Finding dark matter with IceCube

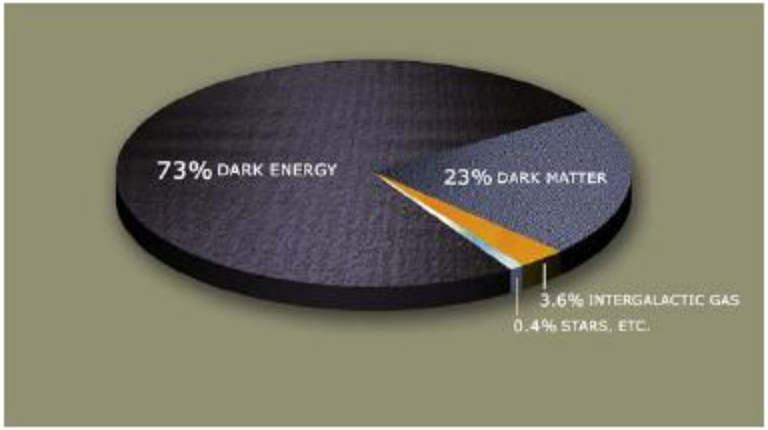
Meike de With
Graduiertenkolleg Fall Block Course, Berlin
October 10, 2012

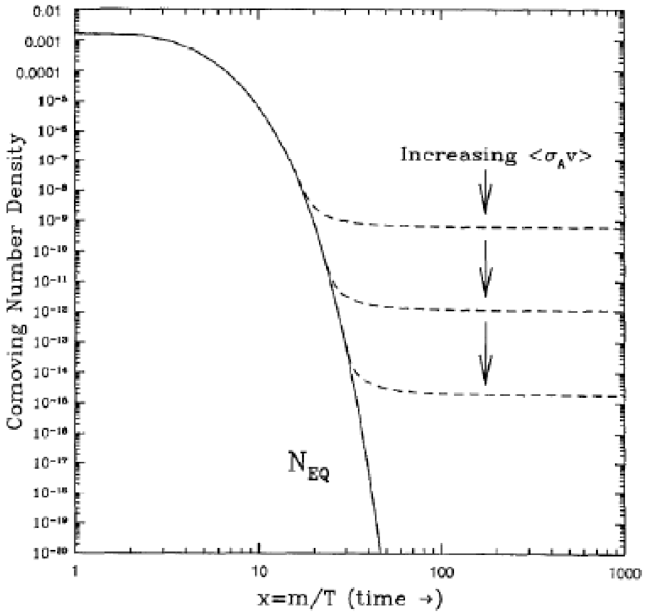
Outline

- Dark matter
- Detecting dark matter
- The IceCube detector
- Detecting WIMPs with IceCube
- Direction reconstructions in IceCube
- Work plan

Dark matter

- Non-luminous matter which must be non-baryonic
- Evidence for dark matter can be found on all scales:
  - Rotation curves of galaxies
  - Gravitational lensing
  - Cosmic Microwave Background anisotropies
- Probably a thermal relic (created in the very early Universe)

