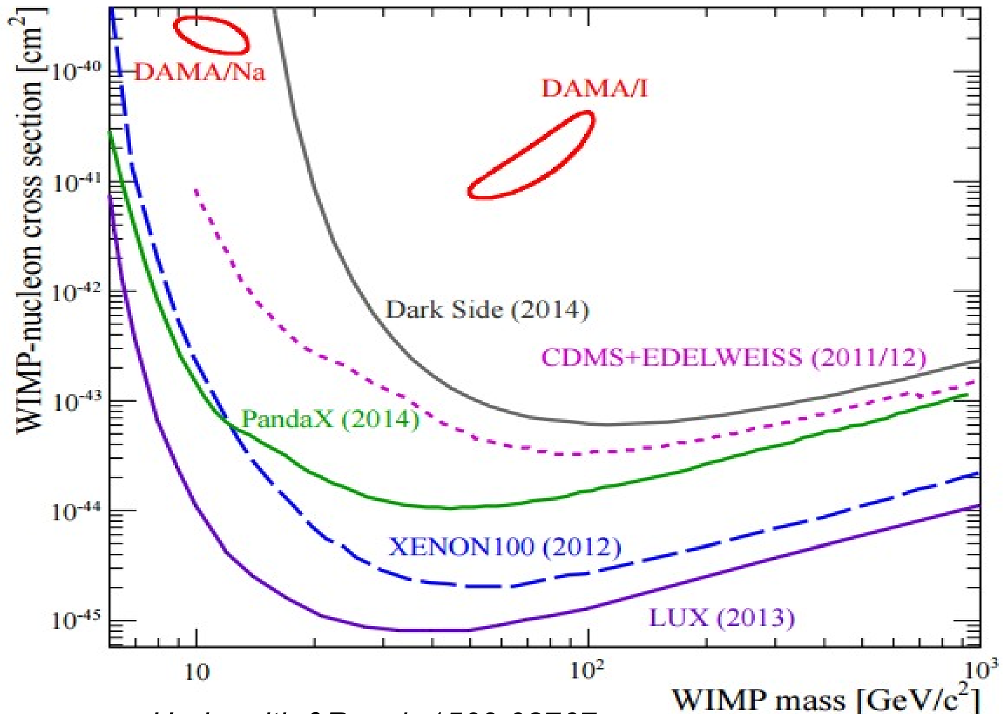
$$\rho_{\odot} = 0.3\, GeV/cm^3 = n_{DM} m_{DM}$$

Undagoitia&Rauch 1509.08767

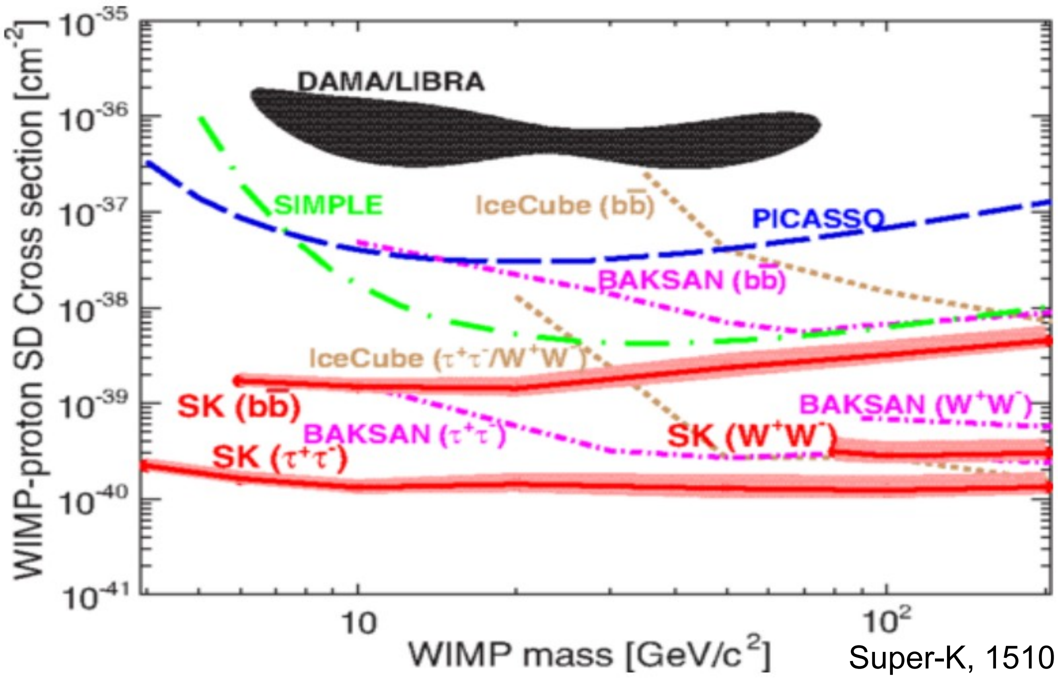
See talks by Lopez (CDMS), Proebst (CRESST), Hasterok (XENON100), Beltrame (LUX)

