DARK MATTER AND INDIRECT DETECTION IN COSMIC RAYS

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Centenary Symposium 2012: Discovery of Cosmic Rays
University of Denver, 27 June 2012

COSMIC RAYS CENTENARY

- At this symposium, we are celebrating 100 years of cosmic rays and looking forward to the future

- As has been recounted, the early years were a glorious period, in part because cosmic rays contributed to the birth of particle physics through the discovery of the positron, muon, and pion

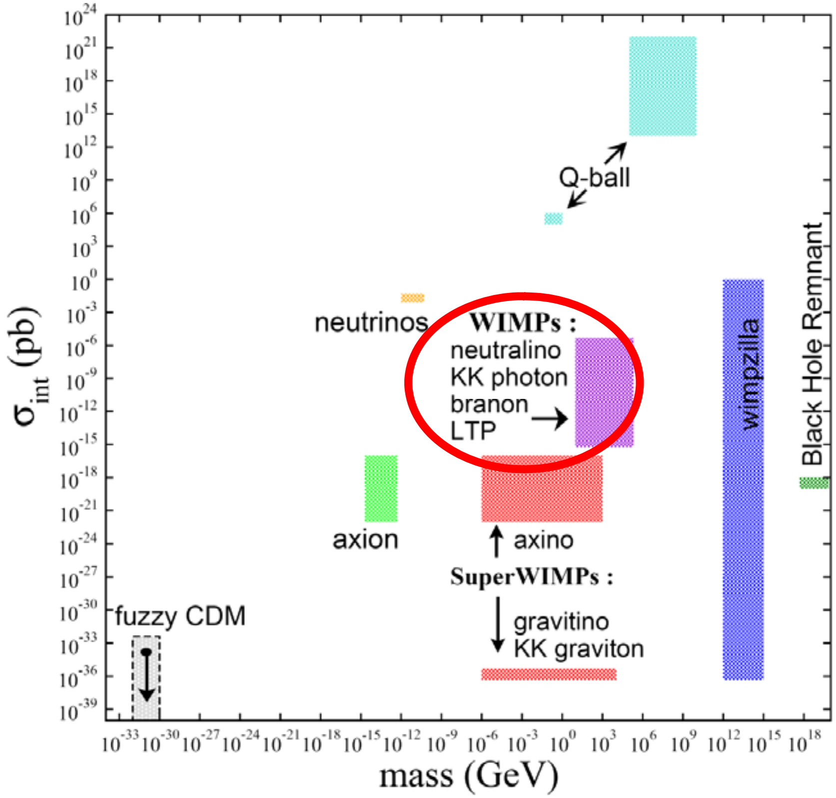
WILL HISTORY REPEAT ITSELF?

- Strong nuclear force
  - 1935: Yukawa postulates a new mass scale ~ 100 MeV
  - 1947: A boson is discovered with this mass, associated with broken (global) symmetry: the charged pion
  - Next 20 years: Many accompanying particles are discovered and studied in both cosmic rays and particle accelerators

- Weak nuclear force
  - 1930's: Fermi postulates a new mass scale ~ 100 GeV
  - 2012: A boson is discovered with this mass, associated with broken (gauge) symmetry: the Higgs boson
  - Next 20 years: Many accompanying particles are discovered and studied in both cosmic rays and particle accelerators

