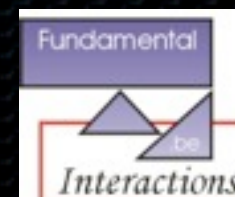
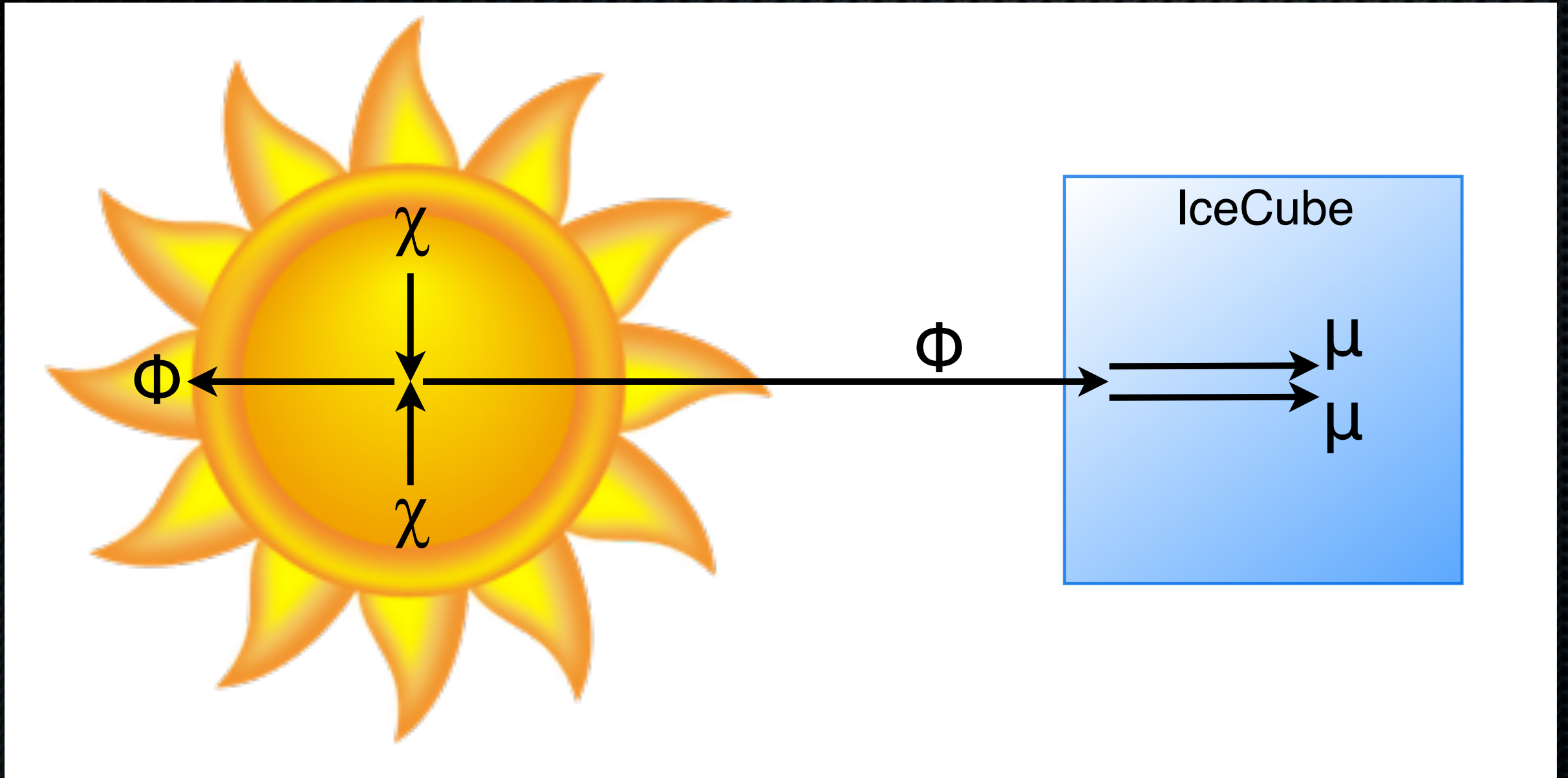


Search for Secluded Dark Matter with the IceCube Neutrino Telescope

Jonathan Miller for the IceCube Collaboration

Vrije Universiteit Brussel, IHE





Search for Secluded DM

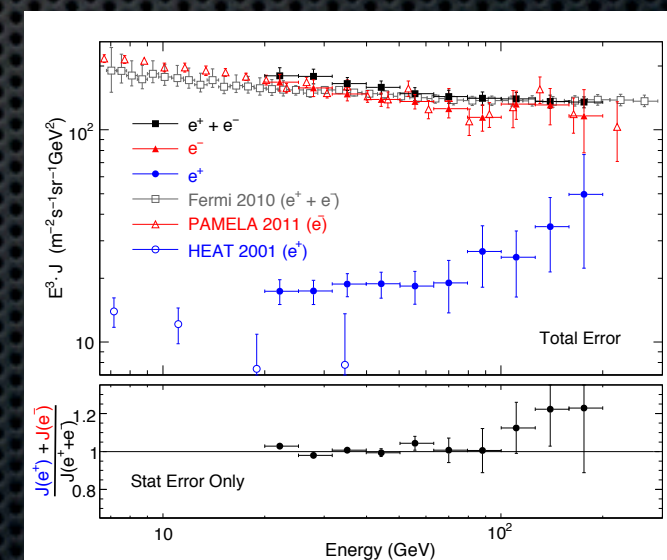
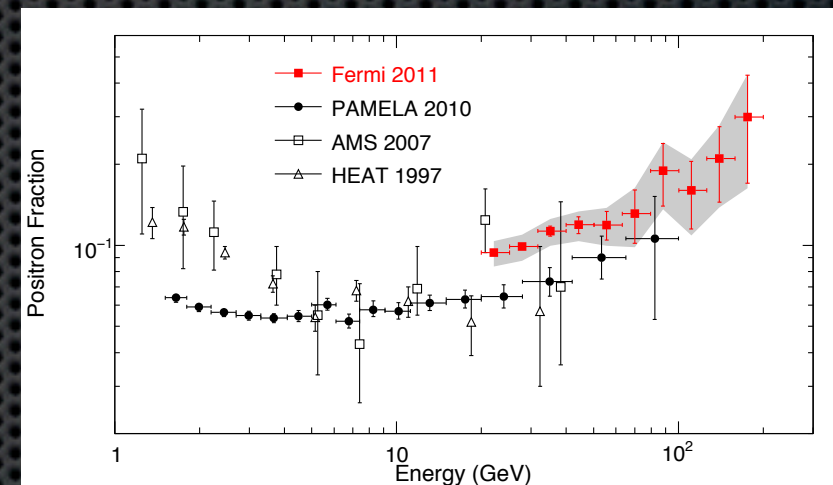
For 'typical' parameters, mediators may be created in sun and decay near the Earth to two co-linear muons.

