Dark Matter with KM3NeT

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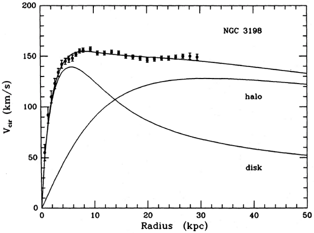
Outline

- Dark Matter
- Simulation and Methods
- Results
- Conlusion and Outlook

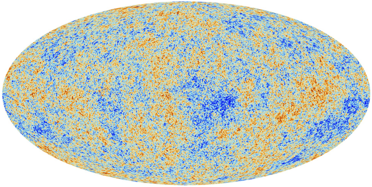
Dark Matter

Gravitational Lensing

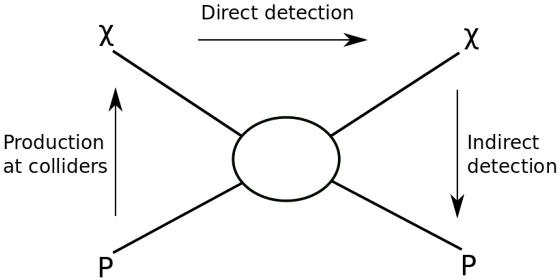
Galactic Rotation Curves



CMB

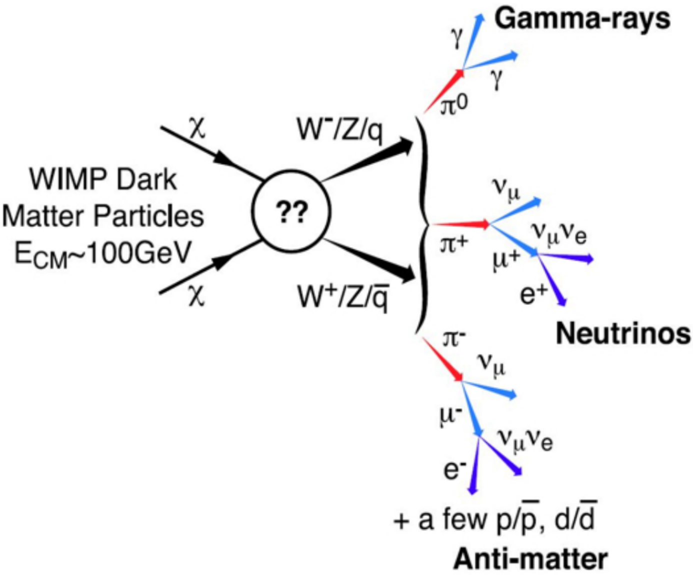


Dark Matter Detection



- Production: LHC
- Direct detection: XENON
- Indirect detection: IceCube

Dark Matter Annihilation

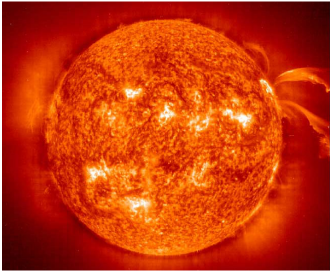


Dark Matter Capture

The number of dark matter particles depends on:

- Capture
- Annihilation
- Evaporation

$$\frac{dN(t)}{dt} = \Gamma_c - 2\Gamma_a - \Gamma_e$$



Dark Matter Capture

To write the annihilation rate as a function of the number of particles:

$$\Gamma_a = \frac{1}{2}\int d^3x\; n^2(\vec{x},t)\langle\sigma v\rangle$$

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$$M_{DM}\phi(r) = \int_0^r dr' \frac{GM_{DM}M(r')}{r'^2}$$

Dark Matter Capture

Assume $\rho_\odot$ is constant near the core of the sun

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$$\begin{aligned} n(r,t) &= n_0(t)\exp\left(-\frac{r^2}{r_{DM}^2}\right) \\ r_{DM} &= \left(\frac{3T_\odot}{2\pi G\rho_\odot M_{DM}}\right)^{1/2} \approx 0.01R_\odot\sqrt{\frac{100\text{GeV}}{M_{DM}}} \end{aligned}$$

