



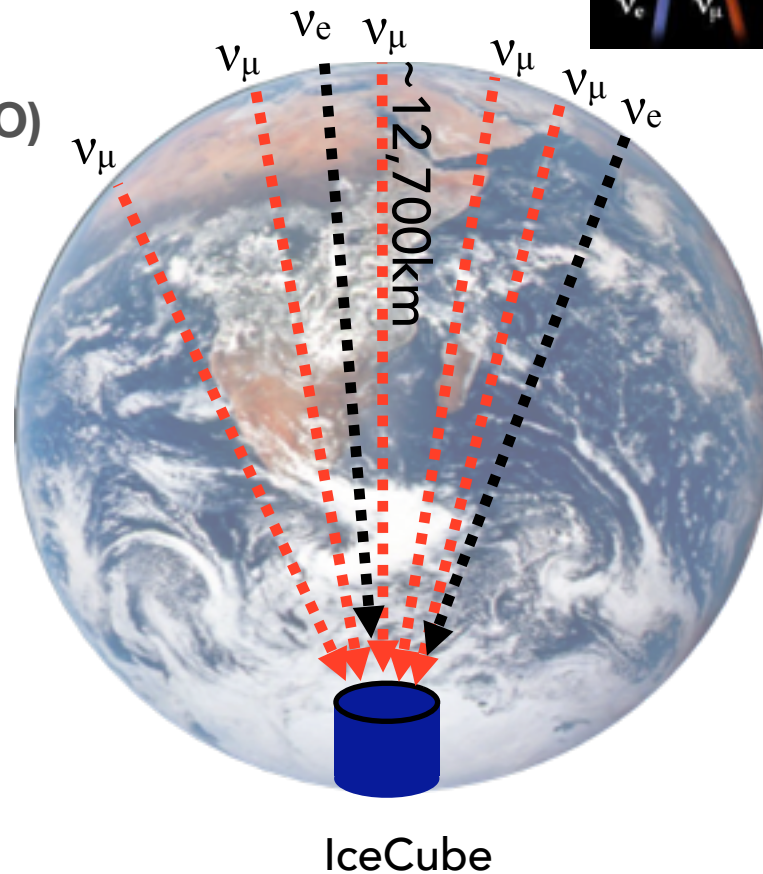
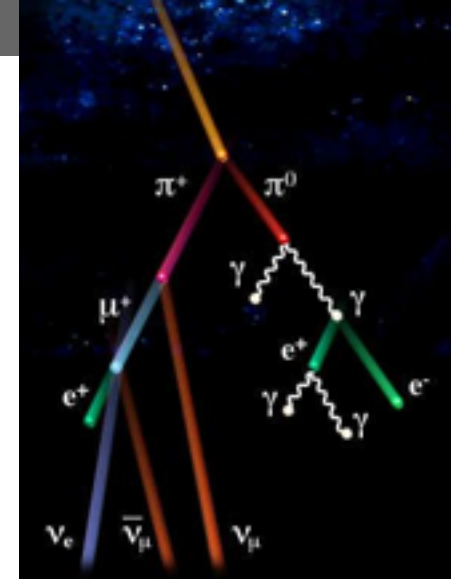
Early atmospheric muon rejection with IceCube-PINGU

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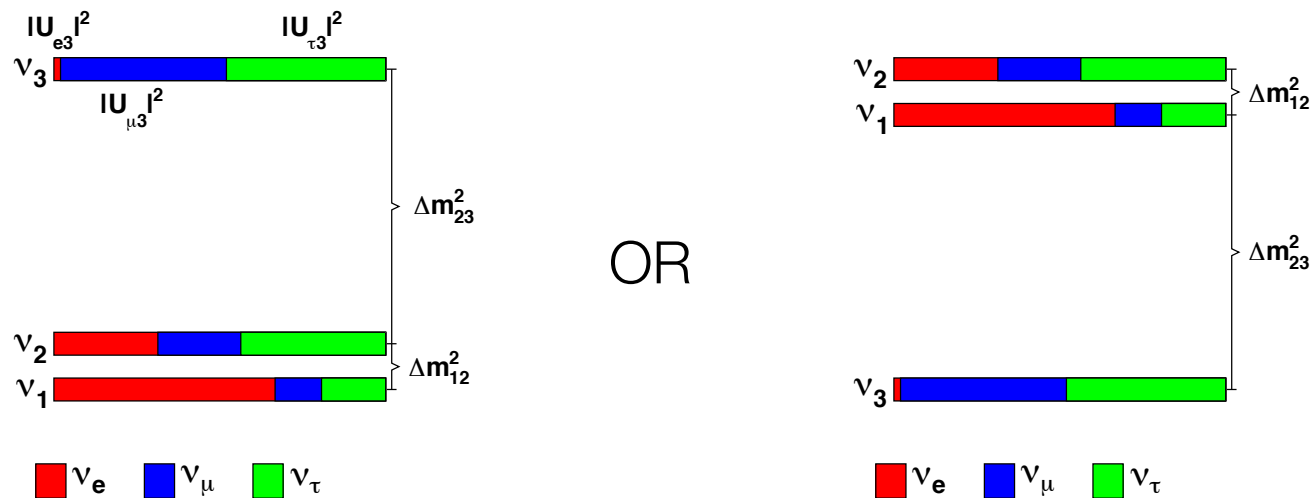
January 3, 2016

Low Energy Atmospheric Neutrinos

- From cosmic rays interacting in the atmosphere
- Offers a wide range of energies and baselines for
 - Oscillation parameters
 - **Neutrino mass ordering (NMO)**
- Also improves sensitivity on
 - Gamma ray bursts
 - Dark matter searches



