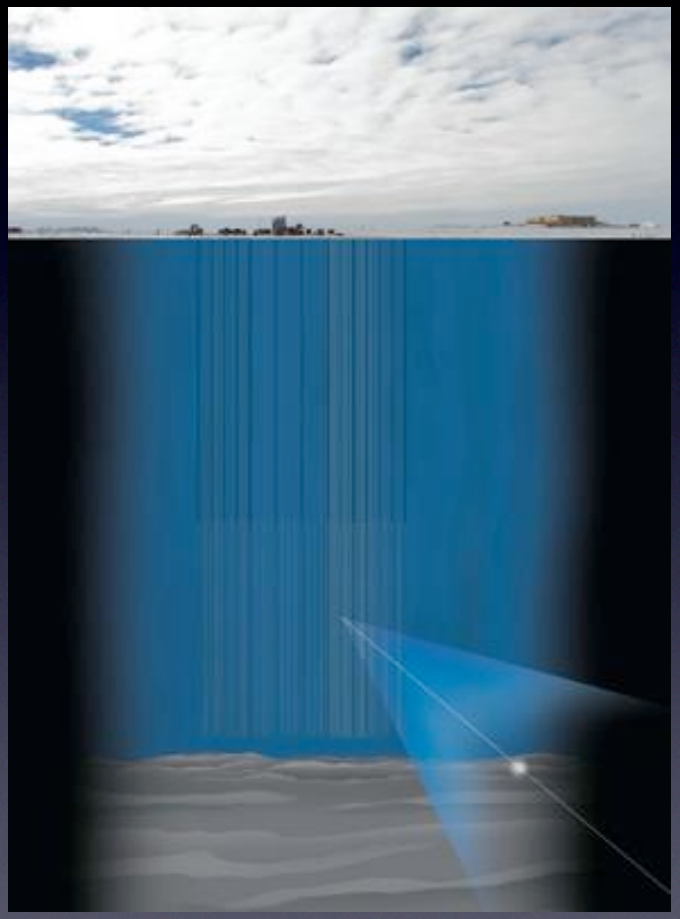
Neutrinos and DM (Galactic)
Deep Core prospects



ArXiv:0905.4764

ArXiv:0907.238

ArXiv: 0911.5188

ArXiv:0912.0512

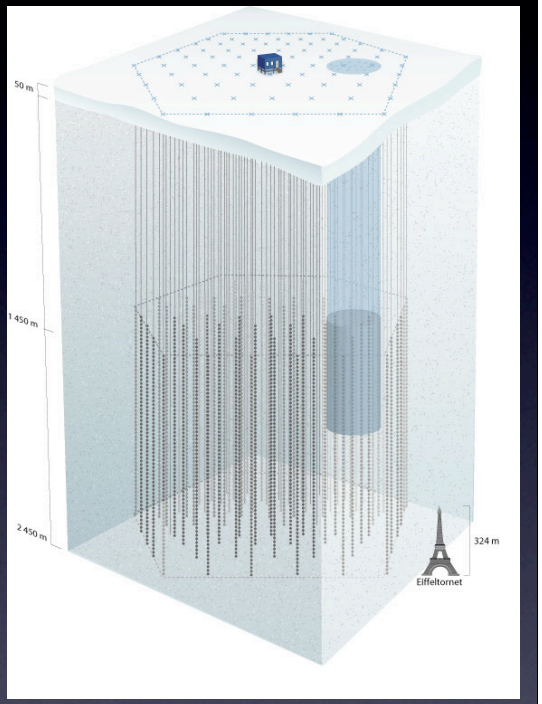
Matt Buckley, Katherine Freese, Dan Hooper, Sourav K. Mandal, Hitoshi Murayama, and Pearl Sandick

Basic Result

- If the electron excess seen by Fermi is DUE TO DM annihilation going leptonic final states $\mu^+\mu^-, \tau^+\tau^-, \text{etc...}$
  - 5+5: ICECUBE will see a 5 σ excess of neutrinos from toward the Galactic center in 5 years
- If we DON'T see any excess neutrinos
  - 2+5: ICECUBE can constrain Leptonic DM as an explanation of Pamela at 2 σ in 5 years
- Even better with some branching fraction directly to neutrinos

Outline

- DM Introduction
- IceCube
  - neutrino as a new handle
    - Galactic Center



Dark Matter
Good news

Don't Need to invent new particles which exist for other reasons

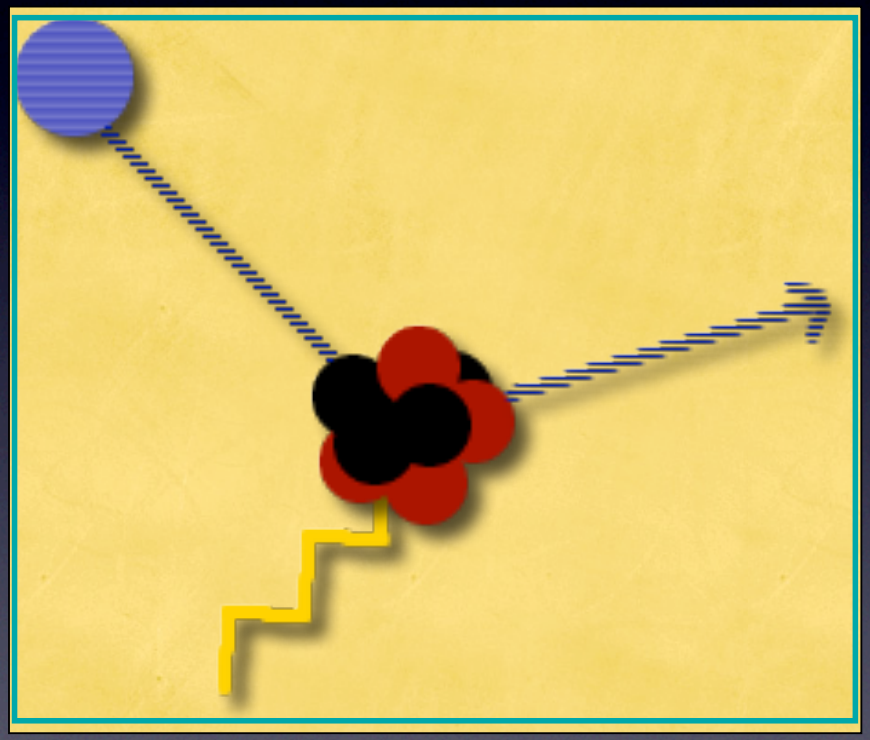
- Weakly Interacting Massive Particles WIMPs
  - e.g. the neutralino (LSP SUSY)
  - Automatically Get the Right Relic Density


Looking For DM
LHC-Making DM
?