Global Picture





Undagoitia&Rauch 1509.08767



Super-K, 1510.07999

Projected limits will be presented later today

Collider Searches

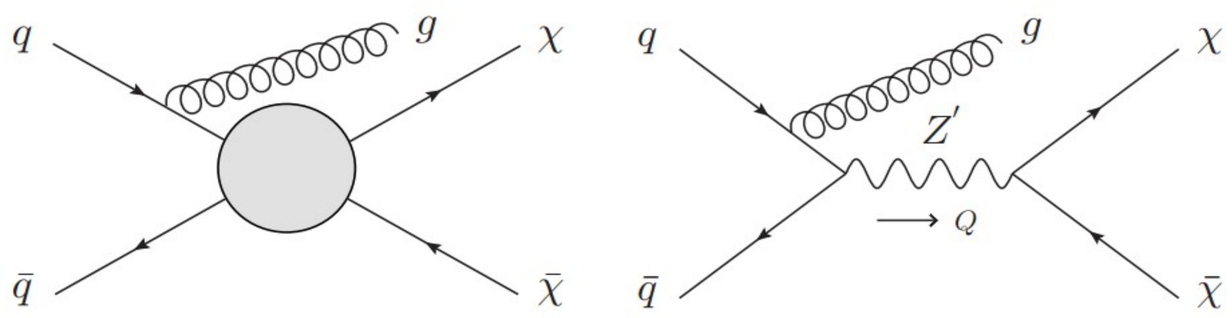
Basic Concepts

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

C. Effective theory typically assumed. Use it wisely.

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



e.g. $$\text{vector}: \frac{\bar{\chi}\gamma_\mu\chi\,\bar{q}\gamma^\mu q}{\Lambda^2}$$

$$\Lambda \equiv \frac{m_{\text{med}}}{\sqrt{g_q\,g_\chi}}$$

Approximation is built-in the EFT

Buchmueller+, 1308.6799

$$\frac{g_q\,g_\chi}{Q^2 - m_{\text{med}}^2} \approx -\frac{g_q\,g_\chi}{m_{\text{med}}^2}\left(1 + \frac{Q^2}{m_{\text{med}}^2} + \mathcal{O}\left(\frac{Q^4}{m_{\text{med}}^4}\right)\right)$$

For a scan over several simplified dark matter models see:

The ATLAS/CMS Dark Matter Forum, 1507.00966

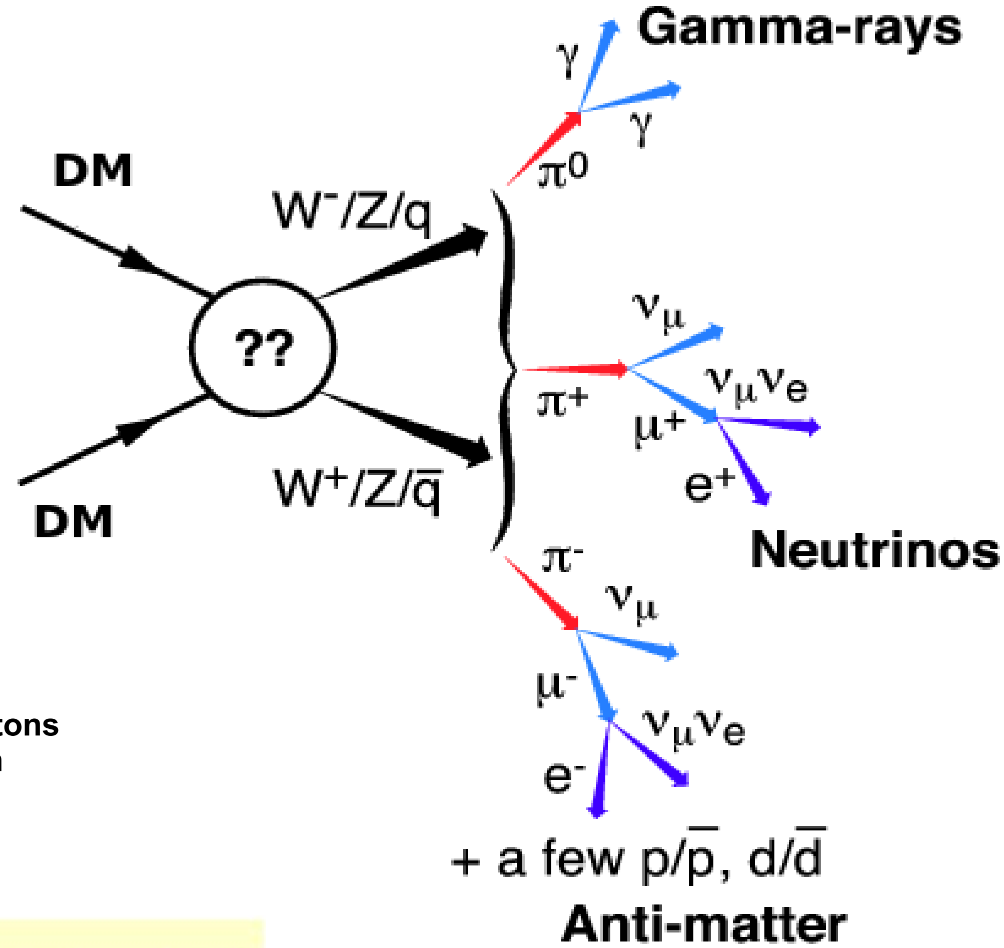
See talk by Cremonesi (dark matter at LHC13TeV)

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**

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

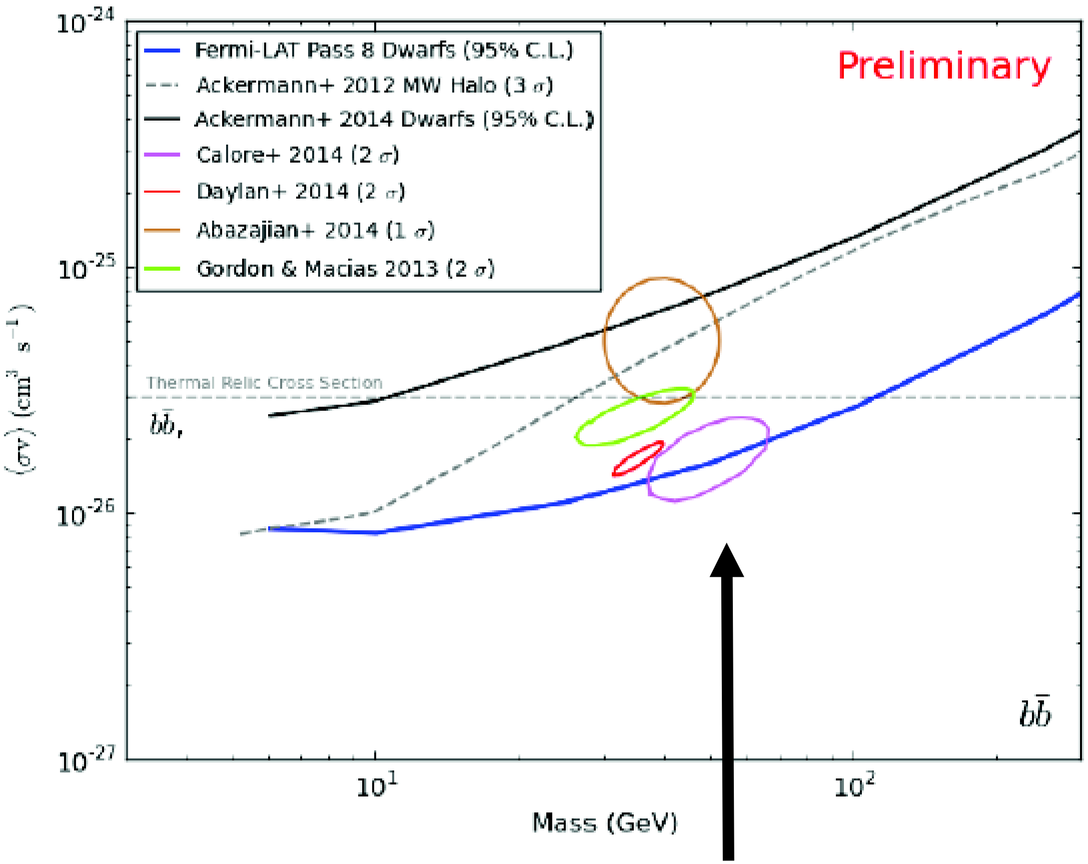
Goodenough, Hooper, 0910.2998

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?