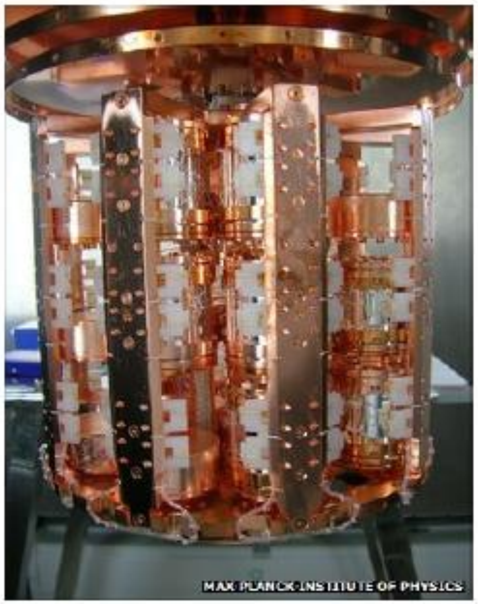




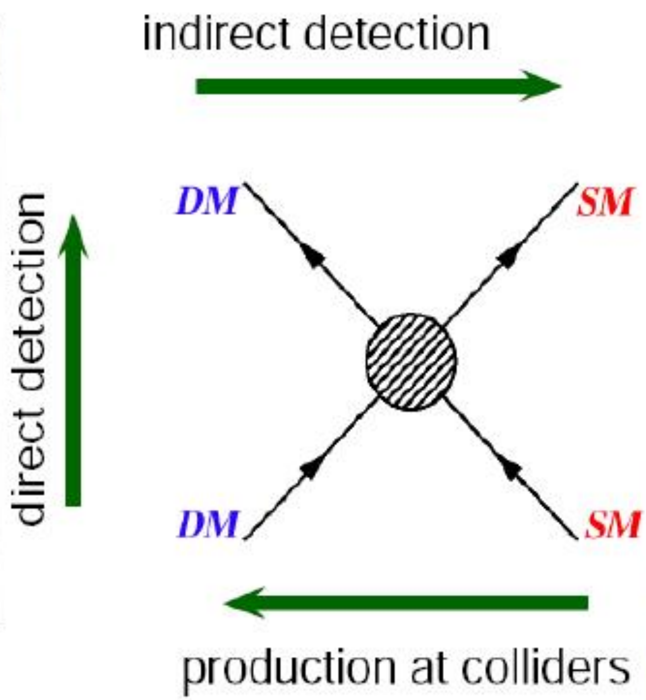
WIMPs

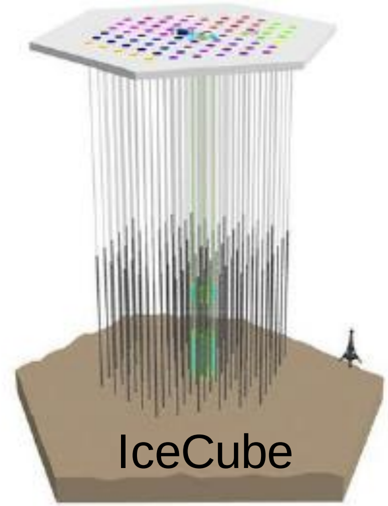
- Weakly Interacting Massive Particles
  ('cold dark matter')
- WIMP miracle: WIMPs have
  ~ right relic density to be dark matter
- Different models:
  - Supersymmetry
  - (Universal) extra dimensions
  - …

Detecting WIMPs



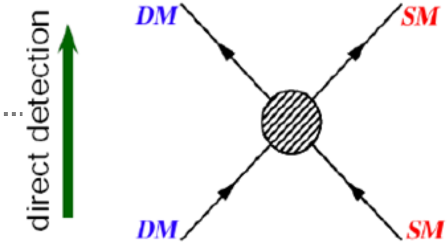
CRESST





LHC

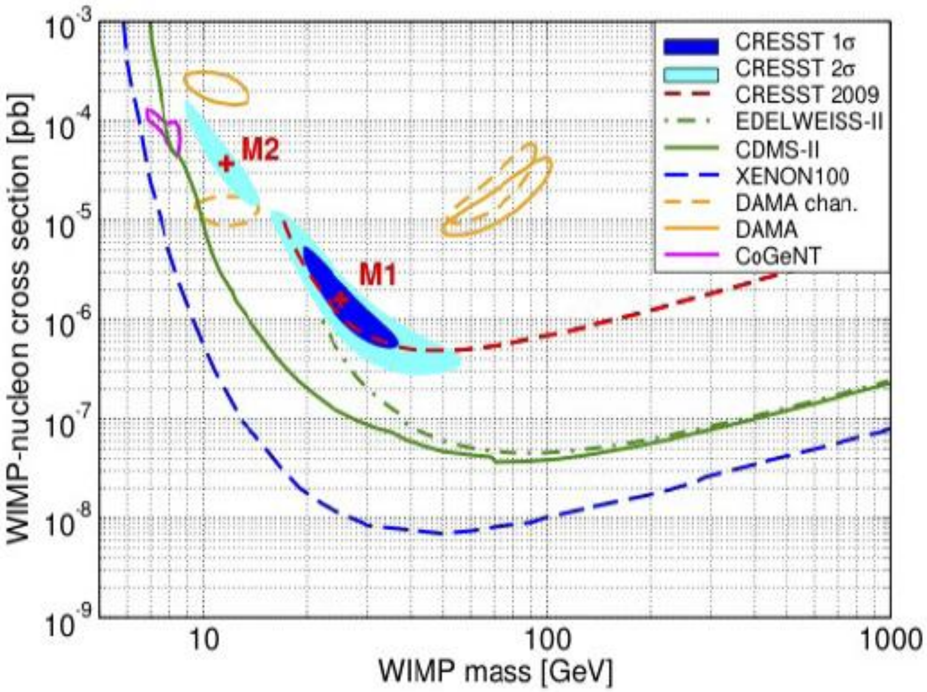
Direct detection



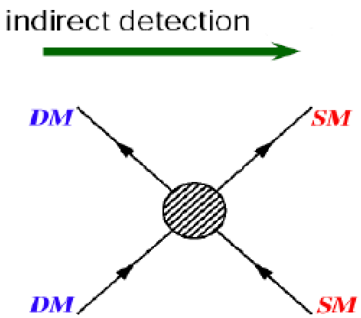
- WIMP scatters off nucleus (energy deposit: ~ keV)