Direct Detection Experiments

A WIMP in the Galaxy travels through our detectors. It hits a nucleus, and deposits a tiny amount of energy. The nucleus recoils, and we detect this energy deposit.

WIMP/NUCLEUS SCATTERING



Indirect Detection WIMP Annihilation

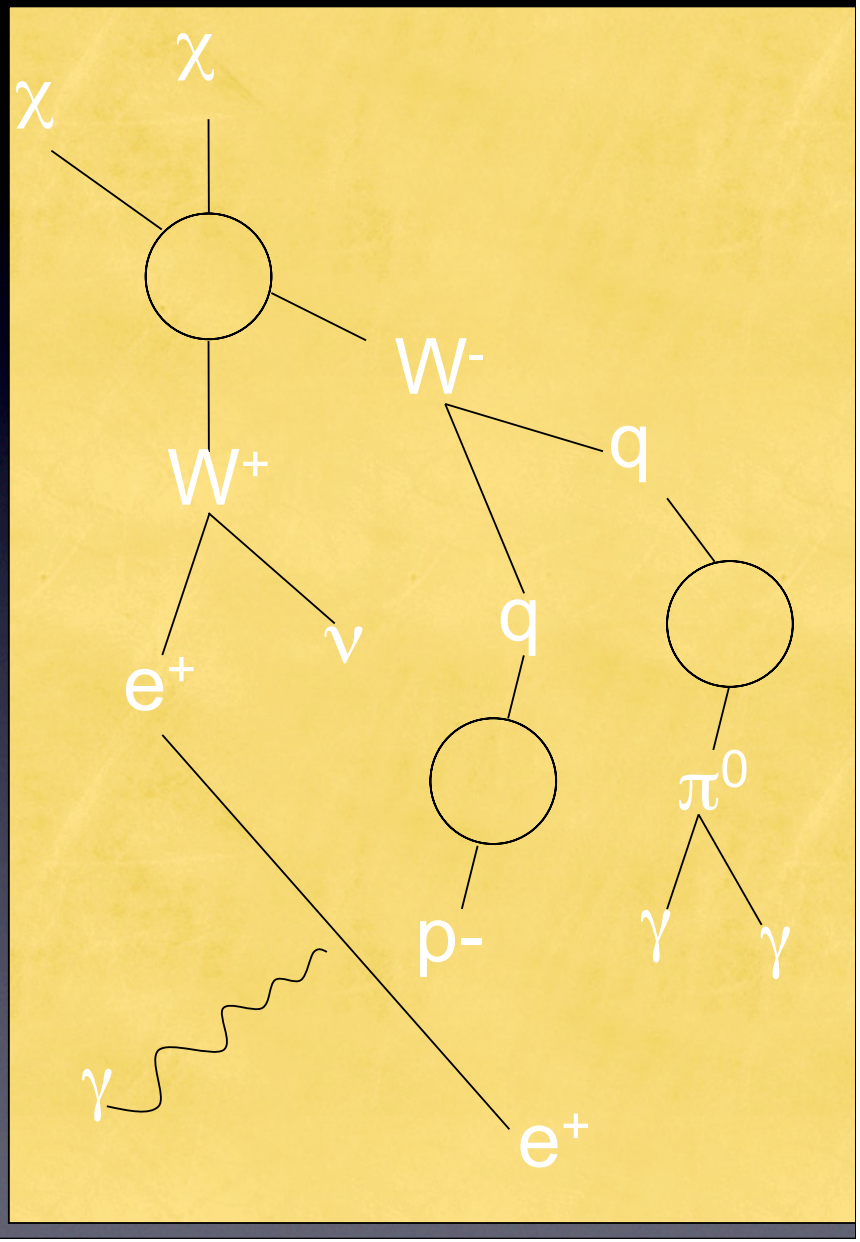
- **WIMP Annihilation**
  Typical final states include heavy fermions, gauge or Higgs Bosons

1. Fragment / Decay

Annihilation products decay and/ or fragment into combinations of electrons, protons, deuterium, neutrinos and gamma-rays

2. Synchrotron and Inverse Compton

Relativistic electrons up-scatter starlight/CMB to MeV-GeV energies, and emit synchrotron photons via interactions with magnetic fields



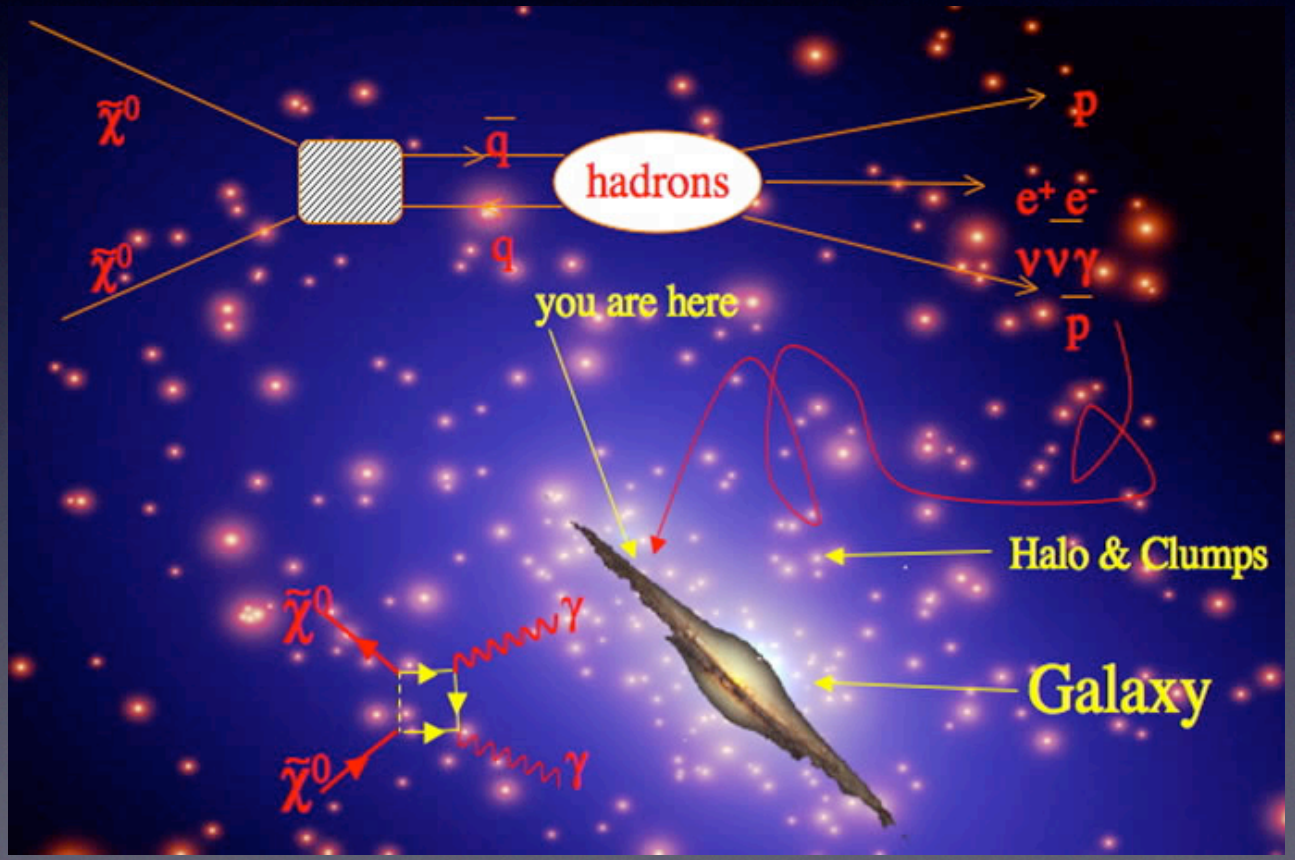
Many anomalous signals: WIMP dark matter detection? how can we be sure?