Neutrino Mass Ordering



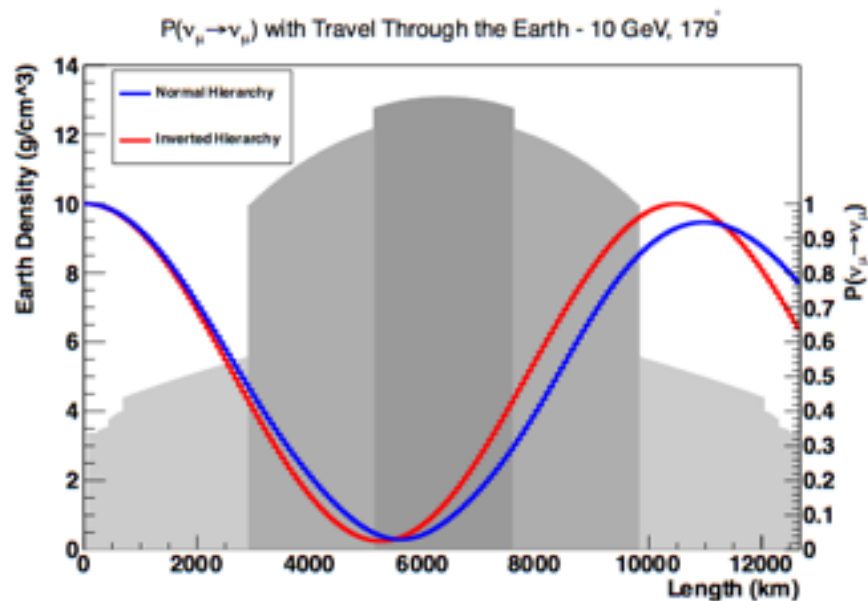
Knowledge of the NMO has implications for

- Neutrino mass determination
- CP violating search
- Neutrinoless double- β decay
- Core-collapse supernovae



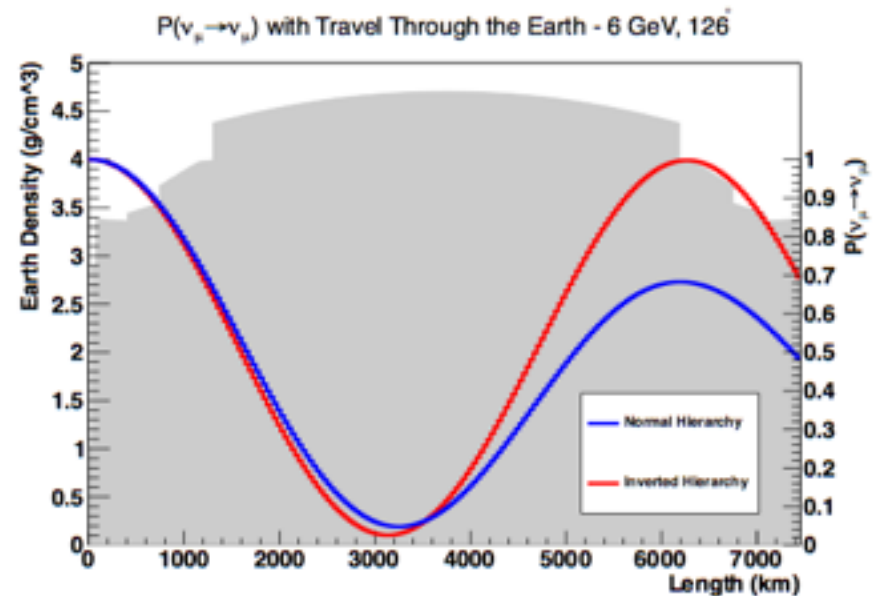
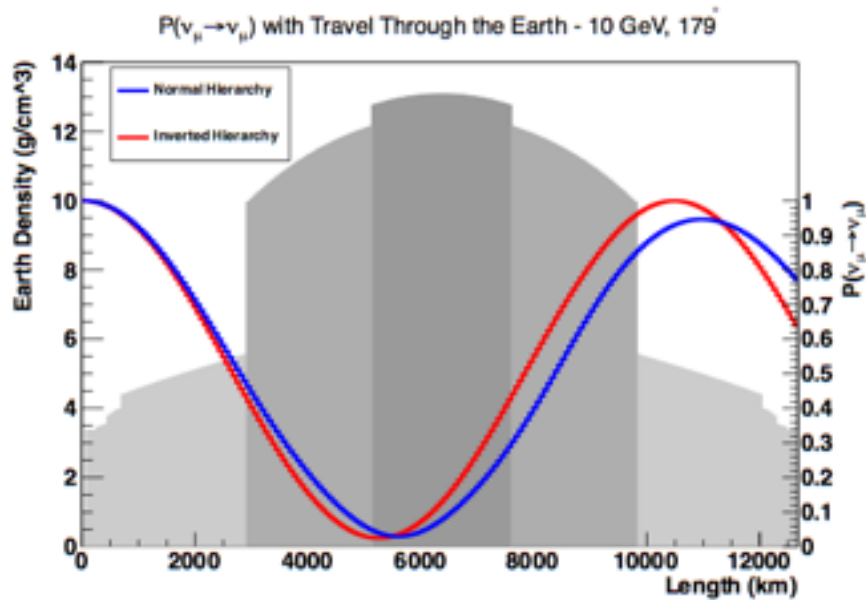
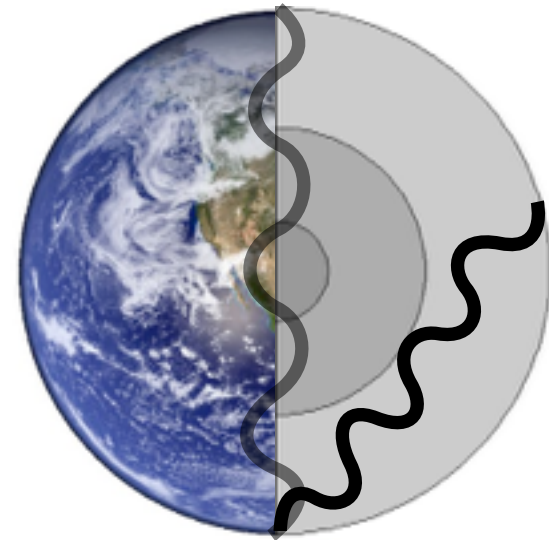
NMO with atmospheric neutrinos