- Two types of interaction:
  - Spin-independent (SD), WIMP couples to nuclear mass
  - Spin-dependent (SI), WIMP couples to nucleon spin

- Discrepancy between results from different experiments



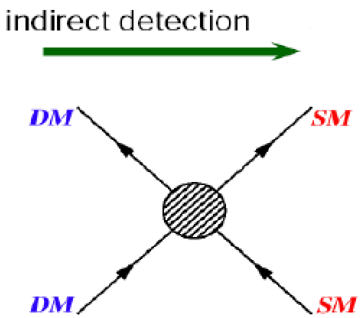
Indirect detection



- Three channels:
  - Antimatter
  - Gamma rays
  - Neutrinos

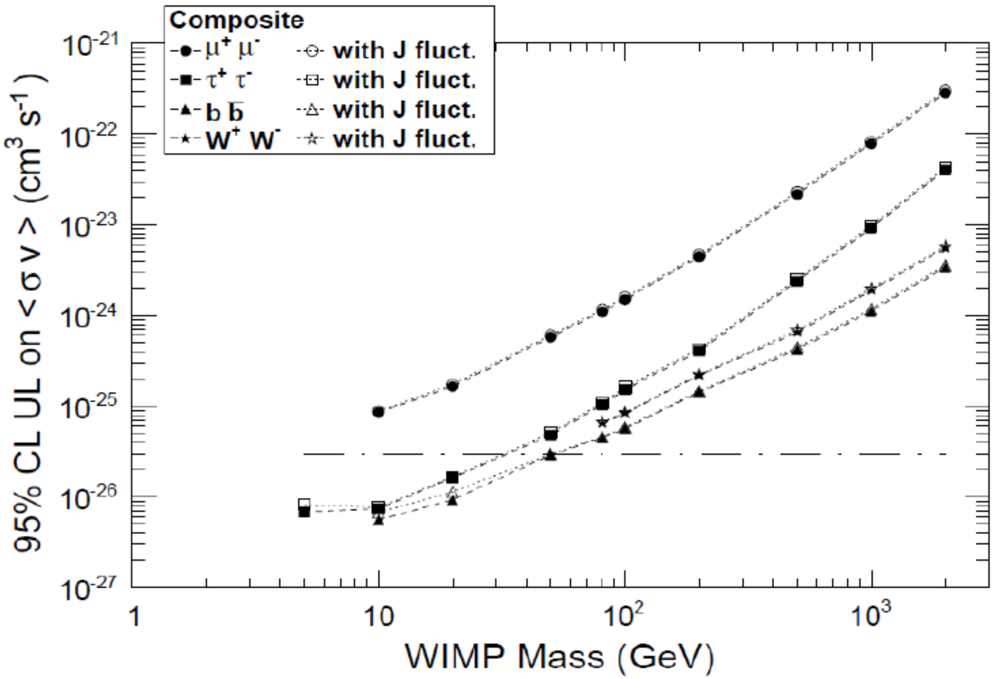
- Search for signal from regions with high dark matter density:
  - Galactic dark matter halo
  - Galactic center
  - Dwarf spheroidal galaxies
  - Galaxy clusters
  - The Sun
  - The Earth

Indirect detection



- Three channels:
  - Antimatter
  - **Gamma rays**
  - Neutrinos

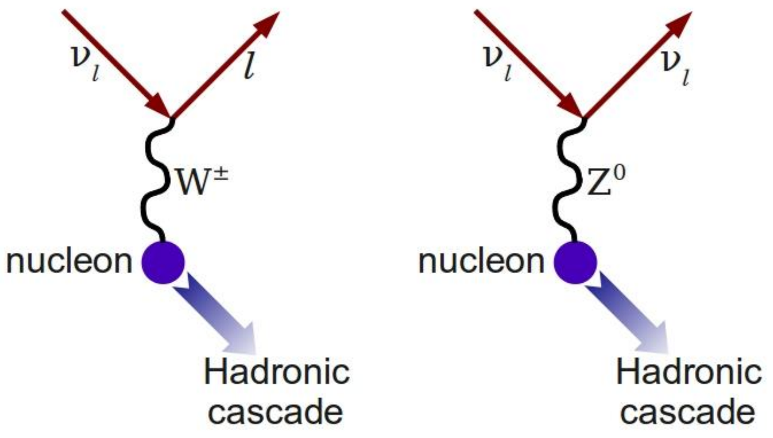
- Search for signal from regions with high dark matter density:
  - Galactic dark matter halo
  - Galactic center
  - **Dwarf spheroidal galaxies**
  - Galaxy clusters
  - The Sun
  - The Earth