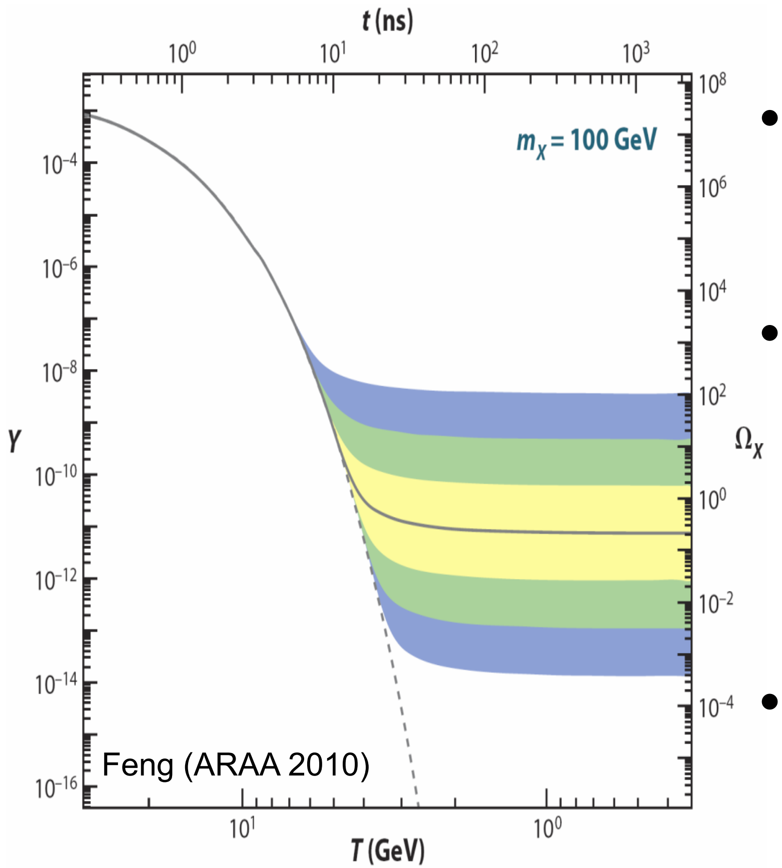
DARK MATTER

- Is this just wishful thinking?
- Higgs discovery √
- Accompanying particles: so far, all attempts (supersymmetry, extra dimensions, …) to explain the weak scale have these
- A further reason for optimism is provided by dark matter
- There are many dark matter candidates, but particles with mass ~ 100 GeV have a privileged position



HEPAP/AAAC DMSAG Subpanel (2007)

