Finding Dark Matter in Galaxy Clusters with IceCube

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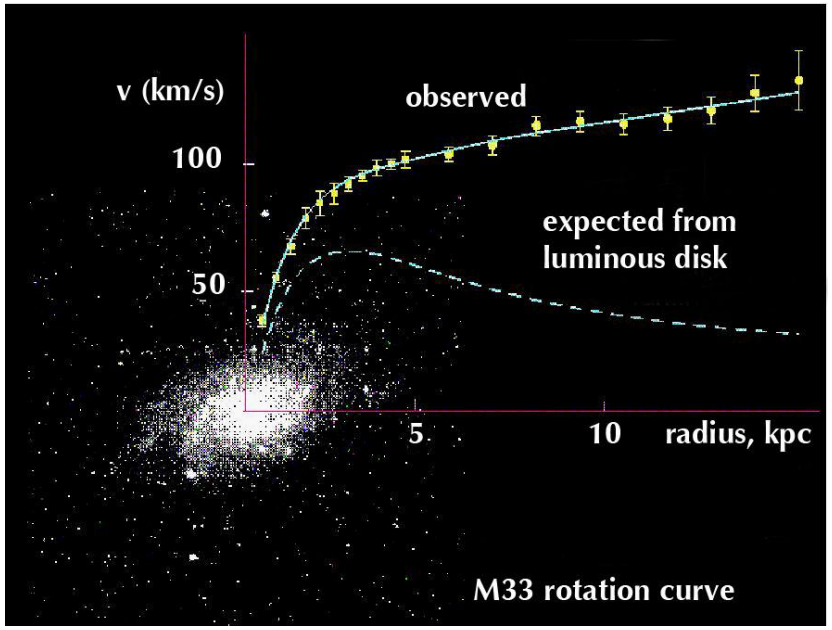
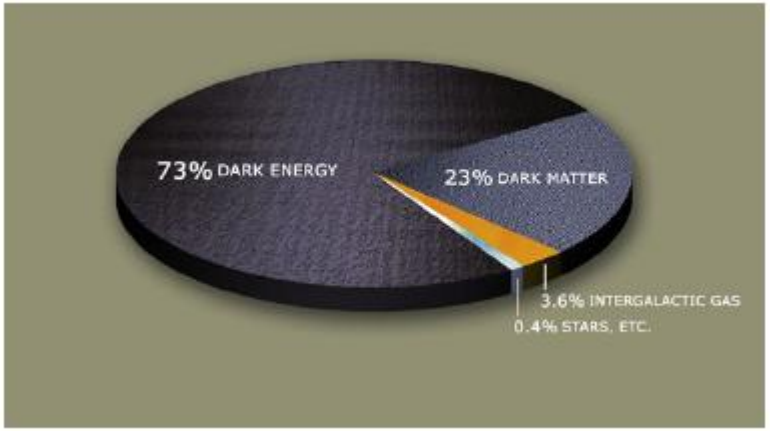
Outline

- Dark matter and how to detect it
- The IceCube detector
- Searching for dark matter in galaxy clusters
- Direction reconstructions in IceCube
- Conclusions

Dark matter

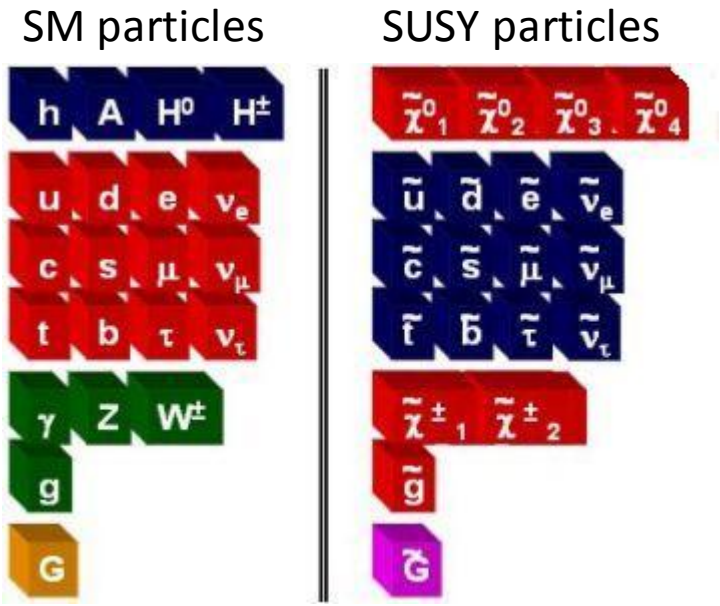
- Non-luminous matter
- Evidence for dark matter can be found on different scales:
  - Rotation curves of galaxies
  - Cosmic Microwave Background anisotropies
  - Gravitational lensing
  - Bullet Cluster
  - …
- Must be non-baryonic