- The DAMA annual modulation
  - (direct detection experiment in Gran Sasso tunnel)
- CoGeNT….CDMS…. Crest.....
- The HEAT, Fermi, PAMELA positron excess
  - (is it WIMP annihilation?)
- INTEGRAL 511 KeV line
- WMAP/Fermi Haze

HAS DARK MATTER BEEN DISCOVERED?

Cosmic Rays

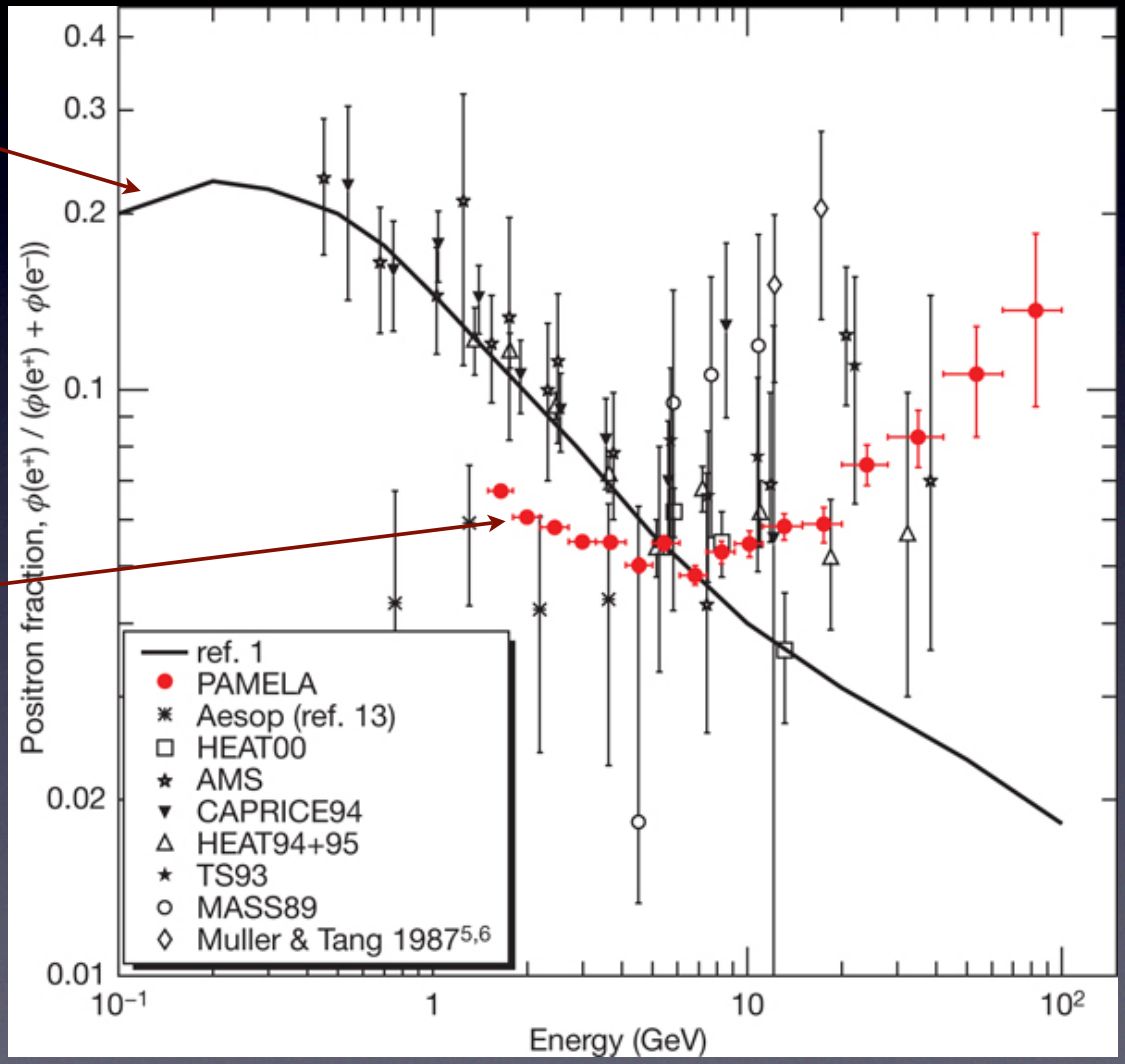
produced from SuperNova, Pulsars, (DM), etc



