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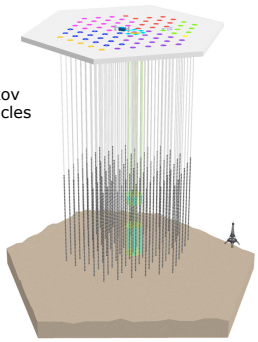
All-Flavor Searches for Dark Matter with the IceCube Neutrino Observatory

Introduction

IceCube

- 1 km^3 of Antarctic ice
- 5160 optical sensors
- neutrino detection through Cherenkov light emission from secondary particles
- DeepCore infill array for energies below 100 GeV



WIMP Searches

Neutrino signal from annihilation of Weakly Interacting Massive Particles (WIMPs) trapped in massive celestial bodies

What's new?

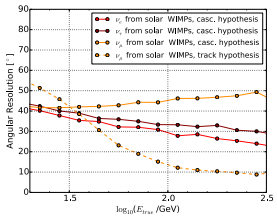
- ν_μ: extended track-like topologies → good angular resolution
  ν_e, ν_τ: cascade-like signatures → good energy resolution
- Earth and solar WIMP searches WIMP searches with IceCube so far focused on ν_μ events due to better pointing precision
- **reasons for analysis sensitive to all flavors:**
  - enhancement of measured flux
  - better precision in determination of neutrino energy
  - backgrounds from atmospheric ν_e and ν_τ are smaller
  - better rejection of cosmic ray muons by requiring cascade-like event signature

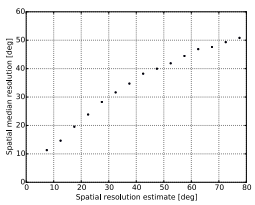
Challenges at low energies:

- simulation of events and detector response
- particle identification
- directional reconstruction (of cascades in particular)

Low Energy Cascade Reconstruction

- pointing back to the source region requires decent angular resolution
- challenging to achieve good pointing:
  - spherical event shape
  - limited topological and timing information at low energies





- individual uncertainty estimate on angular reconstruction desirable
- Cramer-Rao based implementation was coded

$$(\mathrm{cov}^{-1})_{lm} = F_{lm} = -\left\langle \frac{\partial^2 \log L(\vec{\theta})}{\partial\theta_l \partial\theta_m} \right\rangle$$

$$F_{lm} = \sum_{i=1}^{\#\mathrm{hitDOMs}} \sum_{j=1}^{\mathrm{nbins}(i)} \frac{1}{\mu_{\mathrm{h}}(\vec{\theta},i,j)} \frac{\partial\mu_{\mathrm{h}}(\vec{\theta},i,j)}{\partial\theta_l} \frac{\partial\mu_{\mathrm{h}}(\vec{\theta},i,j)}{\partial\theta_m} + \sum_{k=1}^{\#\mathrm{nonhitDOMs}} \frac{\partial^2\mu_{\mathrm{nh}}(\vec{\theta},k)}{\partial\theta_l\partial\theta_m}$$

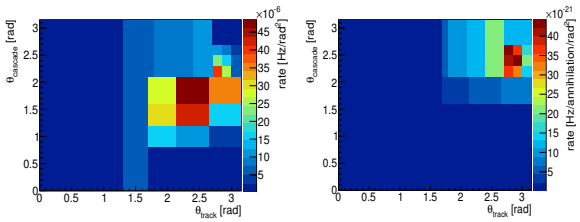
- good correlation with actual resolution taken from MC

Earth WIMP Search

- 50 GeV/c^2 WIMPs and $\tau\tau$ annihilation channel as test case

Objectives:
- independence from precise MC background prediction
- exploitation of features distinguishing between cascade and track signatures
- exploitation of angular distribution of signal and backgrounds

→ basic input for **Likelihood algorithm**:
zenith angle(cascade hypothesis) vs zenith angle(track hypothesis)
→ resolve signal regions and merge background dominated parts



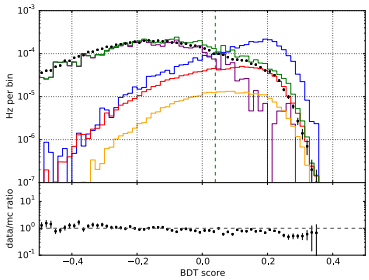
- likelihood-ratio test on simulated data yields:

	annihilation rate [annihilations/s]
Sensitivity (90% C)	$7.7 \cdot 10^{13}$
Evidence (3σ)	$1.7 \cdot 10^{14}$
Discovery Potential (5σ)	$2.2 \cdot 10^{14}$

Expectations for one year of IceCube data taken with its 86-string configuration

Solar WIMP Search

- work in progress
- consider candidate masses: 50, 100, 250, 500, 1000 GeV/c^2
- Background reduction by a factor of 10^6
- for a showcase candidate with mass of 100 GeV/c^2:
  - signal efficiencies at 5.0% (8.4%) for WW (bb) channel (for this analysis efficiencies are larger for lower energies)
  - multivariate technique helps discriminating background: use 12 variables, incl. direction, energy, vertex, as well as geometrical and veto quantities for good background separation



signal: blue, data: black
Atmospheric background contributions also shown for comparison:
total (green) = μ (purple) + ν_μ (red) + ν_e (yellow)

- for limit calculations: plan to use likelihood approach considering energy, direction and directional uncertainty

[2]http://icecube.wisc.edu/collaboration/authors/icrc15_icecube

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