Find Γ_a:

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$$C_a = \langle\sigma v\rangle\left(\frac{GM_{DM}\rho_\odot}{3T_\odot}\right)^{3/2}$$

Dark Matter Capture

Write the differential equation as a function of N:

$$\frac{dN}{dt} = C_c - C_a N^2 \quad \Rightarrow \quad N(t) = \sqrt{\frac{C_c}{C_a}} tanh(\sqrt{C_c C_a} t)$$

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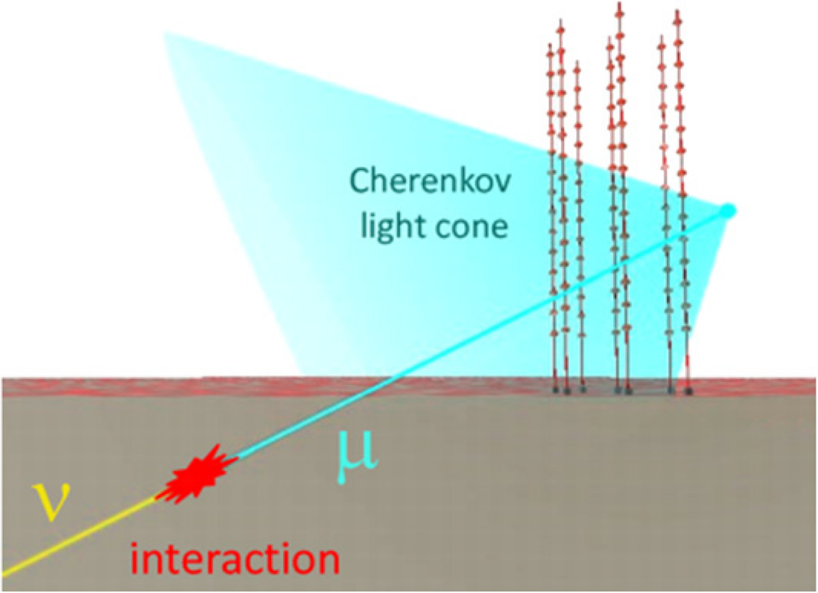
$$\tau_{EQ} = \frac{1}{\sqrt{C_c C_a}}$$

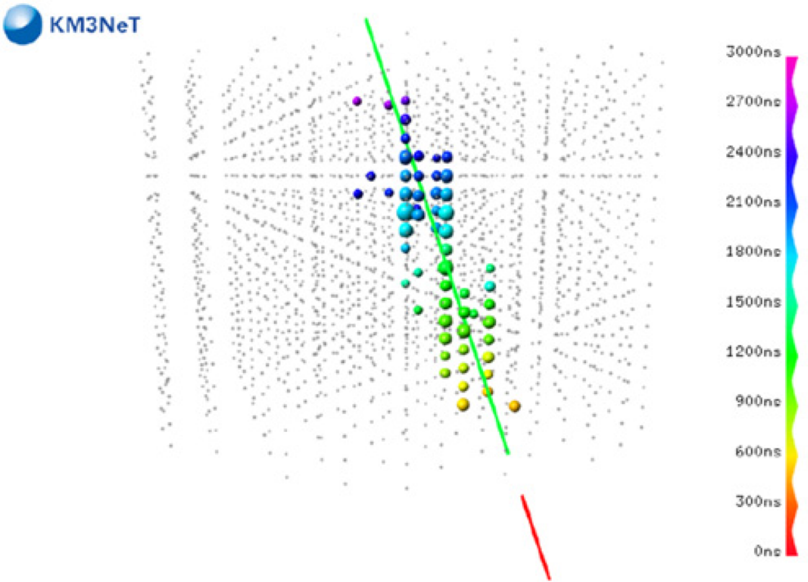
When $t \gg \tau_{EQ} \quad \Rightarrow \quad N = \sqrt{\frac{C_c}{C_a}}$

$$\Gamma_a = \frac{1}{2} C_a N^2 = \frac{1}{2} C_c$$

Cherenkov Detection



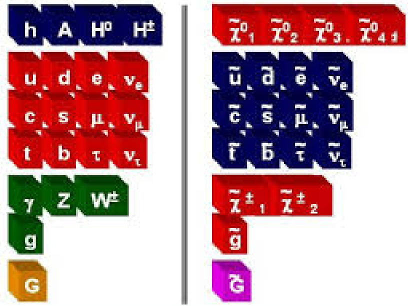
Cherenkov Detection



Dark Matter Models

Supersymmetry:

- Neutralino as dark matter candidate
- DarkSUSY to calculate neutrino flux



Simulation Software

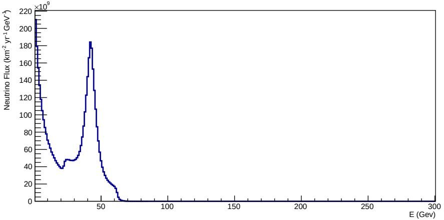
Simulation consists of four steps:

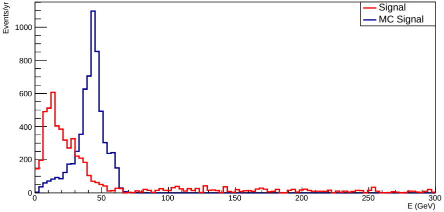
- Event generation
- GEANT4 detector simulation
- Trigger Efficiency
- Track reconstruction

Energy Distribution

$m_\chi = 85$ GeV and annihilates through the WW-channel

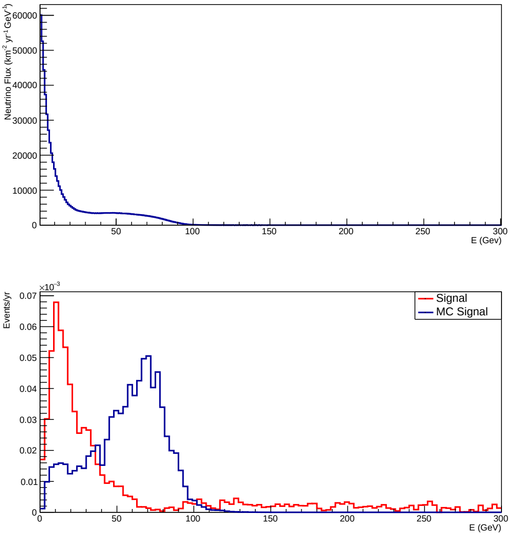
- MC signal: events before simulation
- Signal: events after simulation