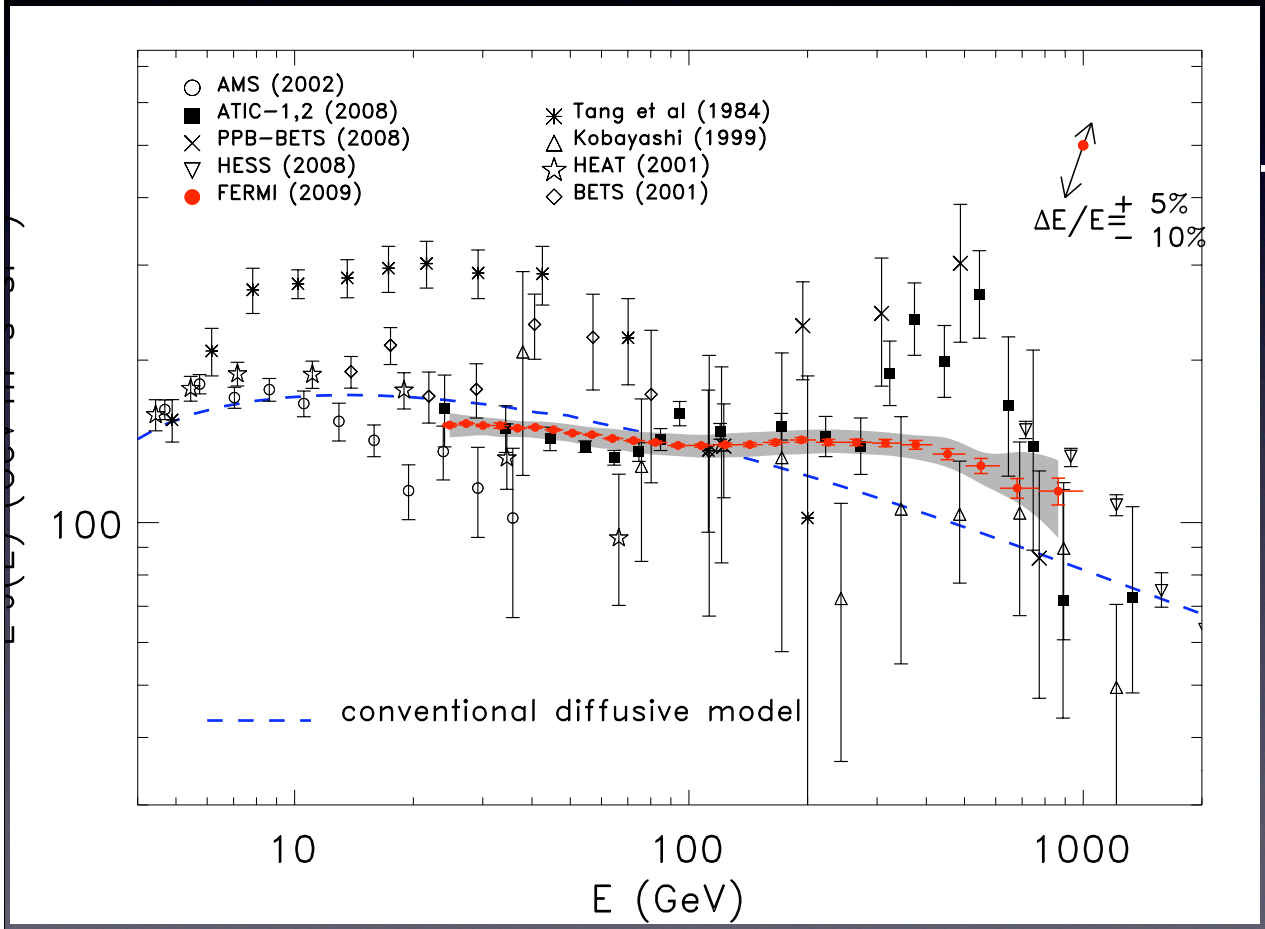
PAMELA Excess

GALPROP

PAMELA



Fermi Excess



Too many electrons and positrons versus too many positrons with PAMELA

Explanations

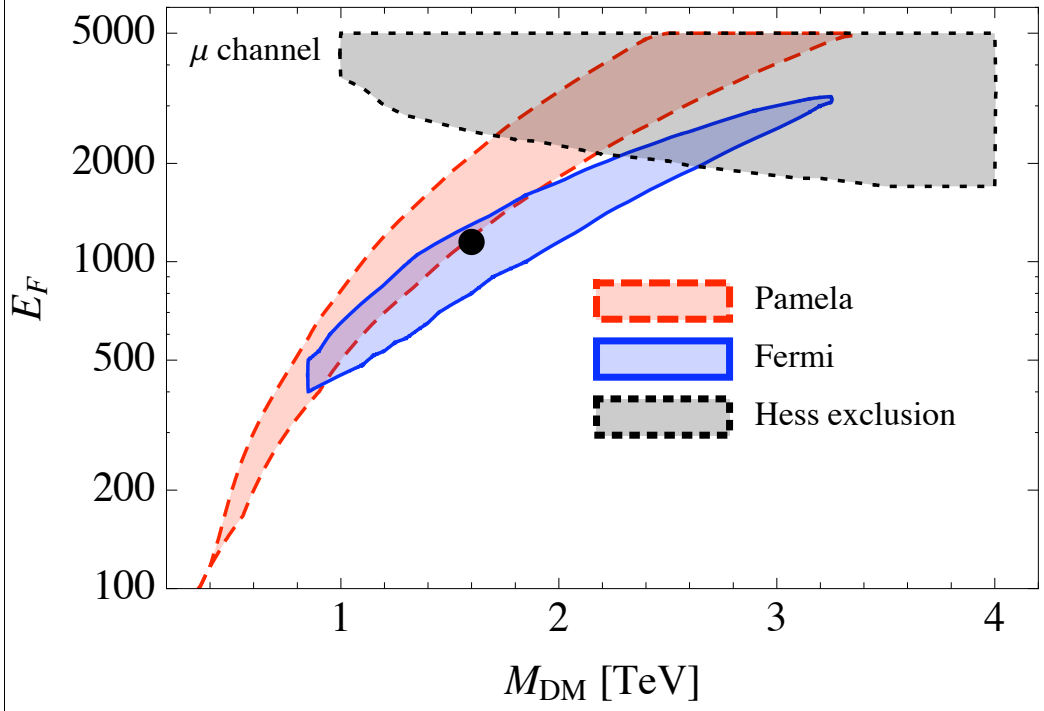
- Astrophysical (S. Profumo)
  - Super Nova and Pulsars
- GALPROP is wrong
  - Different diffusion coefficient etc.
- DM Annihilation Provides the source

DM properties

- Boosted Signal

1. Enhanced Annihilation cross-section over the relic annihilation cross-section
   - Sommerfeld Enhancement
     - quantum mechanical analog of gravitational focusing
   - Breit-Wigner enhancement
     - Resonance effect

Explain Pamela/Fermi



$$\mu^+\mu^-$$

- not dependent upon profile
- assume Isothermal Sphere
- Fit Pamela and Fermi Data annihilation directly to neutrinos

$$E_F = \left(\frac{\rho_0}{0.3\ \mathrm{GeV\,cm^{-3}}}\right)^2 \left(\frac{\tau_0}{10^{16}\ \mathrm{s\,GeV^{-2}}}\right) B_F$$

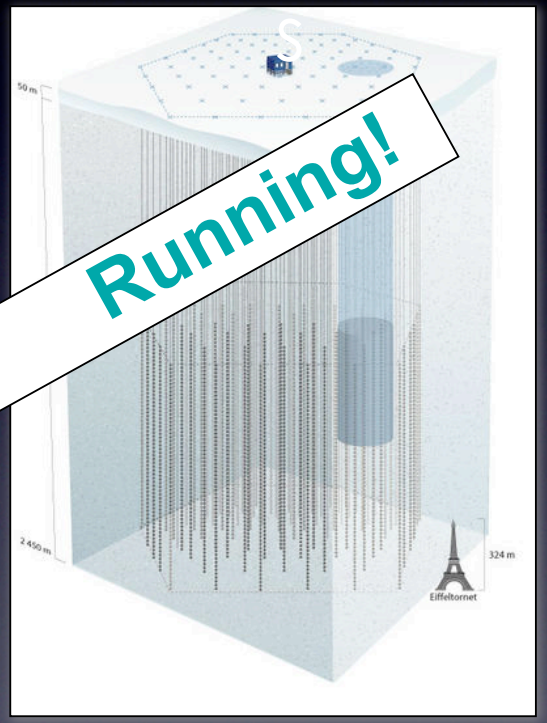
New Indirect Detection Results!