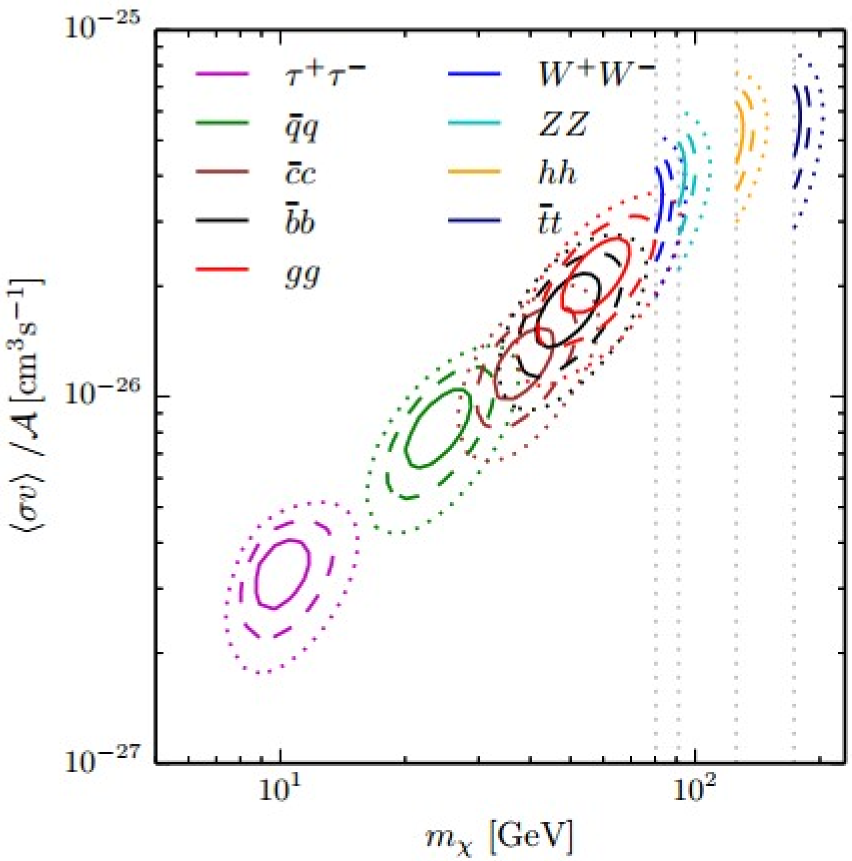
The best-fit regions can move downwards by a factor of two-three

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

The GeV excess will probably be settled in the next 3-5 years.

Gamma-ray Excess at the Galactic Center

Dark Matter — **Interpretations** — **Other Sources**



F. Calore et al, 1411.4647

Many dark matter models fit the Galactic excess easily, but only some are consistent with direct detection and collider bounds.

1. Young Pulsars

   K. N. Abazajian+, 1402.4090.
   R. Bartels+, 1506.05104;
   S. Lee+,1506.05124;

2. Collisions between gas with protons accelerated by a black holes.

   T. Linden+, 1203.3539;
   O. Macias+, 1410.1678

3. Collisions between gas with cosmic-rays (e.g. non-thermal bremsstrahlung from a population of electrons scattering off neutral molecular clouds)