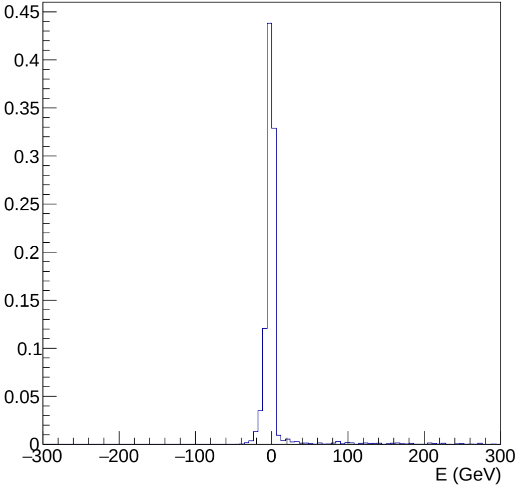
Energy Distribution

$m_\chi = 175$ GeV and annihilates through $t\bar{t}$-channel



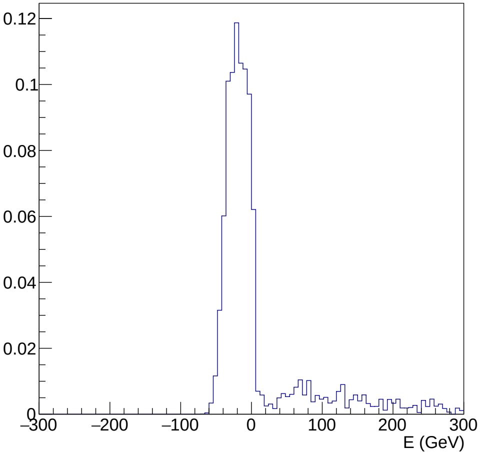
Energy Reconstruction

$m_\chi = 46$ GeV, 89.7% between -10 and 10 GeV



Energy Reconstruction

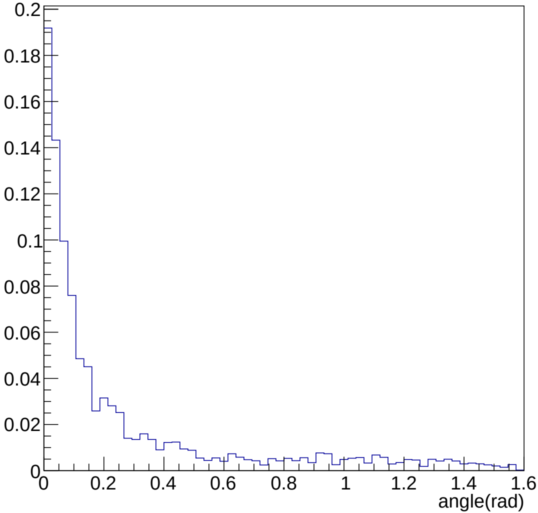
$m_\chi = 85$ GeV, 27.1% between -10 and 10 GeV



Poor energy resolution

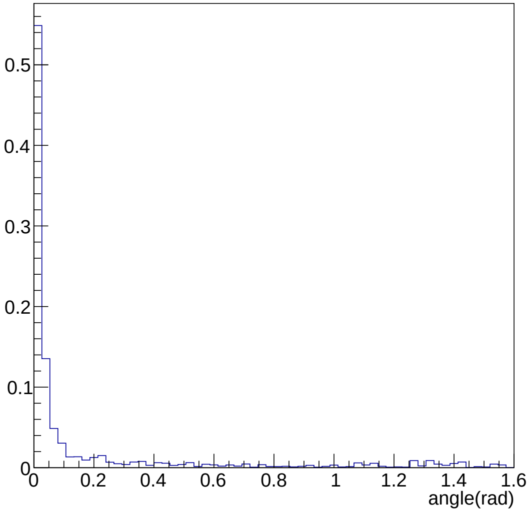
Angular Reconstruction

$m_\chi = 46$ GeV, 51.1% smaller than 0.1 radians



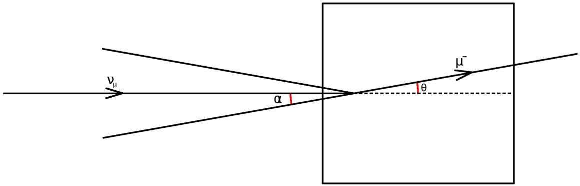
Angular Reconstruction

$m_\chi = 85$ GeV, 76.3% smaller than 0.1 radians



Search Cone

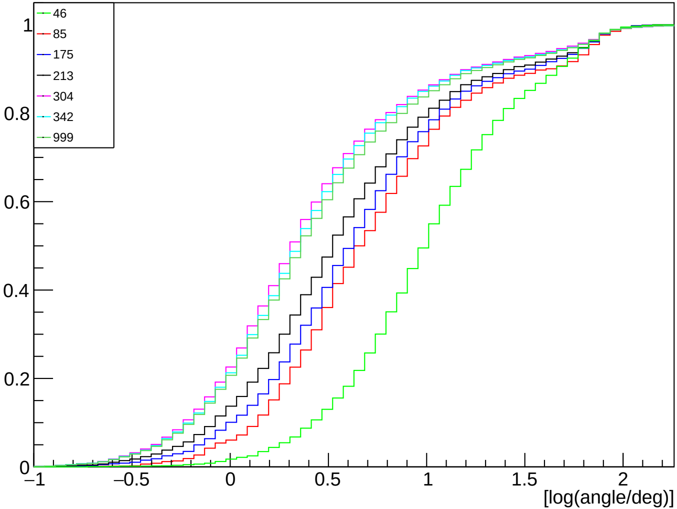
- Measure a night
- Assume all signal events come from same direction
- Assume background event rate equal in all directions: $n(\alpha) = N_{bg}\Omega(\alpha)/4\pi$



