

Status of the PINGU Detector

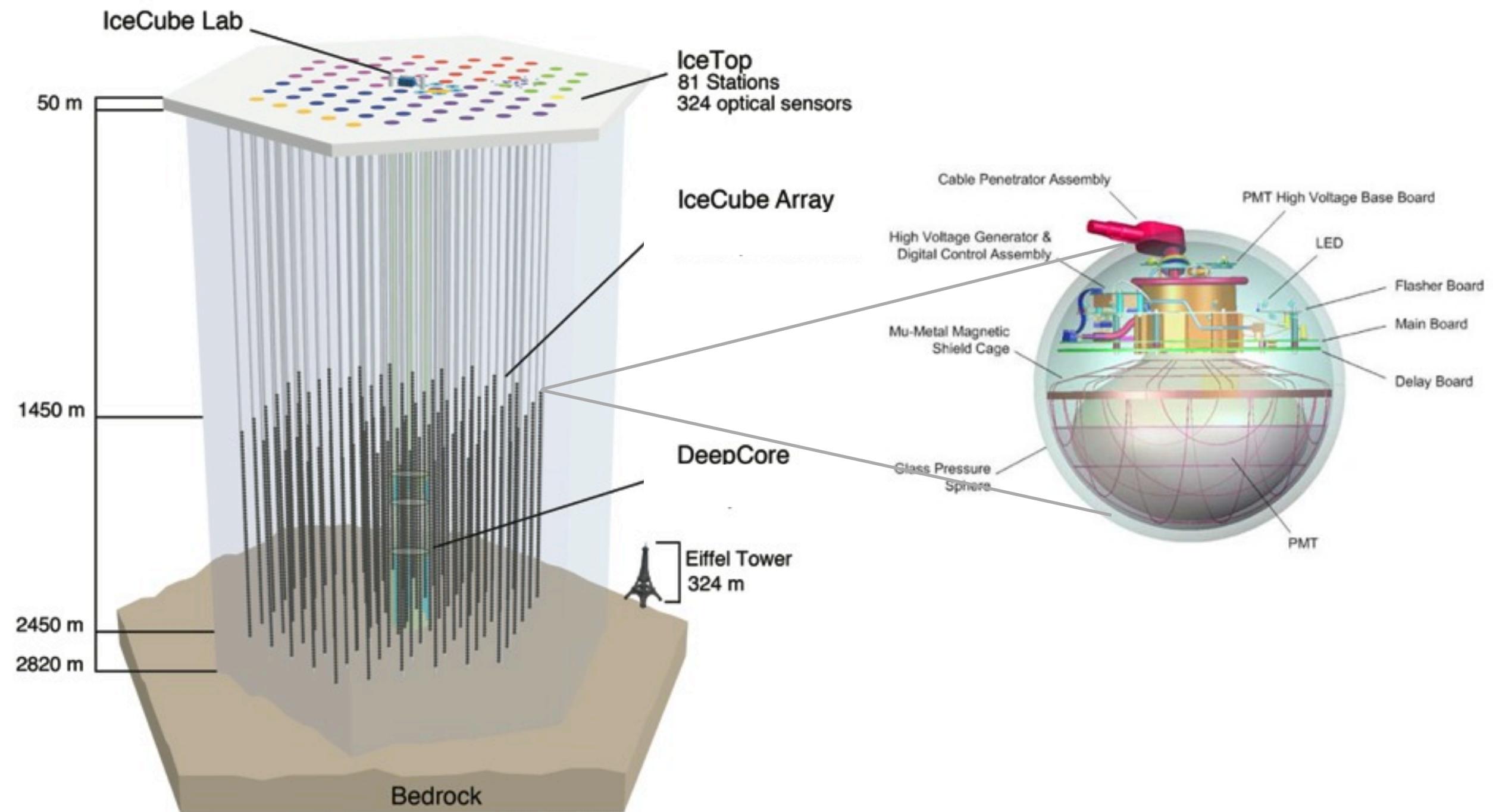
Ken Clark
University of Toronto

For the IceCube/PINGU Collaboration



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The IceCube Neutrino Telescope

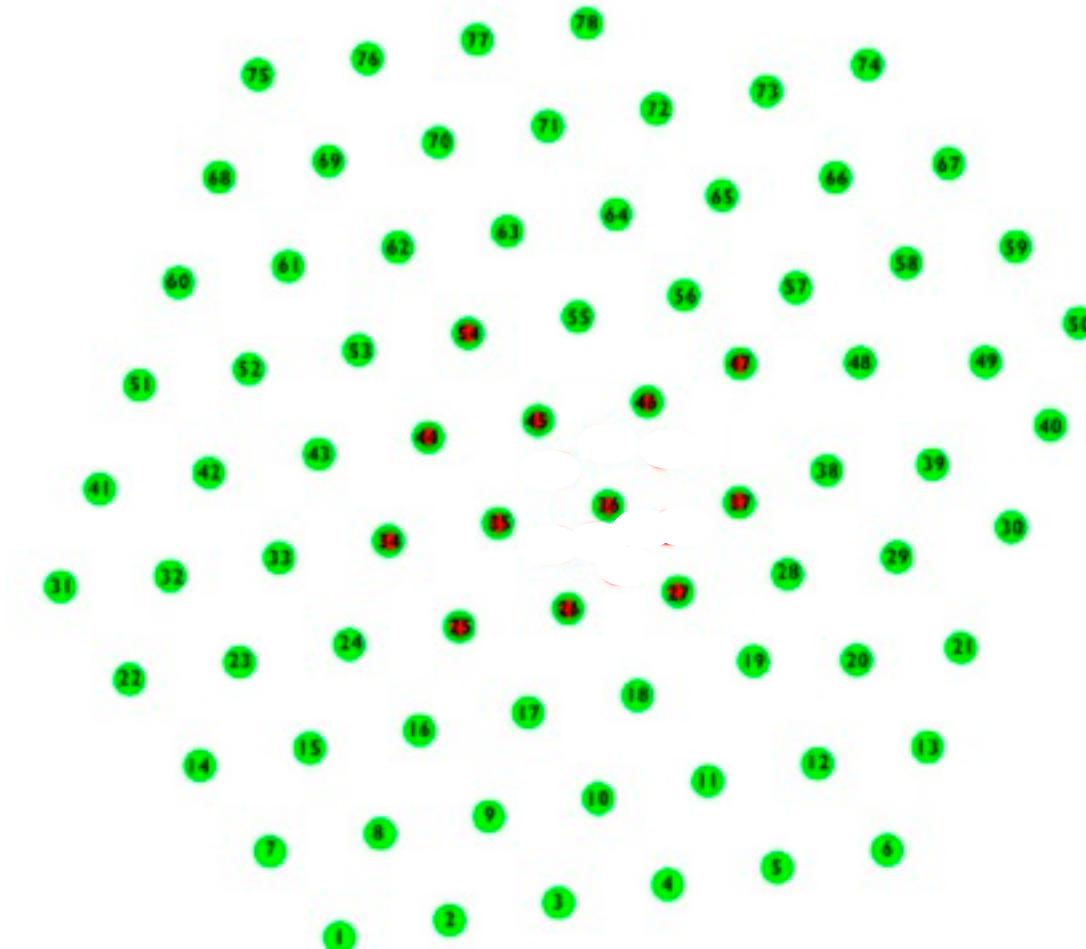


IceCube/DeepCore



IceCube

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



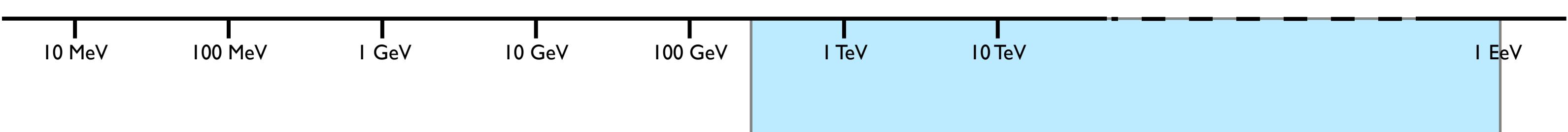
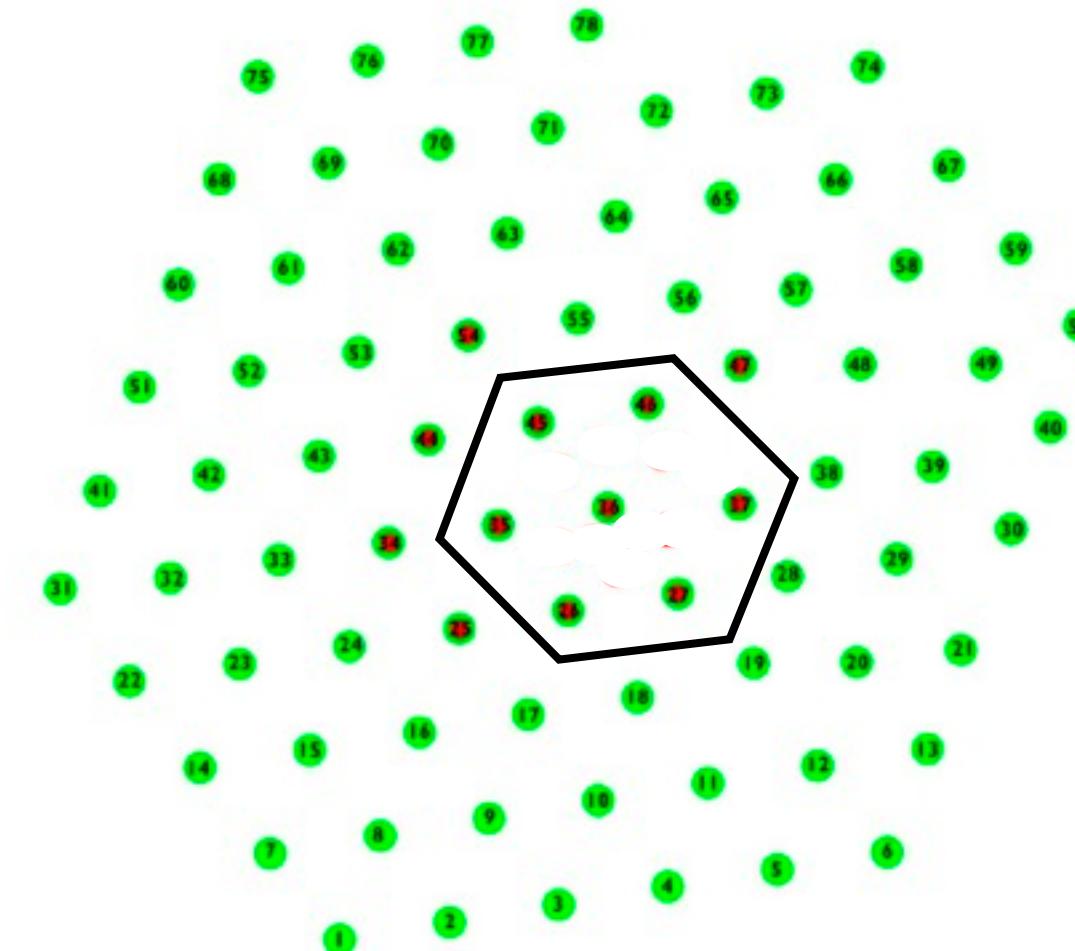
IceCube