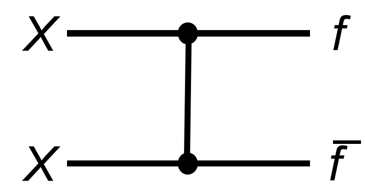
THE WIMP MIRACLE



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

- Its relic density is

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

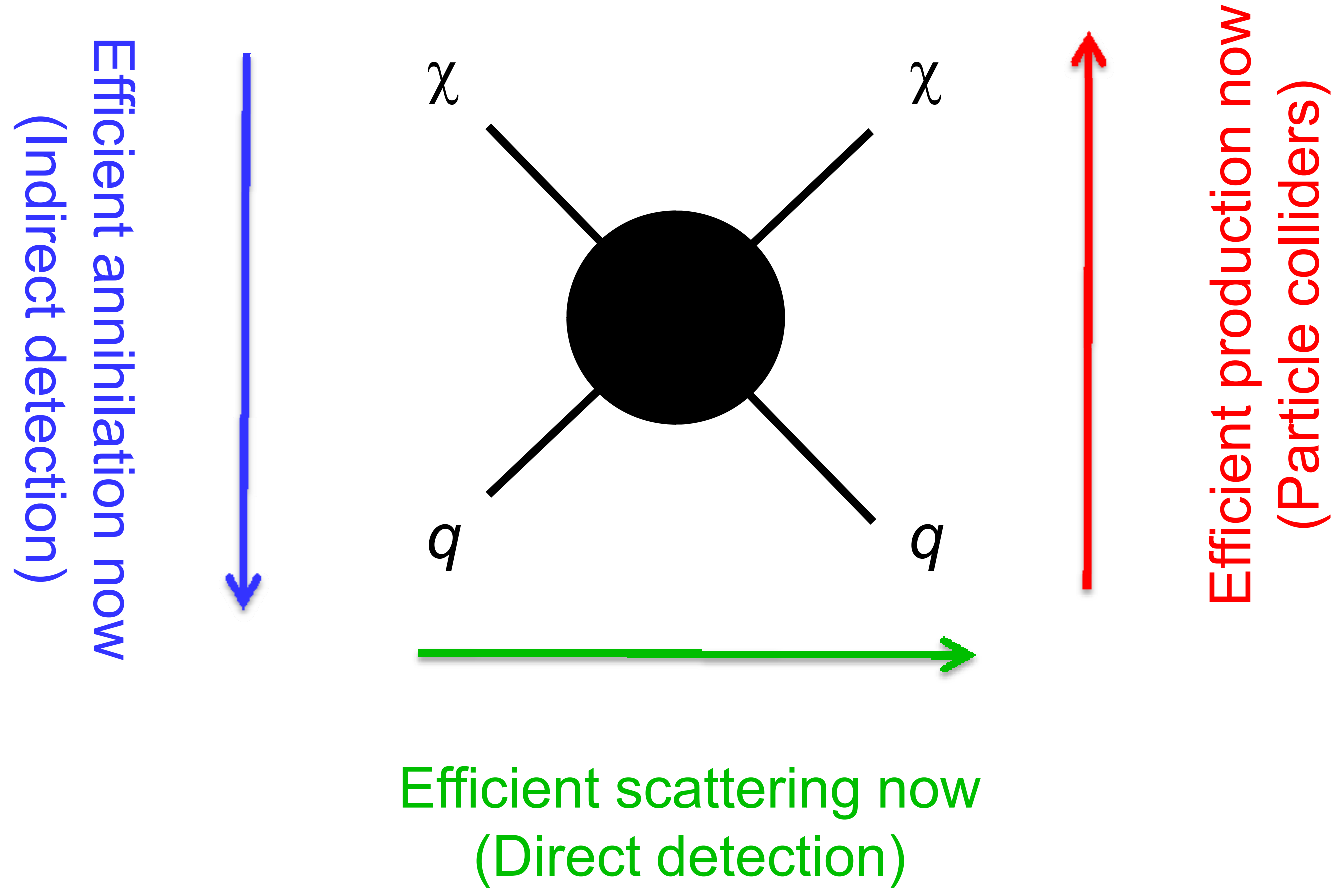


- $m_X \sim 100$ GeV, $g_X \sim 0.6 \rightarrow \Omega_X \sim 0.1$

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

WIMP DETECTION

The correct relic density implies efficient dark matter-normal matter interactions and provides targets for experiments



INDIRECT DETECTION

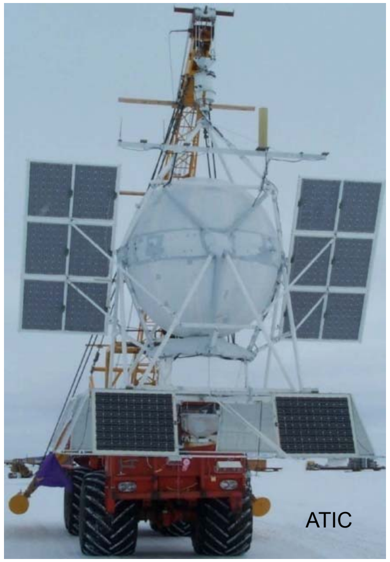
Dark Matter Madlibs!