All events with $\theta \leq \alpha$ are included

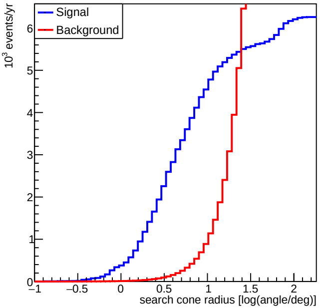
Angular distribution of different models

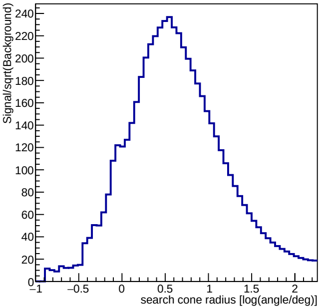
Distribution moves left with higher dark matter mass



Significance

$$\text{Significance} = \frac{F_{sig}\, T}{\sqrt{F_{bg}\, T}} \quad \Rightarrow \quad F_{sig} = \text{Significance} \cdot \sqrt{\frac{F_{bg}}{T}}$$

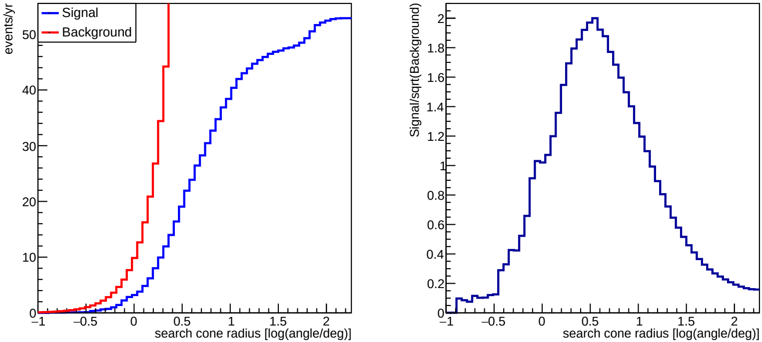




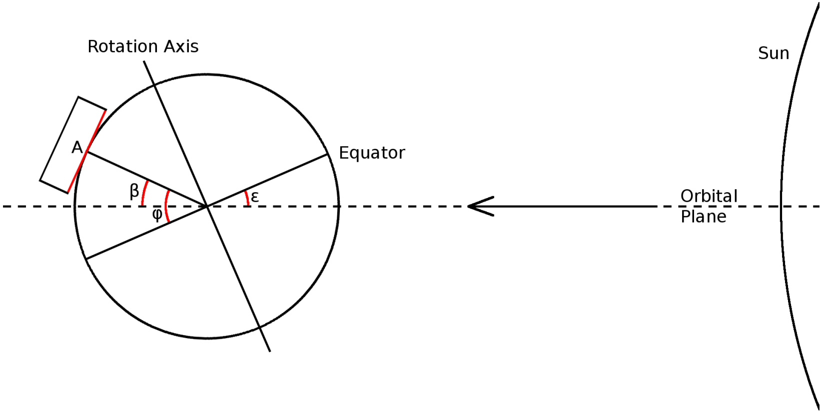
Maximum of significance determines optimal angle

