Neutrinos and DM (Galactic)

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Basic Result

• If the electron excess seen by Fermi is **DUE TO** DM annihilation going leptonic final states $\mu^+\mu^-, \tau^+\tau^-$, etc...

• 5+5: ICECUBE will see a 5 $\sigma$ 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 $\sigma$ in 5 years

• Even better with some branching fraction directly to neutrinos
Outline

• DM Introduction
• IceCube
  • neutrino as a new handle
  • Galactic Center
• Not looking at Captured DM in Sun
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?

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.

Direct Detection Experiments

WIMP/NUCLEUS SCATTERING
**WIMP Annihilation**

Typical final states include heavy fermions, gauge or Higgs Bosons

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1. **Fragment / Decay**

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

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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…. 
- 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

Position fraction, $\phi(e^+)/\phi(e^-) + \phi(e^-)$

- ref. 1
- PAMELA
- Aesop (ref. 13)
- HEAT00
- AMS
- CAPRICE94
- HEAT94+95
- TS93
- MASS89
- Muller & Tang 1987

Energy (GeV)
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

- not dependent upon profile
- assume Isothermal Sphere
- Fit Pamela and Fermi Data
  annihilation directly to neutrinos
New Indirect Detection Results!

(When it rains it pours)

AMS positrons

IceCube neutrino

AMS

2010 Deployment

Looking for Dark matter annihilation

Fermi

Running!

Running!

Running!
IceCube at the South Pole
IceCube + Deep Core

String Space
IceCube 125m
DeepCore 72m

Bead Spacing
IceCube 17m
DeepCore 7m

Look for signal from the galactic Center

Use IceCube as a Veto

Poor angular resolution 30-50 degrees
1-10 TeV (unclear at lower energies)
take resolution to be 1/2 of the Sky (conservative)
Neutrinos Signal Galactic Center From DM Annihilation

\[
\frac{d\Phi(\Delta \Omega, E)}{dE} = \frac{B}{8\pi} \frac{\langle \sigma v \rangle}{m_\chi} \sum_j f_j \frac{dN_j}{dE} \times J(\Delta \Omega) \Delta \Omega
\]

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 et al 2006
may also be an indication that DM species \textit{decay} in the MW.

\[ \Gamma_{\text{ann}} \equiv \langle \sigma v \rangle \times \frac{\rho_{\chi}^2}{m_{\chi}^2} \Rightarrow \Gamma_{\text{ann}} \equiv \Gamma_{\text{dec}} \times \frac{\rho_{\chi}}{m_{\chi}} \]

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

\[ \Gamma_{\text{dec}} \sim 10^{-26} \text{ s}^{-1} \]

\section*{Decaying dark matter}

- Decaying DM species still pass the astrophysical tests since $\Gamma_{\text{ann}} \propto \rho_{\chi}$.
- 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.
DM → 4μ, Einasto profile

DM → μ⁺μ⁻, Einasto profile

DM → τ⁺τ⁻, Einasto profile

DM → 4μ, isothermal profile

DM → μ⁺μ⁻, isothermal profile

DM → τ⁺τ⁻, isothermal profile
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

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