(When it rains it pours)

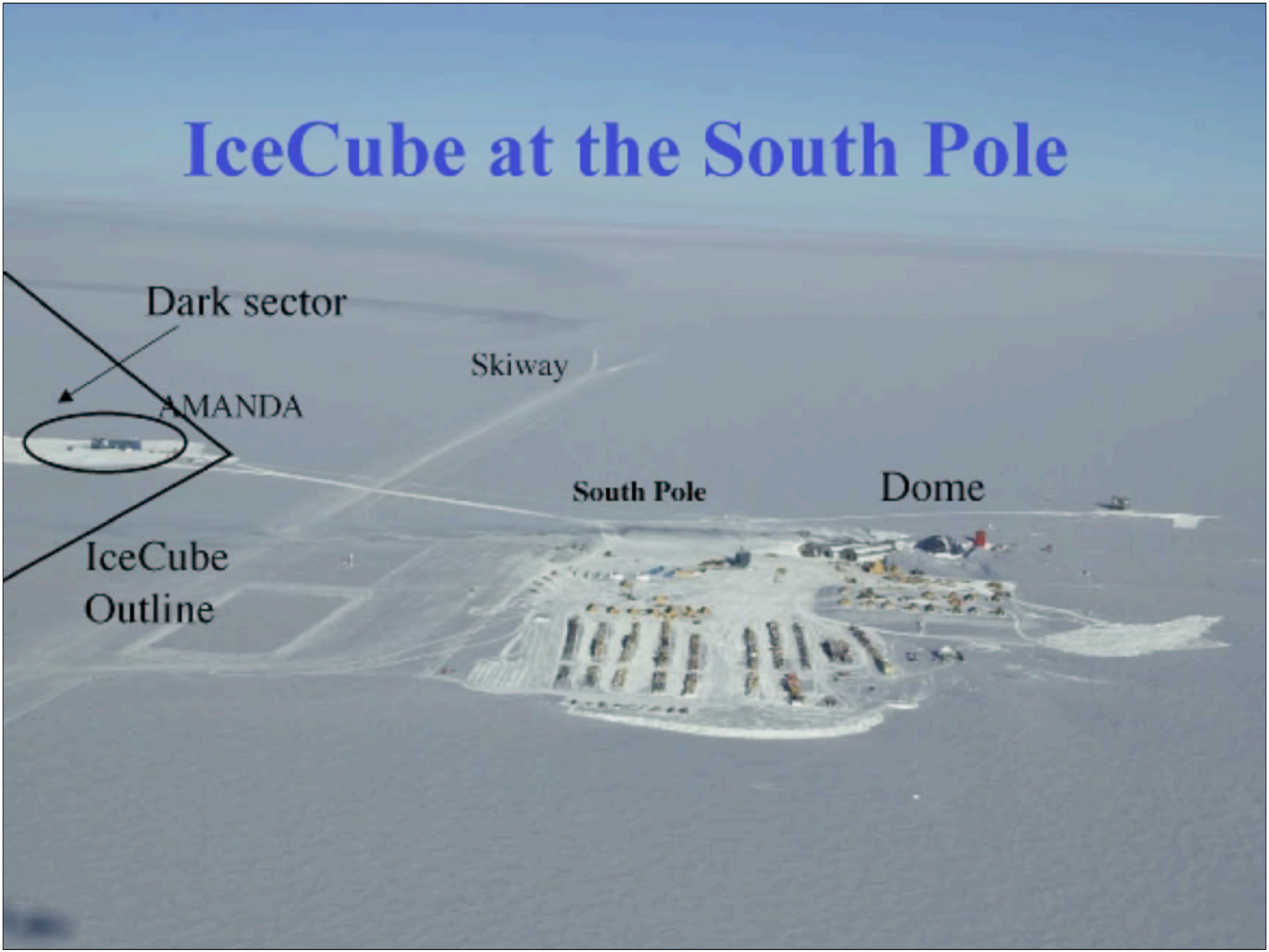
AMS positrons

Fermi

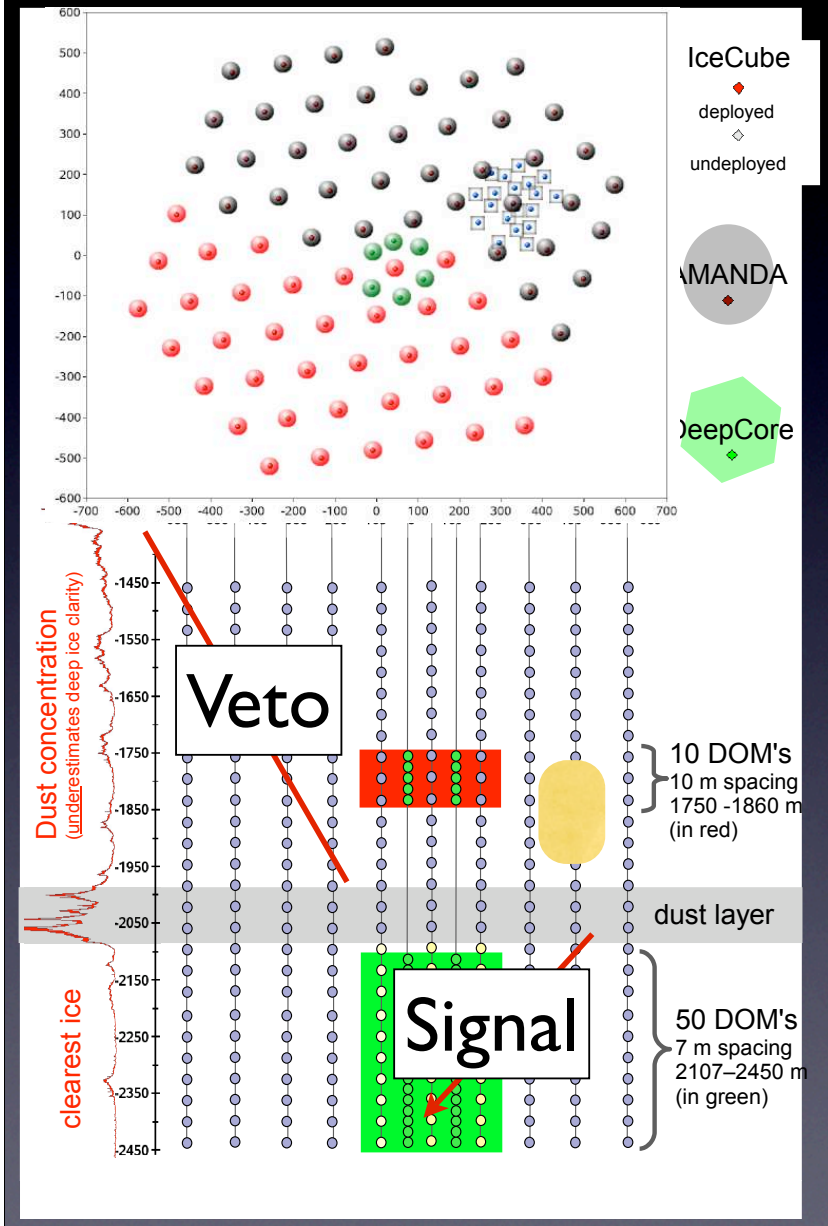
IceCube neutrino



Looking for Dark matter annihilation


IceCube at the South Pole
Dark sector
Skiway
AMANDA
South Pole
Dome
IceCube
Outline

IceCube + Deep Core



String Space	Bead Spacing
IceCube 125m	IceCube 17m
DeepCore 72m	DeepCore 7m

Look for
signal from the galactic Center

Use IceCube as a Veto

Poor angular resolution 30-50 degrees
1-10TeV (unclear at lower energies)
take resolution to be 1/2 of the Sky (conservative)

Neutrinos Signal Galactic Center From DM Annihilation

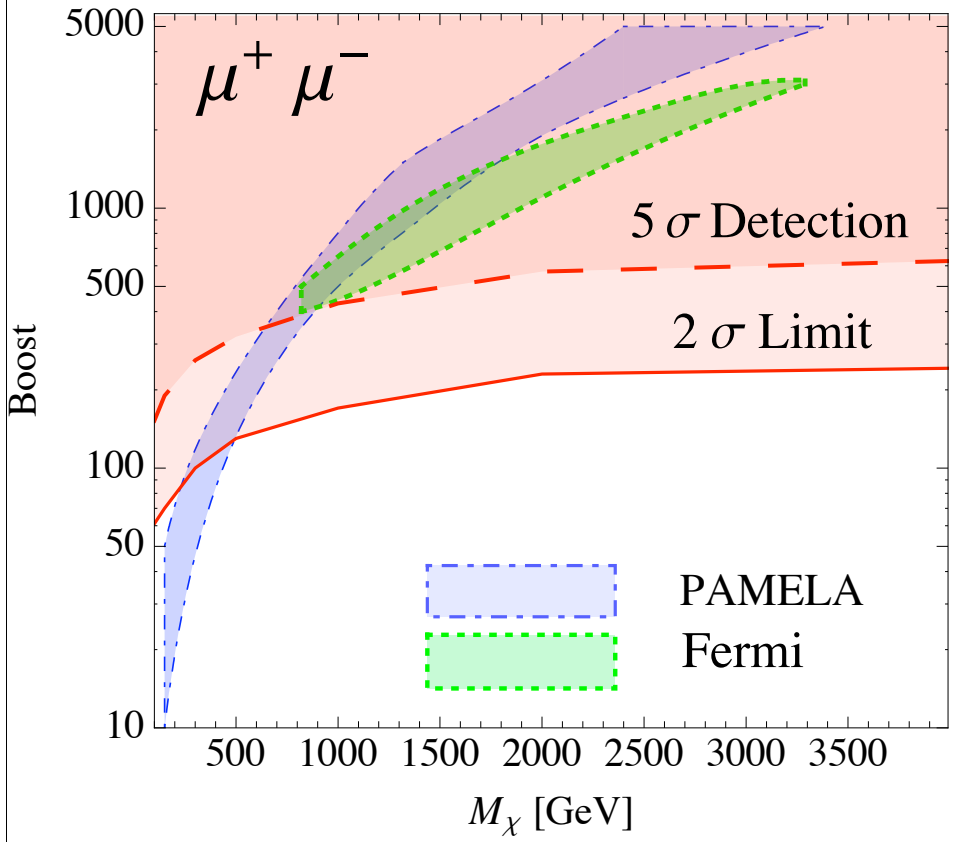
Signal

$$\frac{d\Phi(\Delta\Omega, E)}{dE} = \frac{B}{8\pi} \frac{\langle \sigma v \rangle}{m_\chi^2} \sum_j f_j \frac{dN_\nu^j}{dE} \times \bar{J}(\Delta\Omega)\Delta\Omega$$

Particle Physics

Astrophysics

Neutrino Bounds



- 5 years of Data
- assume NFW profile
  - similar to Isothermal sphere factor of 2 smaller
- no Substructure (additional boost of 2)

Bounds calculated with poisson statistics assuming a few sigma excess over background

Calculate background with Honda etal 2006

PAMELA positron excess

May also be an indication that DM species **decay** in the MW.

$$\Gamma_{\rm ann} \equiv \langle \sigma v \rangle \times \frac{\rho_\chi^2}{m_\chi^2} \Rightarrow \Gamma_{\rm ann} \equiv \Gamma_{\rm dec} \times \frac{\rho_\chi}{m_\chi}$$

$$\langle \sigma v \rangle = 3 \times 10^{-23}\ {\rm cm}^3\ {\rm s}^{-1},\ \rho_\odot = 0.3\ {\rm GeV\ cm}^{-3}\ \&\ m_\chi = 1\ {\rm TeV}$$