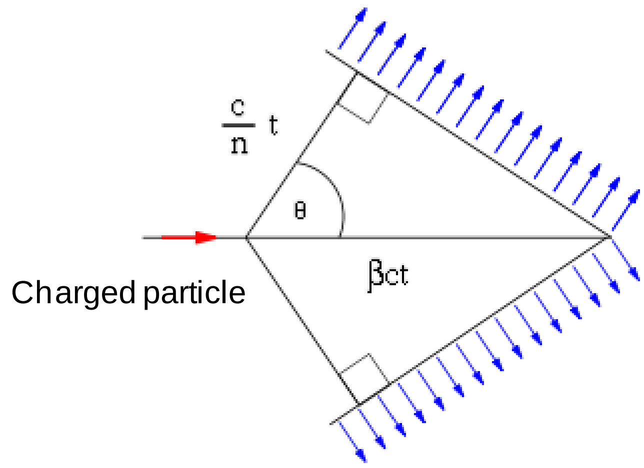


Fermi-LAT

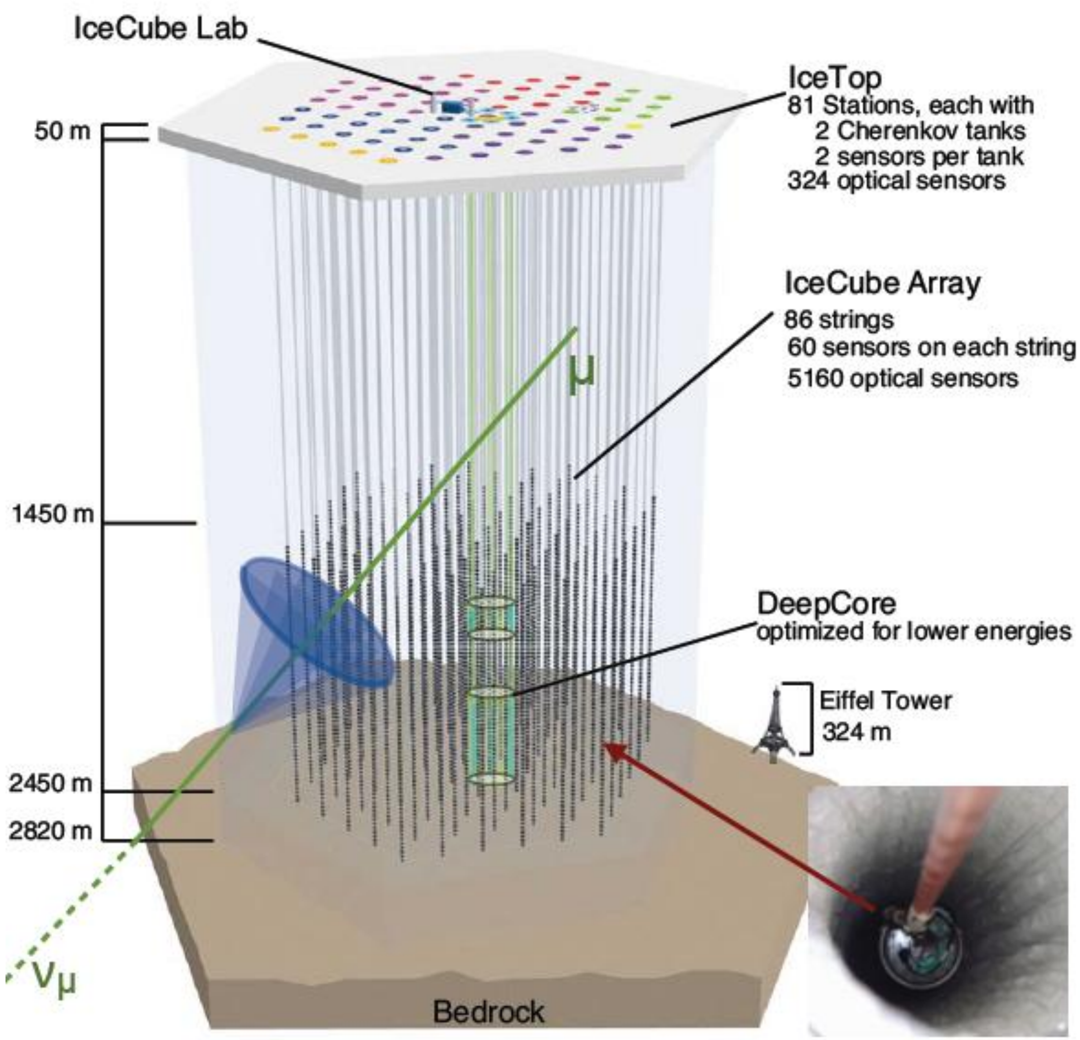
Neutrino detection principle

- Neutrinos can interact, result:
  - Tracks from charged current ν_μ interactions
  - Cascades from other interactions (neutral current, ν_e, ν_τ)
- In a medium, charged particles will emit Cherenkov radiation
- Record intensity and arrival times of Cherenkov radiation -> allows to reconstruct energy and direction of charged particle