   F. Yusef-Zadeh+,1206.6882

4. Series of Burst-like events during an active past of our galaxy

   E. Carlson+,1405.7685
   J. Petrovic+, 1405.7928

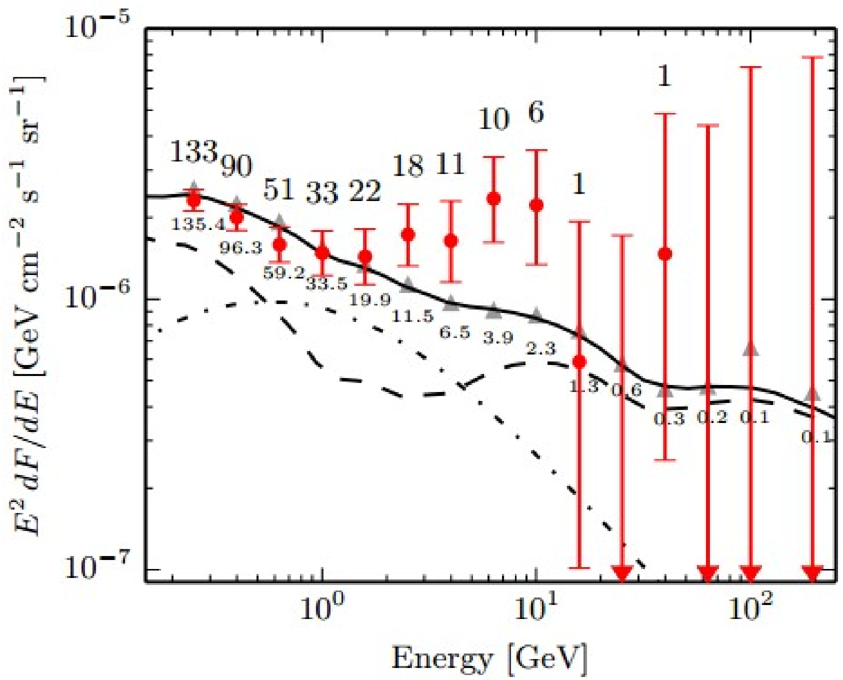
5. Different distributions of distribution cosmic-ray sources

   E. Carlson+,1510.04698
   D. Gaggero+, 1507.06129

Dark Matter Annihilation: Other gamma-rays signals

Reticulum-II Dwarf Galaxy

A. Geringer-Sameth+, 1503.02320

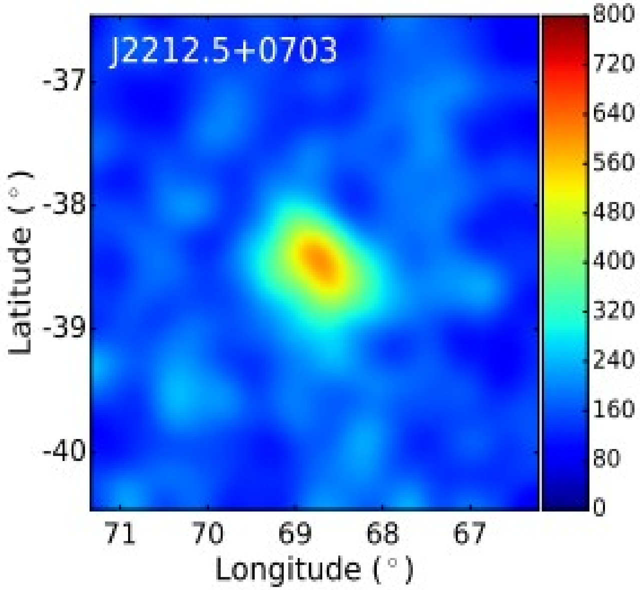


Recently discovered dwarf galaxy

Fermi-LAT collab. did not see the excess

Subhalo in the Fermi-LAT Catalog

B. Bertoni+, 1602.07303



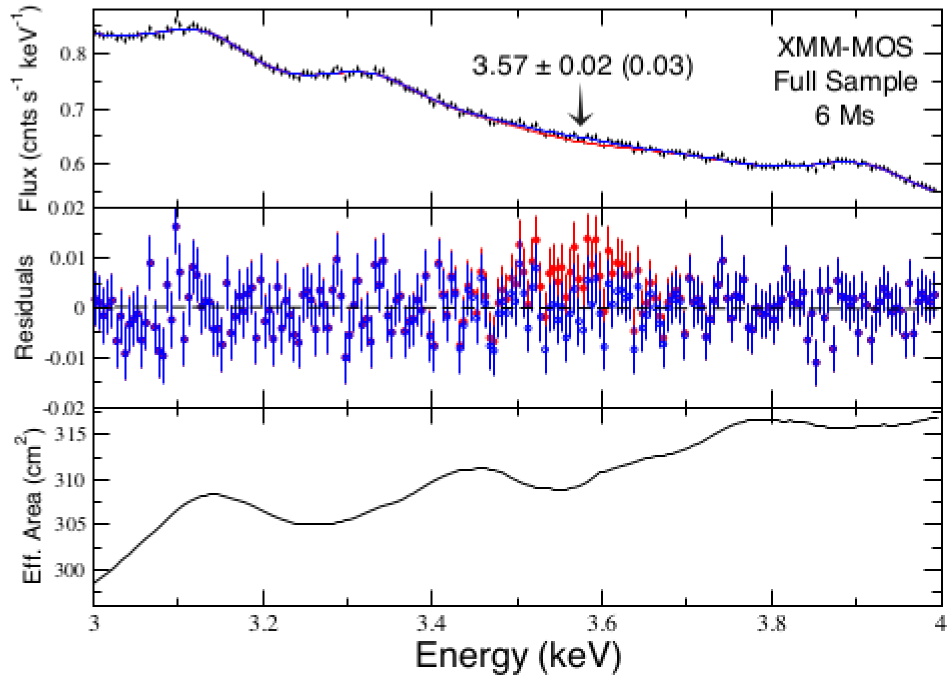
They sifted the third Fermi-LAT catalog and found some sources with gamma-ray emission roughly consistent with galactic center excess.