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IceCube

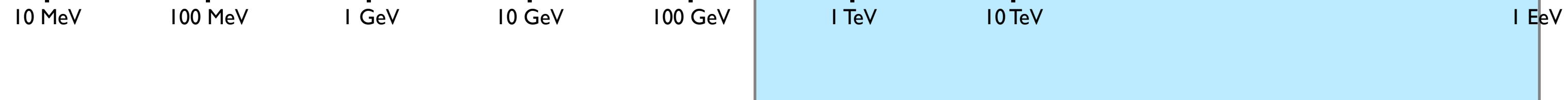
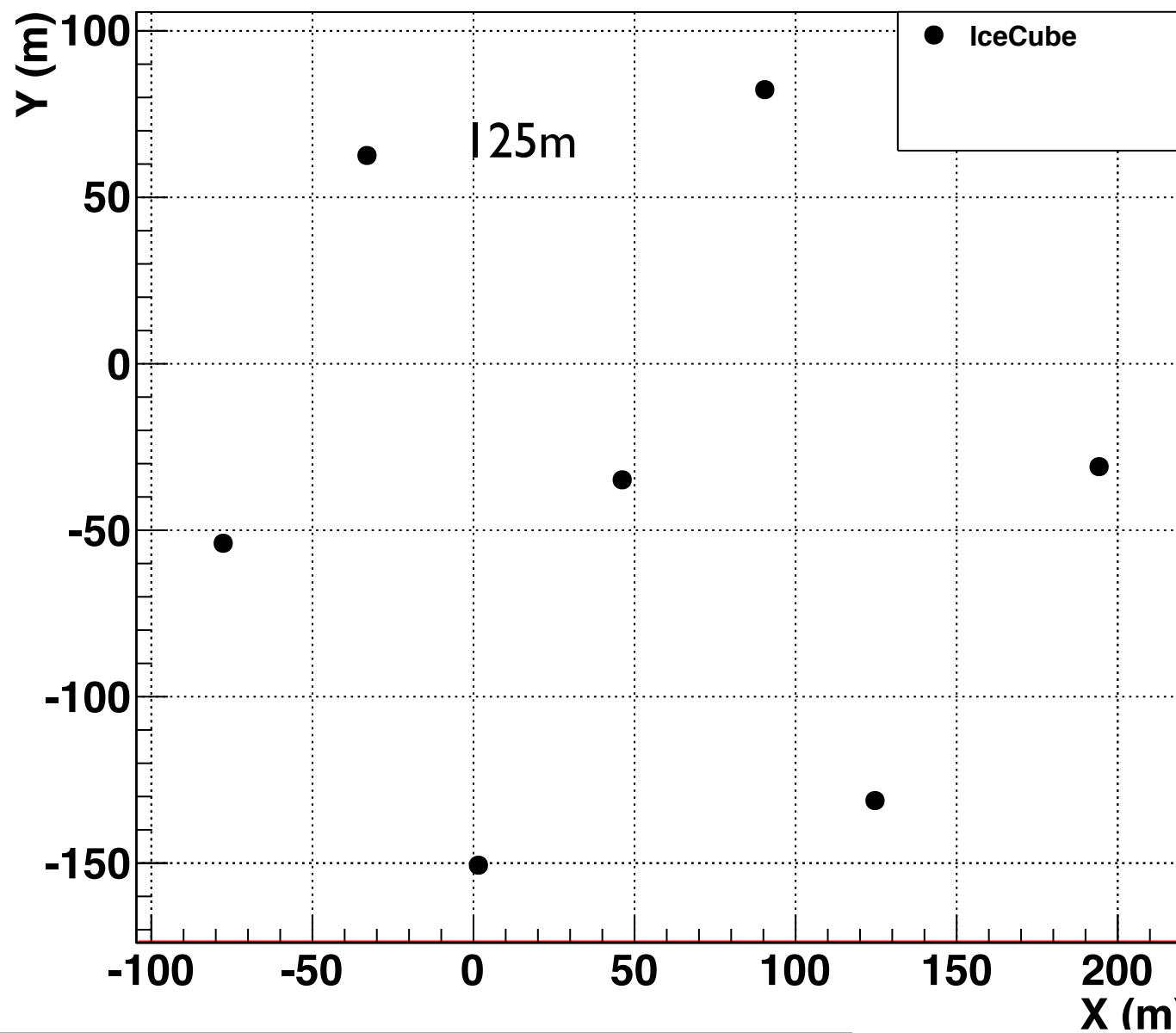
- 78 Strings
- 125m string spacing
- 17m DOM spacing



IceCube

IceCube

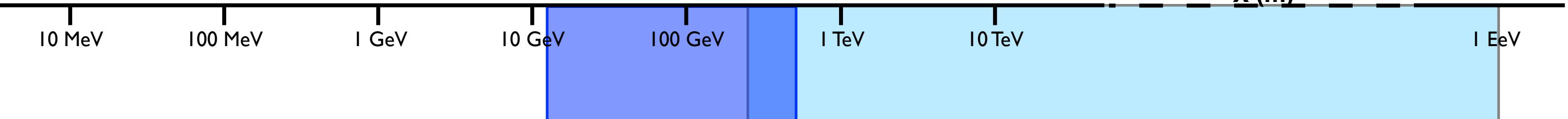
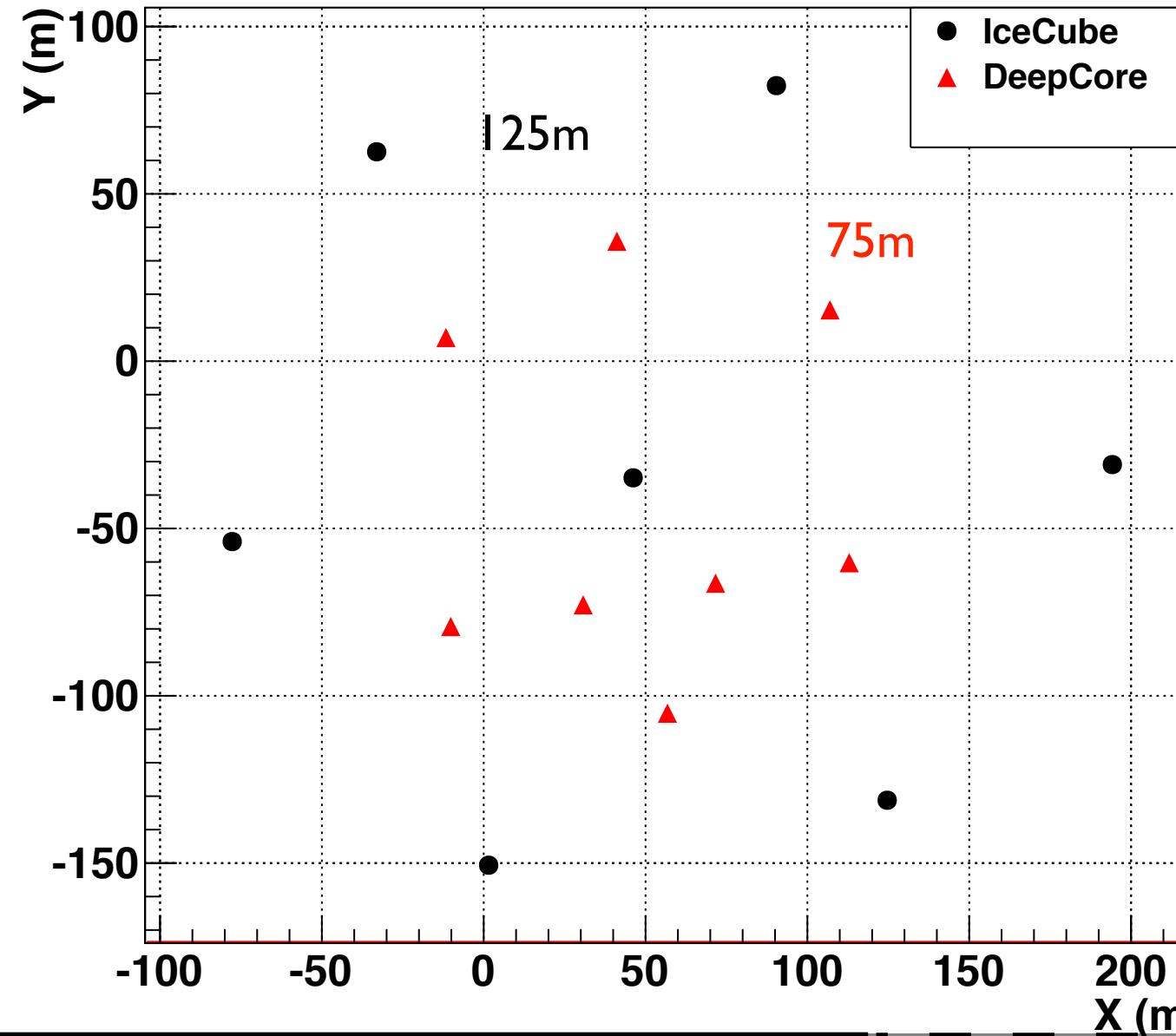
- 78 Strings
- 125m string spacing
- 17m DOM spacing



IceCube

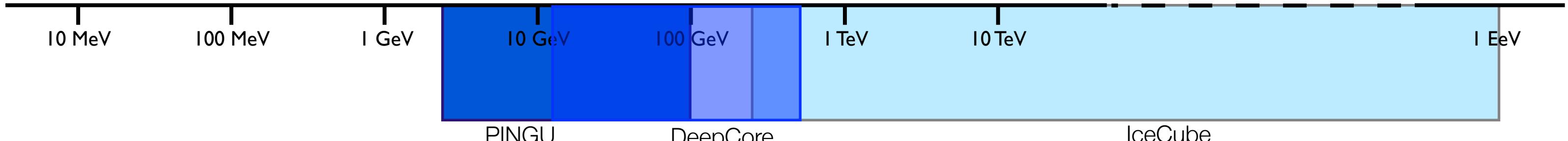
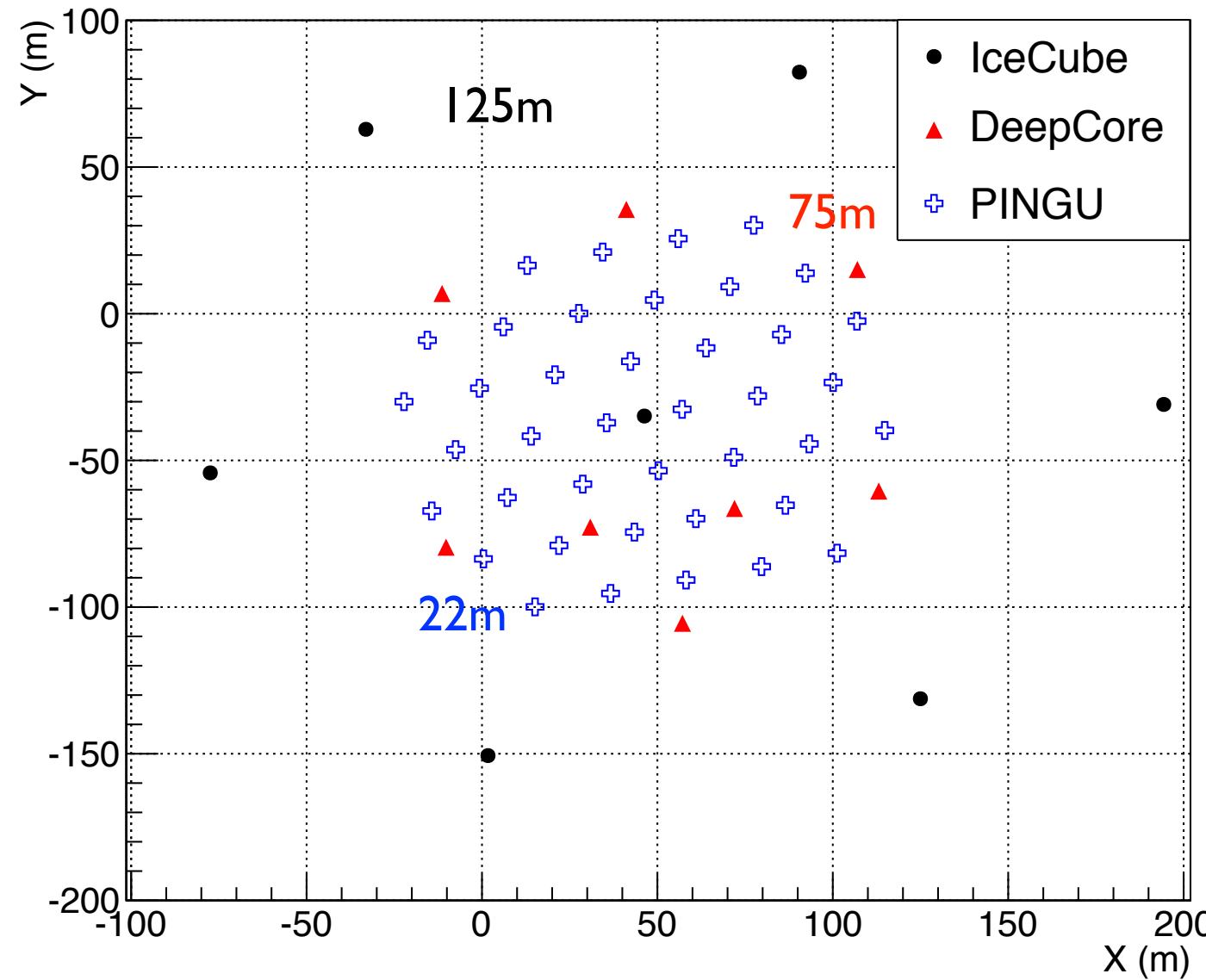
IceCube + DeepCore

- 78 Strings
 - 125m string spacing
 - 17m DOM spacing
- Add 8 strings
 - 75m string spacing
 - 7m DOM spacing