The IceCube detector



- IceCube:
  - 125 m string spacing
  - 17 m DOM spacing
- DeepCore:
  - 70 m string spacing
  - 7 m DOM spacing

DOM: Digital Optical Module

Detecting dark matter with IceCube

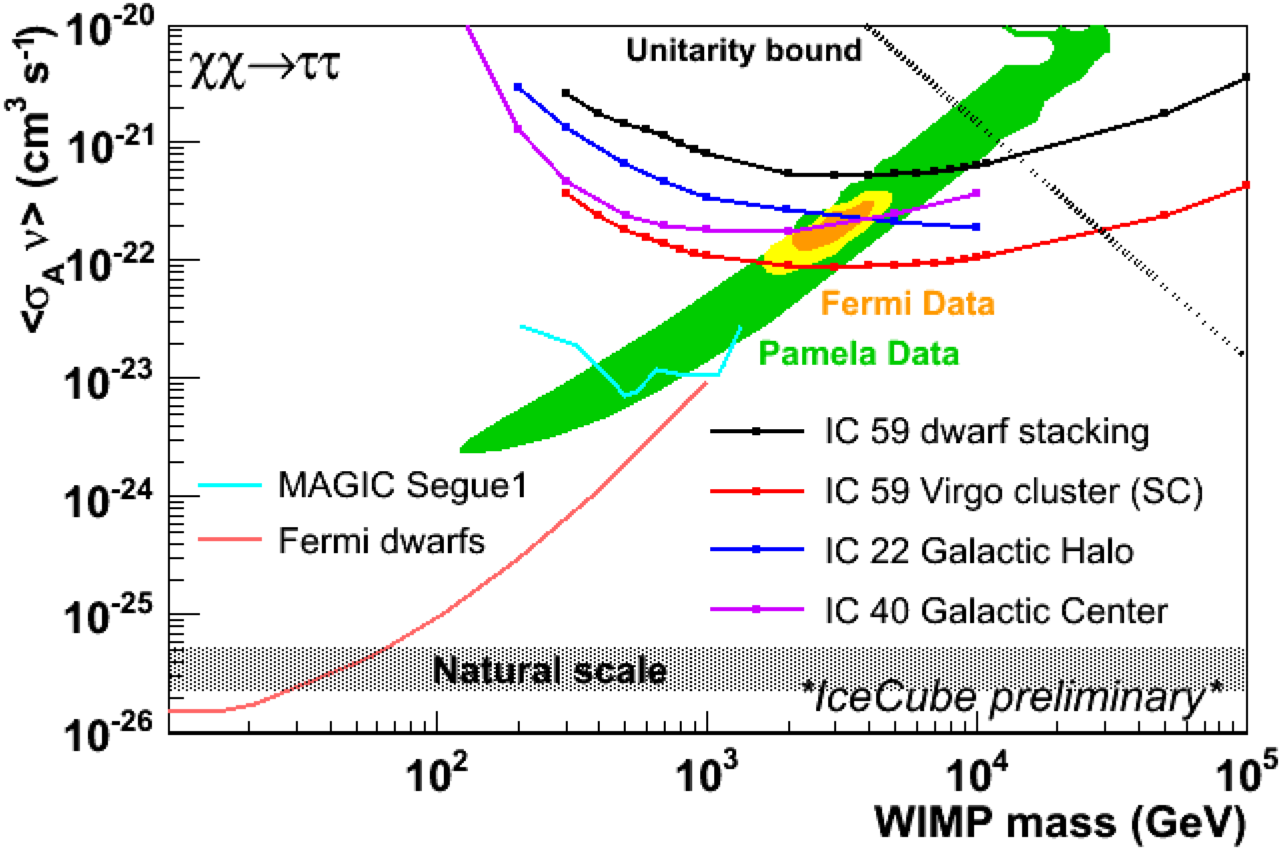
- Benchmark channels are used:
  - $\chi\chi \rightarrow WW/\tau\tau$
  - $\chi\chi \rightarrow bb$
  - $\chi\chi \rightarrow \upsilon\upsilon$

- Resulting neutrinos have GeV to TeV energies:
  DeepCore is important here!

- Search for an excess of neutrinos from a certain direction -> good direction reconstruction is very important!