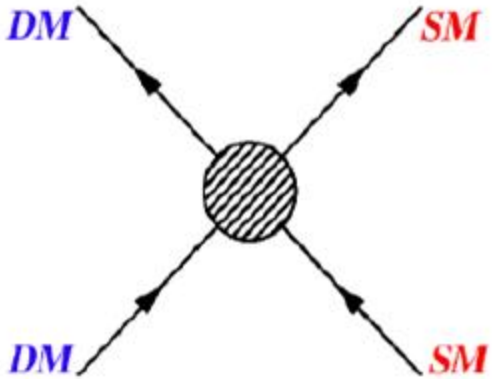


WIMPs

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



Detecting WIMPs



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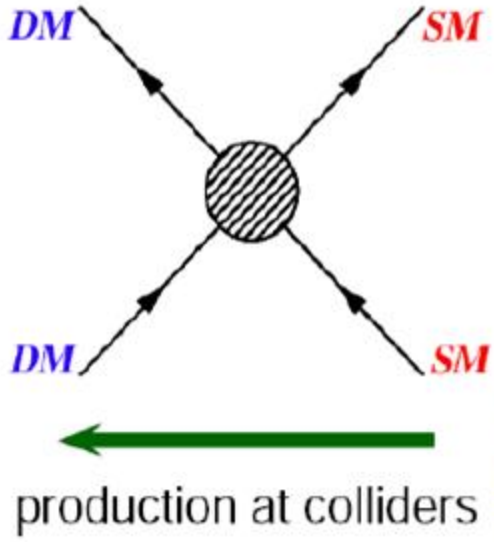