Smallest Detectable Event rate

Example of the smallest detectable flux with a significance of 2



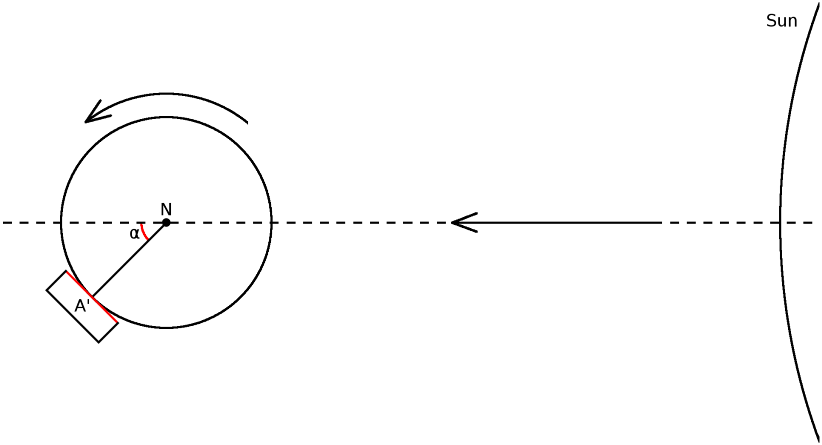
Detector Area



Area perpendicular to the sun: $A\cos\beta$

$\varphi - \epsilon \leq \beta \leq \varphi + \epsilon$

Detector Area



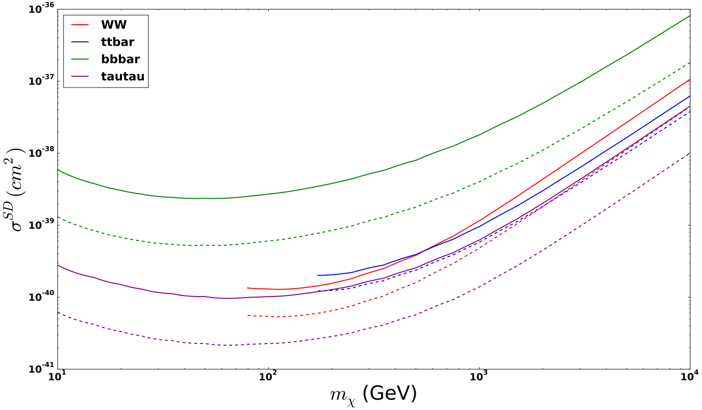
Conversion to cross-section

The cross-section limit can be calculated using: $\sigma = \kappa(m_\chi)\,\frac{F(m_\chi)}{A_{eff}}$

- κ: conversion factor
- F: smallest detectable event rate
- A_{eff}: detector area

