Search for Secluded Dark Matter with the IceCube Neutrino Telescope

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Search for Secluded DM

For ‘typical’ parameters, mediators may be created in sun and decay near the Earth to two co-linear muons.
Outline

- Secluded Dark Matter
- IceCube: Neutrino Observatory and Signatures
- Selection using Energy Deposition Topology
- Sensitivity, Conclusions, and Outlook
Evidence of new physics?

- Galaxy Rotation Curves
- Gravitational Lensing
- Pamela/Fermi/ATIC
  - large cross section into $e^+, e^-$
  - excess of $e^+ / (e^+ + e^-)$
  - leptophilic dark matter

Evidence of new physics?

- Galaxy Rotation Curves
- Gravitational Lensing
- Pamela/Fermi/ATIC
- INTEGRAL
  - excess of 511 keV x-rays
  - low mass dark matter, or inelastic scattering

N. Prantzos et al., Reviews of Modern Physics 83 (2011)
Evidence of new physics?

- Galaxy Rotation Curves
- Gravitational Lensing
- Pamela/Fermi/ATIC
- INTEGRAL
- Direct detection discrepancy
  - Inelastic scattering due to lower mass of Na
Secluded Dark Matter

- Dark Matter, $X$, is secluded from ‘normal’ matter by a mediator, $\Phi$.
- Mediator could be some new gauge boson from the dark sector, or some other candidate.
- The dark sector may be simple or more complicated, in the simplest picture the dark matter annihilates into the mediator.

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{WIMP} + \mathcal{L}_{mediator} \quad \chi \chi \rightarrow \phi \phi$$

Secluded DM: Properties

- If non-abelian symmetry exists in the dark sector.
  - **XX** annihilation
    - Sommerfeld enhancement -> large cross-section
  - symmetry splitting possible, due to ‘dark’ Higgs (or small coupling to Higgs)
  - Excited Dark Matter (XDM) \( \chi \chi \rightarrow \chi \chi' \rightarrow \chi \chi e^+ e^- \)
  - Inelastic Dark Matter (iDM) \( \chi_1 \chi_1 \rightarrow \chi_2 \chi_3 \)
- Possible explanation of observations of new physics

Pamela/ATIC/Fermi  INTEGRAL  Direct Detection
Leptophilic DM due to interaction with the SM through the kinetic mixing portal

‘Typical’ mediator boosted due to DM mass being greater than mediator mass

Lifetime of mediator could be long, could decay in the vicinity of the earth

**Secluded DM: Signal**

\[ \epsilon_{\nu} F'_{\mu \nu} B^{\mu \nu} \]

\[ m_\chi > m_\phi \]

\[ \phi \sim 1 \text{GeV} \]

\[ \chi \sim 1 \text{TeV} \]
IceCube Neutrino Detector

1 km cube instrumented array in the Antarctic ice. Analysis with 79 string configuration.
IceCube Neutrino Observatory

- \( \sim O(10^8) \) muons per day filter level
- \( \sim O(10^2) \) neutrinos per day filter level
- Typical signal is \( \sim 10 \) events per year

Difficult to distinguish signal from background
IceCube Signatures

- Standard signals:
  - Muons, Neutrinos, Cascades
- Secluded DM Signal:
  - Di-muon
- Key Selection Mechanism: Zenith

Down-going Muon

Cascade

Di-muon simulation

Up-going Di-muon

Monday, July 23, 12
Di-muon Signature

- Di-muon signal traveling through the ice looks like a much more energetic muon.
- Energy deposited for stopping di-muon event is twice that of a single muon event.

High Energy

Energy Deposition
Analysis: Energy Deposition

- Energy deposition topology provides a key handle to differentiate signal and background.
- Independent of Zenith.

Machine Learning Algorithm
Analysis: Direction

- Blind to data within 29° direction of the sun (azimuth)
- Azimuth randomized for background sample (in time)
- Shown 1.0 TeV signal (blue) and background (black) before final event selection.

90° < Θ < 113°

Probability Density Function

Data collected when the Sun is below the horizon at the South Pole

$\mu = \mu_s V_{eff} \% T$

Joanna Kiryluk (LBNL)
24-29 July 2011 (PANIC11)
Sensitivity

Before final topological event selection, 1.0 TeV DM annihilating into 1.0 GeV mediator which decays to two muons.
Theoretical Limits

Conclusions and Outlook

- Dark matter may be more complicated than the traditional NMSSM candidates, this complication may provide new methods to discover them.
- Analysis for secluded Dark Matter using IceCube almost complete, systematic studies and final event selection on-going.
- Look for results soon.