Outline

- ✦ Secluded Dark Matter
- ✦ IceCube: Neutrino Observatory and Signatures
- ✦ Selection using Energy Deposition Topology
- ✦ Sensitivity, Conclusions, and Outlook

Evidence of new physics?

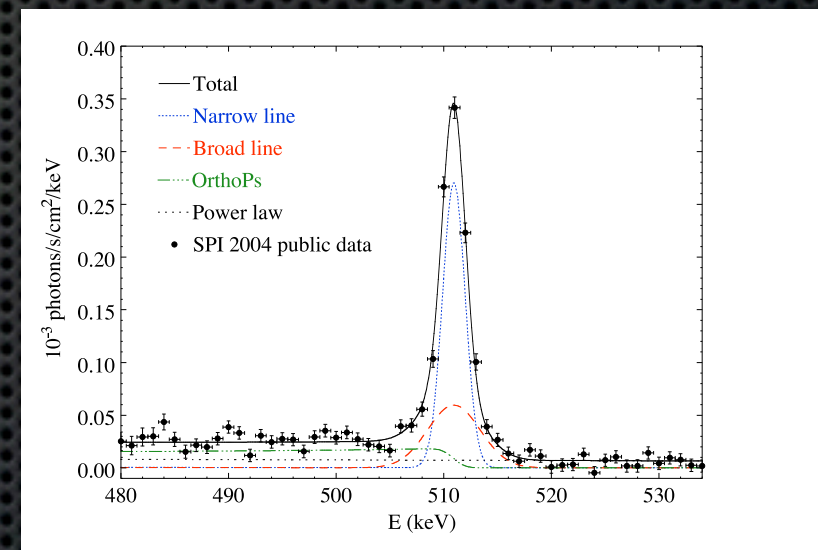
- ✦ Galaxy Rotation Curves
- ✦ Gravitational Lensing
- ✦ Pamela/Fermi/ATIC
 - ✦ large cross section into e^+, e^-
 - ✦ excess of $e^+ / (e^+ + e^-)$
 - ✦ leptophilic dark matter



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
 - ✦ 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

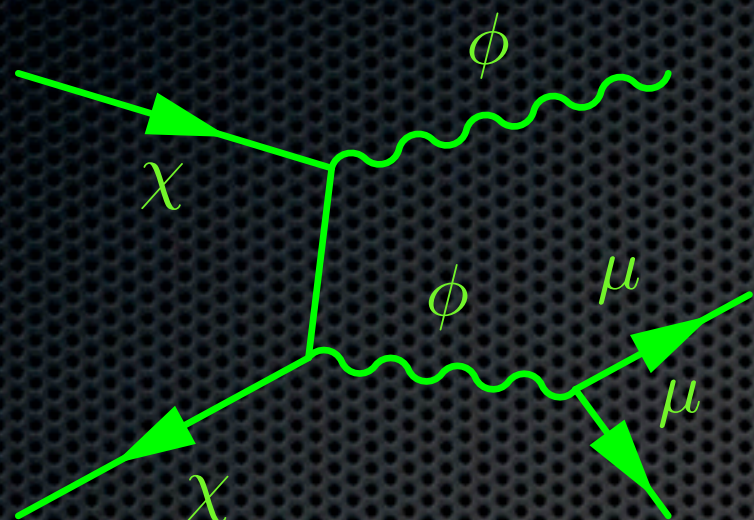
- Dark Matter, χ , is secluded from 'normal' matter by a mediator, ϕ .
- Mediator could be some new gauge boson from the dark sector, or some other candidate.
- The dark sector may be simple or more complicated, in the simplest picture the dark matter annihilates into the mediator.

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

Secluded DM: Properties

- ✦ If non-abelian symmetry exists in the dark sector.
 - ✦ XX annihilation
 - ✦ Sommerfeld enhancement \rightarrow 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