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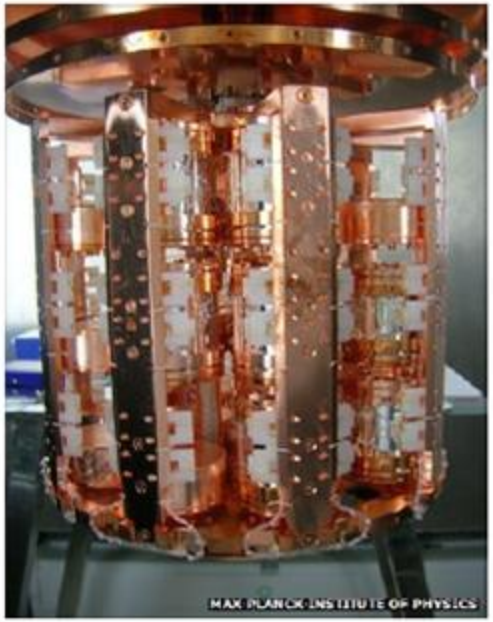
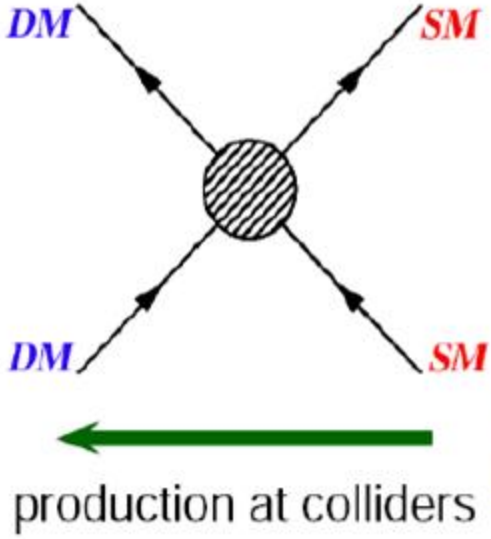
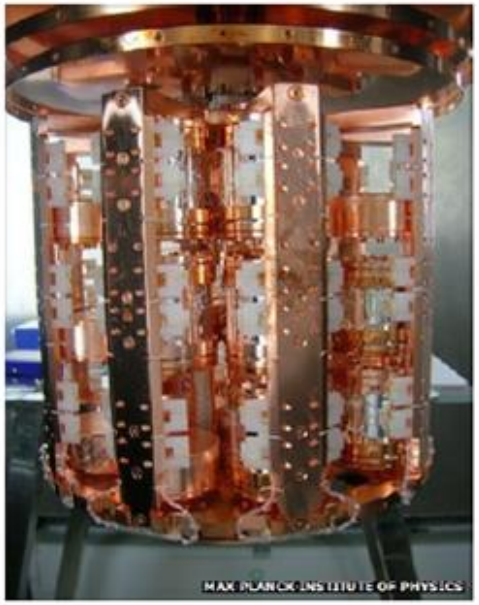
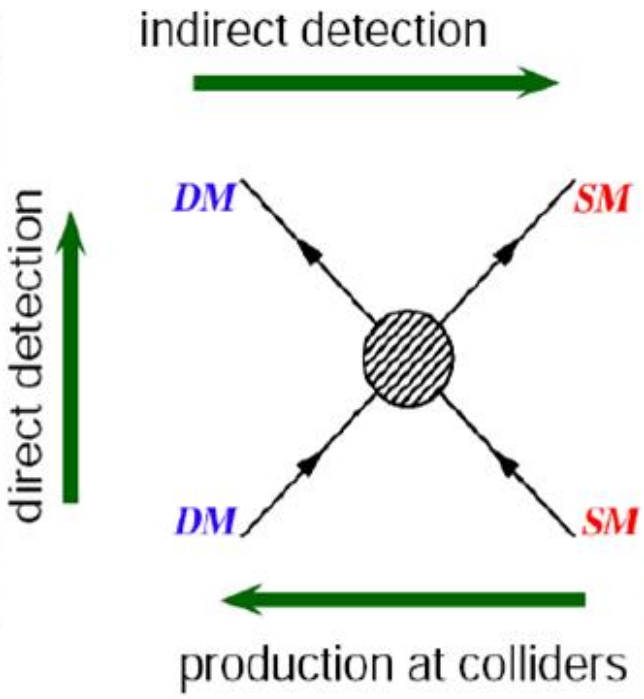