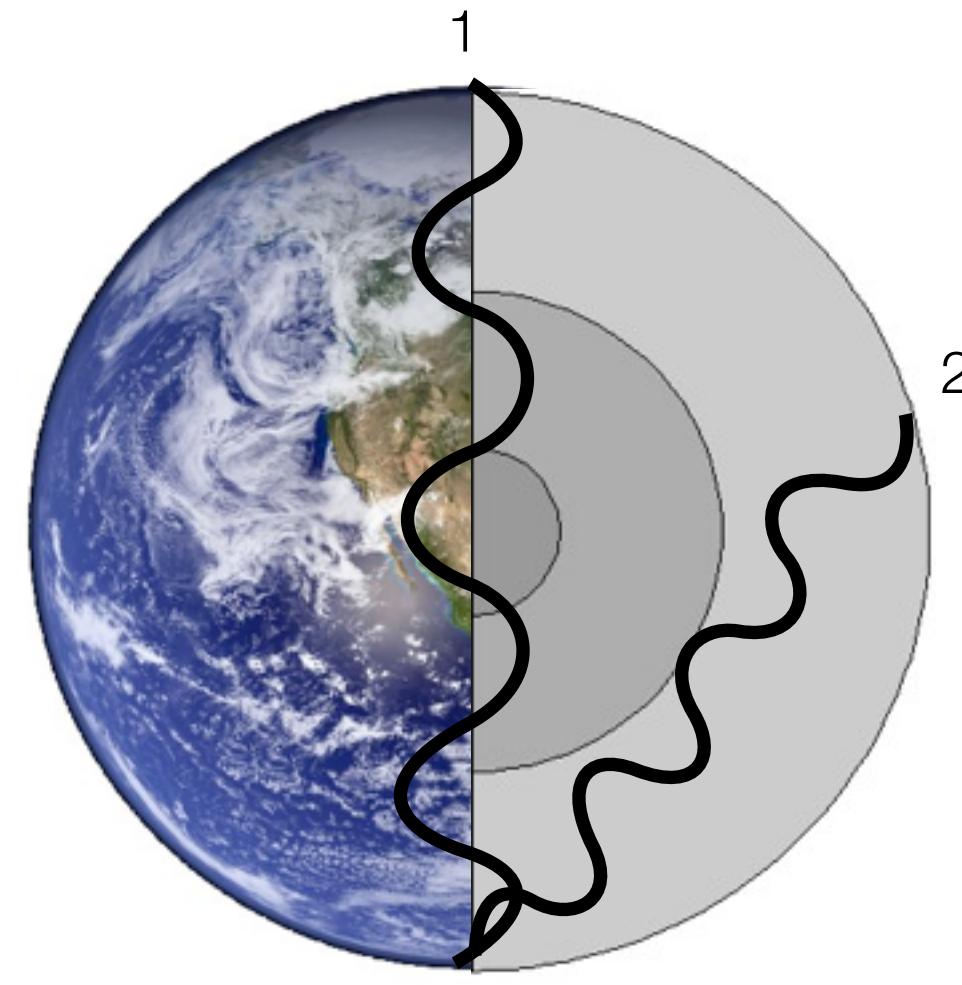
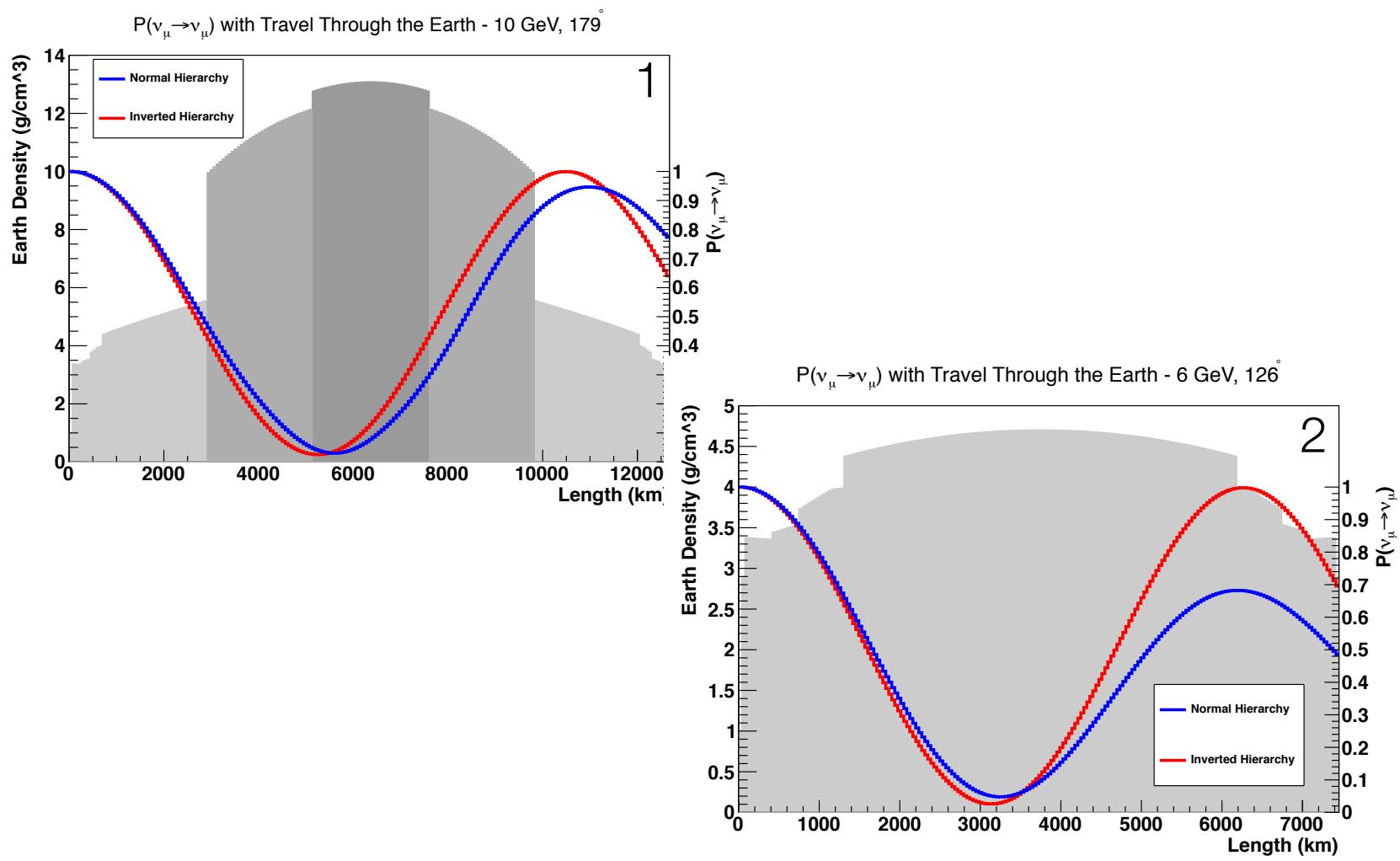
IceCube + DeepCore + PINGU

- 78 Strings
 - 125m string spacing
 - 17m DOM spacing
- Add 8 strings
 - 75m string spacing
 - 7m DOM spacing
- Add 40 strings
 - 22m string spacing
 - 3m DOM spacing

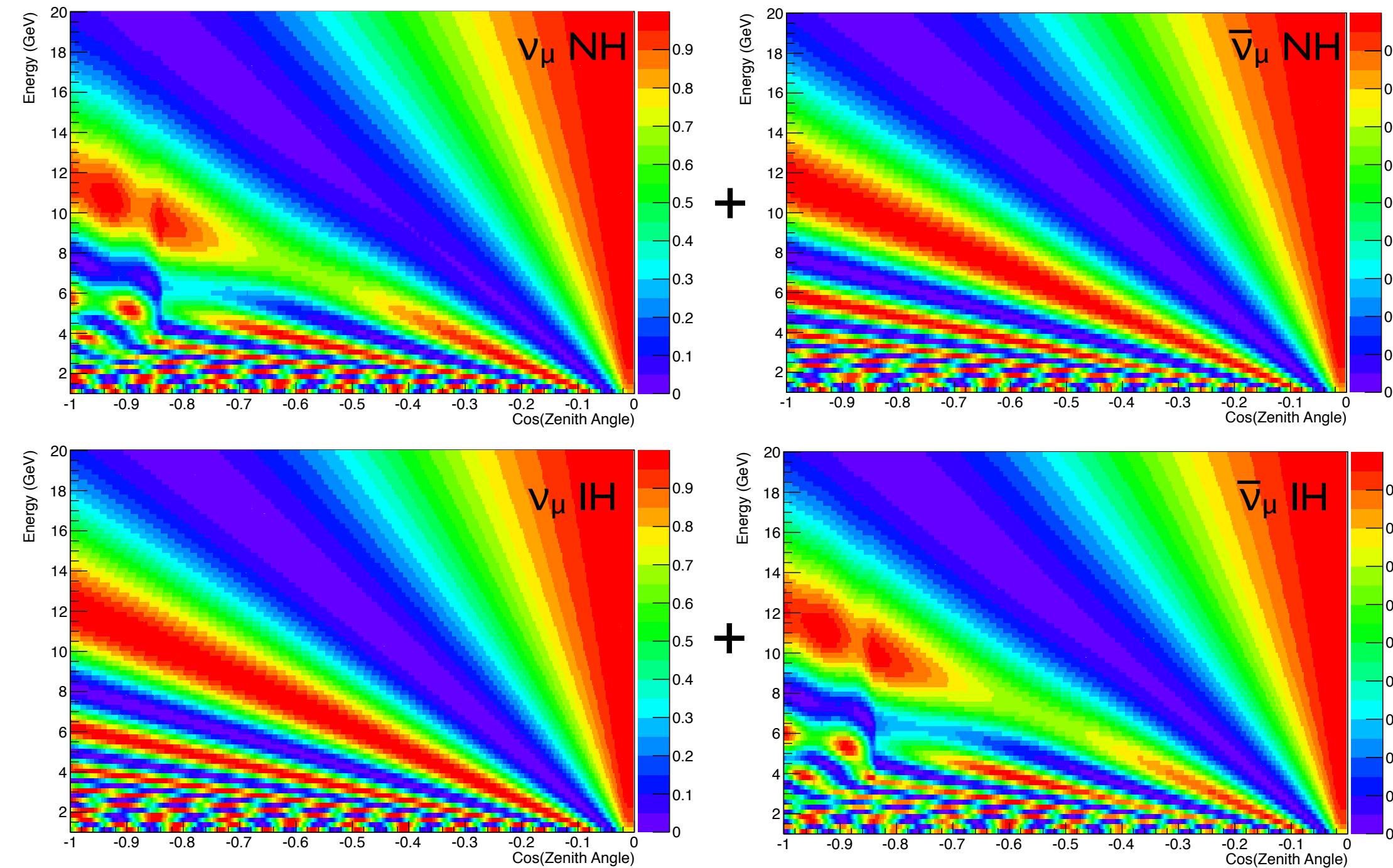


Mass Hierarchy Determination

- Experiments use the difference in probability for ν and anti- ν
- Combine with difference in ν and anti- ν cross-section, flux