- Matter effects on oscillation probabilities differ for normal and inverted hierarchy below 12 GeV



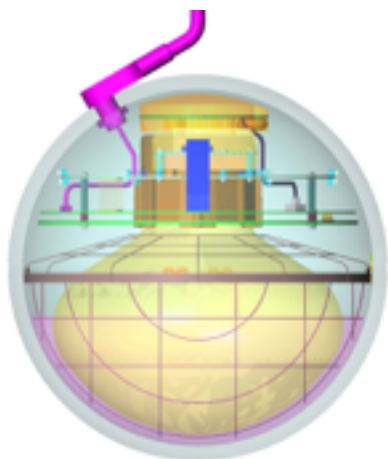
NMO with atmospheric neutrinos

- Matter effects on oscillation probabilities differ for normal and inverted hierarchy below 12 GeV
- At certain angles and energies up to 20 %

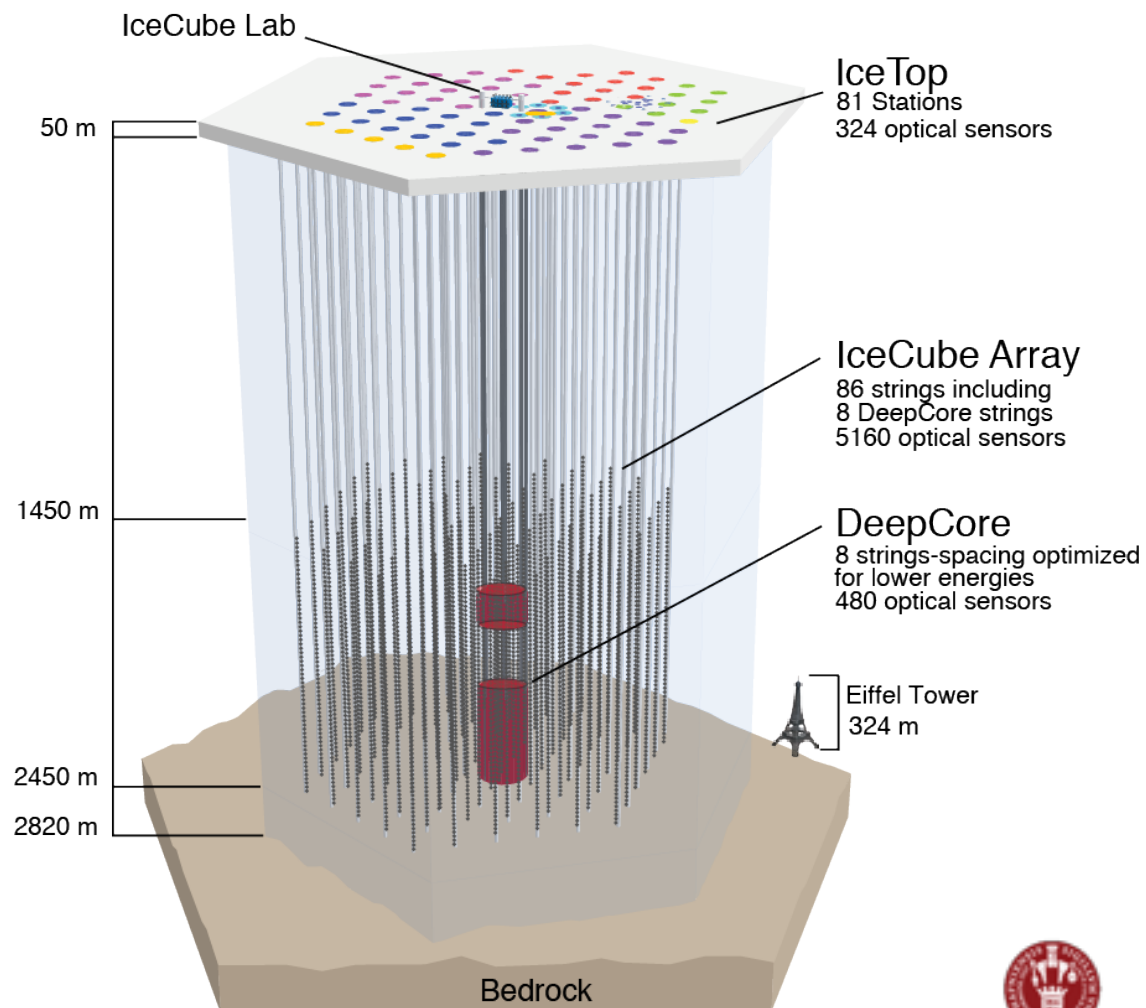


The IceCube Neutrino Observatory

- $\sim 1\text{km}^3$ instrumented ice
- 86 strings
- 5160 Digital Optical Modules (DOMs)
- DeepCore: Densely instrumented central region