Dark Matter Decay: KeV Excess at the Galactic Center and Galaxy Clusters

Detection of an unidentified emission line in the stacked x-ray spectrum of 73 galaxy clusters using XMM-Newton instrument

E. Bulbul+, 1402.2301

A. Boyarsky+, 1402.4119 and 1408.2503



"we argue that there should be no atomic transitions in thermal plasma at this energy"

KeV Sterile Neutrino as dark matter

$$\Gamma_\gamma(m_s,\theta) = 1.38 \times 10^{-29}\ \mathrm{s}^{-1} \left(\frac{\sin^2 2\theta}{10^{-7}}\right)\left(\frac{m_s}{1\ \mathrm{keV}}\right)^5$$

Dodelson&Widrow hep-ph9303287

Dark Matter Decay: KeV Excess at the Galactic Center and Galaxy Clusters

Dark Matter Searches going bananas...

Jeltema,Profumo, 1408.1699

1.They focused on the 3-4KeV energy range, differently from the previous paper

2. They a public version of the tool used to compute the line emissions, differently from the previous papers

3. They found no evidence for a 3.5KeV line emission.

4. Updated limits on decaying DM are closing in

Mambrini, Profumo, **Queiroz**, 1508.06635

Null result from Draco is consistent with the 3.5 KeV line at 95% C.L.

Ruchayskiy, Boyarsky+, 1512.07217

Null result from Draco is excludes the the 3.5 KeV line at 99% C.L.

