2013 IEEE Nuclear Science Symposium and Medical Imaging Conference (2013 NSS/MIC)

The IceCube Neutrino Telescope

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for the IceCube Collaboration

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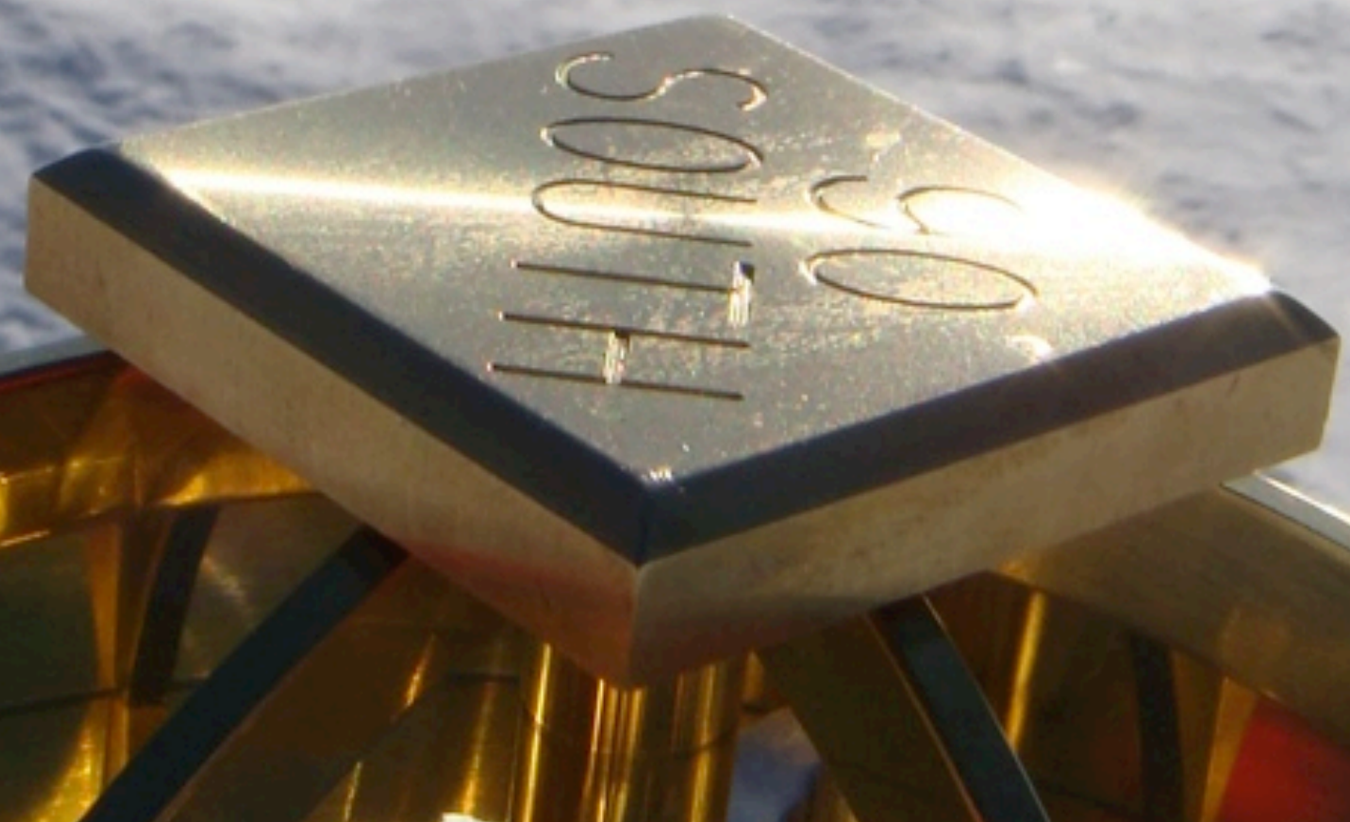
- Motivation
- The IceCube Neutrino Telescope
- Science Program and results
- PINGU
- Conclusions