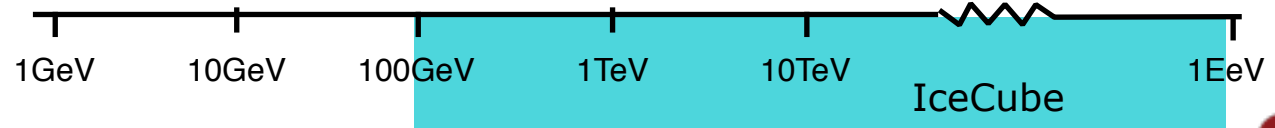
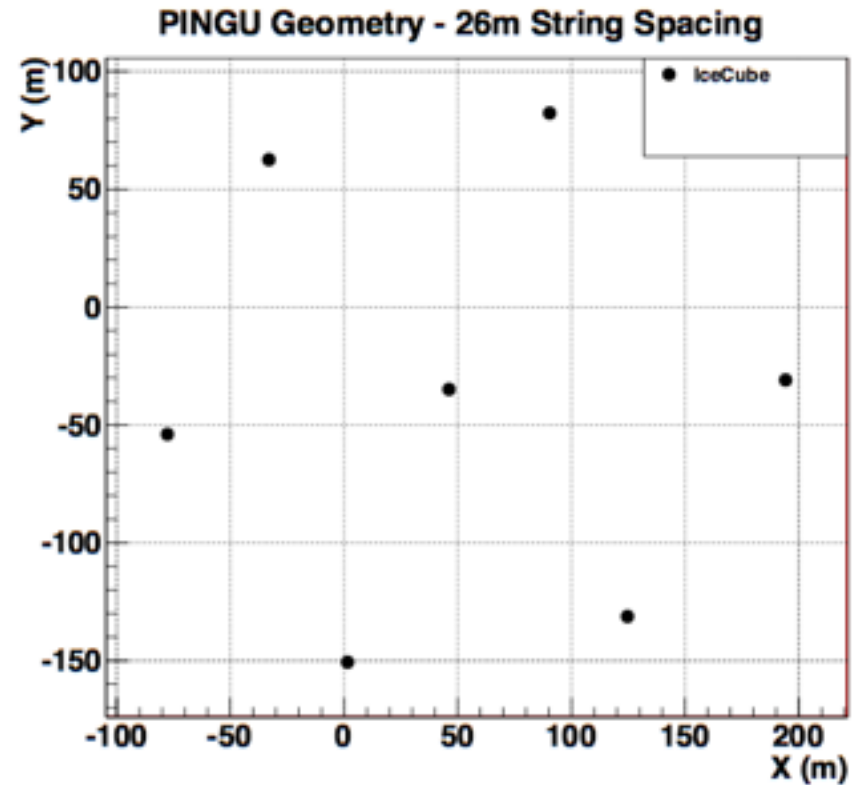
b



IceCube

IceCube:

- 78 strings
- 125m string spacing
- 17m DOM spacing



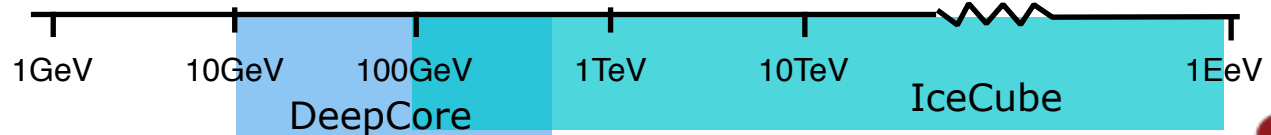
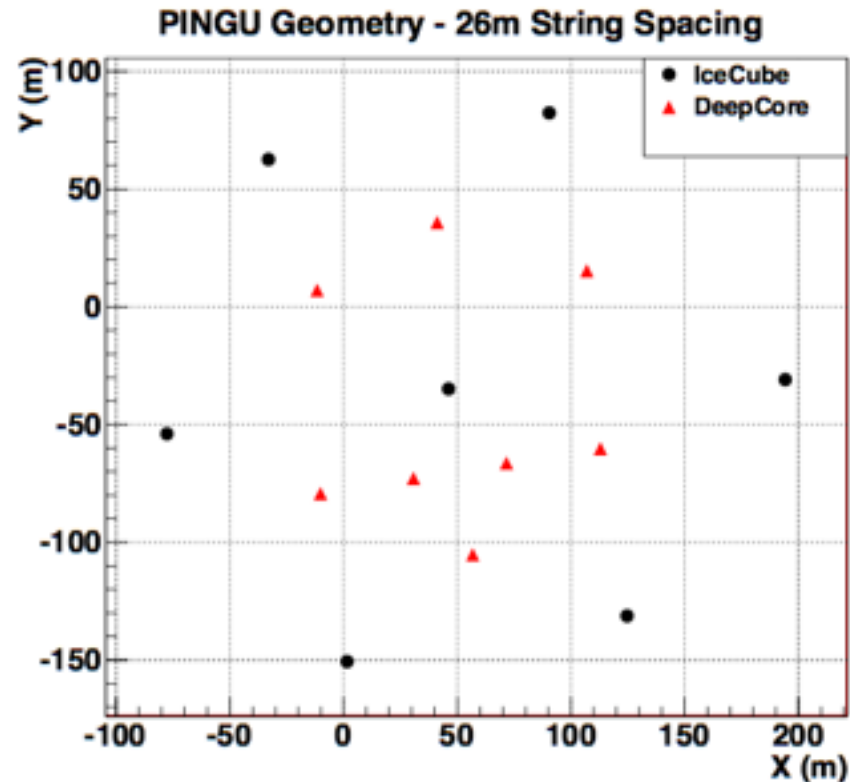
IceCube + DeepCore

IceCube:

- 78 strings
- 125m string spacing
- 17m DOM spacing

DeepCore:

- 8 strings
- 75m string spacing
- 7m DOM spacing



IceCube + DeepCore + PINGU

IceCube:

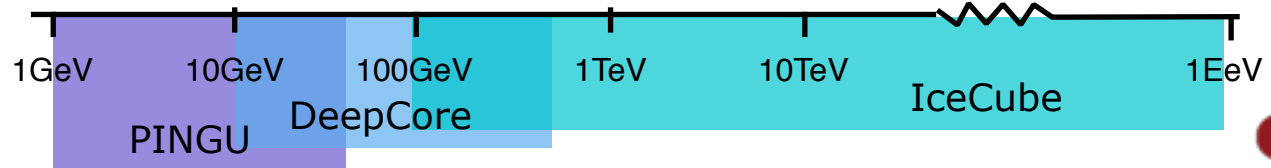
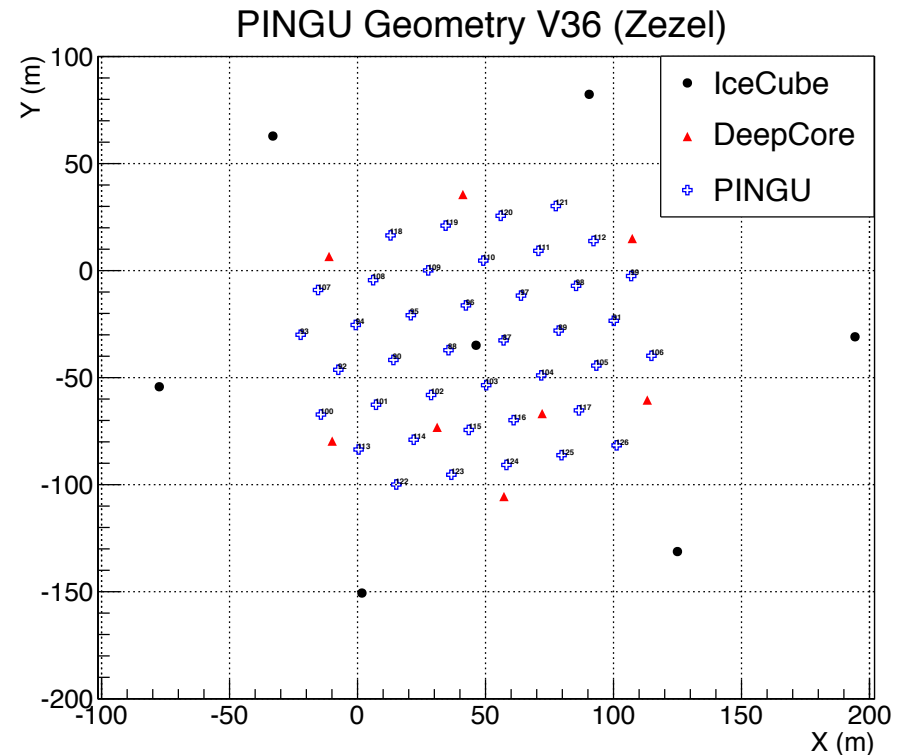
- 78 strings
- 125m string spacing
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DeepCore:

- 8 strings
- 75m string spacing
- 7m DOM spacing

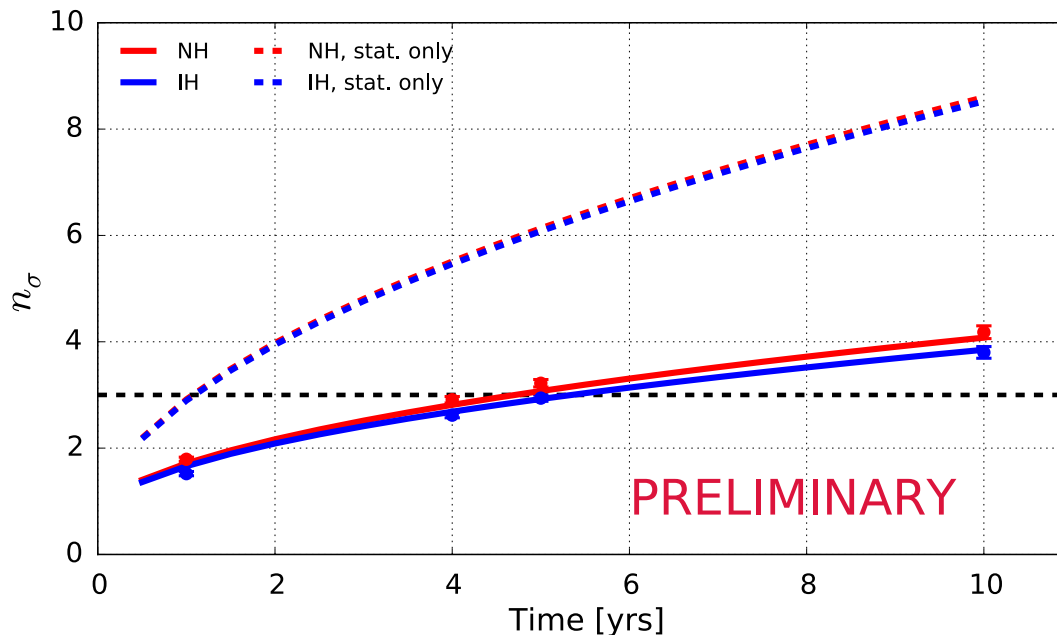
PINGU:

- 40 strings
- 22m string spacing
- 3m DOM spacing



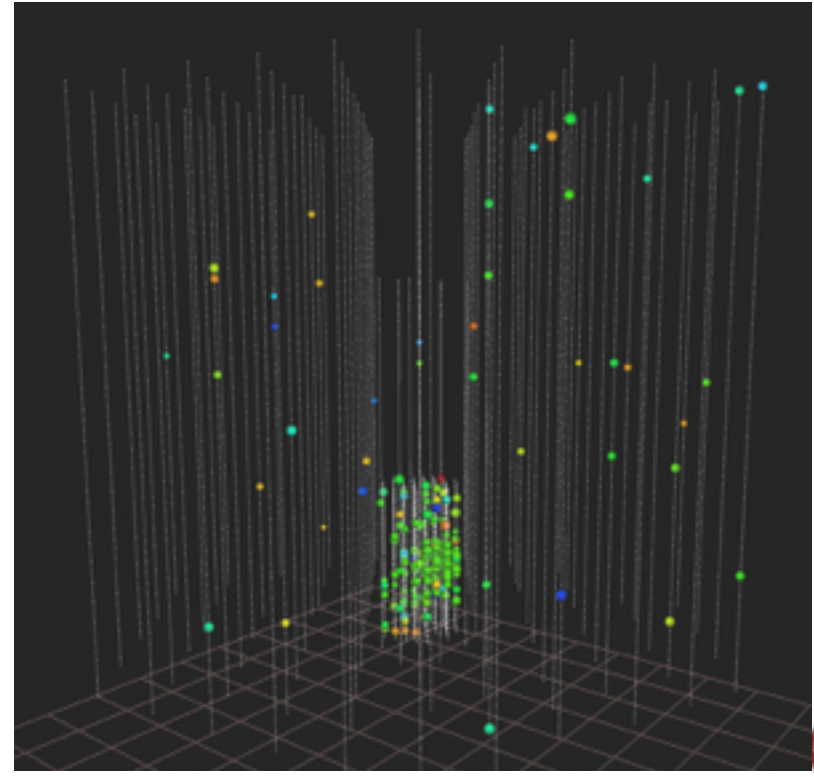
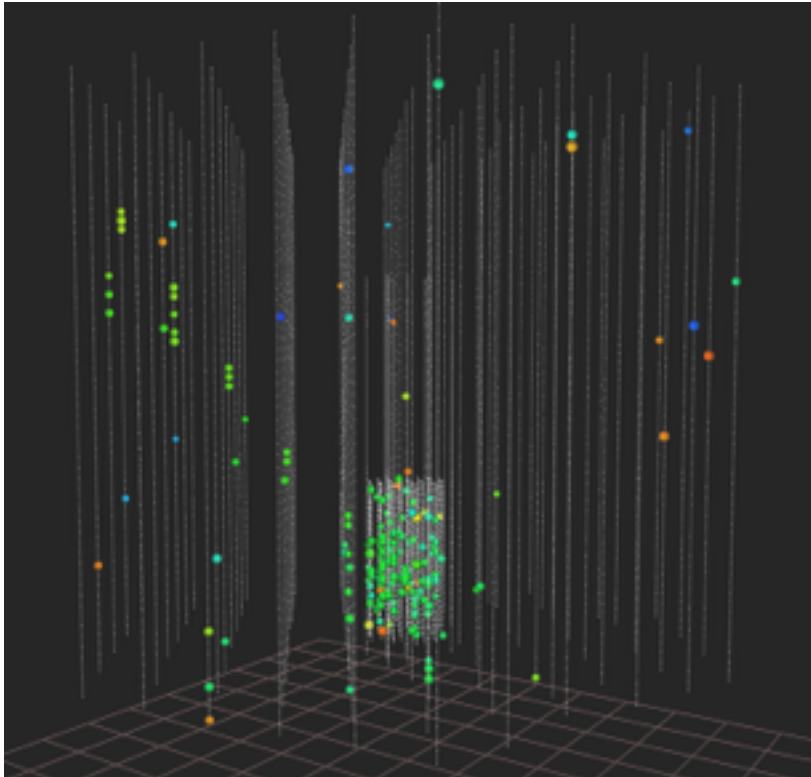
NMO with PINGU

- With baseline geometry 3σ significance appears possible with 3.5 years of data
- Particle ID performance not currently included in systematics
 - Enter the NBI group!



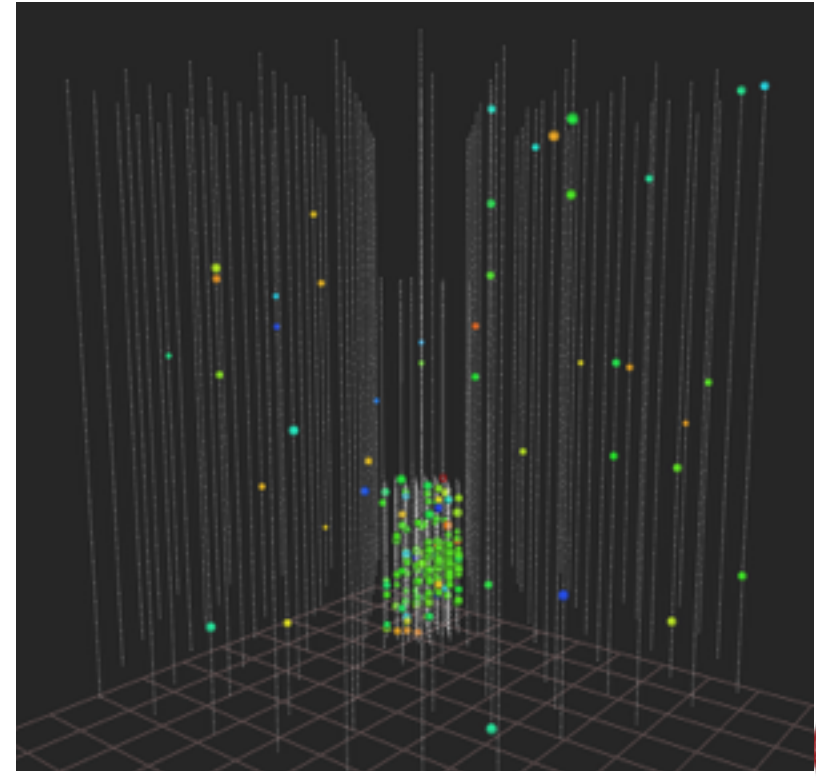
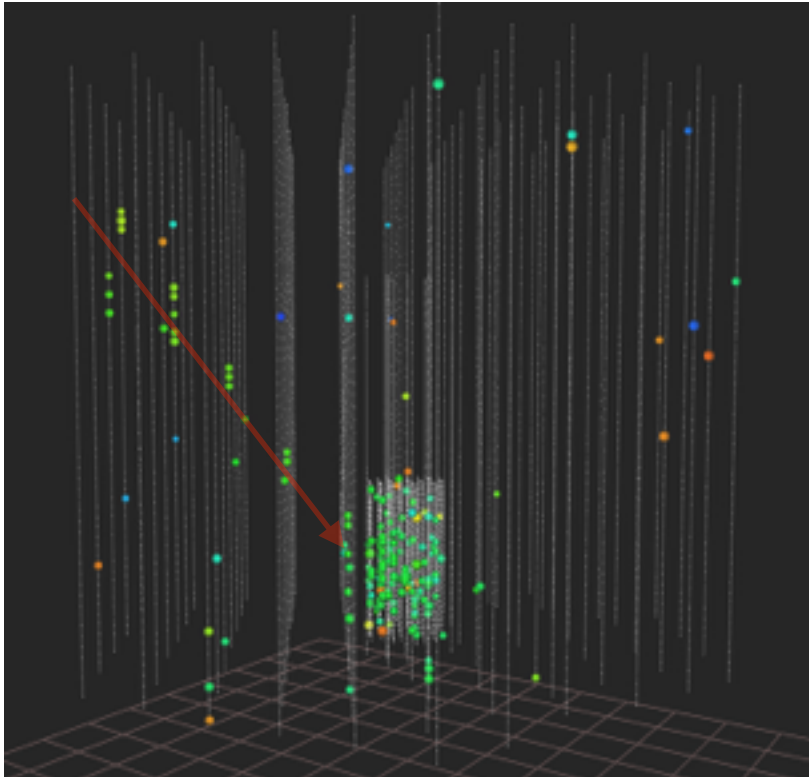
Muon Background - trigger level