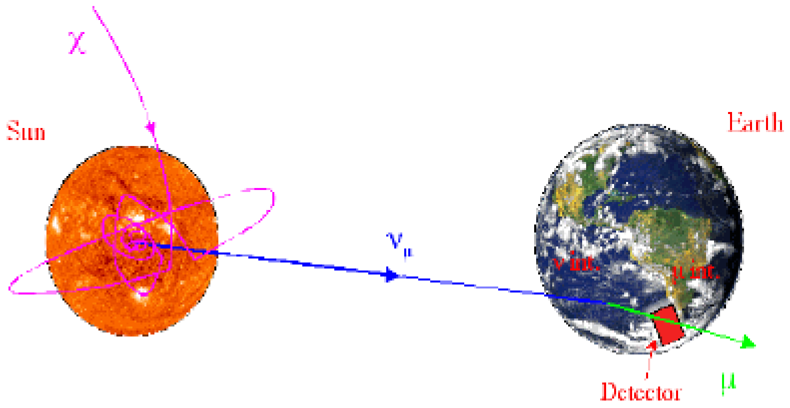
- Can constrain annihilation cross section (like gamma rays) or WIMP-nucleon interaction cross section (like direct detection experiments)

Constraining the annihilation cross section

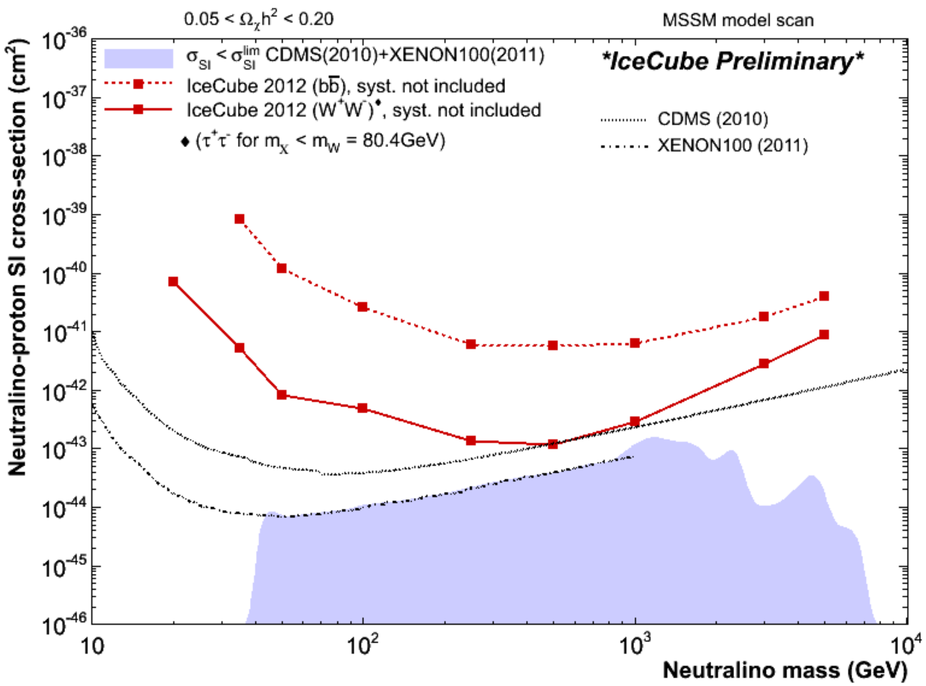


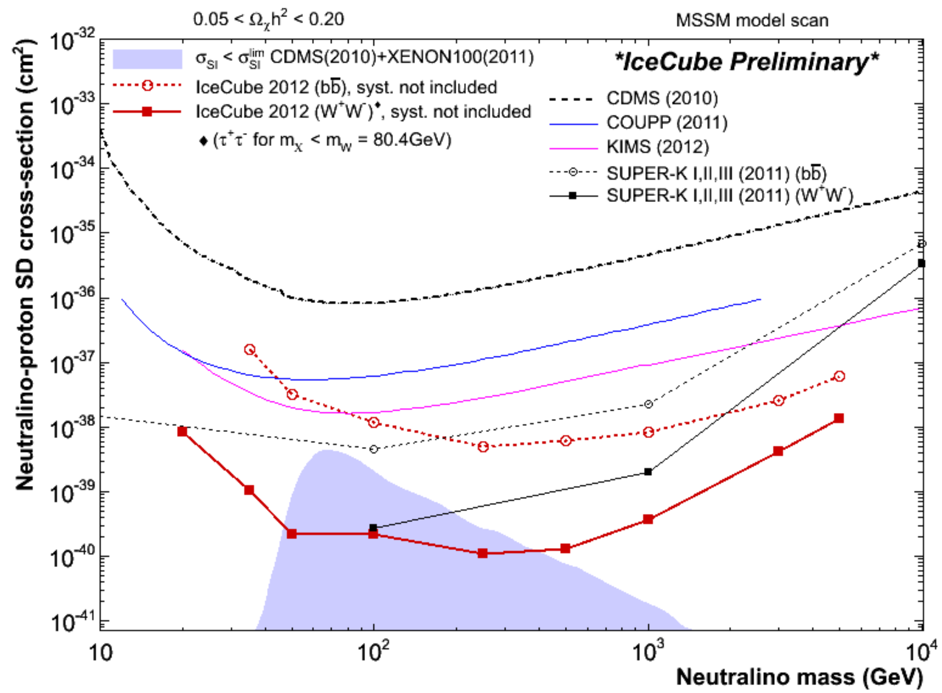
Neutrino capture and annihilation

- WIMPs lose energy by scattering in the Sun with capture rate Γ_C
- They annihilate in the Sun with annihilation rate Γ_A
- Equilibrium ($\Gamma_C = 2\Gamma_A$) is usually reached for the Sun, not always for the Earth
- Probe nucleon-WIMP interaction cross section