Dark matter annihilates in ___________________ to
a place

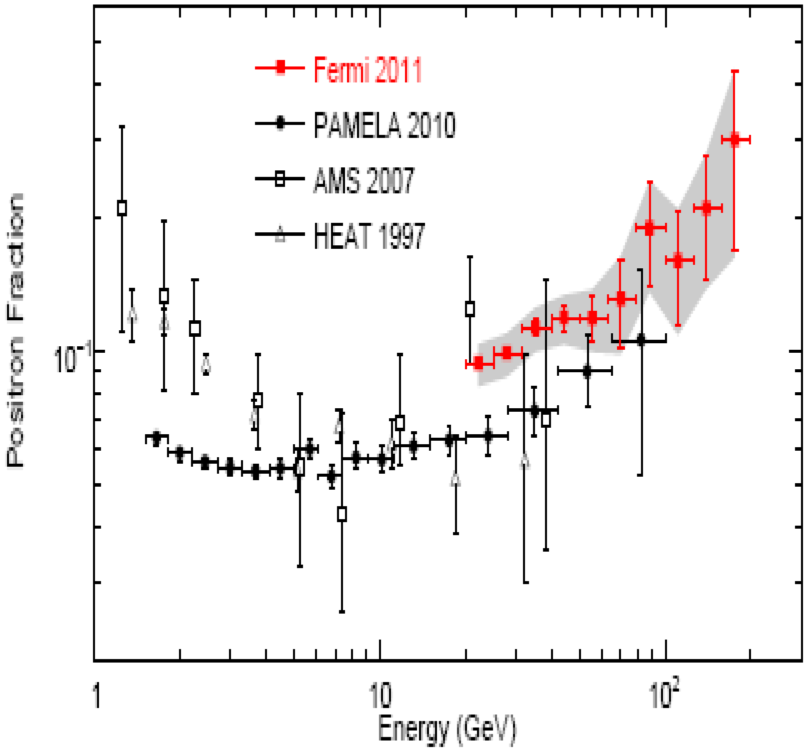
____________ , which are detected by _______________ .
particles an experiment

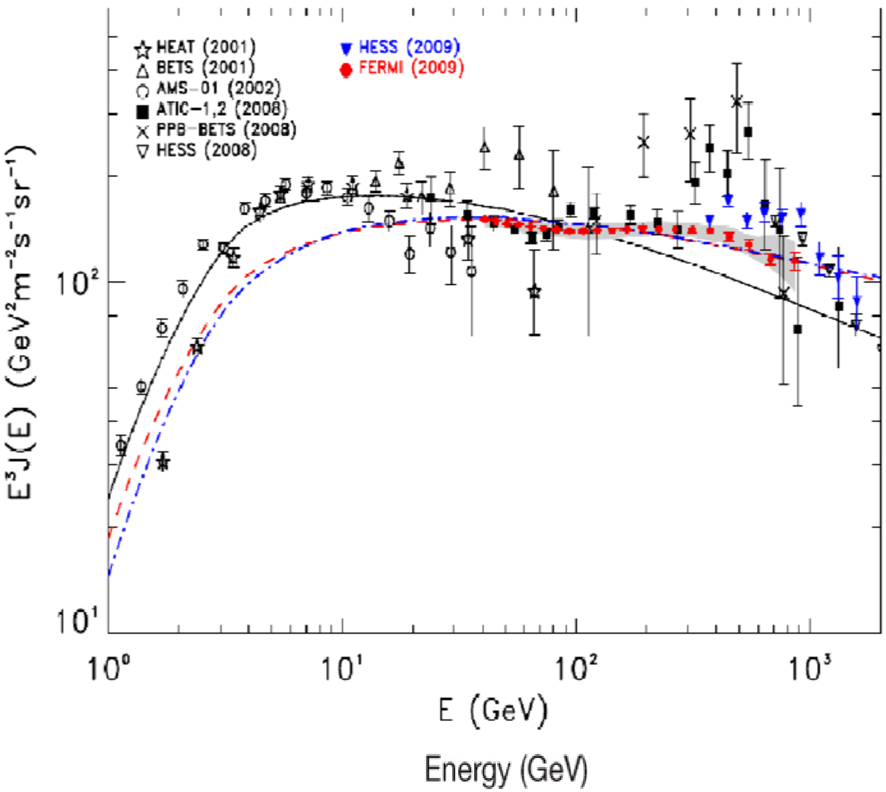
A SMALL SAMPLE OF THE MANY POSSIBILITIES:

Dark Matter annihilates in the halo (a place) to positrons (some particles), which are detected by PAMELA/ATIC/Fermi… (an experiment).