$$\Downarrow$$

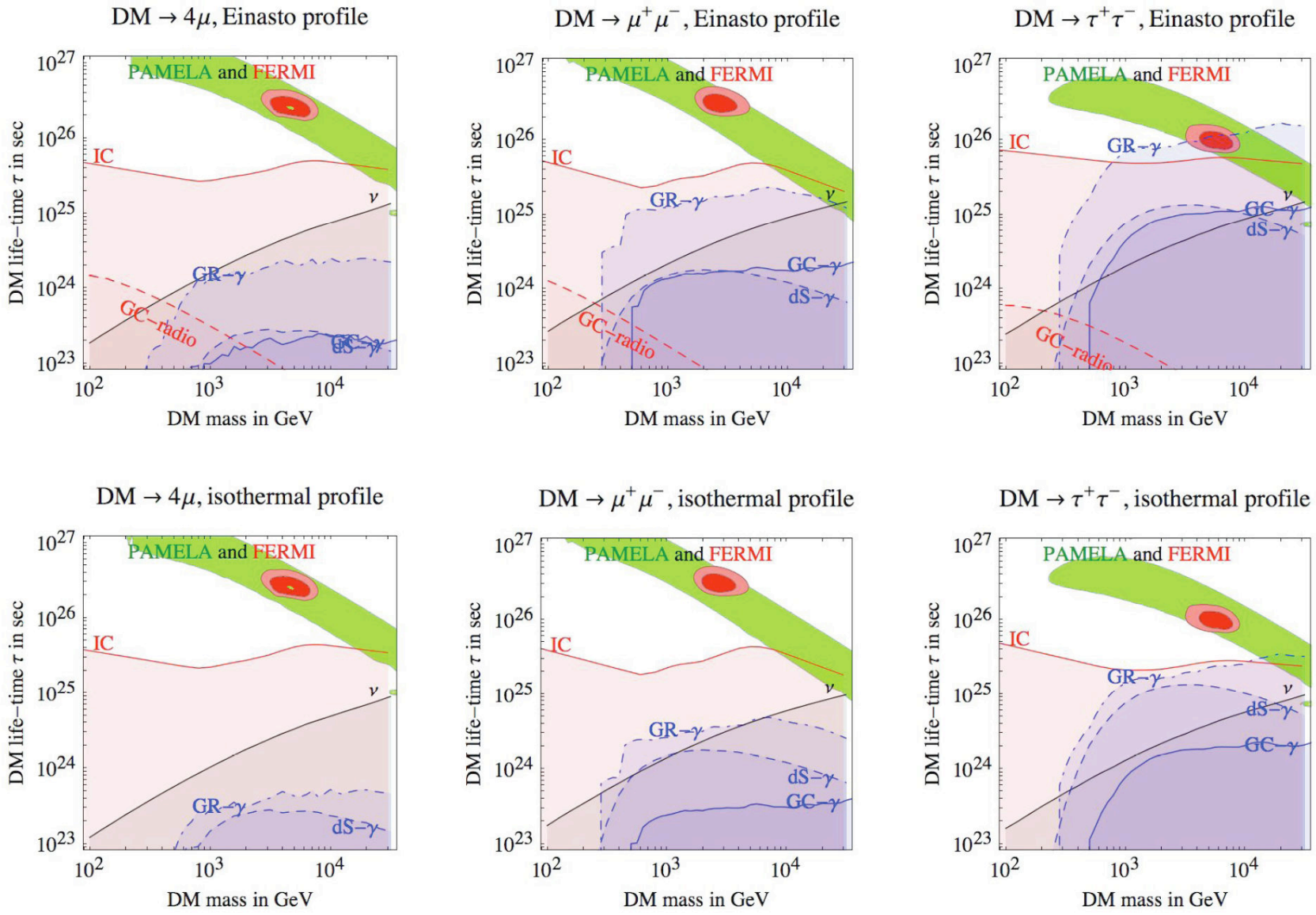
$$\Gamma_{\rm dec} \sim 10^{-26}\ {\rm s}^{-1}$$

4) Decaying dark matter

- Decaying DM species still pass the astrophysical tests since $\Gamma_{\rm ann} \propto \rho_\chi$.
- The lifetime needs to be fine–tuned though.
- Why is it so large – dimension 5 or 6 operators ?
- FERMI should be able to detect the ICS WIMP signal.

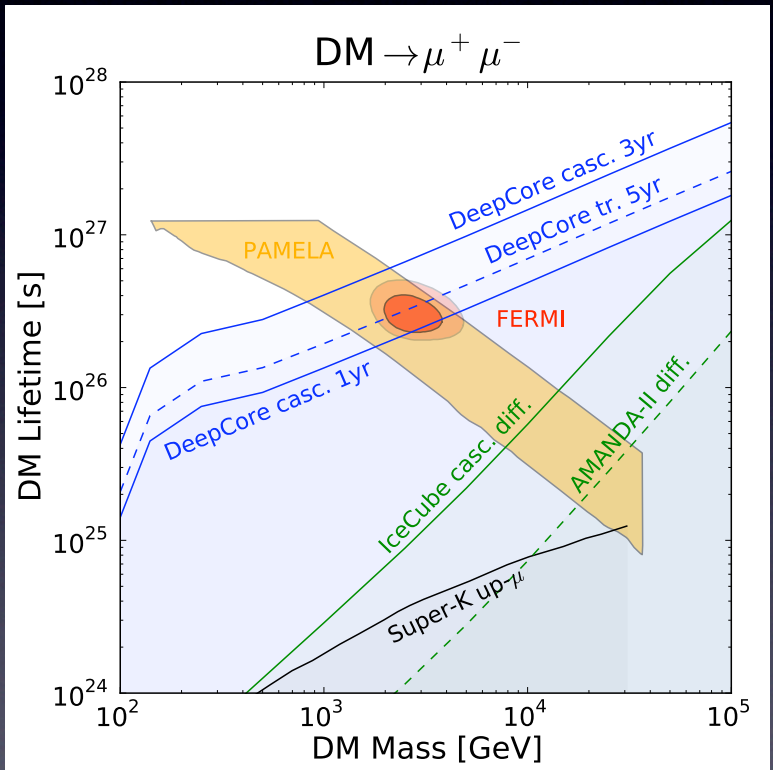
P. Salati

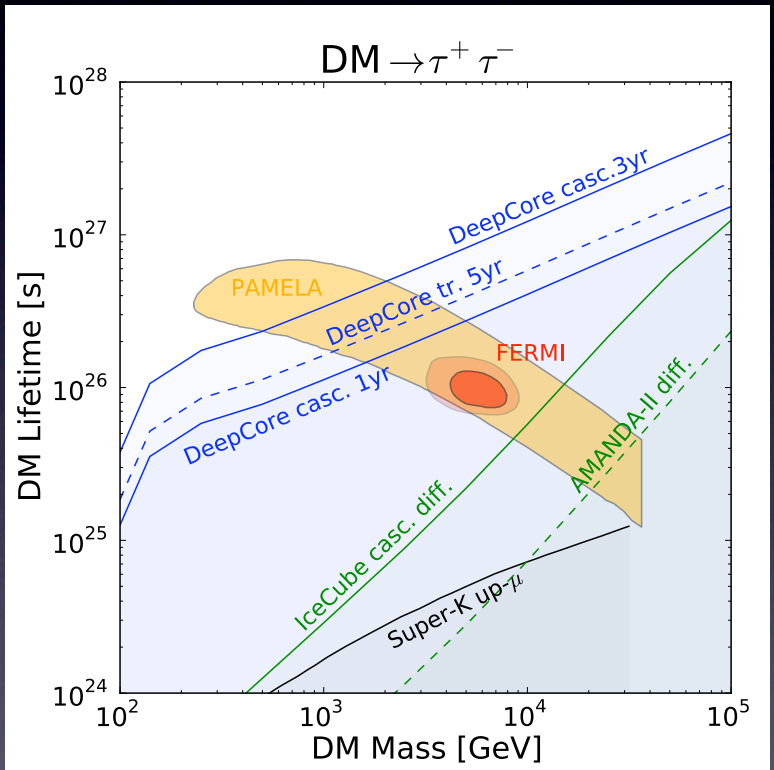
P. Meade, M. Papucci, A. Strumia & T. Volansky, arXiv:0905.0480