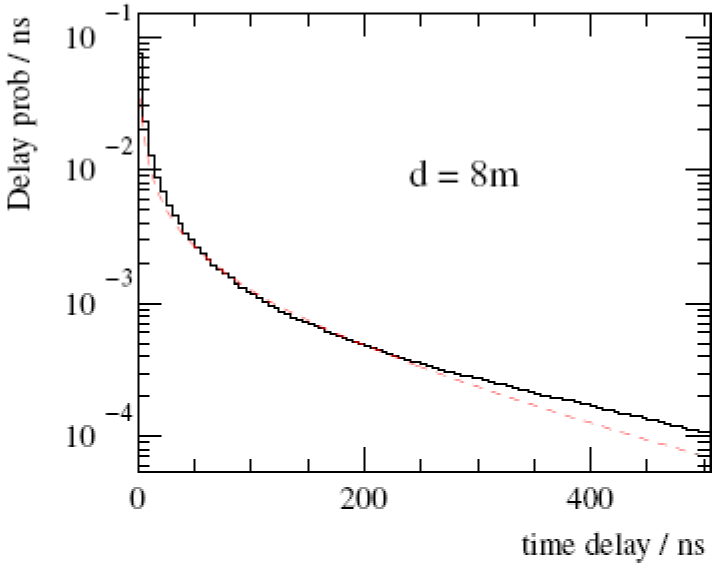
Constraining the nucleon-WIMP cross section

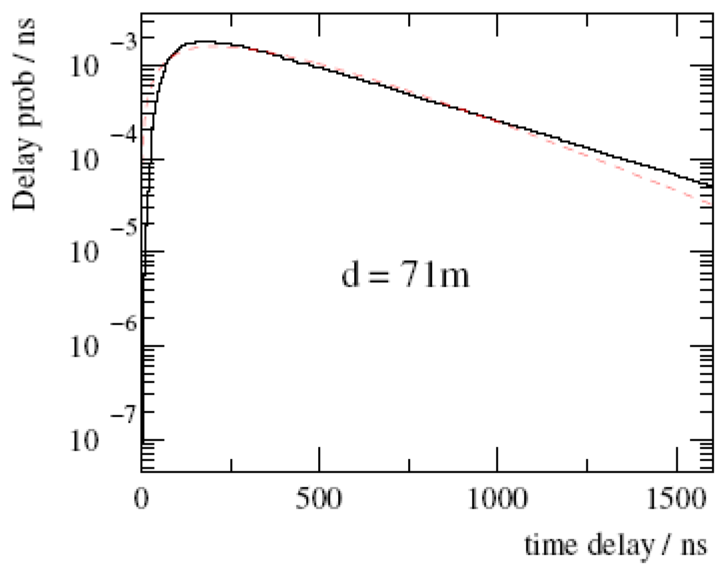




- For SI scattering, direct detection limits are better
- For SD scattering, IceCube limits are better (Sun consists of protons)