IceCube

1398

The IceCube Collaboration

International Funding Agencies

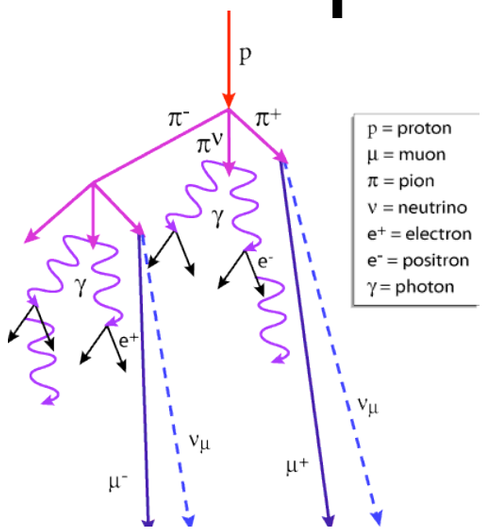
Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Inoue Foundation for Science, Japan
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

Motivation

- Neutrino astro-particle physics is a newly emerging field
  - Rich connection between astro-physics and particle physics
  - Instruments are multi-purpose detectors with extremely diverse science programs
- Tremendous progress has been made in the last years on neutrino astro-particle physics
  - Are we on the verge of discoveries ?

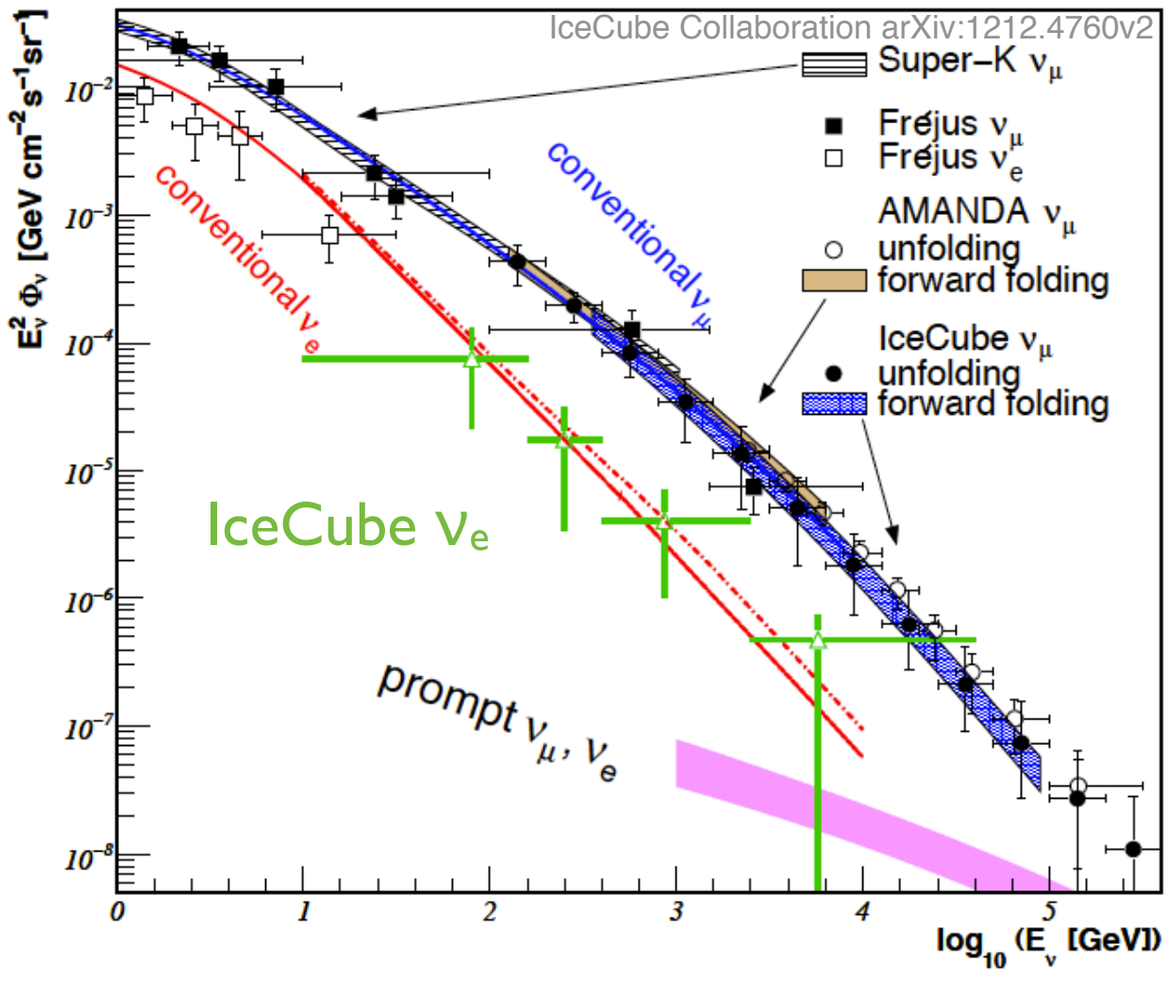
Sources of Neutrinos

Atmospheric Neutrinos



Cosmic rays interact in the upper atmosphere:

$p + A \rightarrow \pi^{\pm} (K^{\pm}) +$ other hadrons ... $\pi^{+} \rightarrow \mu^{+}\nu_{\mu} \rightarrow e^{+}\nu_{e}\nu_{\mu}\nu_{\mu}$



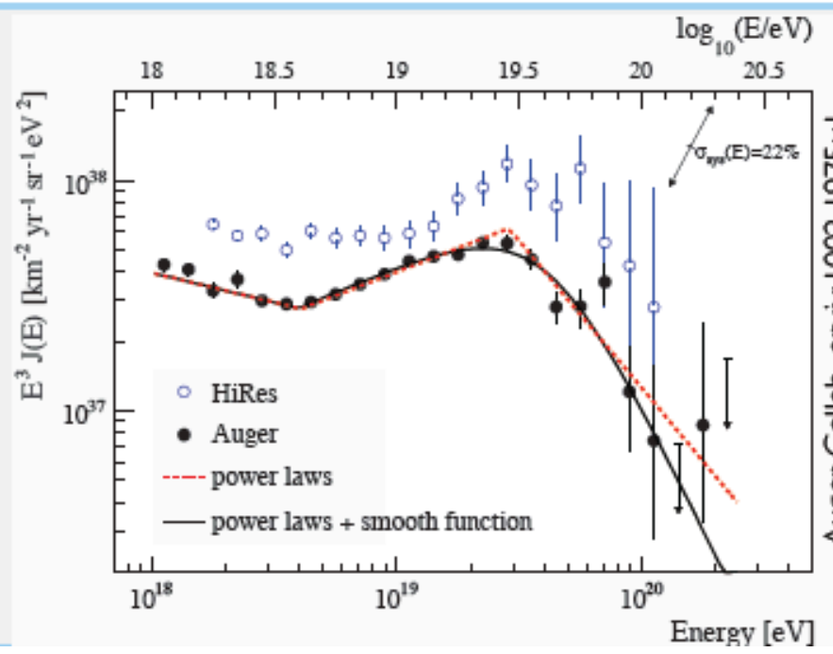
Astrophysical

$p + (p,\gamma) \rightarrow \pi^{\pm} \rightarrow \nu$

Gamma-ray Bursts

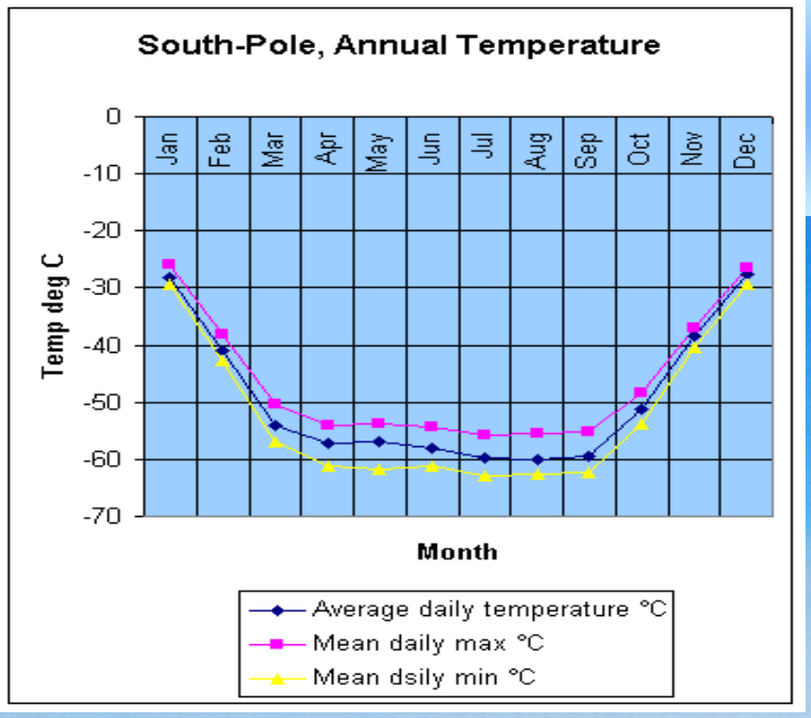
Active Galactic Nuclei

$p+\gamma_{3K} \rightarrow \Delta^{+}$ (GZK)