POSITRON SIGNALS





Solid lines are the astrophysical bkgd from GALPROP (Moskalenko, Strong)

ARE THESE DARK MATTER?

- Energy spectrum shape consistent with WIMPs; e.g., Kaluza-Klein dark matter

Cheng, Feng, Matchev (2002); Servant, Tait (2002)

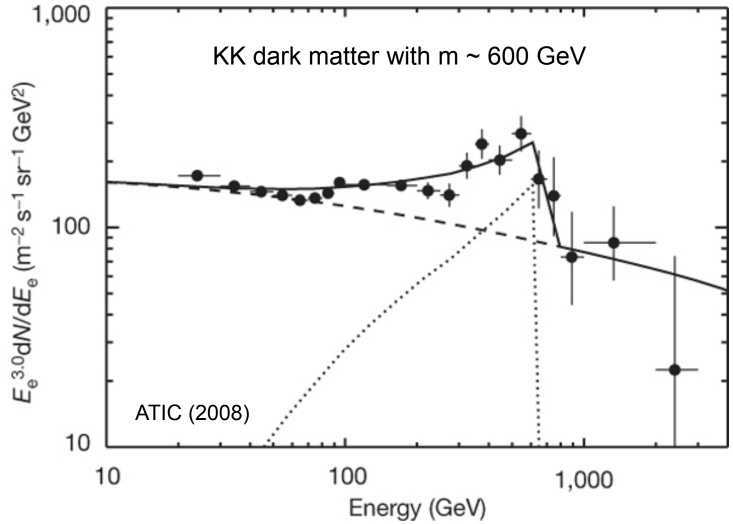
- Flux is a factor of 100-1000 too big for a thermal relic; requires
  - Enhancement from particle physics
  - Alternative production mechanism

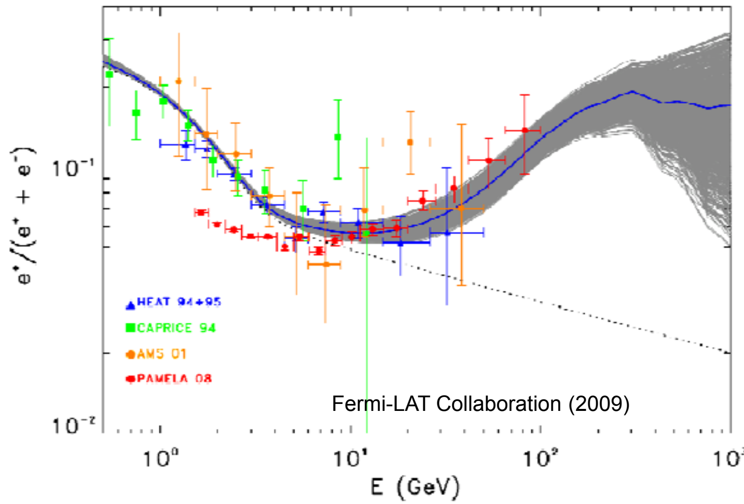
Cirelli, Kadastik, Raidal, Strumia (2008)
Arkani-Hamed, Finkbeiner, Slatyer, Weiner (2008)
Feldman, Liu, Nath (2008); Ibe, Murayama, Yanagida (2008)
Guo, Wu (2009); Arvanitaki et al. (2008)