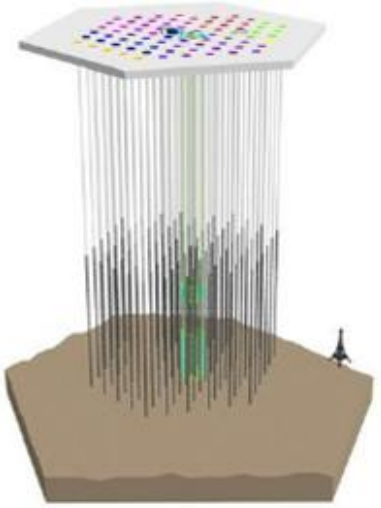
direct detection



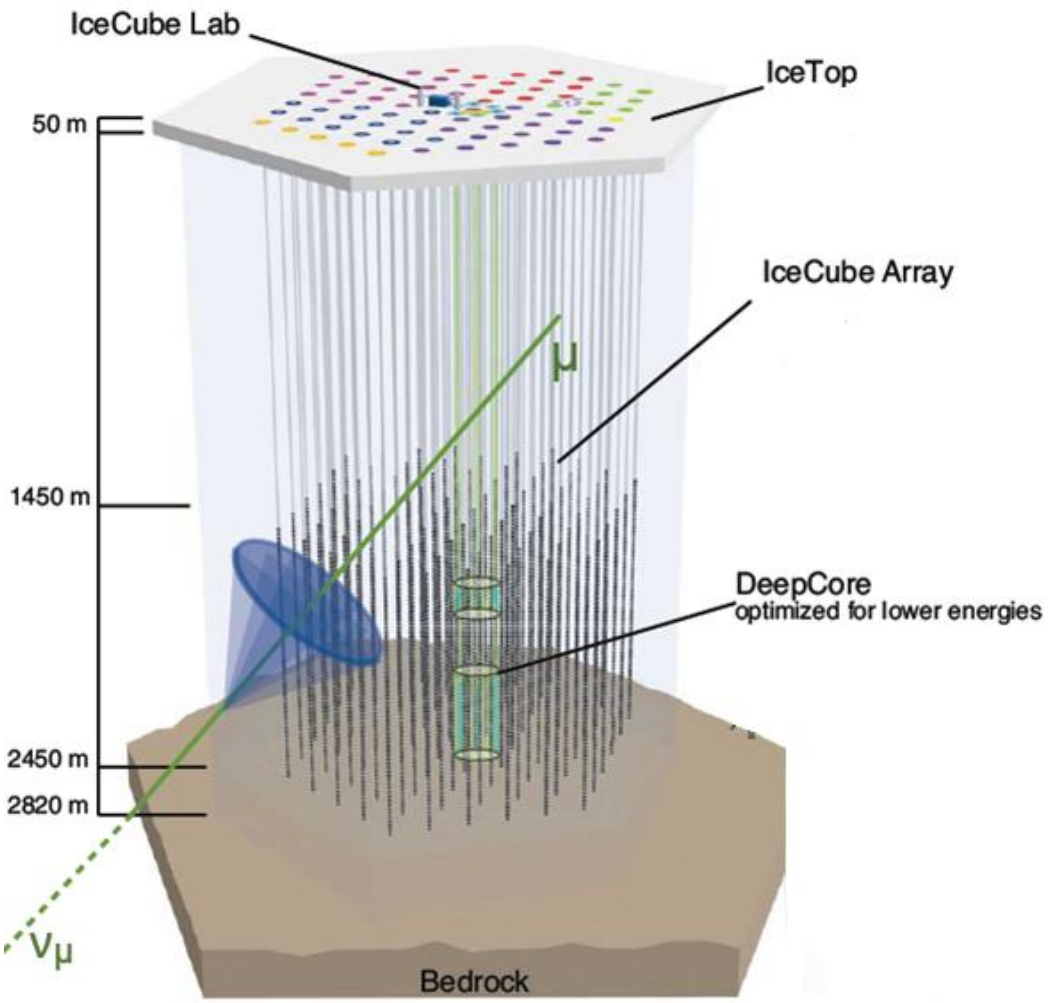
Detecting WIMPs







The IceCube observatory

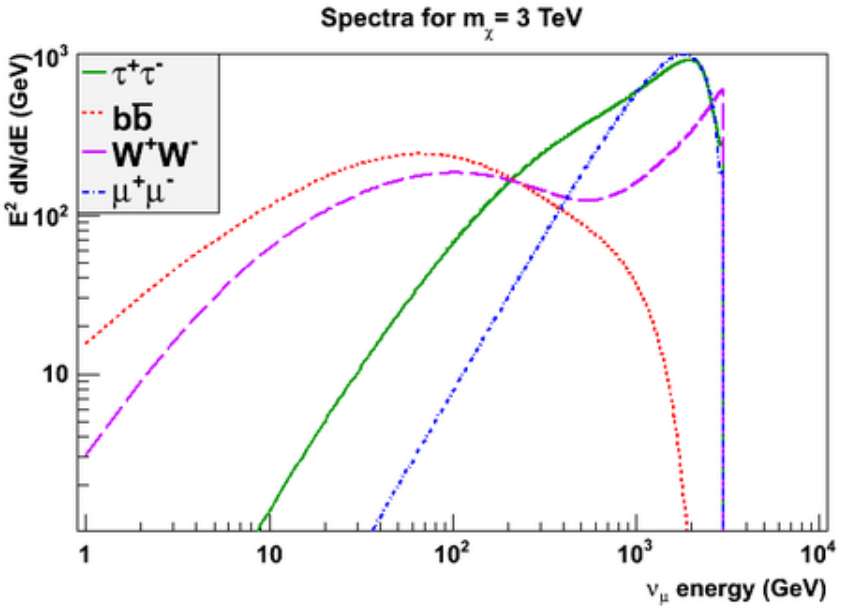


- IceCube:
  - 125 m string spacing
  - 17 m DOM spacing
- DeepCore:
  - 70 m string spacing
  - 7 m DOM spacing