Secluded DM: Signal



$$\epsilon_V F'_{\mu\nu} B^{\mu\nu}$$

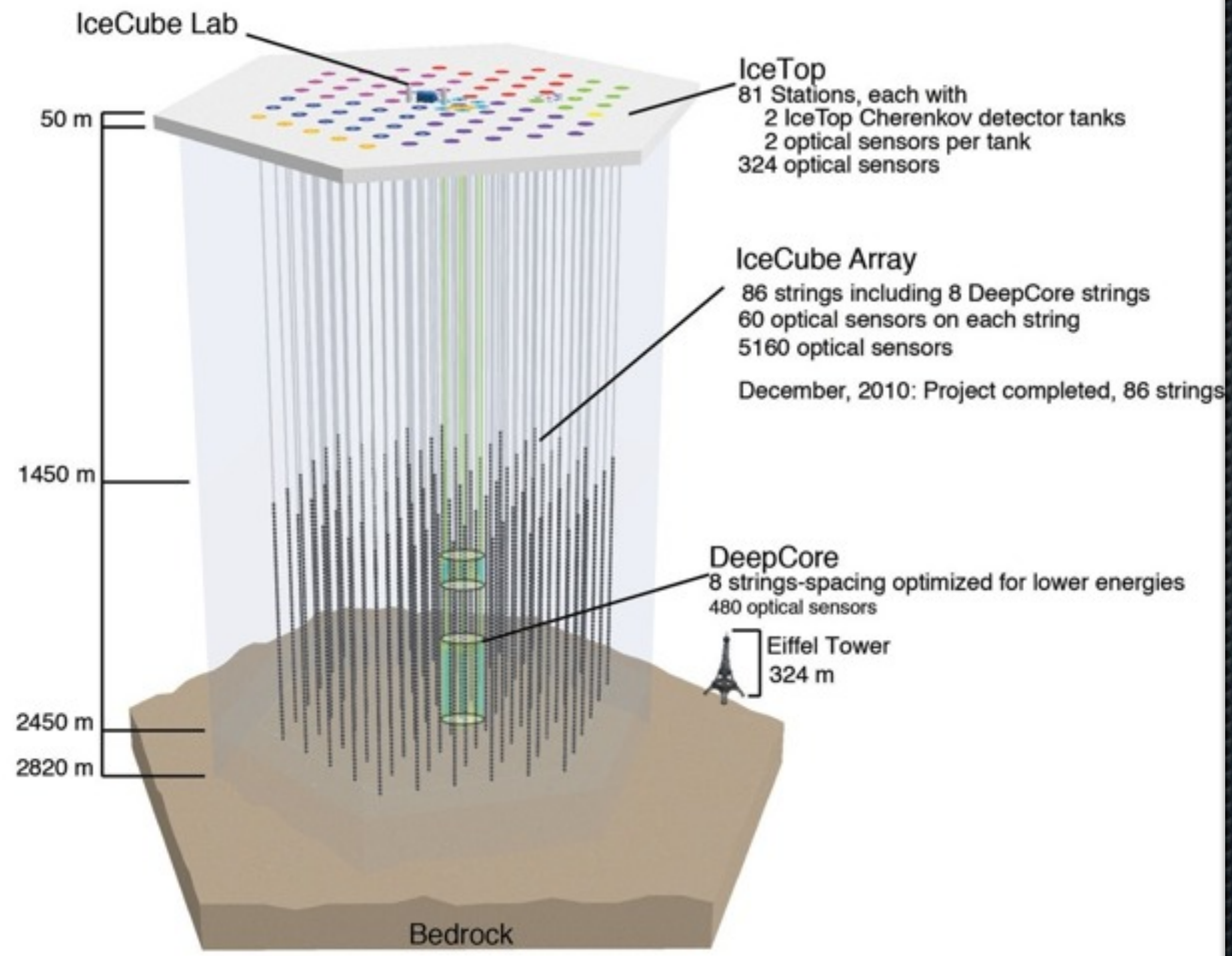
$$m_\chi > m_\phi$$

‘Typical’