- Pulsars can explain PAMELA

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

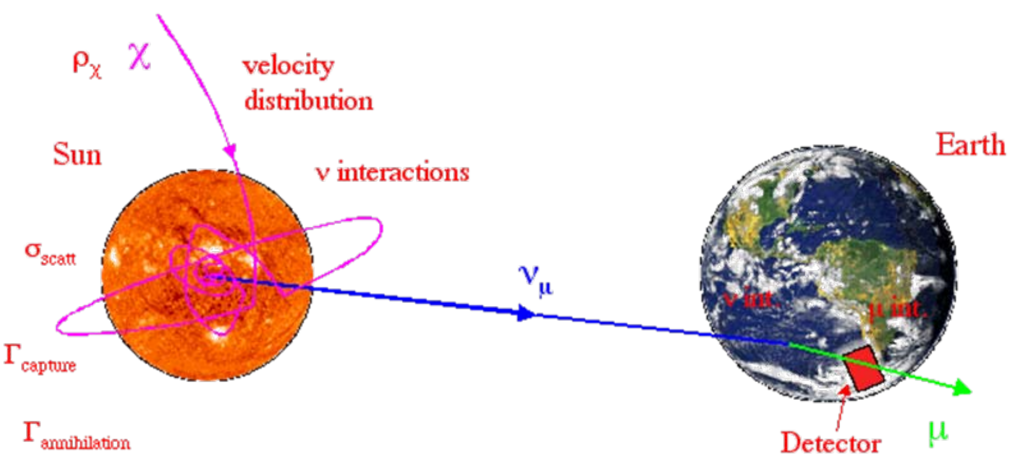
- Future: AMS, …

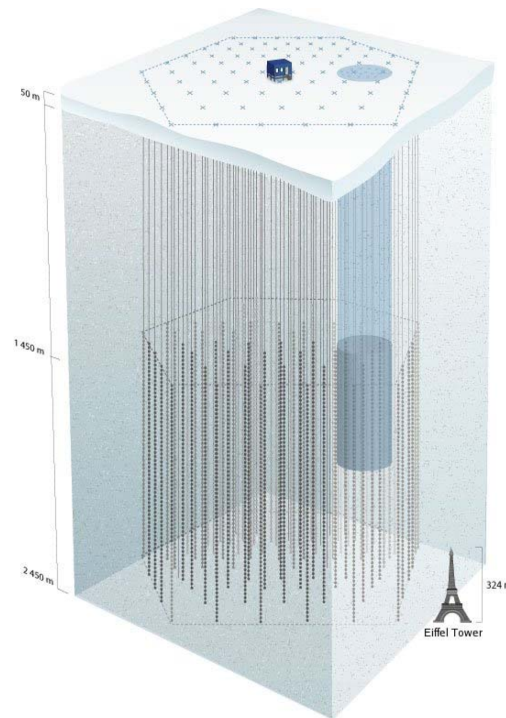




Dark Matter annihilates in __the center of the Sun__ to
a place

__neutrinos__ , which are detected by ______IceCube______ .
some particles an experiment



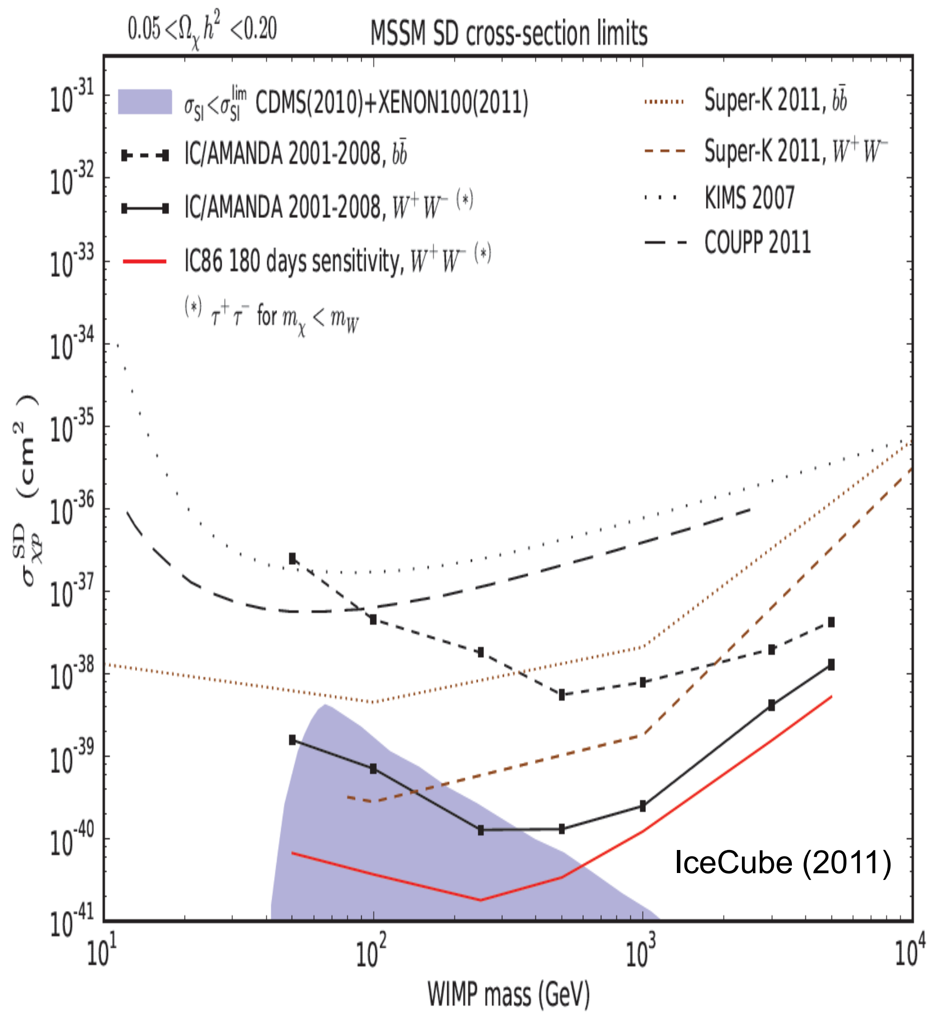


NEUTRINO SIGNALS