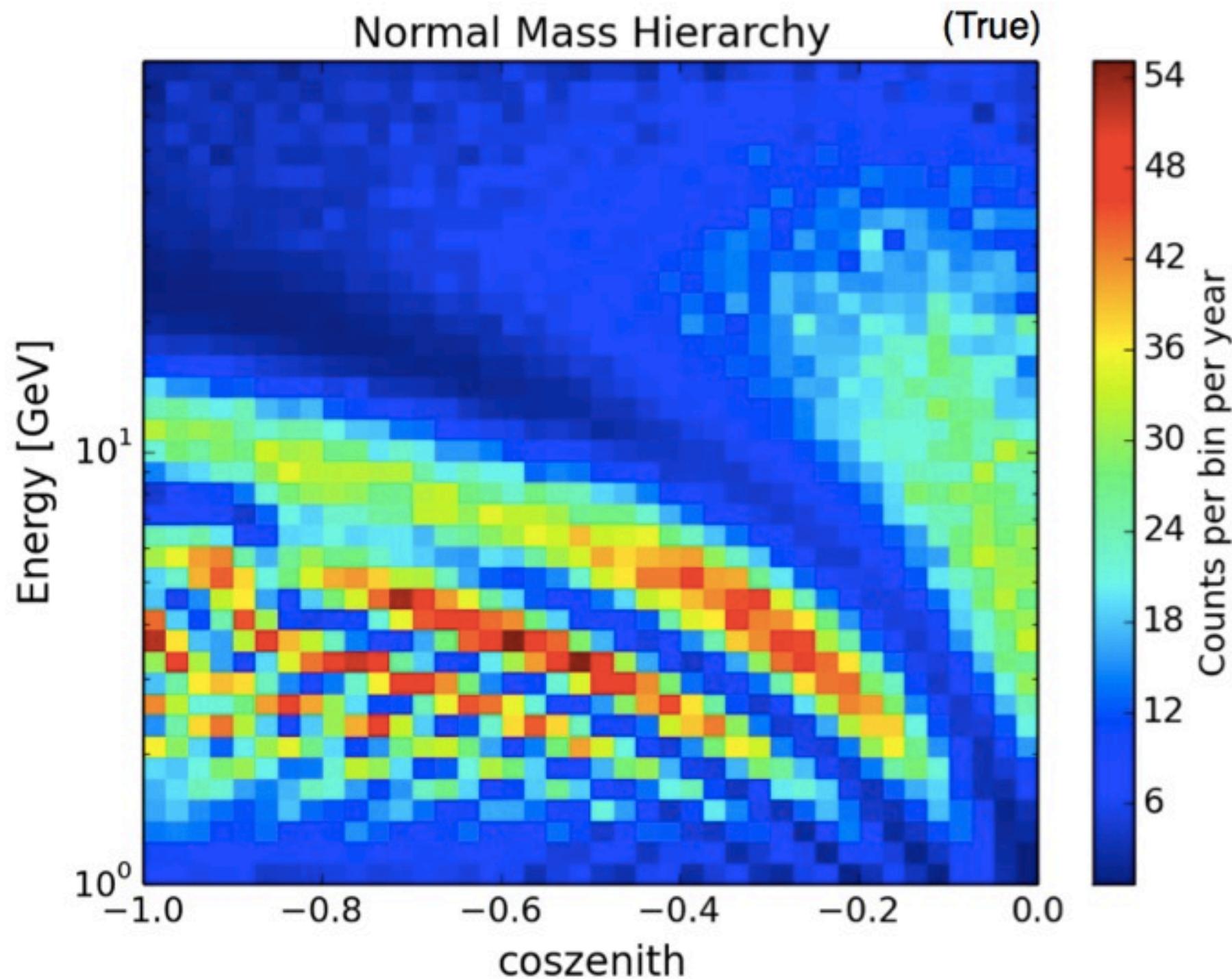


Neutrino Oscillograms



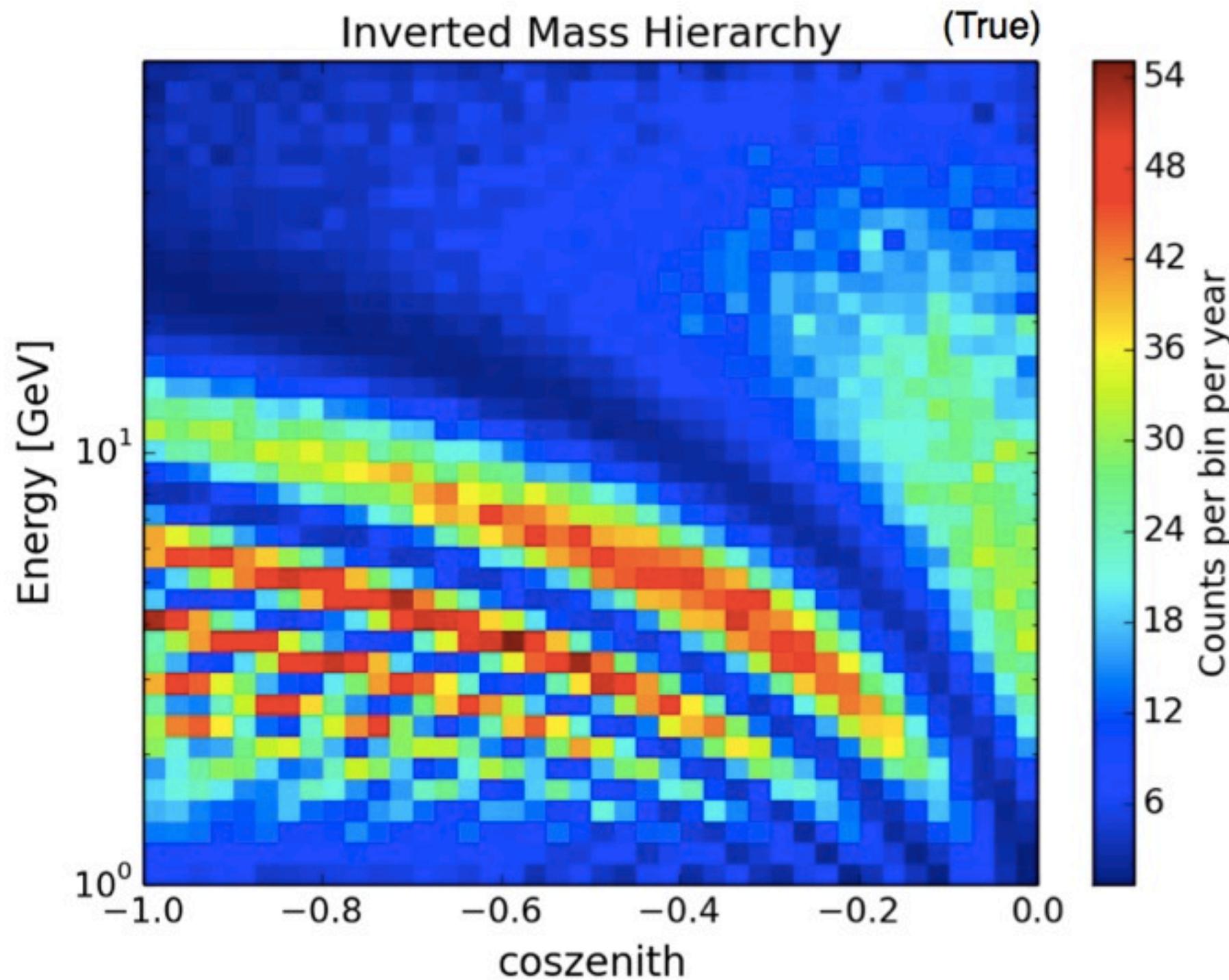
- The cross-section and flux are different for v_μ and \bar{v}_μ
- The patterns are therefore different even after addition
- This is probabilities only

Neutrino Oscillograms



- Sum of ν_μ and $\bar{\nu}_\mu$
- Expect ~50k per year (38k for ν_e)
- Reconstruction and PID not included here

Neutrino Oscillograms



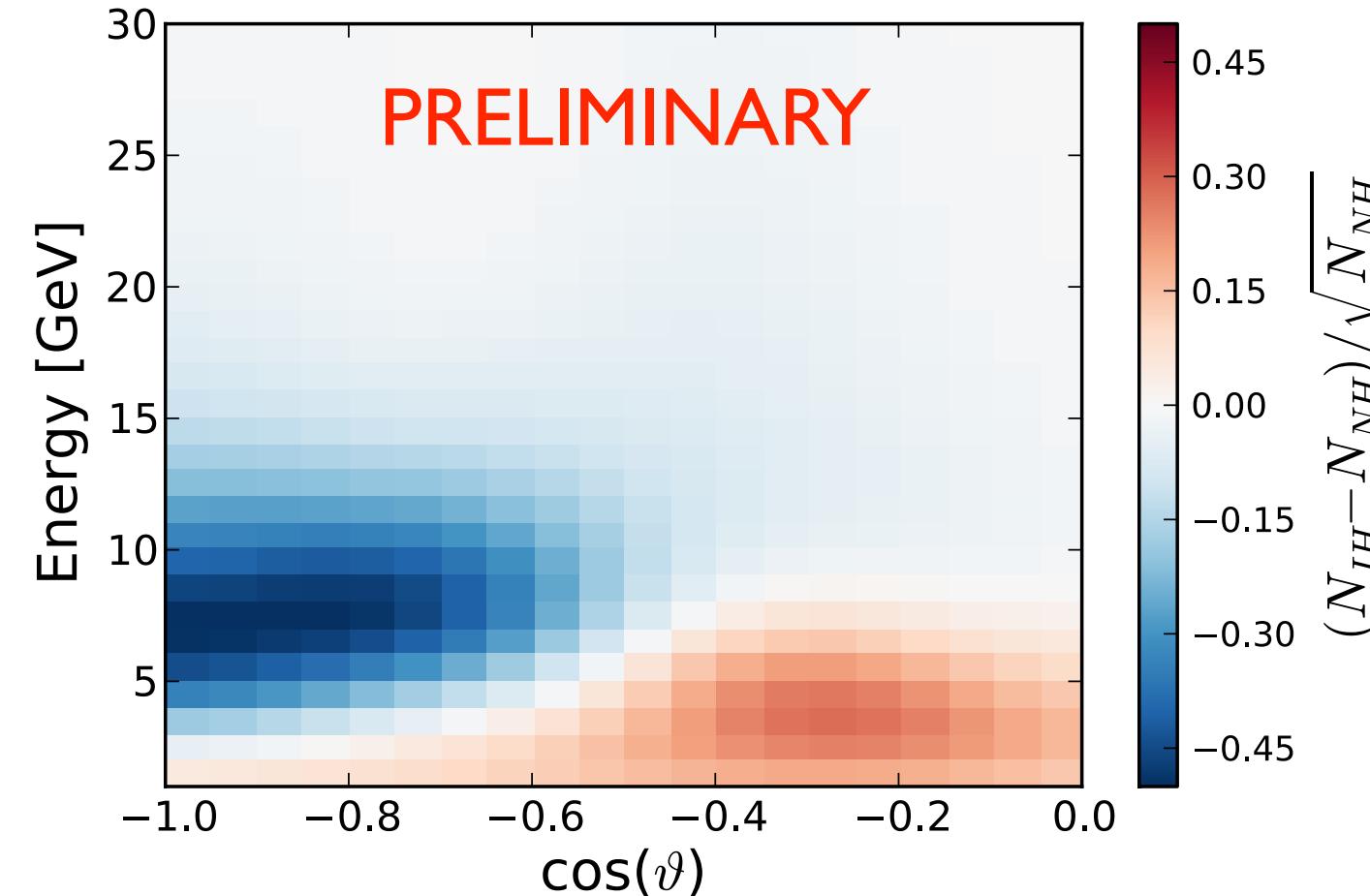
- Sum of ν_μ and $\bar{\nu}_\mu$
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Resolutions, Particle ID

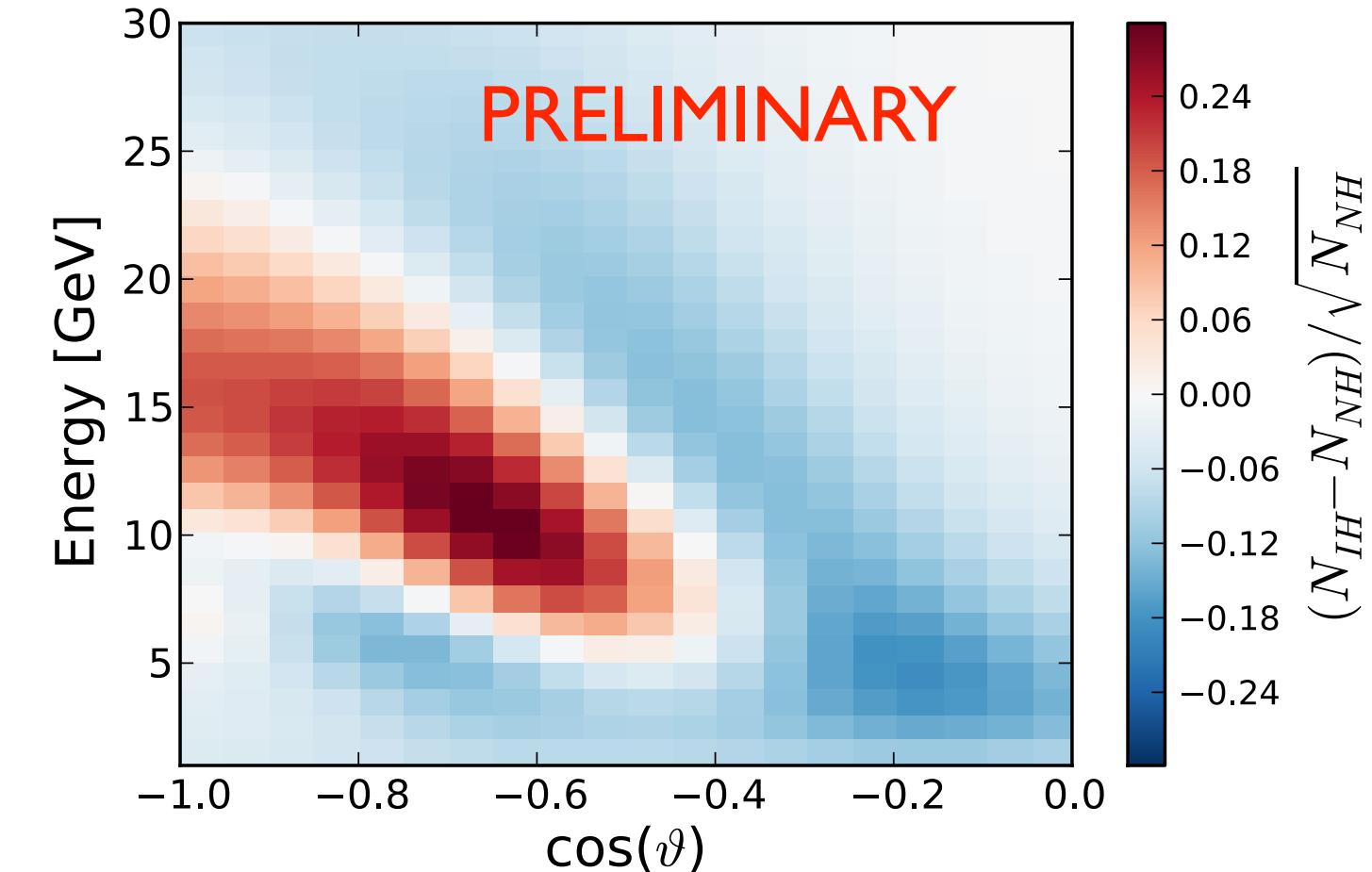
- Angle resolution: $\delta \cos\theta \approx 0.15$ at 10 GeV (improves with higher energy)
- Energy resolution: $\delta E/E \approx 20\%$ above 10 GeV
- Particle ID: ν_μ CC correctly identified 80% above 10 GeV