DOM: Digital Optical Module

Detecting dark matter with IceCube

- Search for an excess of neutrinos from regions with high dark matter density:
  - Galactic dark matter halo and center
  - Dwarf spheroidal galaxies and galaxy clusters
  - The Sun and the Earth
- For setting limits, benchmark channels are used:
  - $\chi\chi \rightarrow WW$
  - $\chi\chi \rightarrow \tau\tau$
  - $\chi\chi \rightarrow bb$
  - $\chi\chi \rightarrow \upsilon\upsilon$
- Signal neutrinos have energies up to ~ 100 TeV



Dark matter in galaxy clusters

- Mass ~ 10^{14} to 10^{15} $M_{\odot}$, about 85 % of their mass consists of dark matter
- Diameter is a few Mpc, for close-by clusters this is a few degrees
- Exact form of dark matter profile is not known at the moment

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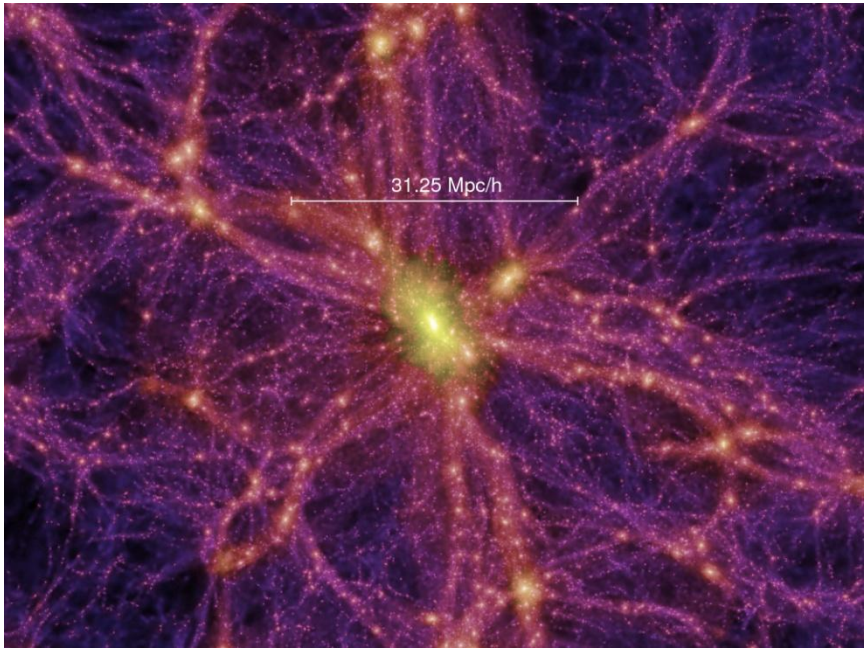
Substructures