- If the Sun is in equilibrium, scattering (direct detection) and annihilation (indirect detection) are related

$$\frac{dN}{dt} = C - C_A N^2$$

- Indirect detection surpasses direct detection for spin-dependent scattering, is beginning to probe viable theoretical models



Dark Matter annihilates in __GC, dwarf galaxies__ to
a place

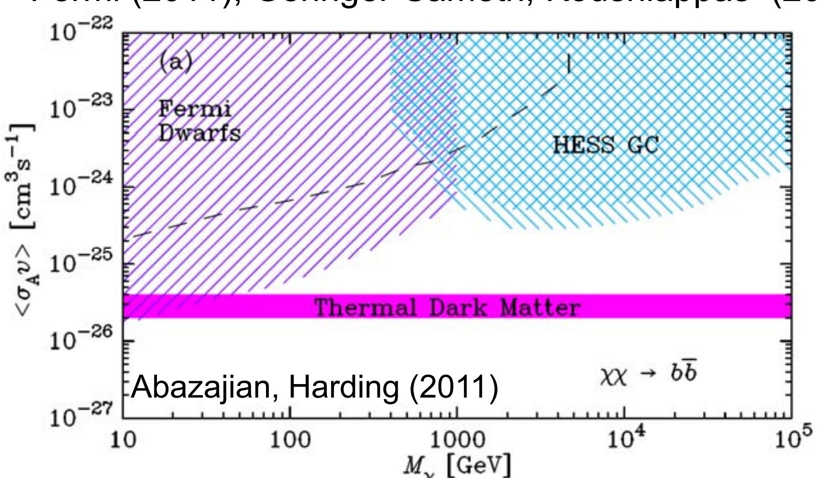
__photons__ , which are detected by __Fermi, HESS, VERITAS, …__
some particles an experiment