Mass Hierarchy Determination

Cascade-Like Events



Track-Like Events



- Difference in counts between hierarchies illustrates distinguishability
- Background rejection cuts not included here

Analysis Methods

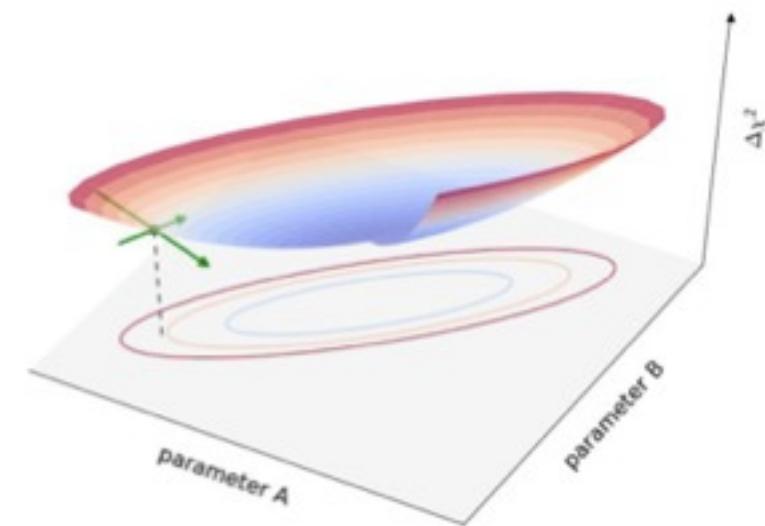
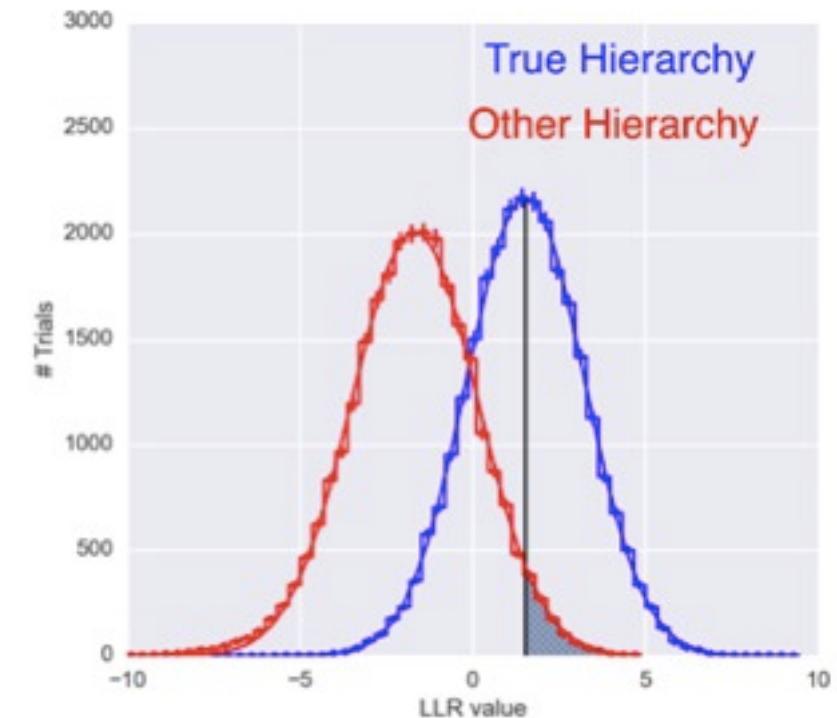
Currently studying two methods:

1. Log Likelihood Ratio

- uses Monte Carlo pseudo-data to build up a distribution of the test statistic

2. $\Delta\chi^2$ pull method

- use error propagation for linear parameters, scan the non-linear ones
- analytically minimize the test statistic

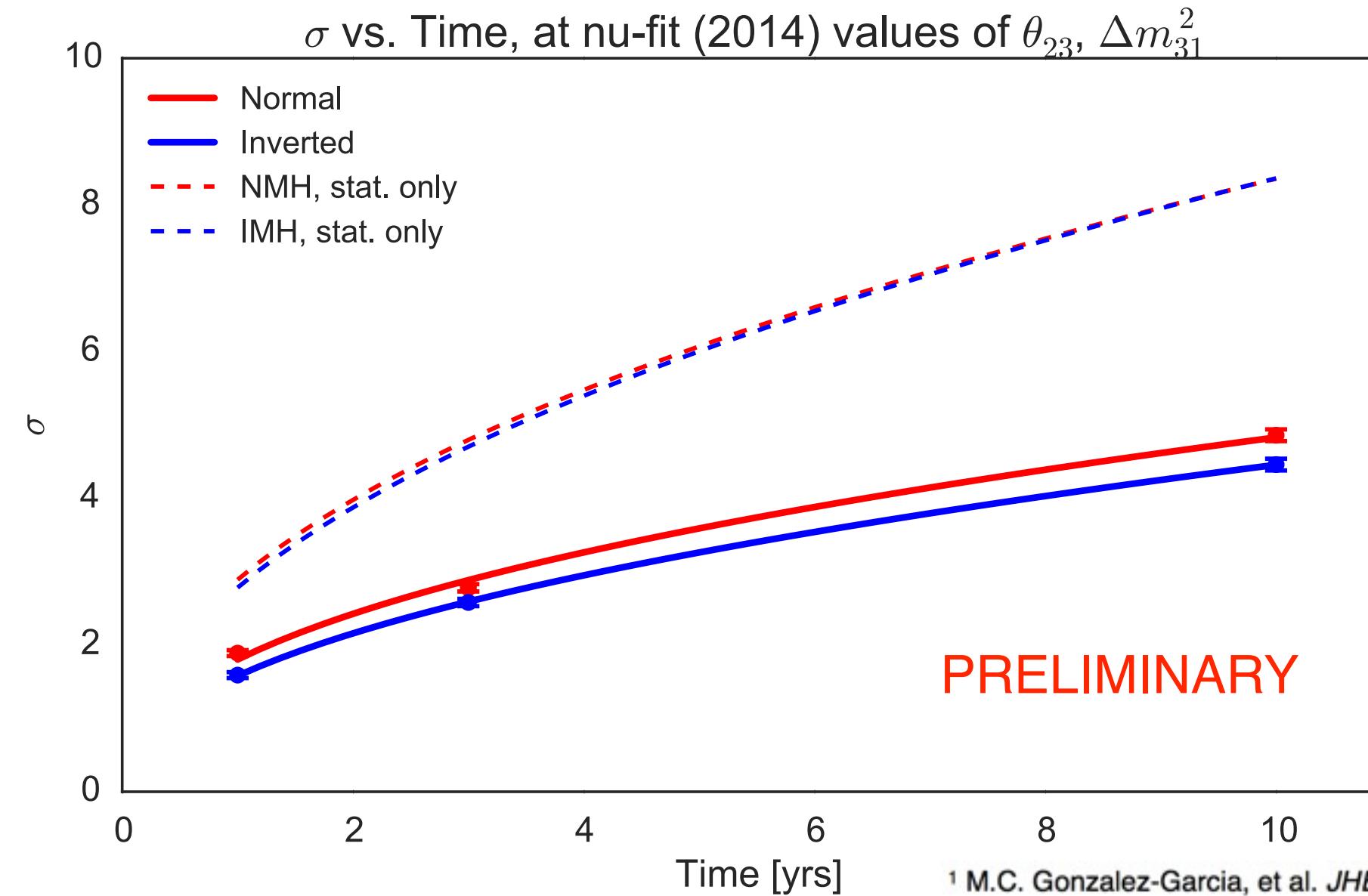


Systematics

- Oscillation parameters
 - θ_{23} , Δm^2_{31} , θ_{13}
- Detector systematics
 - effective area, energy scale, ν_e/ν_μ ratio, $\nu/\bar{\nu}$ ratio, atmospheric spectral index
- Others
 - GENIE cross-section systematics, atmospheric flux uncertainties

The Bottom Line

- Most important question is how long does it take to make a measurement?