Decaying Dark Matter

IceCube Future Constraints

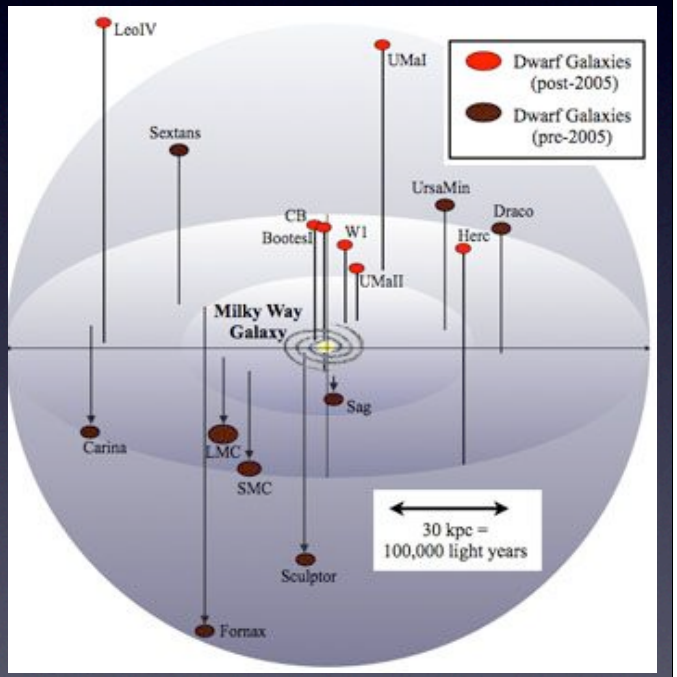




IceCube can do roughly an order of magnitude better job!

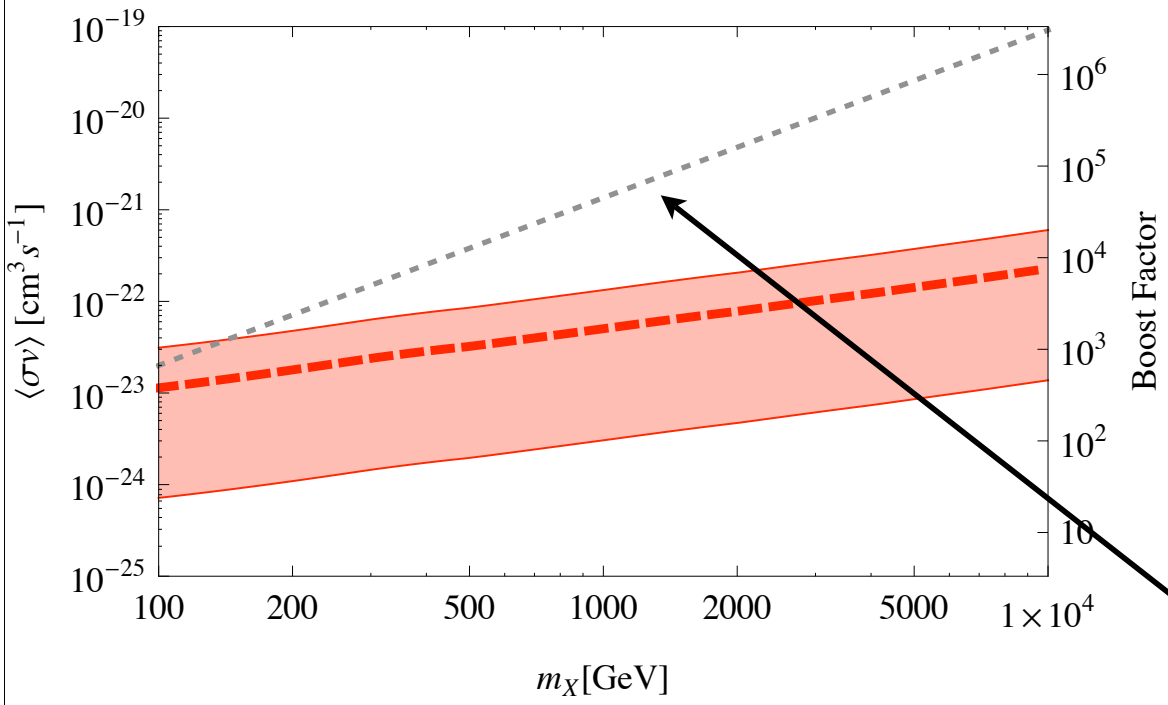
Dwarf Galaxies

- Dark Matter Dominated
- Can't "fake a Signal
- Interesting point sources



With Pearl Sandick

Dwarf Galaxies Placing Limits



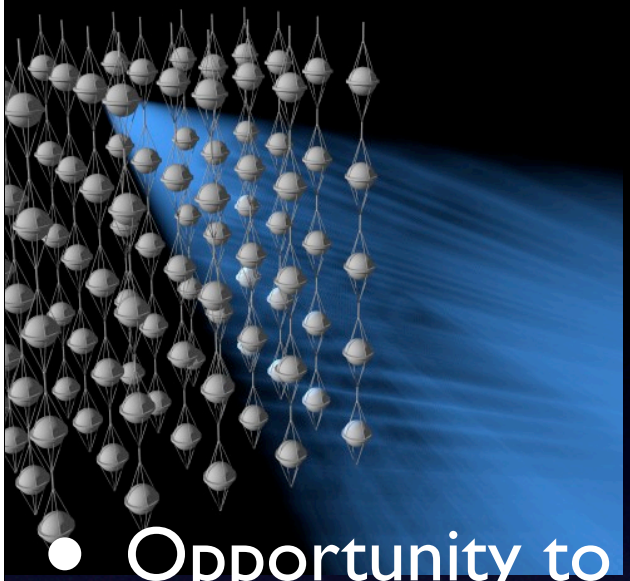
$$\chi\chi \rightarrow \mu^+\mu^- + \nu_\mu\bar{\nu}_\mu$$

- 50-50 branching ratio
- Segue 1

Present Bounds

Pearl Sandick

R. Essig, N. Sehgal, L.E. Strigari (2009)



Conclusion

- Opportunity to discover or strong constrain DM
  - Due to DM annihilation
- Also an opportunity to place the strongest constraints on decaying DM
- Finally, dwarf galaxies can be very helpful in constraining the scenario if there is a sizable branching fraction directly to neutrinos