A new way to study the universe ... high-energy neutrinos

Laboratory at the South Pole



Geographic South Pole

Amundsen Scott South Pole Station

Road to work

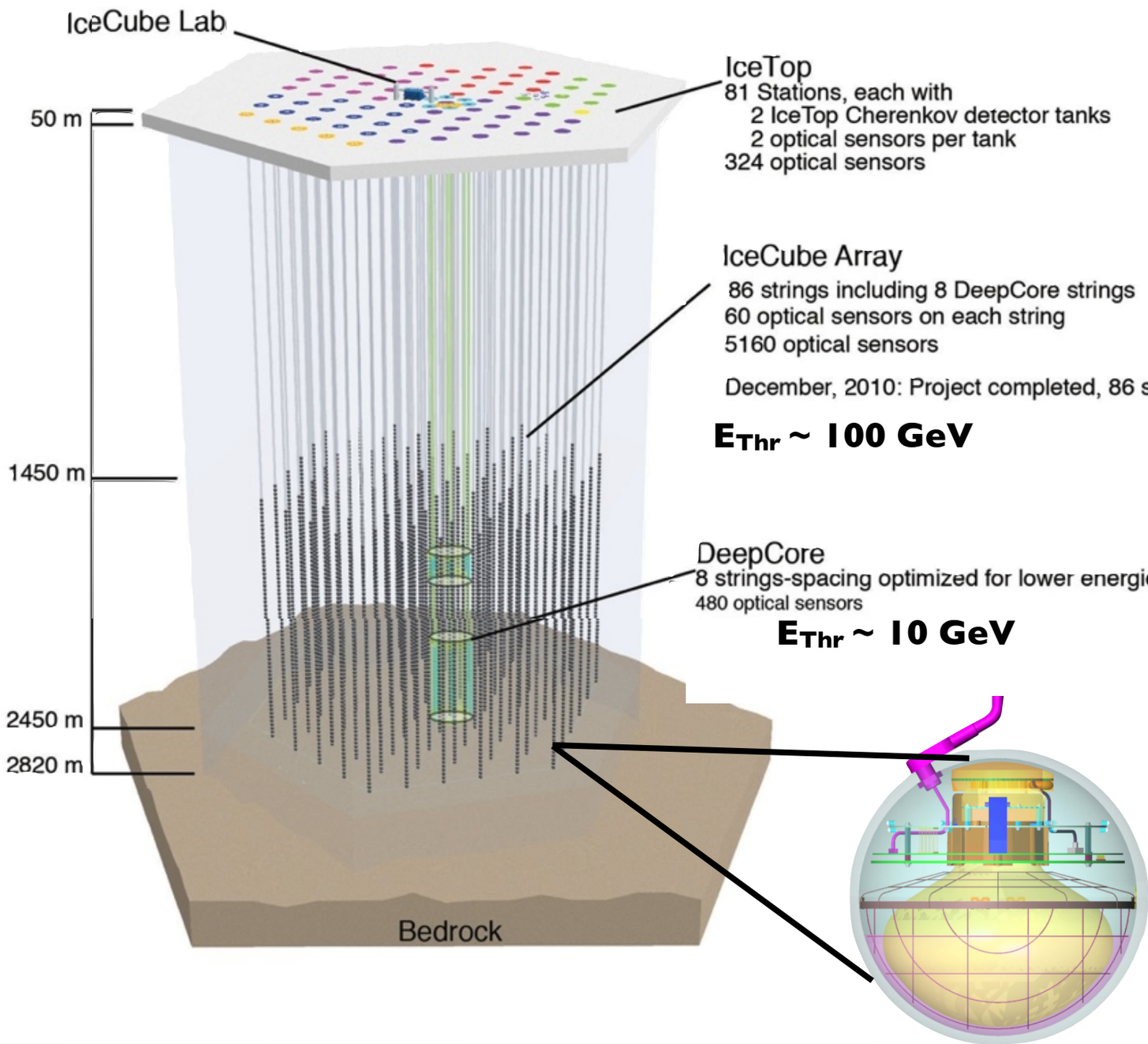