GAMMA RAY SIGNALS

- Continuum: $X\,X \rightarrow f\,f \rightarrow \gamma$
- For some annihilation channels, bounds exclude light thermal relics

$$\frac{d\Phi_\gamma}{d\Omega dE} = \sum_i \underbrace{\frac{dN_\gamma^i}{dE}\sigma_i v \frac{1}{4\pi m_\chi^2}}_{\text{Particle Physics}} \underbrace{\int_\psi \rho^2 dl}_{\text{Astro-Physics}}$$

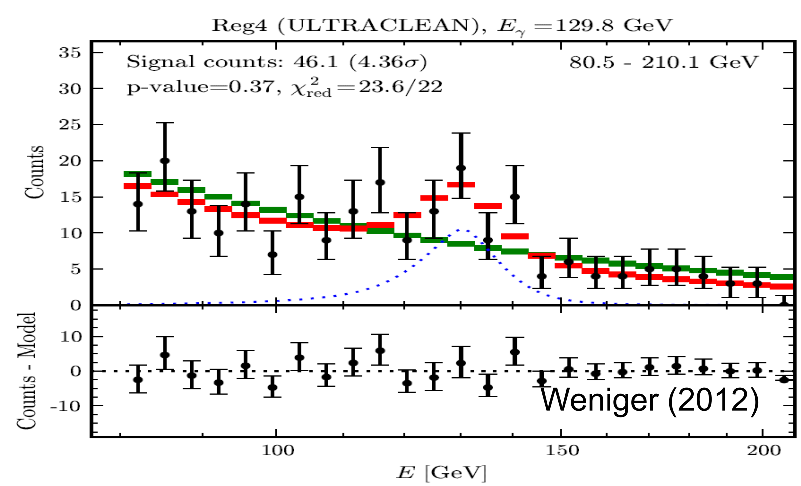
Fermi (2011); Geringer-Sameth, Koushiappas (2011)



- Lines: $X\,X \rightarrow \gamma\gamma$, γZ (loop-level)
- Great current interest: 3-5σ signal at E_γ =130 GeV, $\langle\sigma v\rangle = 1{\cdot}10^{-27}$ cm^3/s

Weniger (2012); Tempel, Hektor, Raidal (2012); Rajaraman, Tait, Whiteson (2012); Su, Finkbeiner (2012); …

Future: HAWC, CTA, GAMMA-400, CALET, …



CONCLUSIONS

- Dark matter candidates at the weak scale are promising, and indirect detection is becoming sensitive to them
- Rapid progress on many fronts
  - indirect detection (including many topics not covered here)
  - direct detection
  - Large Hadron Collider
- Cosmic ray history (over-simplified)
  - Early period: cosmic rays → particle physics
  - Later period: cosmic rays ← particle physics
  - The arrow may become ←→ in the near future

THE NEAR FUTURE: "SNOWMASS" 2013

Groups

- All
- Energy Frontier
- Intensity Frontier
- Cosmic Frontier
- Frontier Facilities
- Instrumentation Frontier
- Computing Frontier
- Education and Outreach

Google Search

www.snowmass2013.org

WWW

Cosmic Frontier

Conveners: Jonathan Feng (UC Irvine), Steve Ritz (UC Santa Cruz)

ANNOUNCEMENTS

June 20, 2012: We are currently soliciting community input for subgroup conveners, topics, and experiments (see below).

CHARGE

The Cosmic Frontier working group is charged with summarizing the current state of knowledge and identifying the most promising future opportunities at the interface of particle physics, astrophysics, and cosmology. Topics include dark matter, dark energy, the matter--anti-matter asymmetry, cosmic particles, and astrophysical probes of fundamental physics.

ORGANIZATION

The work of the Cosmic Frontier is divided into 6 subgroups:

- CF1: WIMP Dark Matter Direct Detection
- CF2: WIMP Dark Matter Indirect Detection
- CF3: Non-WIMP Dark Matter
- CF4: Dark Matter Complementarity
- CF5: Dark Energy and CMB
- CF6: Cosmic Particle Probes of Fundamental Physics

Cosmic rays are central to at least CF2 and CF6. This is a critical time – all community input welcome!