- Muon to neutrino rate ratio: $\sim 10^4:1$
- Muons leave tracks going through the detector



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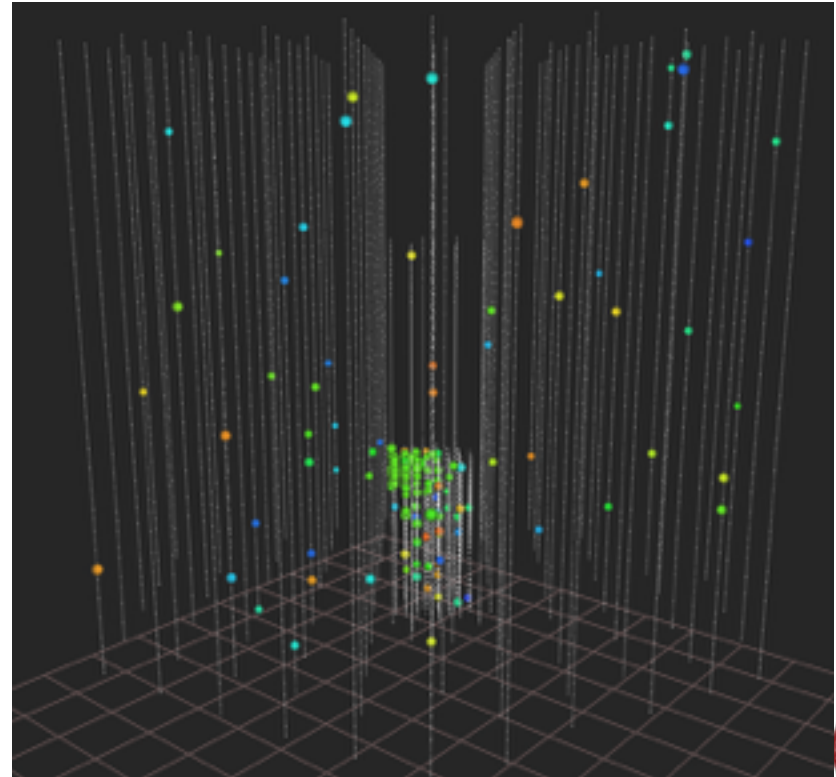
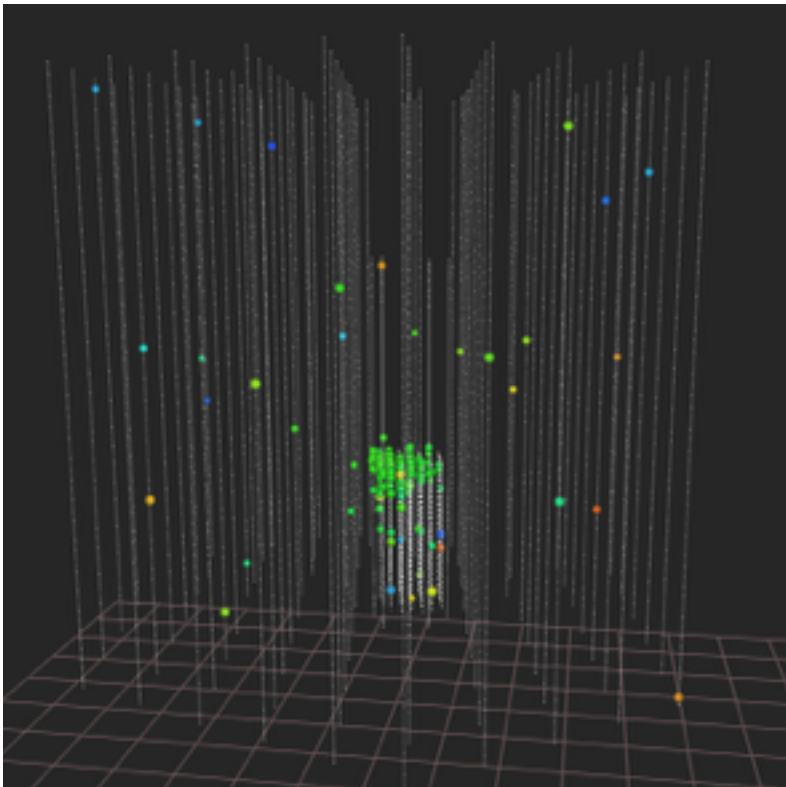
Muon background rejection with PINGU

- Limited bandwidth requires initial processing before transmission
- Processing must be independent of analyses (Dark matter, NMO, etc.)
- Current status:
 - Muon rate reduced by 4 orders of magnitude
 - Retain $\sim 50\%$ of all flavour, isotropic neutrinos