¹ M.C. Gonzalez-Garcia, et al. JHEP 11 052, 2014

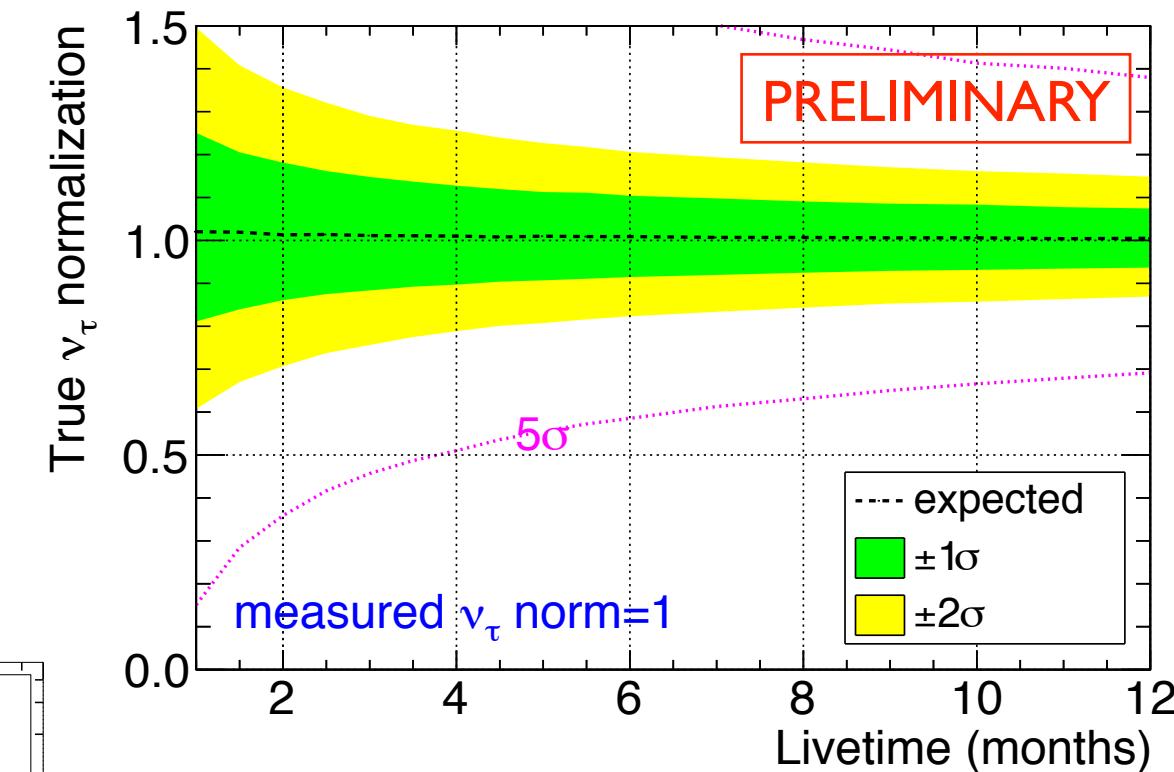
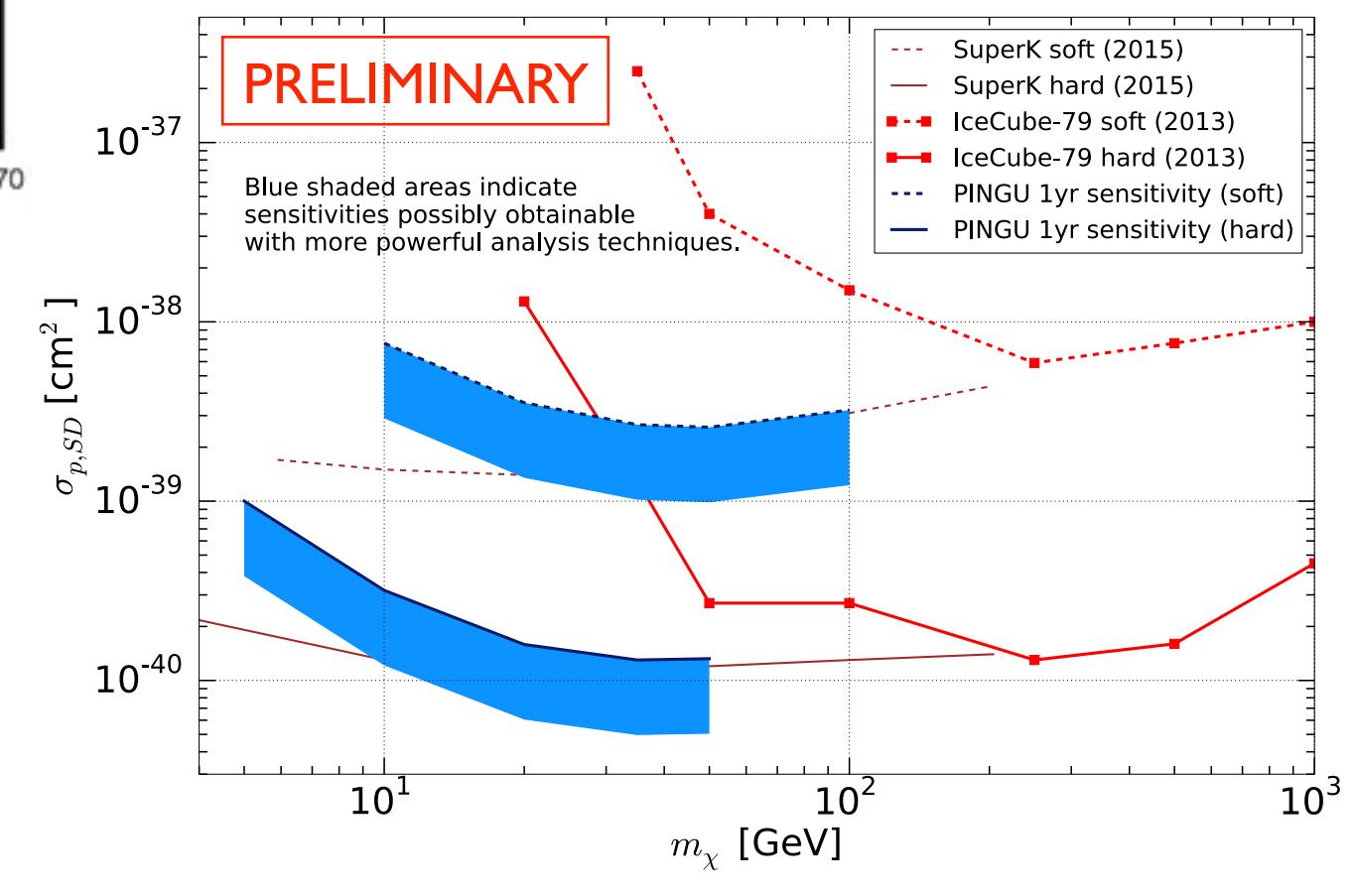
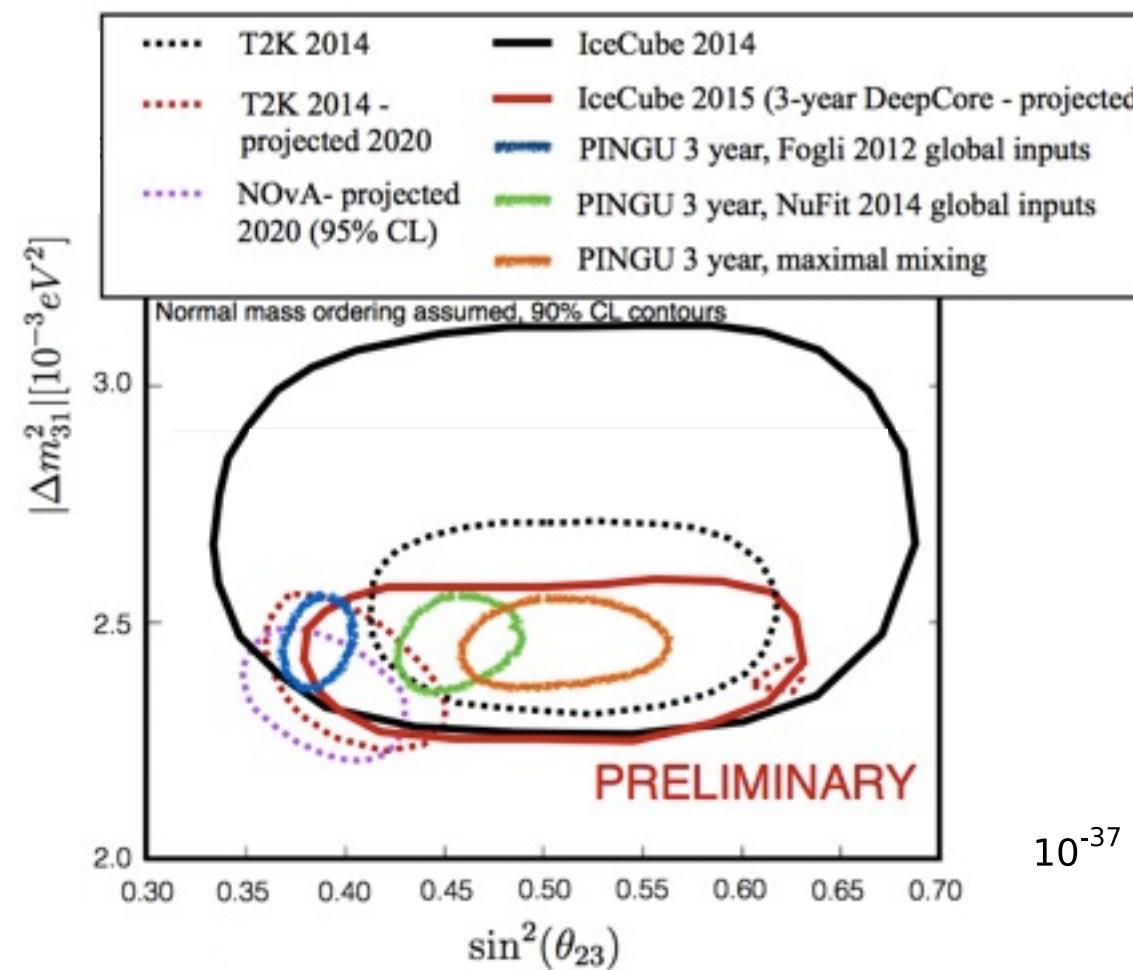
Systematic Effects

PRELIMINARY

- Investigate the most significant systematics
- Oscillation parameters have the largest effect, primarily θ_{23}

Type	3y σ (NMH)	3 y σ (IMH)
stat only	4.84	4.82
flux only	4.55	4.56
det only	4.06	3.99
θ_{23} only	3.52	3.26
osc only	2.96	2.53
All	2.90	2.51

Other Analyses

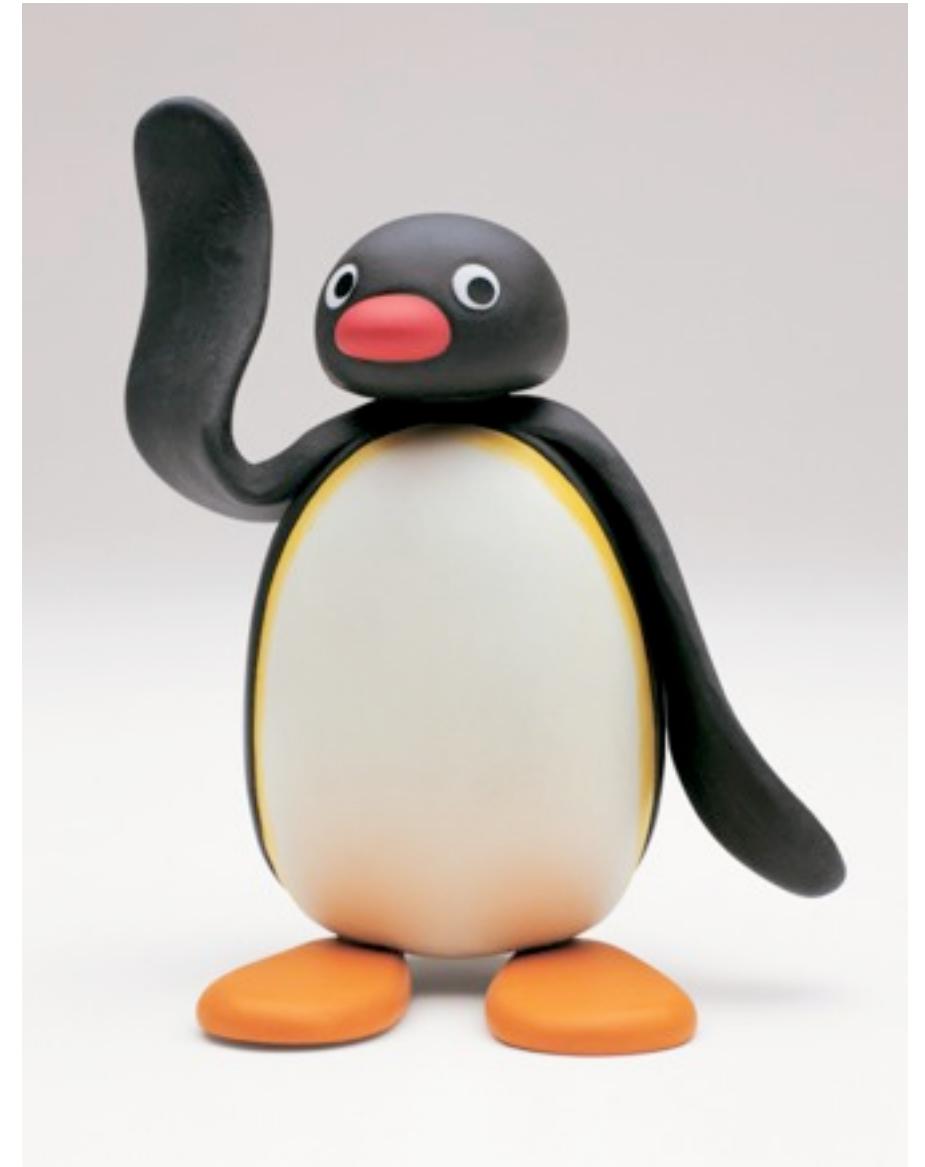


Future Outlook

- PINGU is an integral part of the IceCube-Gen2 observatory which will enhance the existing IceCube/DeepCore neutrino program
- PINGU will be the first deployed of the new strings
- Data taking could start 4-5 years following funding approval
- A revised Lol will be available soon (current version at arXiv: 1412.5106)

Conclusion

- IceCube and DeepCore have been very successful and have shown that particle physics is possible in ice
- PINGU will provide insight into the nature of the NMH as well as the oscillation parameters