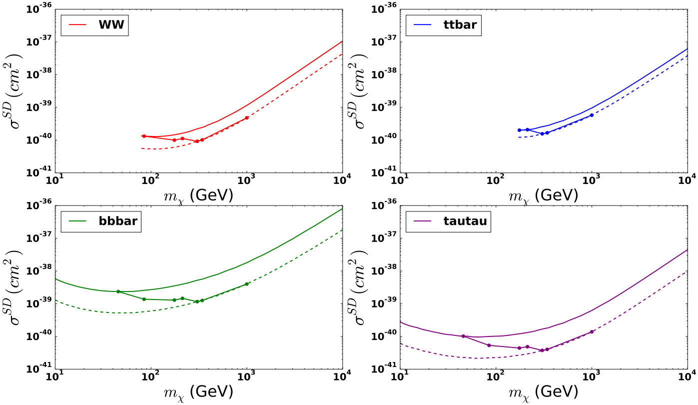
Cross-section Limits

Spin-dependent cross-section

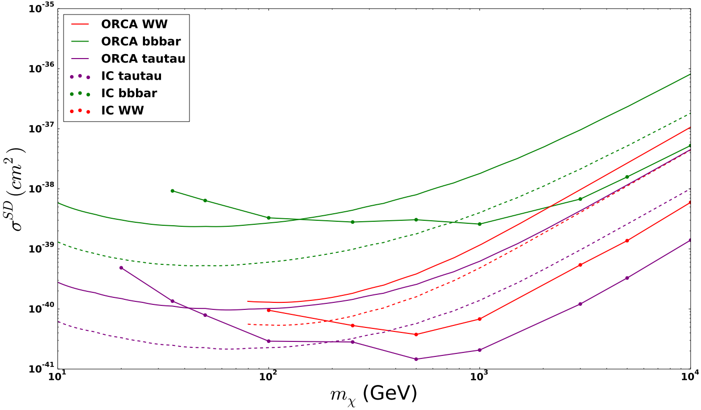


Limits for all Models

Low angular resolution for model with small dark matter mass



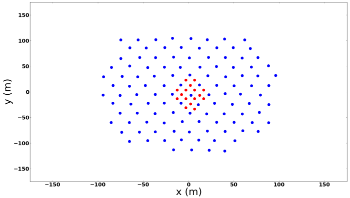
Comparison with IceCube

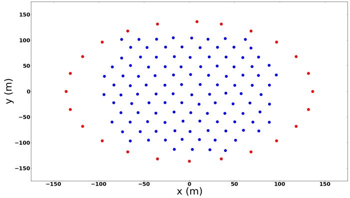


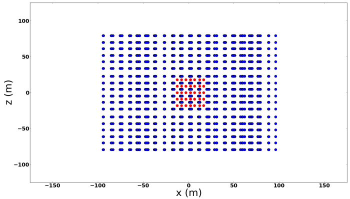
Detector Modifications

Two additions:

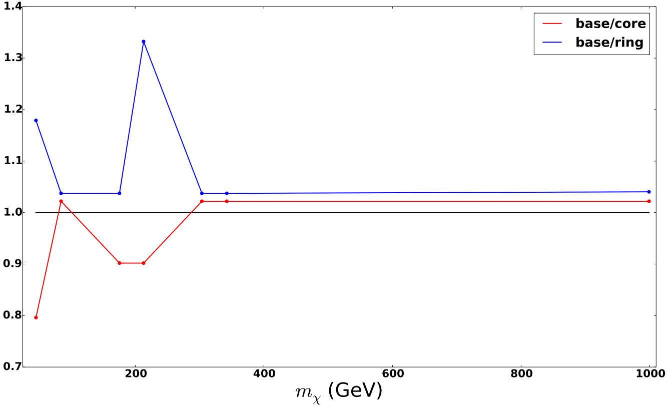
- Ring: Improve energy resolution
- Core: Copy IceCube





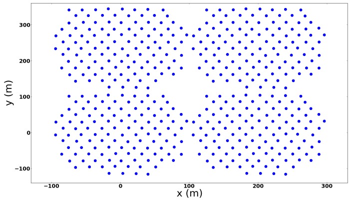


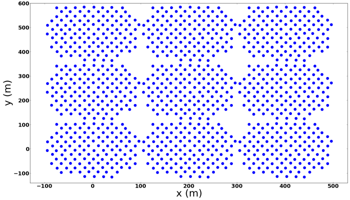
Detector Comparison



Detector Modifications

The detector is duplicated several times:

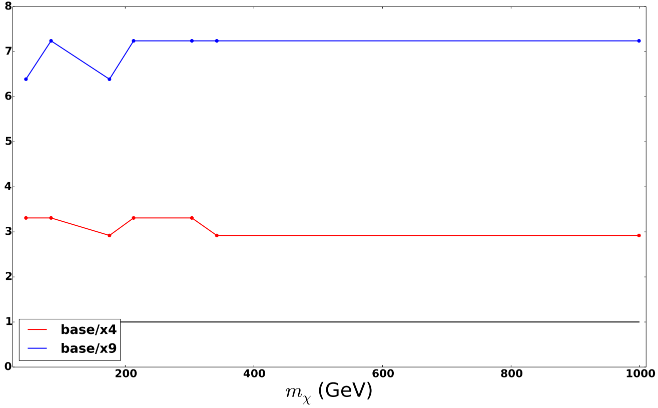




Other modifications:

- ARCA detector layout
- Stretching the ORCA detector

Detector Comparison



Conclusion and Outlook

- Energy resolution is problematic
- Good angular resolution to filter background and signal
- Cross-section limits comparable to IceCube
- Core and Ring modifications too similar to original detector
- Extra detectors improved limits less than expected

Conclusion and Outlook

- More dark matter models required
- Simulate orientation of detector
- More different designs

Dark matter detection may be viable in the future with the ORCA detector

Thank you for your attention