$$\chi \sim 1\text{TeV}$$

$$\phi \sim 1\text{GeV}$$

- 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

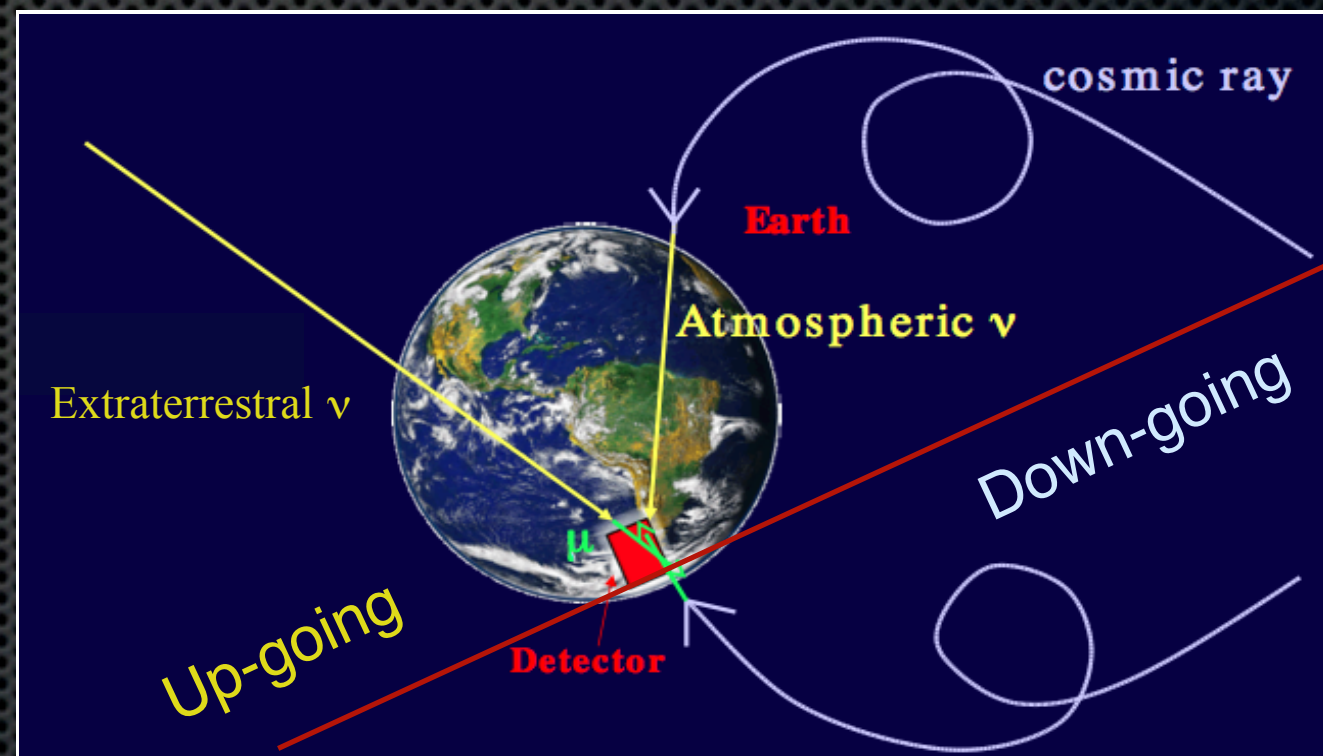


IceCube Neutrino Detector

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

IceCube Neutrino Observatory

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



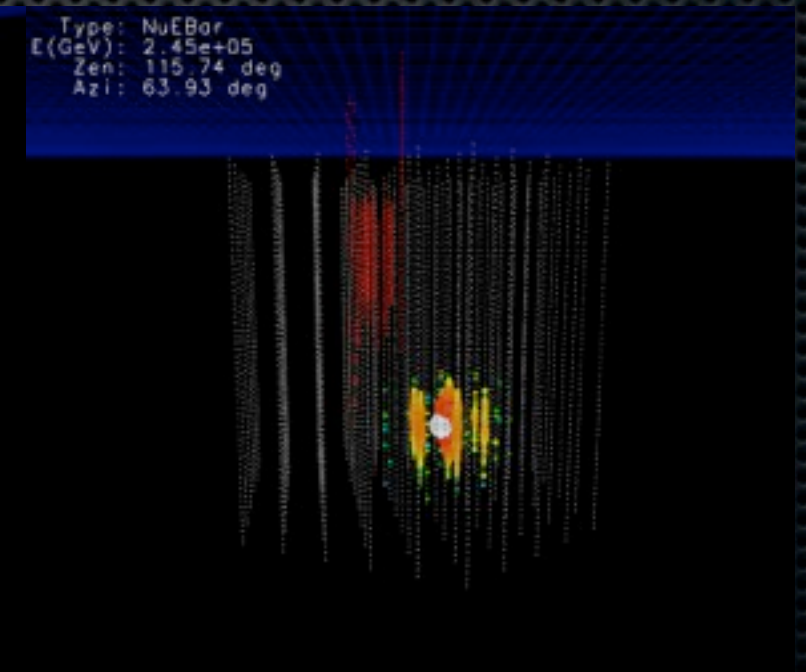
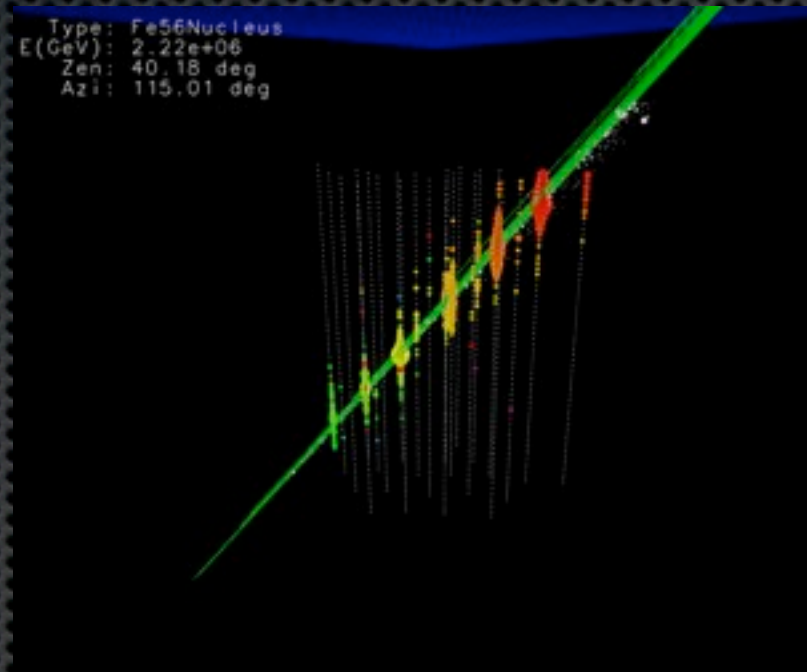
Difficult to distinguish signal from background