Jeltema,Profumo, 1512.01239

Searches for Dark Matter Annihilation and Decays

Neutrino Lines

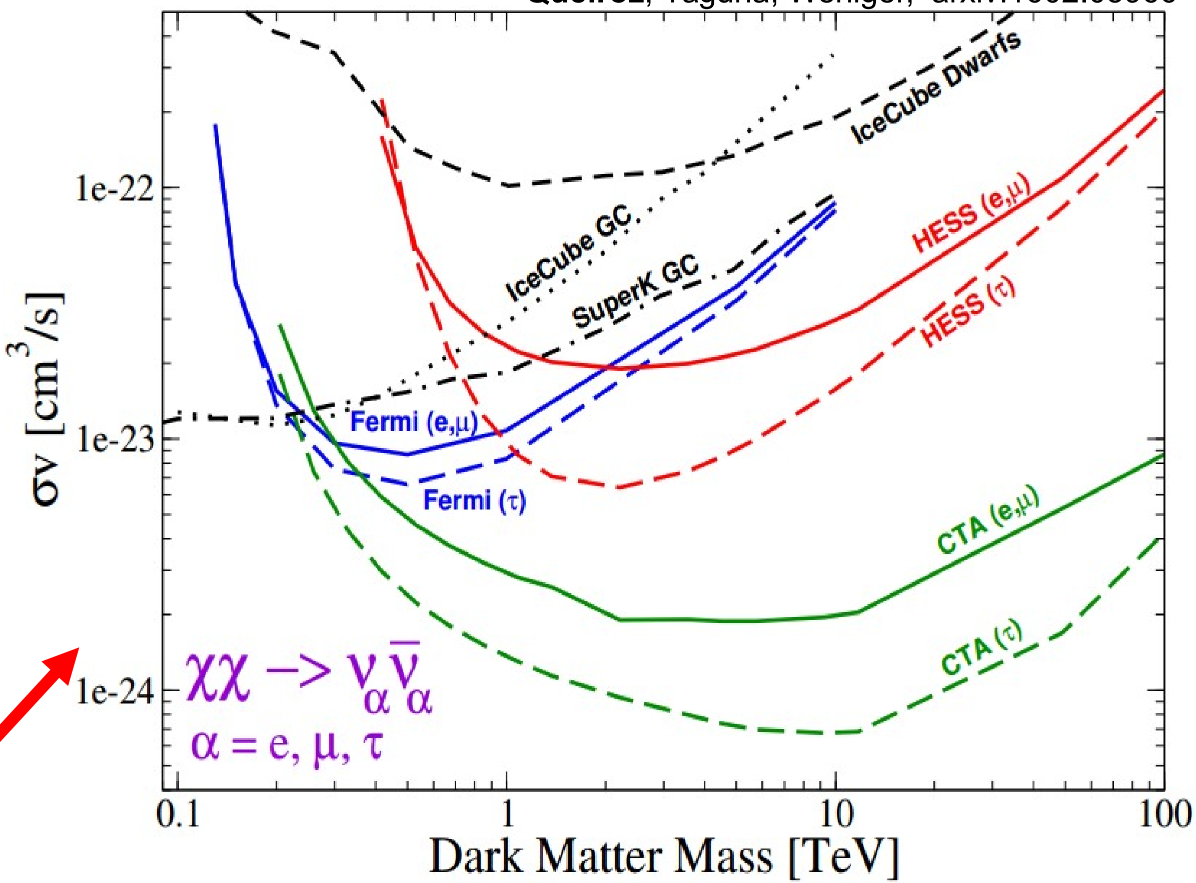
Neutrino telescopes have the advantage of being sensitive to both the WIMP-nucleus scattering and dark matter self-annihilation cross section.

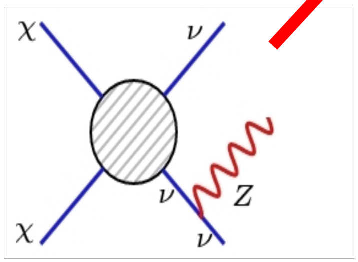
Several searches for neutrinos flavors from dark matter annihilations have been Conducted by Super-K, IceCube and ANTARES collab. as well as by independent groups.

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 see El Aisati et al,151005008; **(See her talk later today).**

Conclusions/Perspectives

1. Different targets present a similar gamma-ray excess: Reticulum-II, Subhalo, Galactic Center

2. The GeV gamma-ray excess at the galactic center might be resolved in 3-5 years

(Inclusion of recently discovered dwarf galaxies)

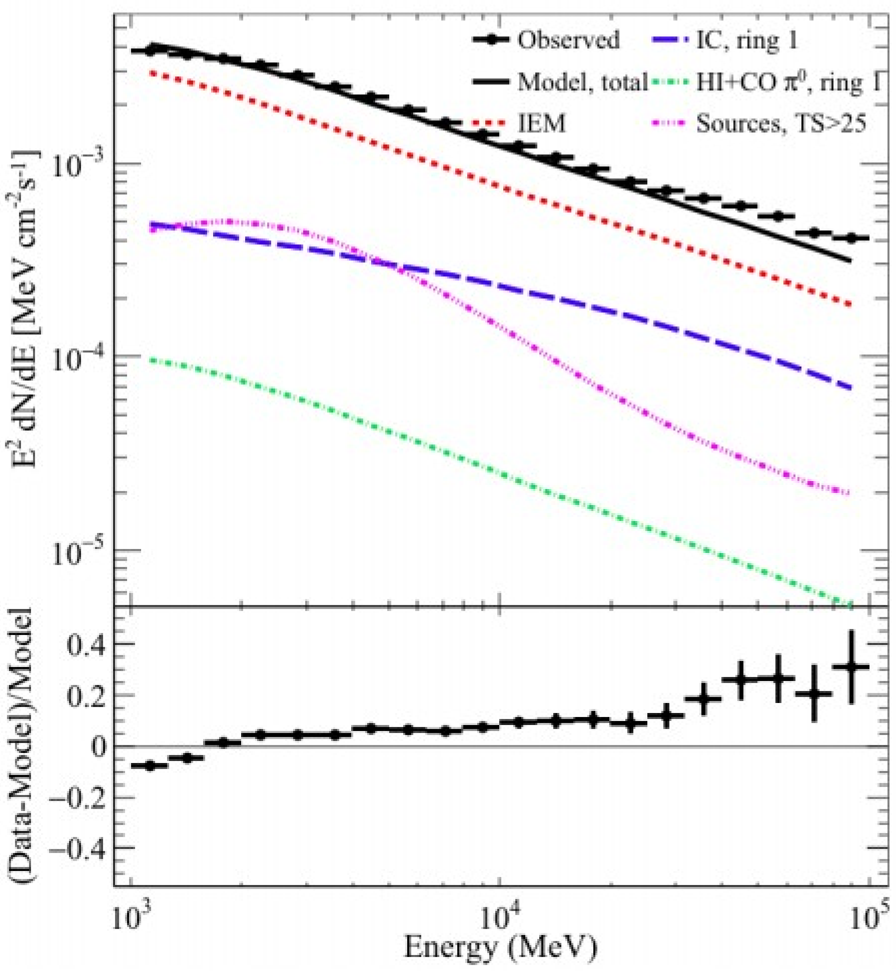
3. The KeV line excess should be clarified in 3-5 years