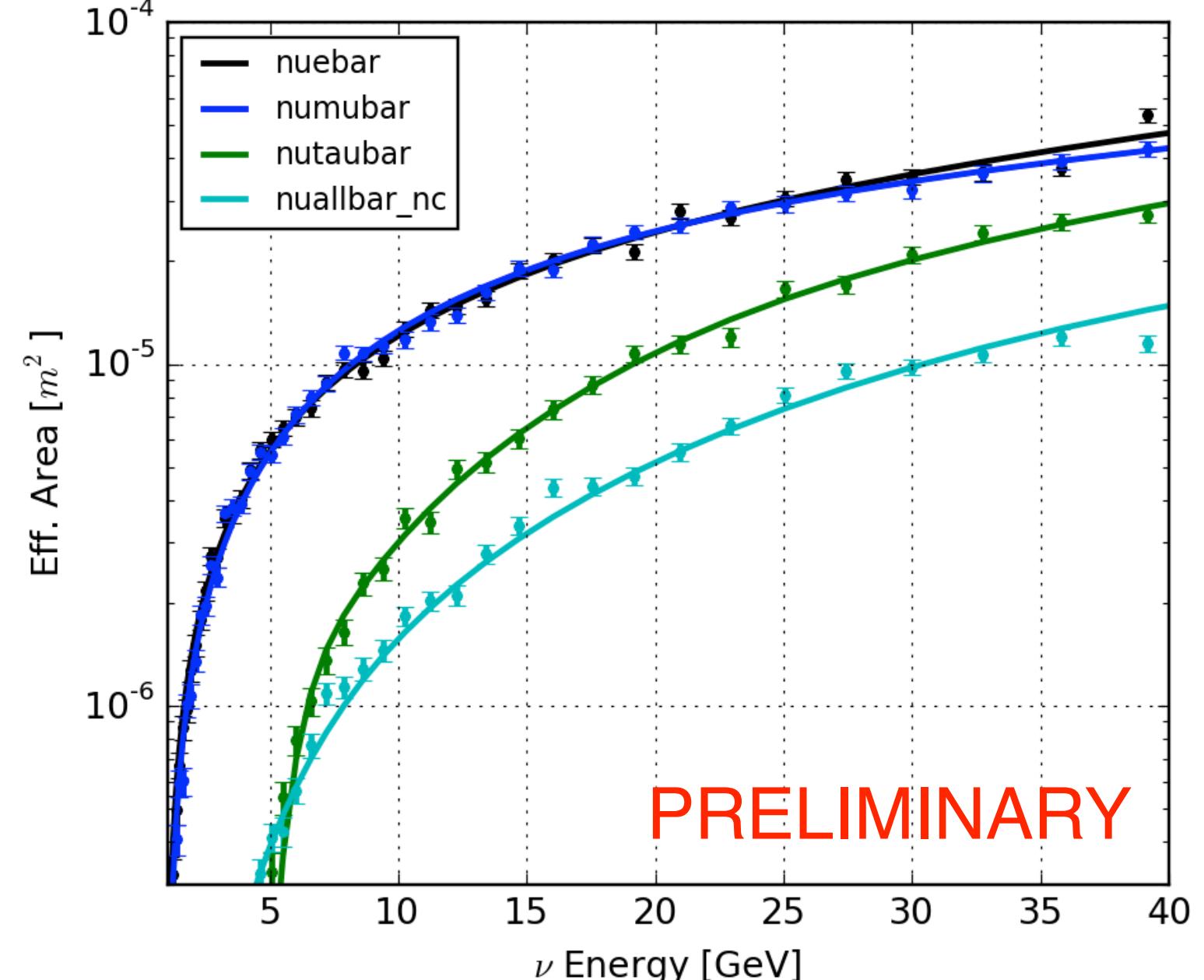
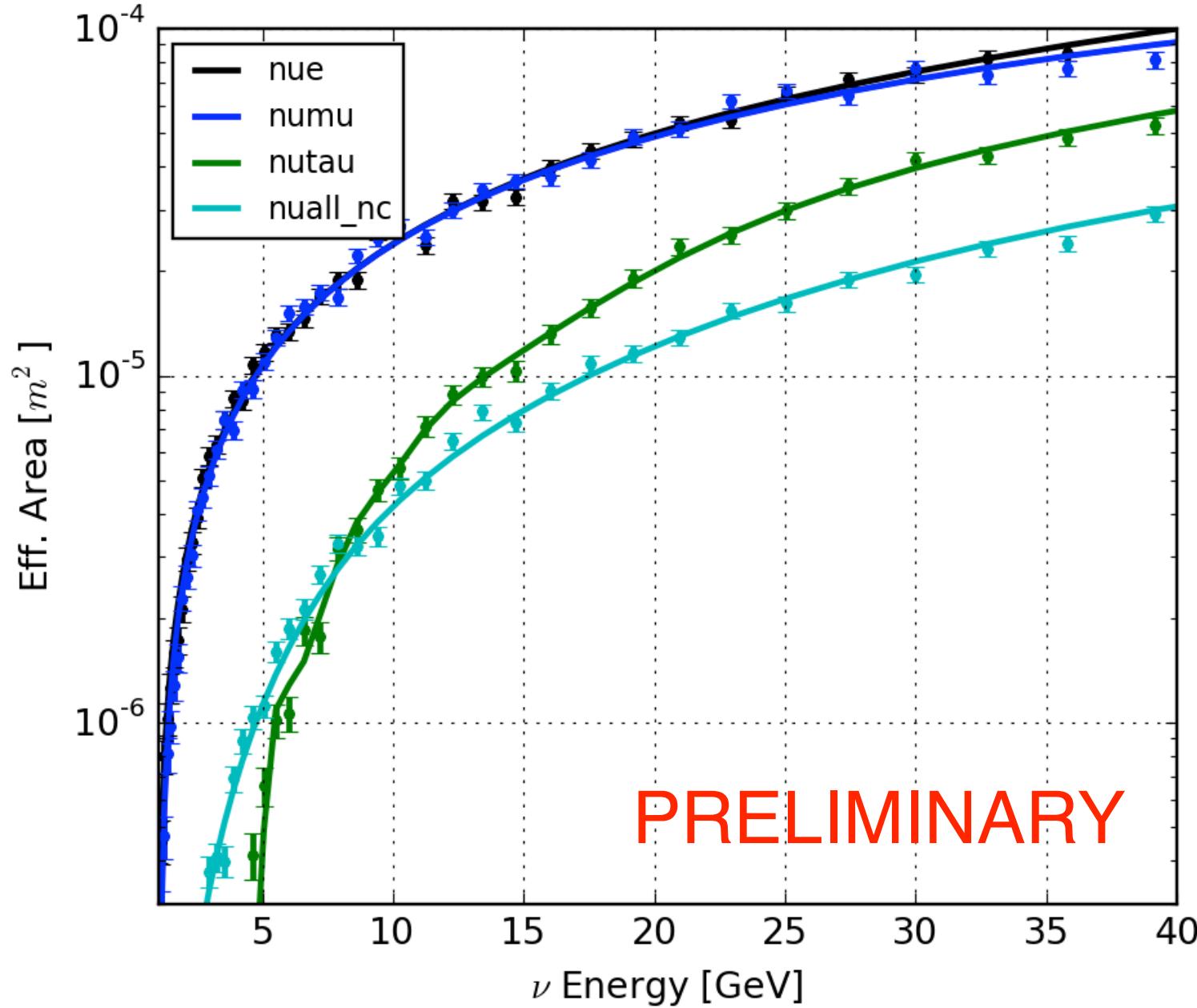


The IceCube–PINGU Collaboration



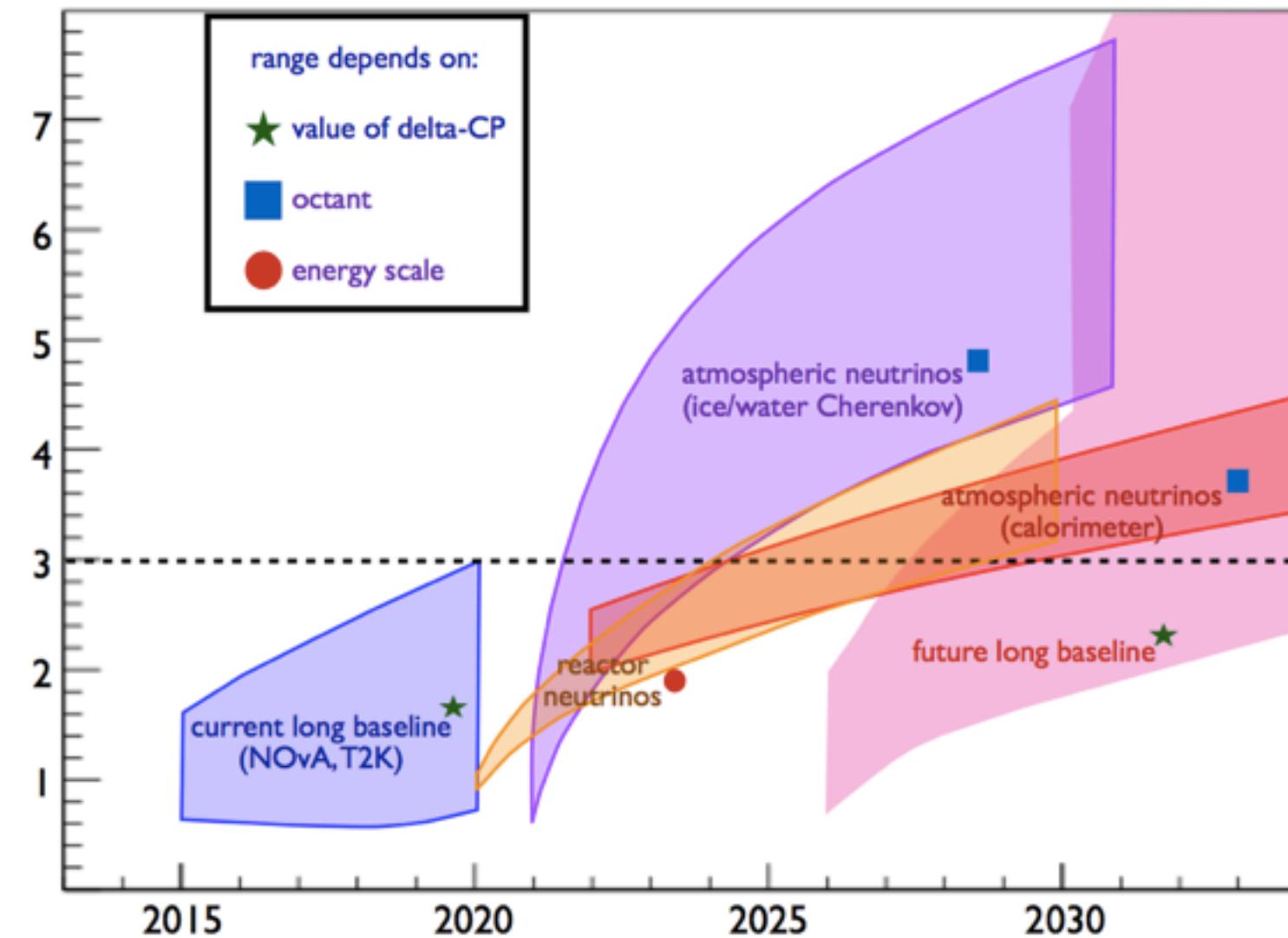
BACK UP

Events per Year

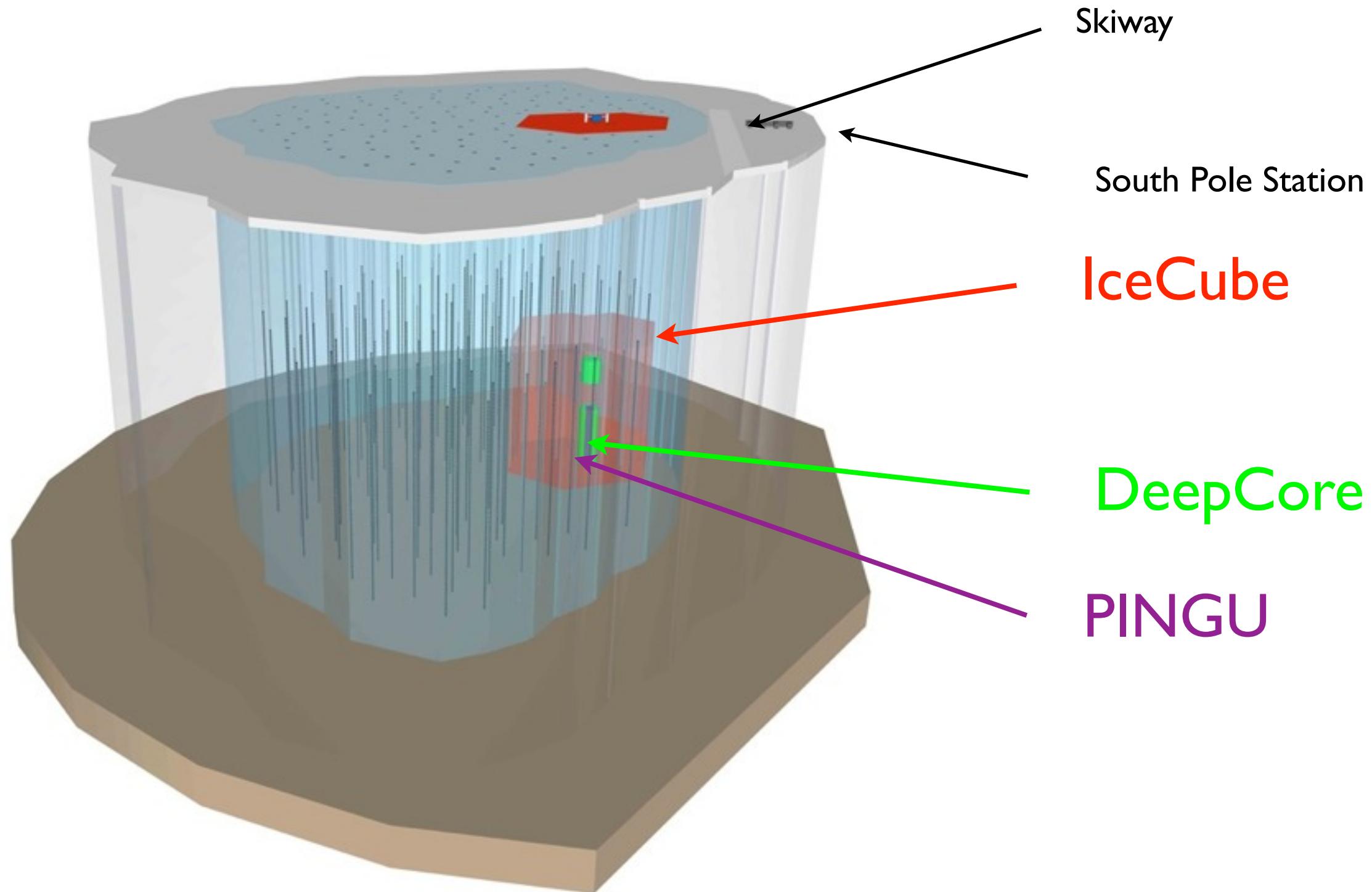


Future of the NMH Measurement

- **MANY** caveats
 - median outcome shown
 - width indicates effect of main uncertainty (δ_{CP} , θ_{23})
 - dates are also bound to change as time goes on