IceCube Signatures

Down-going Muon

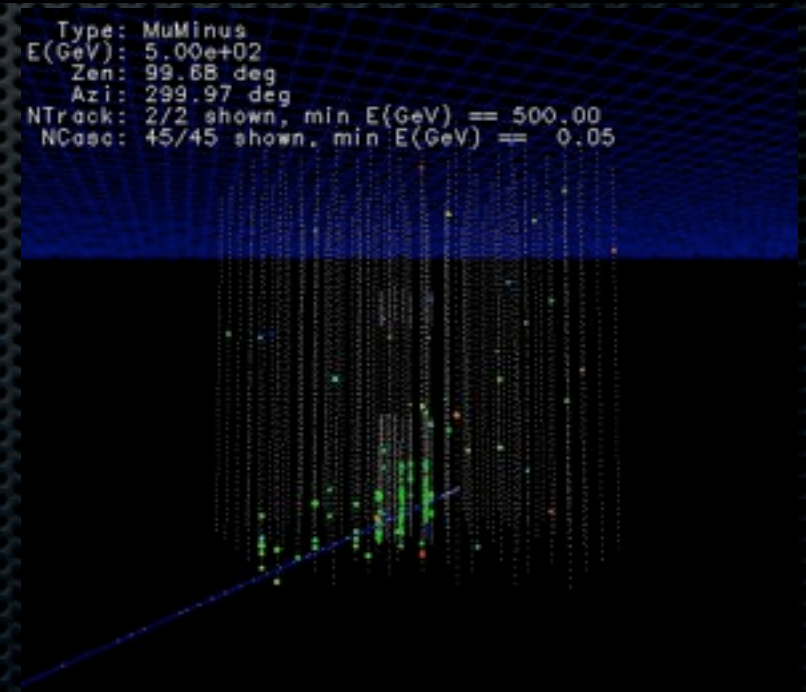
Cascade

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



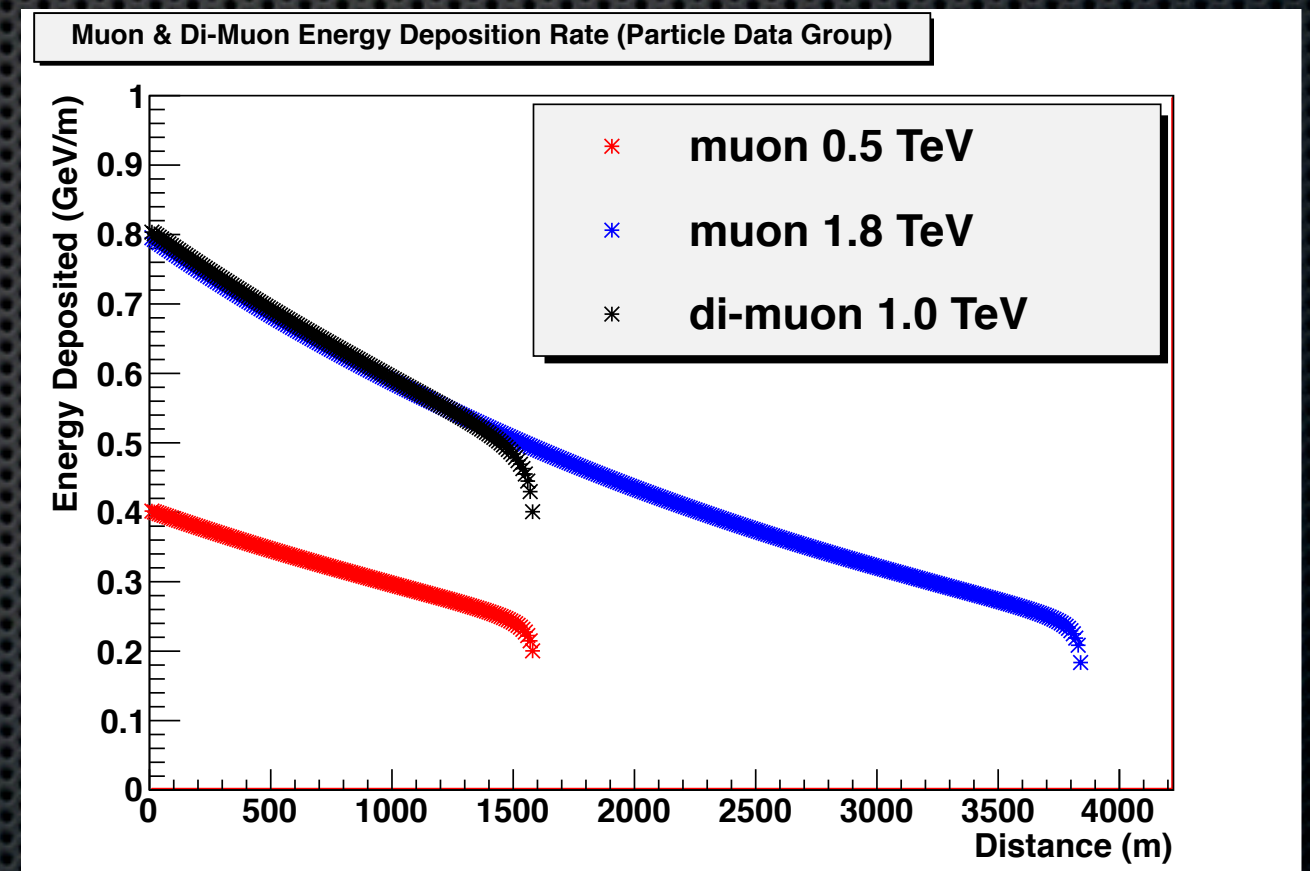
simulation

Up-going
Di-muon



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.