Direction reconstruction in IceCube/DeepCore

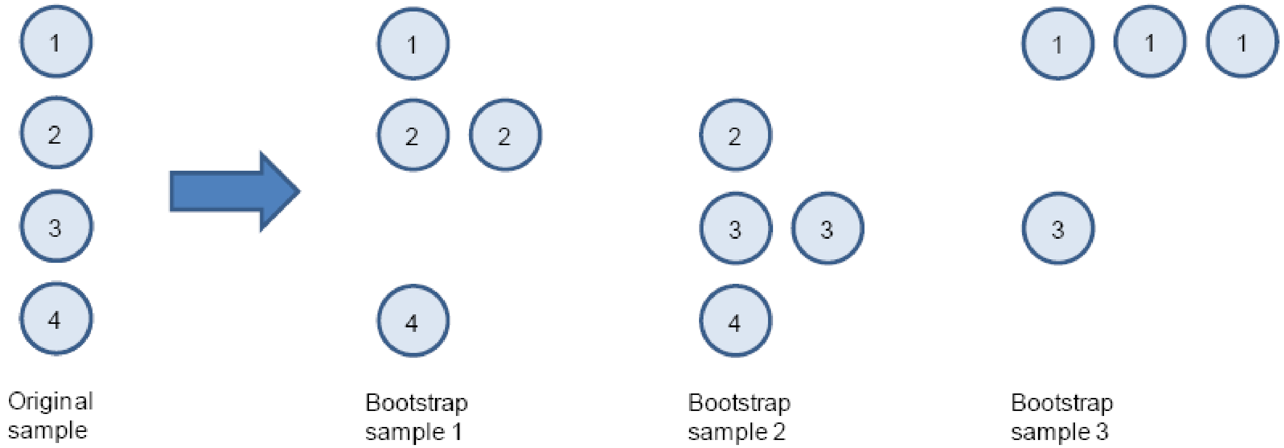




- Current ‘standard’: SPEFit
- Input: times and locations of ‘pulses’ in DOMs
- For certain track hypothesis, determine for each pulse the time delay (real arrival time – expected arrival time)
- Determine likelihood for each pulse from Pandel function
- Find track hypothesis for which total likelihood is maximal

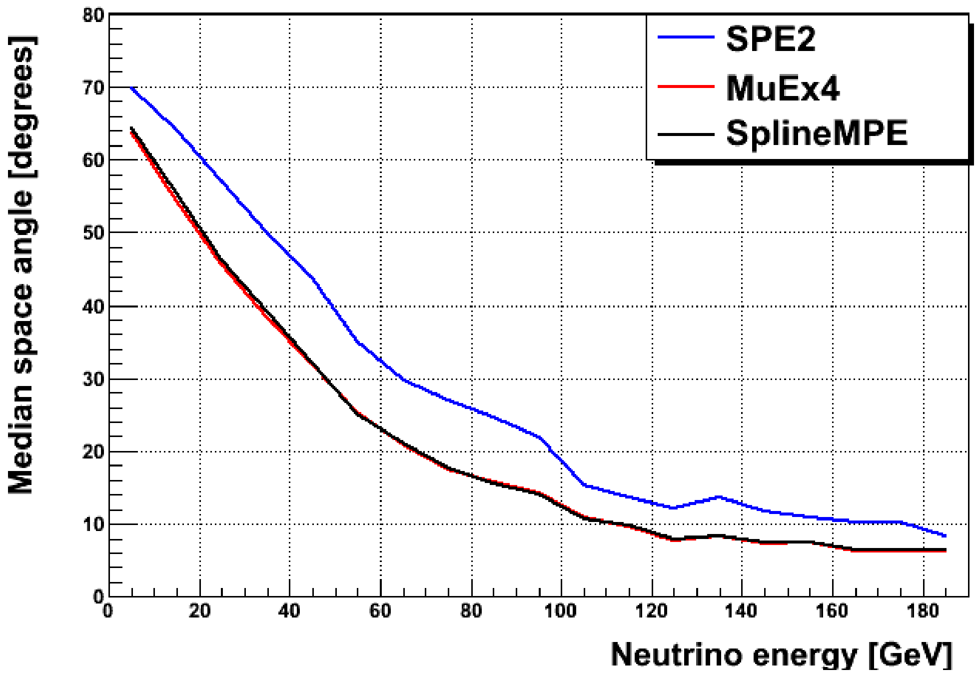
Possible improvements

- SplineMPE:
  - determine time delay distributions from Monte Carlo simulations, tabulate them, fit them with spline functions
- MuEx:
  - Start with input pulses (original sample)
  - Create N ‘bootstrap samples’ by sampling with replacement
  - Do Pandel fit to each bootstrap sample (bootstrap fits)
  - Determine average of bootstrap fits
  - Use average of bootstrap fits as seed for a fit on the original sample



Testing reconstructions for low-energy events

- Using Monte Carlo events with E_ν between 1 and 190 GeV
- Determine space angle: angle between true and reconstructed muon track
- Clearly improvement w.r.t. standard fit (SPE2)



Work plan

- Decide on a region to use for this analysis
- Simulate signal and background events
- Determine optimal cuts to remove background events
- See if there is an excess

- Work on combining limits from different experiments

Conclusions

- Current evidence point to a significant fraction of the total matter density in our Universe being ‘dark’ matter
- WIMPs are an important dark matter candidate for which many experiments (LHC, direct, indirect) are searching
- Indirect searches with neutrinos can probe the WIMP-nucleon scattering cross section (Sun, Earth) and the self-annihilation cross section (Galactic Center, Galactic Halo, galaxy clusters, dwarf spheroidal galaxies)
- To determine the mass and properties of the dark matter, searching in different channels is important

Back-up slides

Signs of dark matter on all scales

- Rotation curves of galaxies
- Gravitational lensing
- Cosmic Microwave Background anisotropies
- About 22% of the Universe consists of Dark Matter