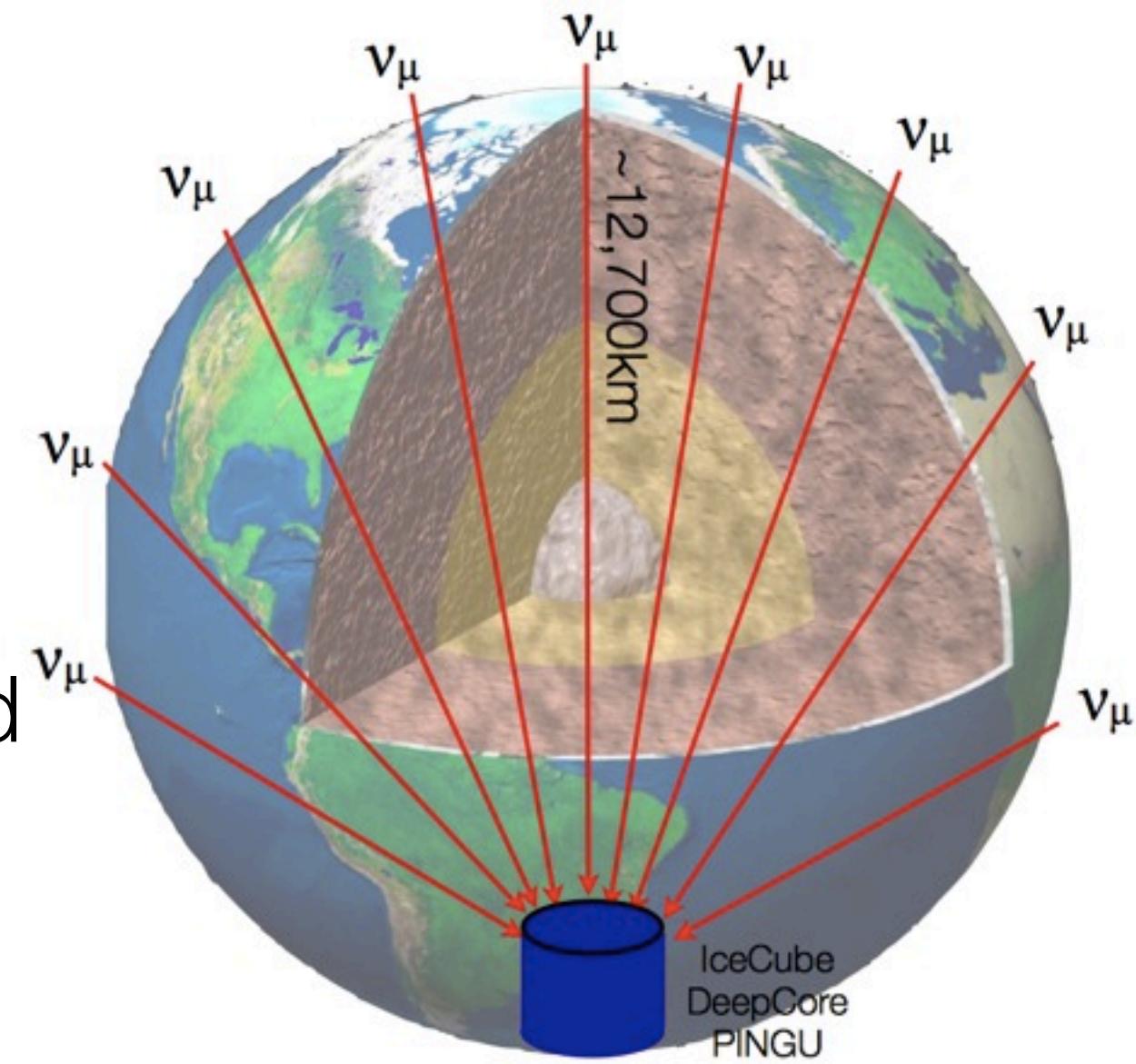


The IceCube Neutrino Telescope

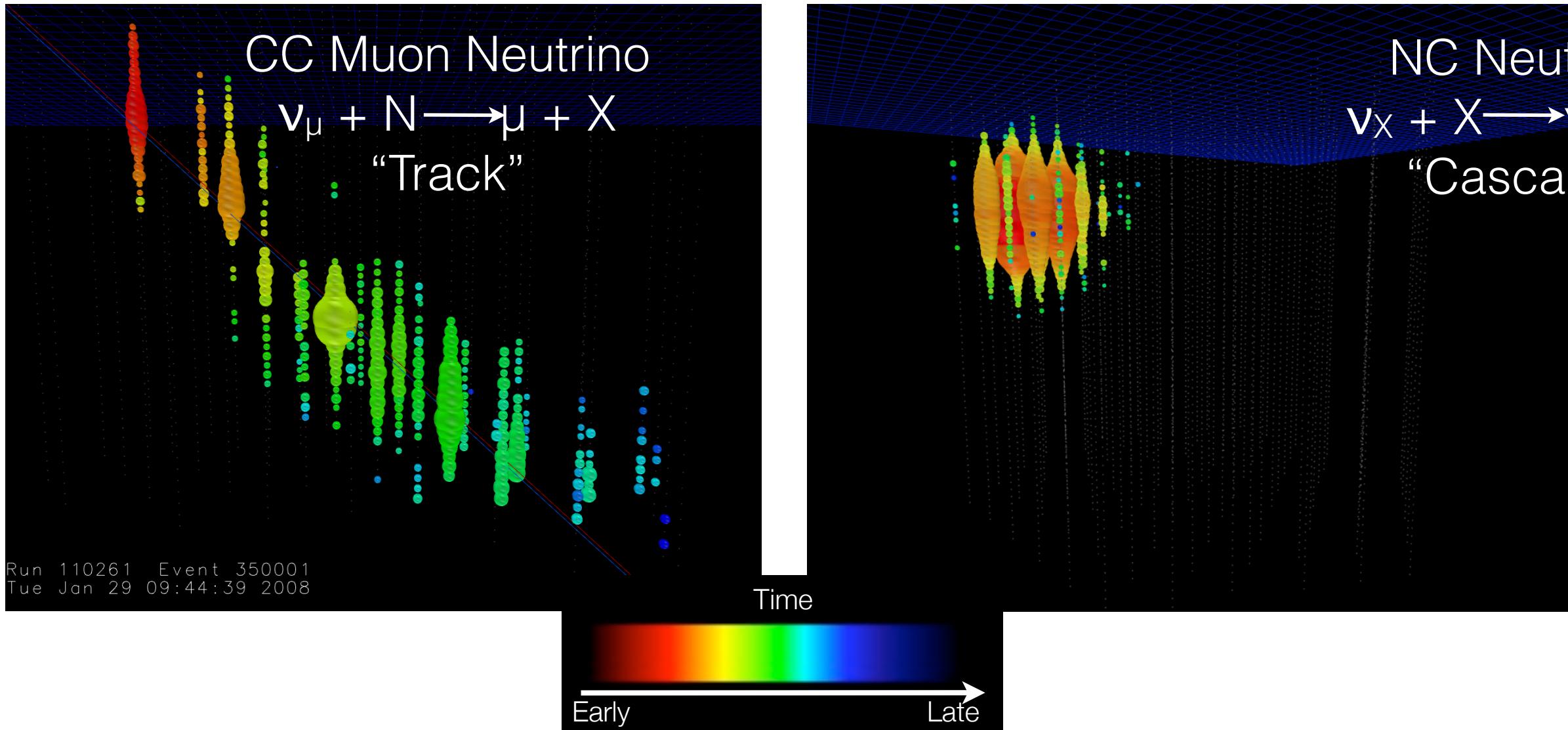


Atmospheric Neutrinos

- Source of neutrinos is the interaction of particles in the atmosphere
- These interactions produce neutrinos with an understood flux and flavour content

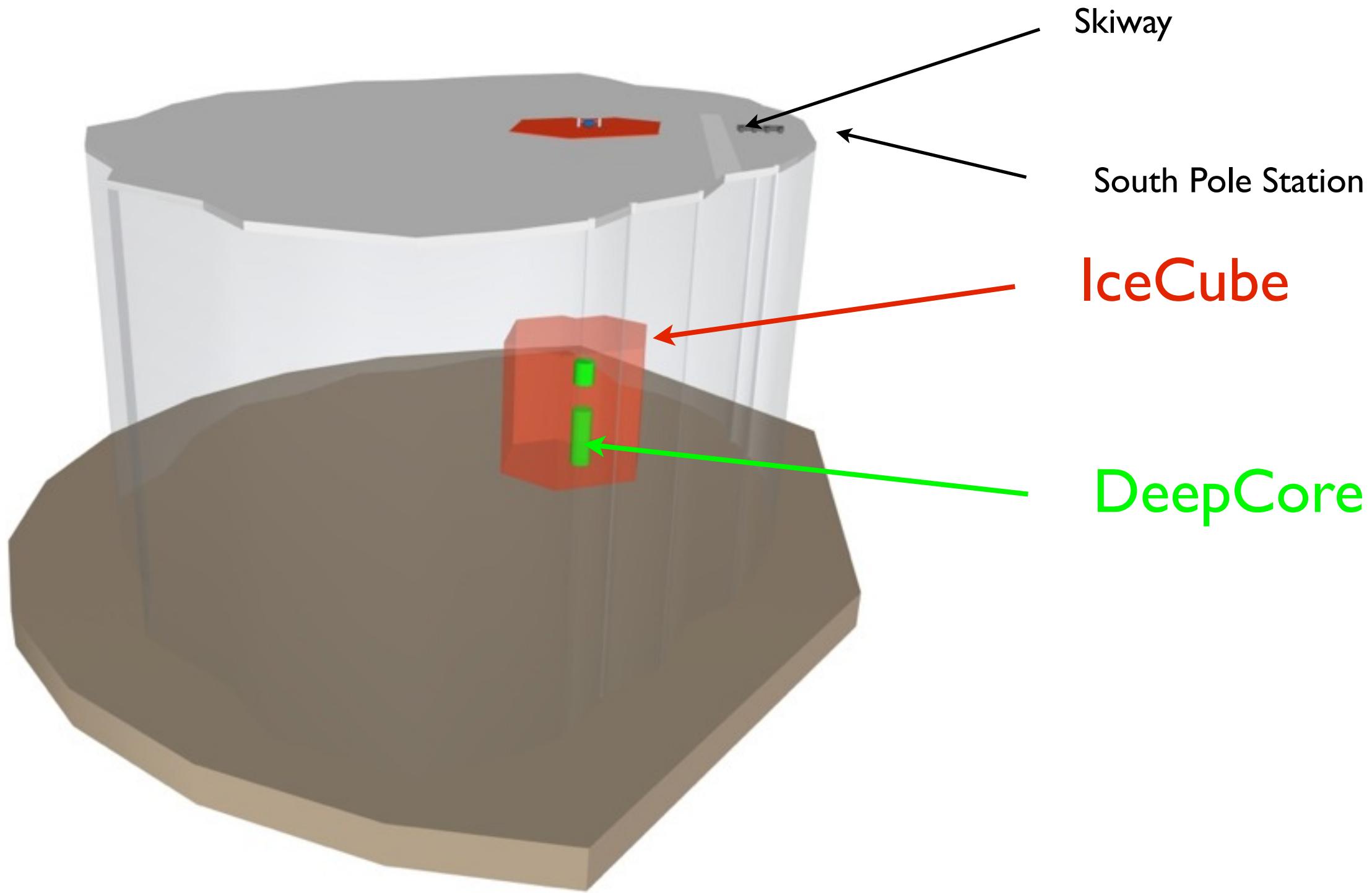


Events in the Detector



- Events are separable using their signature in the detector

The IceCube Neutrino Telescope



Timeline