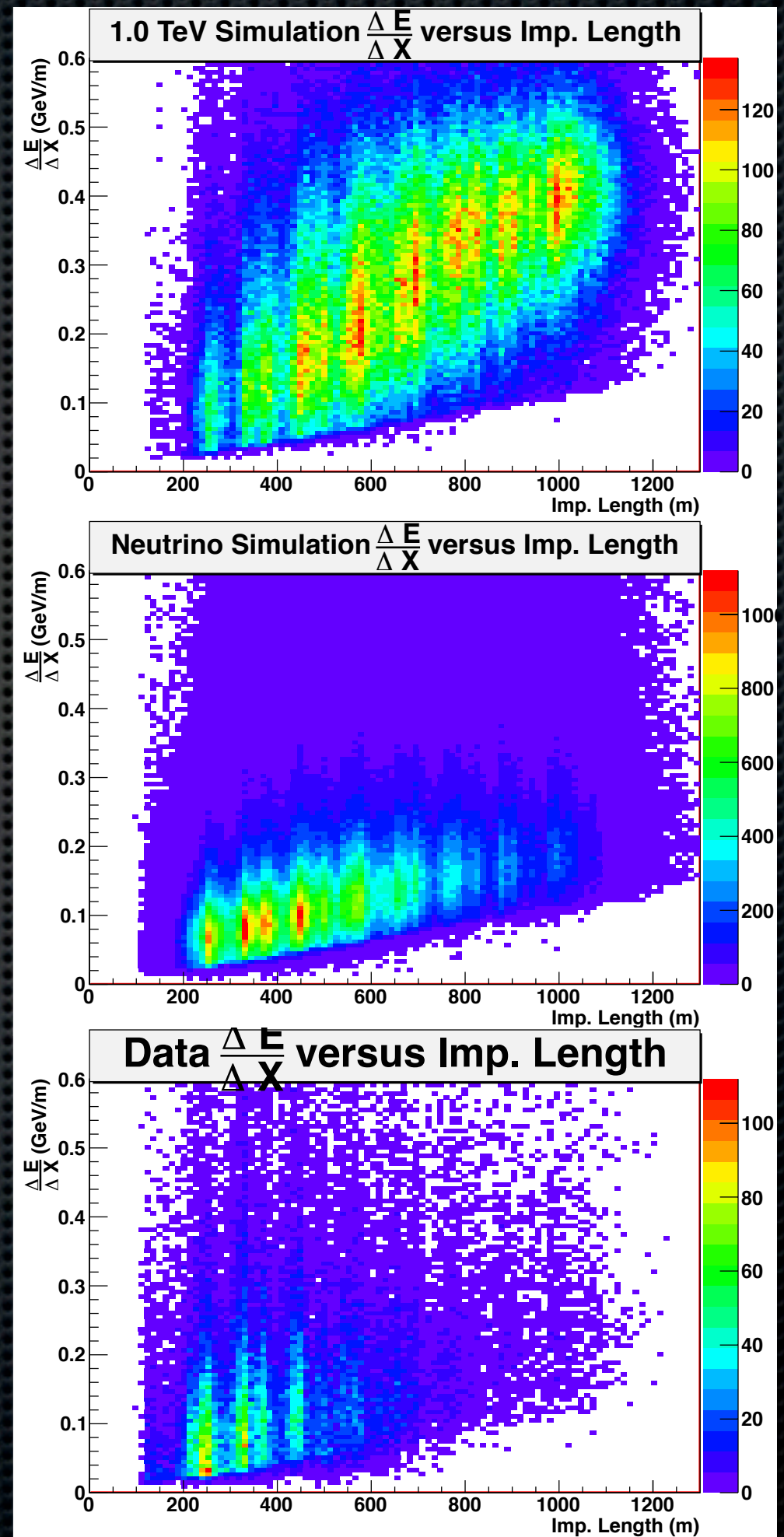
High Energy

Energy Deposition

Analysis: Energy Deposition

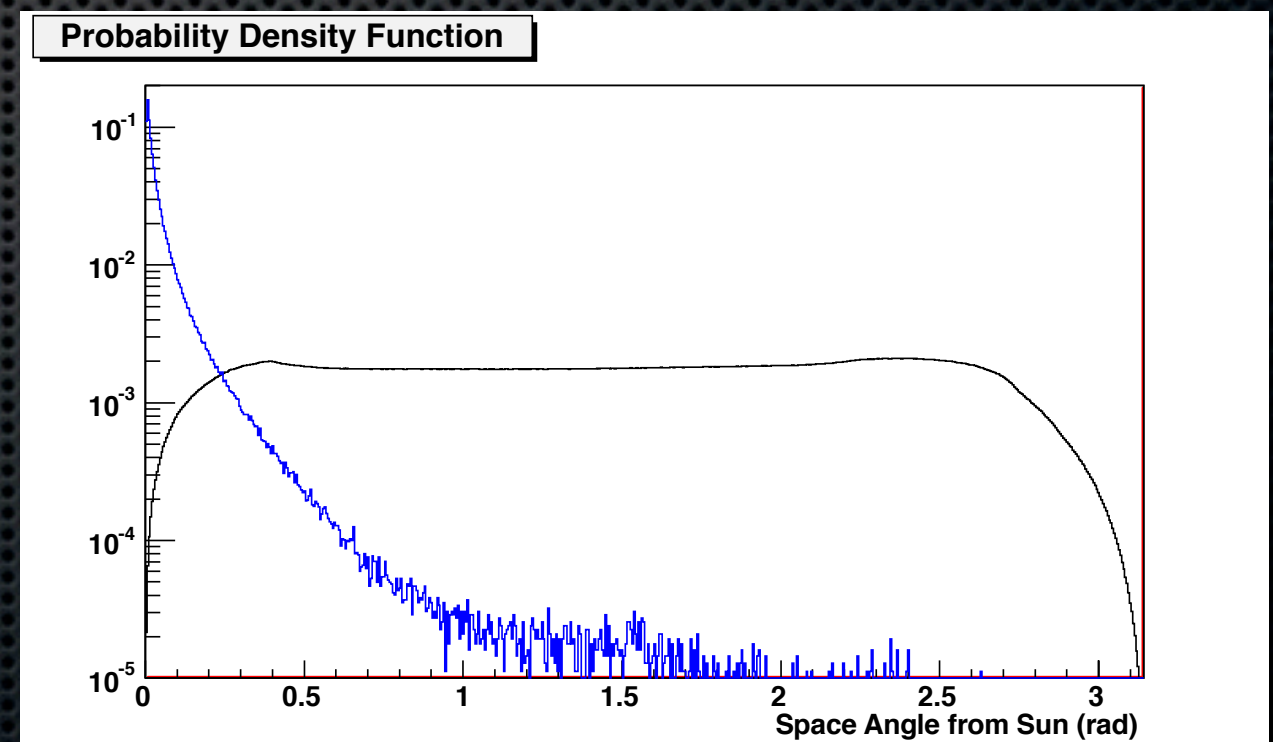
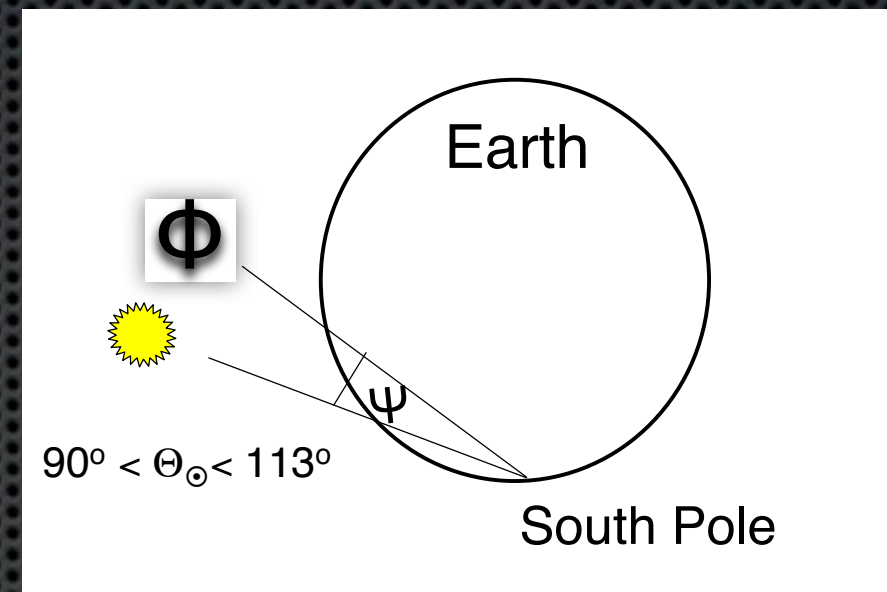
- ✦ Energy deposition topology provides a key handle to differentiate signal and background.
- ✦ Independent of Zenith.