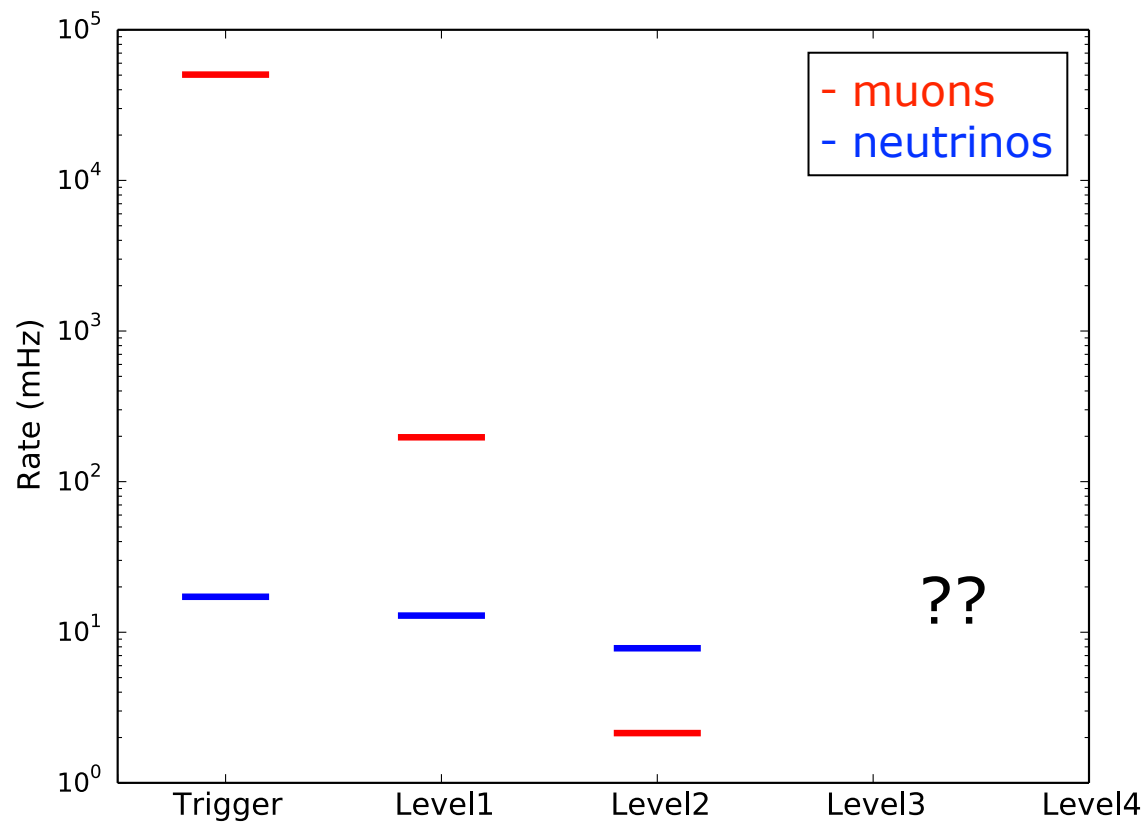


Muon background - final level

- Muon to neutrino rate ratio: $\sim 1:4$
- No obvious differences in event topology “by eye”



Rates at final level



Summary and future work

- PINGU will have sensitivity to interesting physics
- Muon background not yet included in PINGU analyses
- The NBI cuts allow for background MC files to be processed
 - Reduces background rate to 1/4 of isotropic neutrino rate
- Next up: study the systematic effects of the muon background on NMO and tau appearance analysis

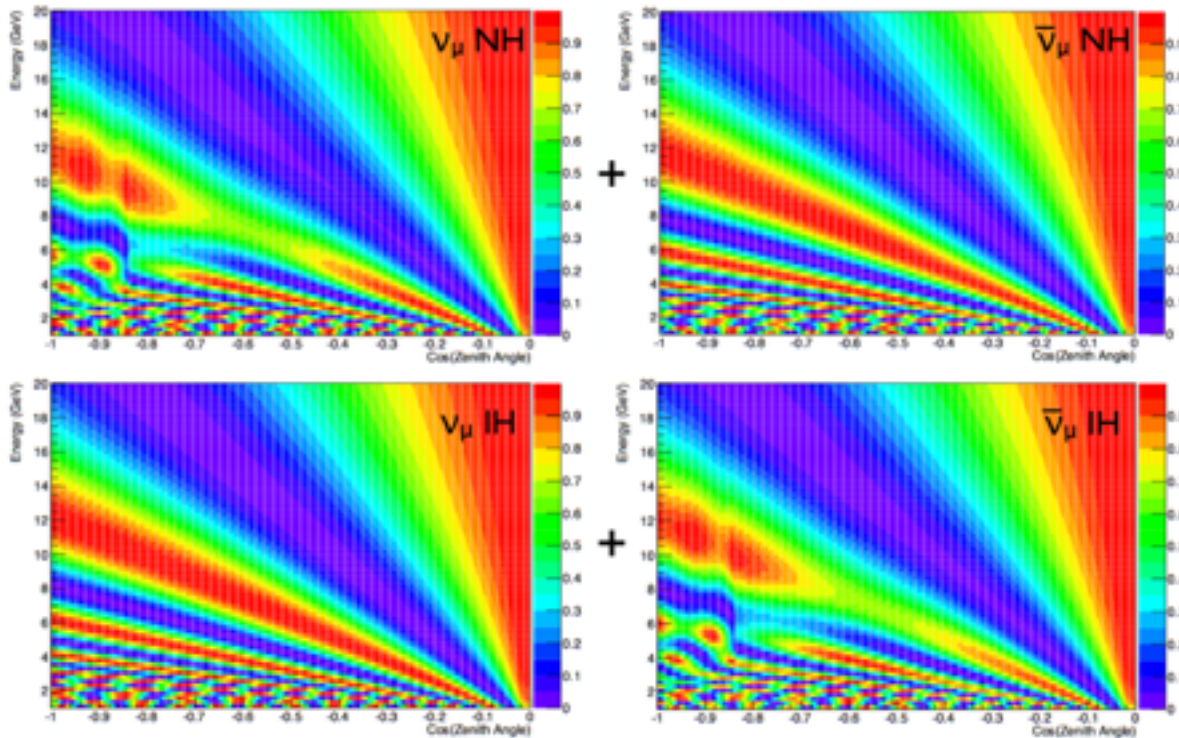


BACKUP



NMO with atmospheric neutrinos

Oscillation probabilities



- Matter effects different for ν and anti- ν
- Combine with difference in flux and σ
- Patterns differ after addition for normal and inverted



Mena, Mocioiu & Razaque *Phys. Rev. D* 78, 093003 (2008)