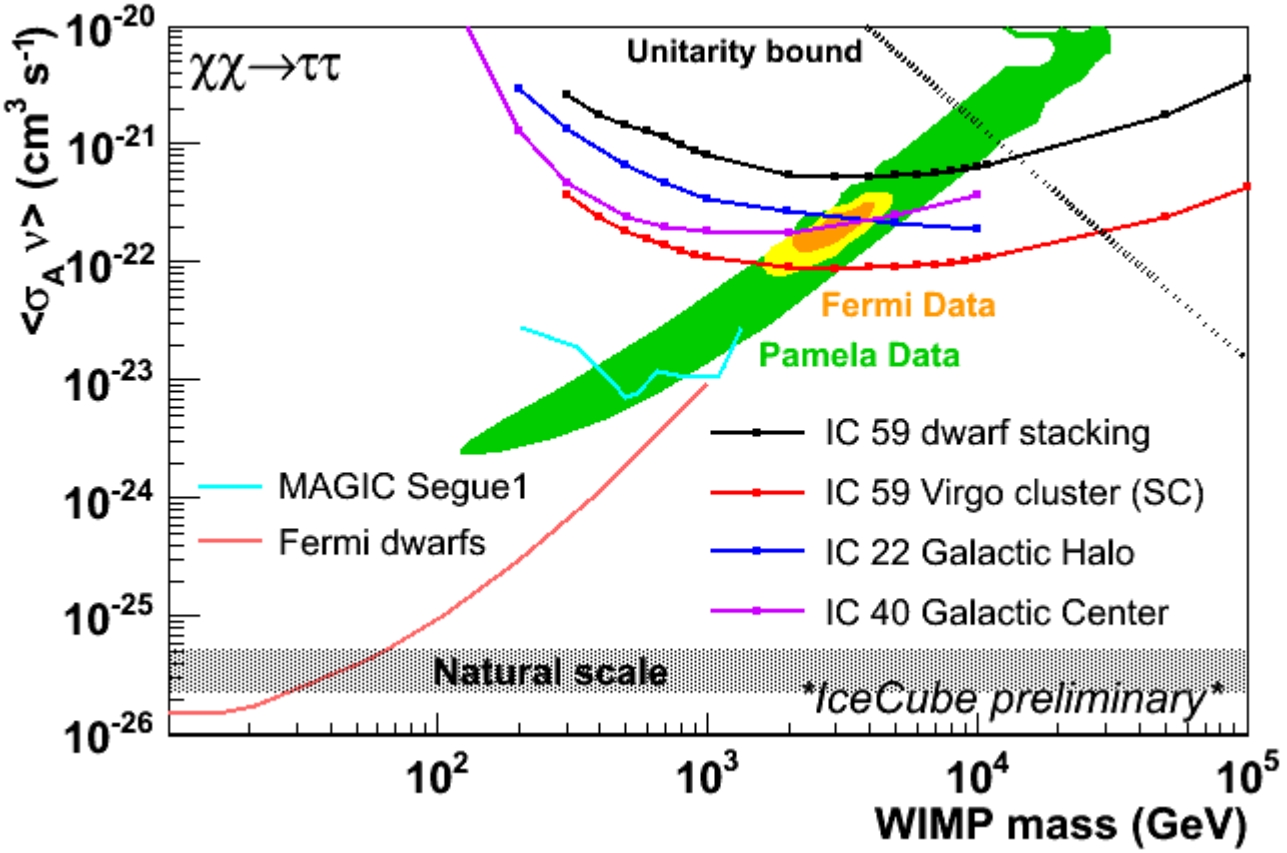
- N-body simulations show that a large population of dark matter substructures is present:
  - gives boost factor of ~ 1000 (but still many uncertainties)
  - dark matter signal extended (a few degrees for clusters that are close)

- Galaxy clusters interesting targets for neutrino telescopes



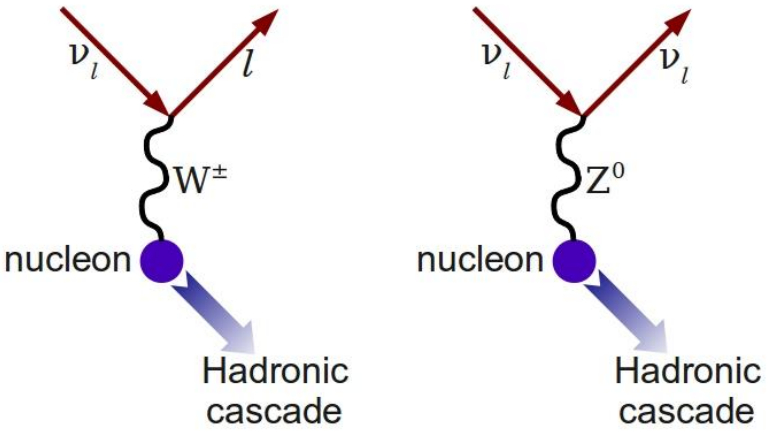
V. Springel et al., *Nature* **435**, 2005