Machine Learning Algorithm



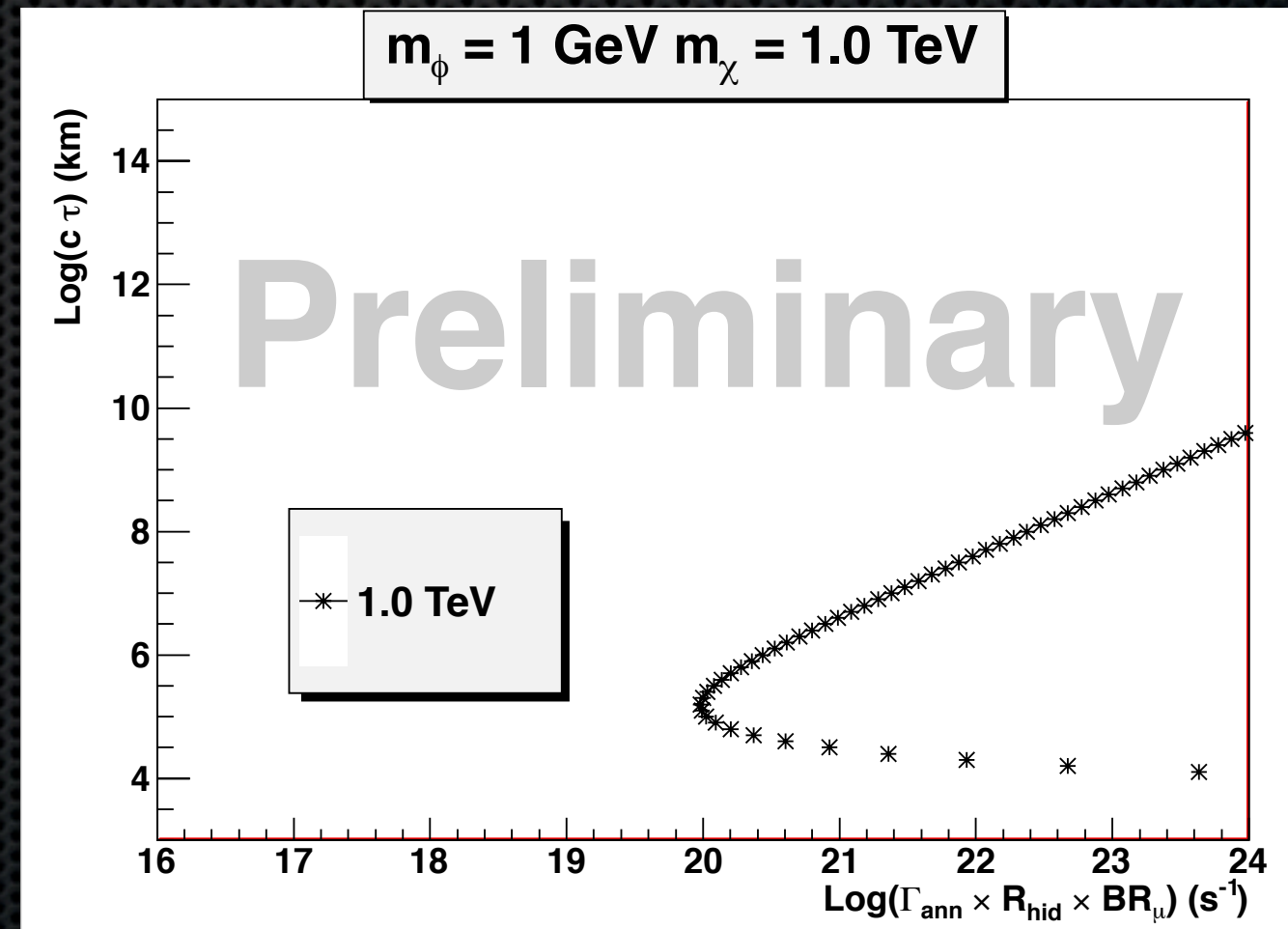
Analysis: Direction

- 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.