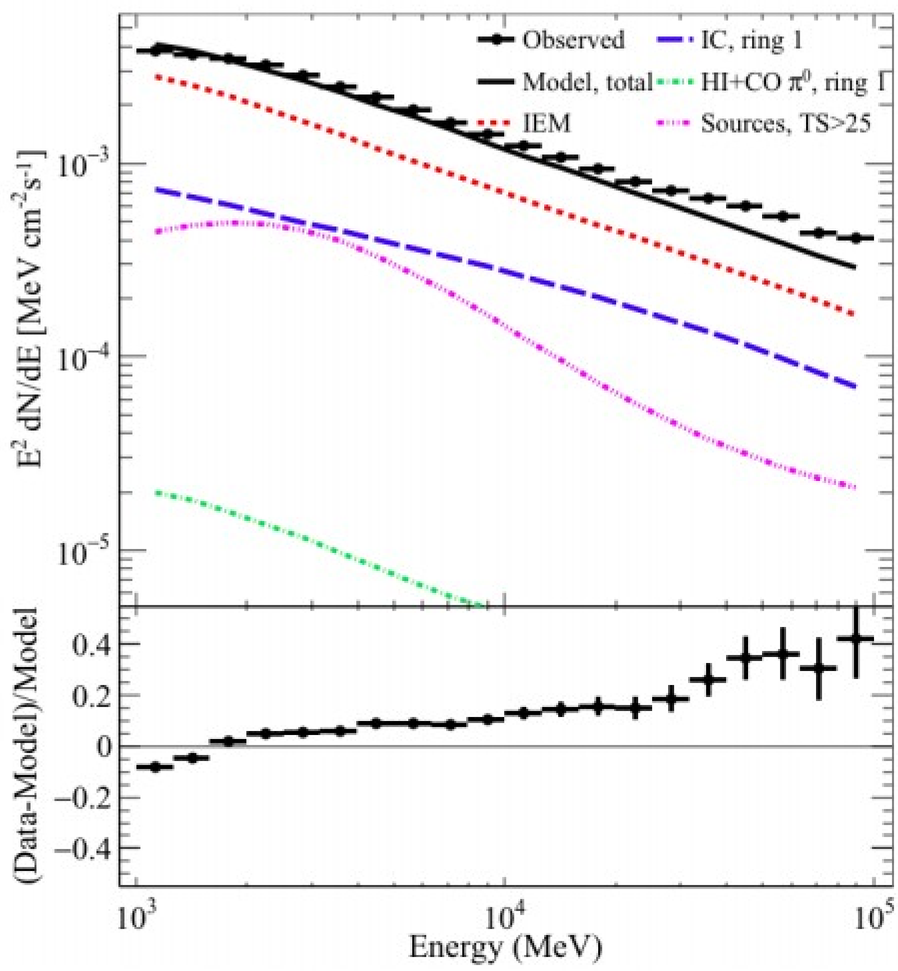
(Reticulum-II and improvement in the modeling of the 3.5 KeV line emissions)

4. New era where gamma-ray telescopes are more sensitive (comparable to) than neutrino detectors to neutrino lines from dark matter annihilation

(Inclusion of electroweak corrections and the improvement in sensitivity to gamma-rays)

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