Constraining the annihilation cross section



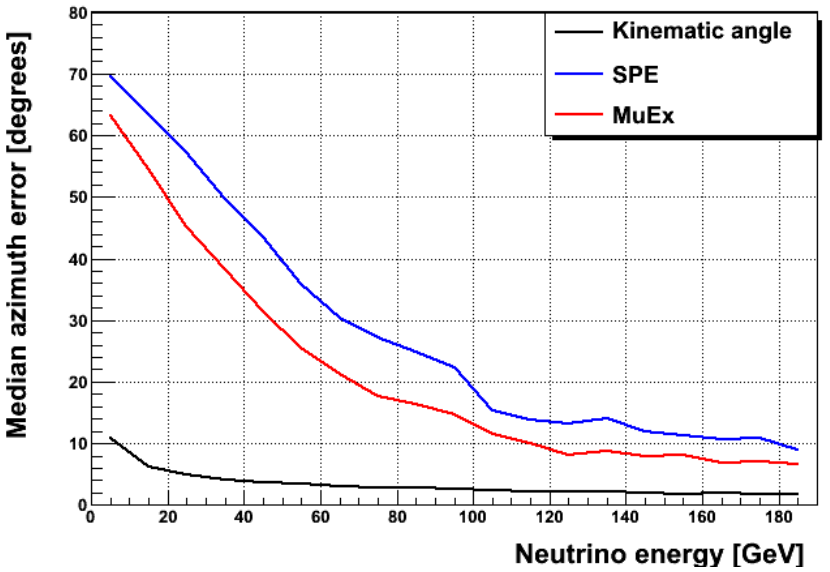
Direction reconstructions in IceCube

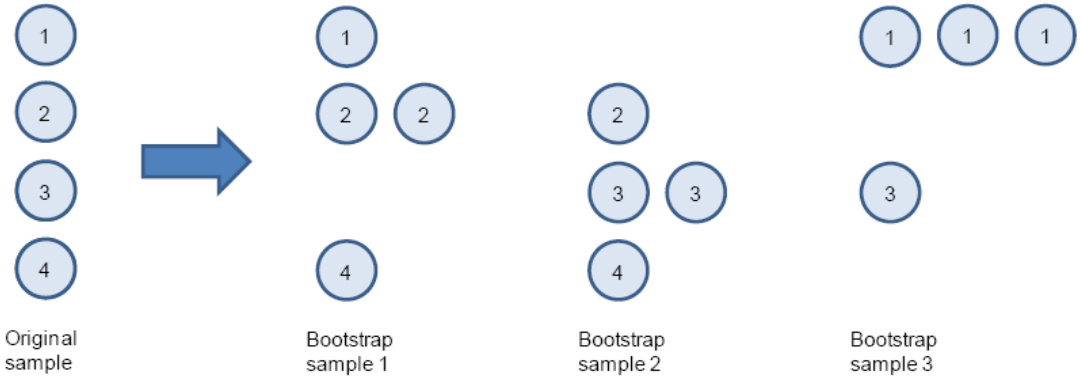
- Use only track-like events (where muon is created)
- $E_\upsilon > 1$ TeV: angular resolution < 1º
- For lower energies, the angular resolution is (much) larger, so there is room for improvement
- Take into account kinematic angle



Improving low-energy direction reconstruction

- SPE (current standard):
  - Search for track hypothesis which has maximal likelihood of this track giving the times and locations of the hits that we see in the DOMs
- MuEx:
  - Create bootstrap samples from original sample
  - Do SPE fit on bootstrap samples
  - Use average of ‘bootstrap fits’ as seed for fit on original sample





Conclusions

- Overwhelming evidence points 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
- Galaxy clusters with substructure are a promising source for neutrino searches, current results will be improved by using more galaxy clusters and using low-energy extension (DeepCore)
- Combining constraints from different experiments very important

Backup slides

Dark matter creation

- Dark matter is probably a thermal relic
- If $T_{uni} > m_\chi$: $\chi\chi \leftrightarrow ll$
- If $T_{uni} < m_\chi$: $\chi\chi \rightarrow ll$
- If reaction rate < Hubble expansion rate : χ no longer annihilate