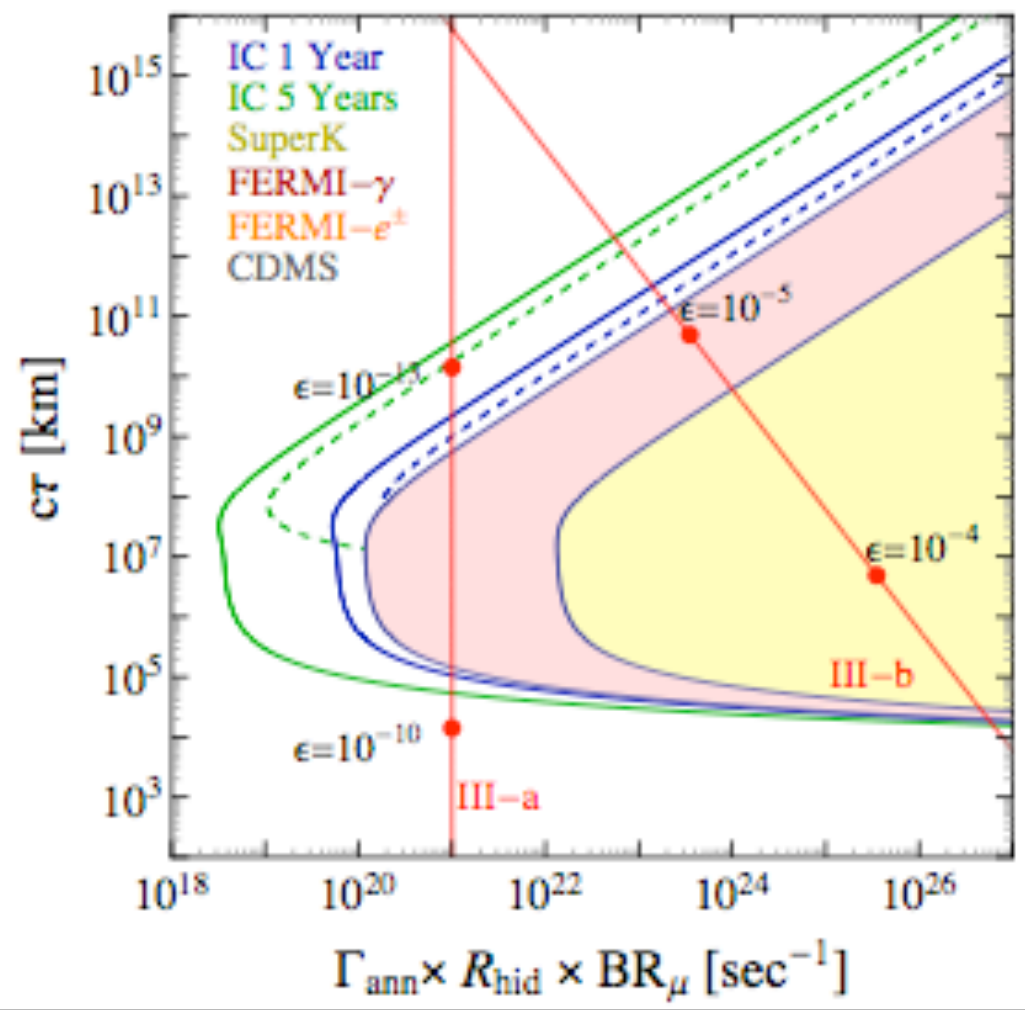
Sensitivity

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



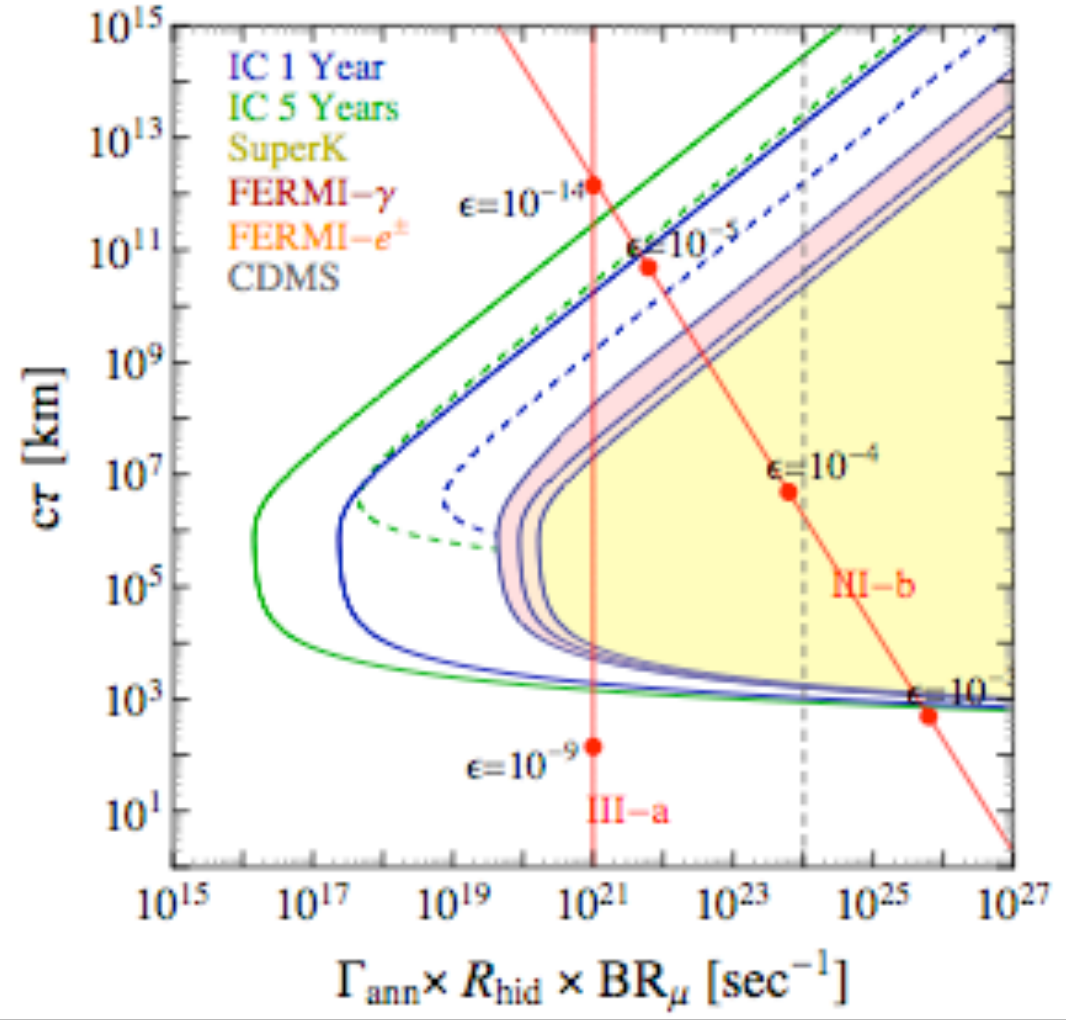
Sun μ^\pm reach

$m_\chi = 100$ GeV, $\delta = 200$ keV, $m_{\text{LOLiP}} = 500$ MeV



Sun μ^\pm reach

$m_\chi = 2$ TeV, $\delta = 200$ keV, $m_{\text{LOLiP}} = 500$ MeV



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



International Funding Agencies

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