Search for Secluded Dark Matter with the IceCube Neutrino Telescope Jonathan Miller for the IceCube Collaboration Vrije Universiteit Brussel, IIHE







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
 - Iarge cross section into e⁺,e⁻
 - excess of $e^+ / (e^+ + e^-)$
 - Ieptophilic dark matter



Fermi LAT Collaboration, PRL 108 011103 (2012)

Evidence of new physics?

- Galaxy Rotation Curves
- Gravitational Lensing
- Pamela/Fermi/ATIC
- INTEGRAL
 - excess of 511 keV x-rays



N. Prantzos et al., Reviews of Modern Physics 83 (2011)

Iow mass dark matter, or inelastic scattering

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, Φ .
- 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.

 $\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{WIMP} + \mathcal{L}_{mediator} \qquad \chi \chi \to \overline{\phi \phi}$

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)
 - 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

 $\chi\chi \to \chi\chi' \to \chi\chi e^+ e^-$



- 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



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

IceCube Neutrino Top of the atmosphere P Proton collides with an atmospheric molecule. π π^+ π^{0} cosmic ray $\overline{\nu}_{\mu}$ Atmospheric v Down-going -7 10 sr⁻¹, Extraterrestral v 10 s, atmospheric muons Up-going $d\Phi/d\Omega \ (cm^{-2}$ 10 -10 10

10⁶

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ignal from background

-11 10

-12

muons induced by atmospheric

newtrinos

10

10

IceCube Signatures

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

simulation Up-going Di-muon

Down-going Muon

shown, min E(GeV) == 500.00 5 shown, min E(GeV) == 0.0

deg

Cascade

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.





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





Theoretical Limits Theoretical calculation by Meade, Nussinov, Papucci, Volansky (2009).

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.

The IceCube Collaboration

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