Skiway

1 km

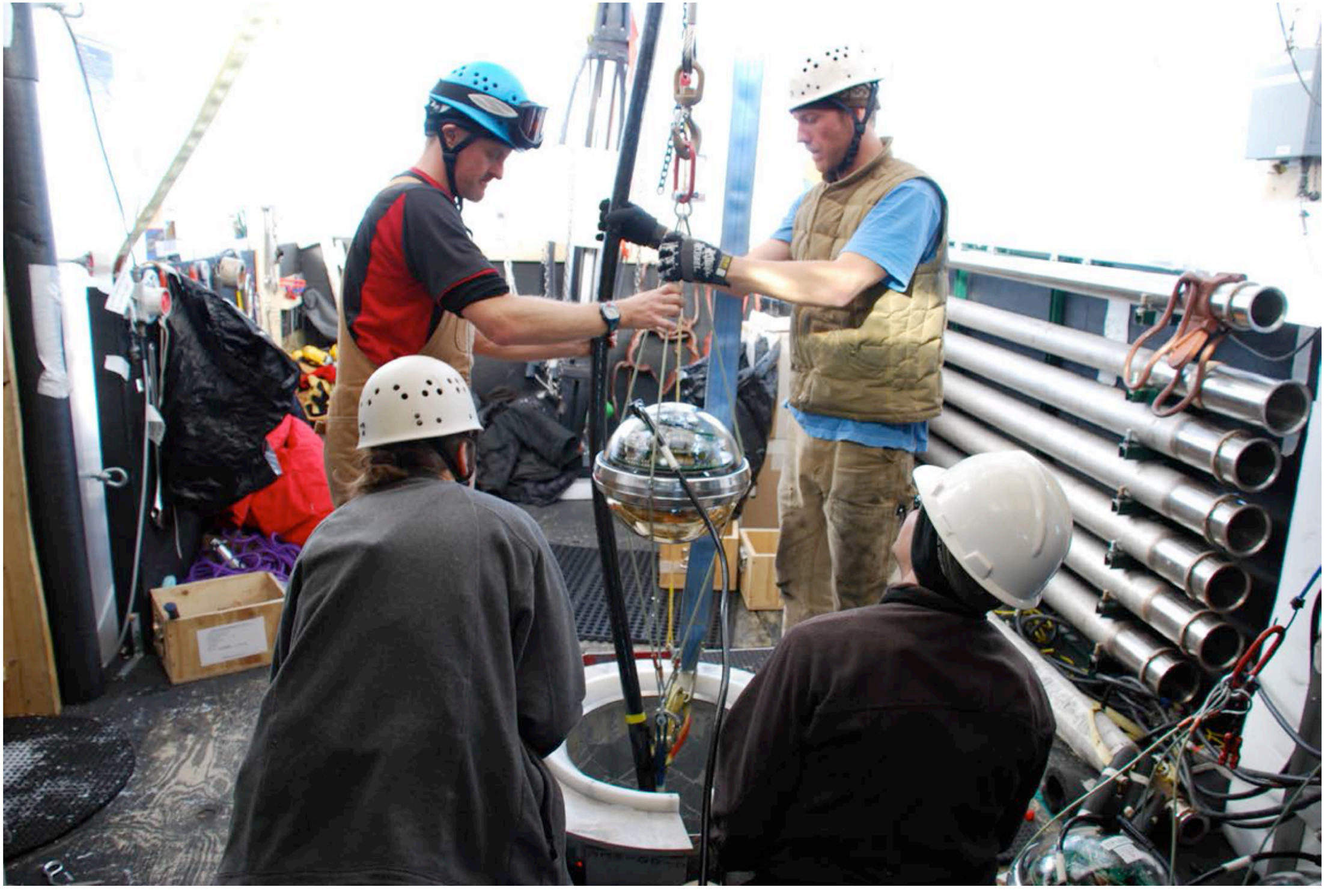
IceCube

The IceCube Neutrino Telescope

- Gigaton Neutrino Detector at the Geographic South Pole
- 5160 Digital optical modules distributed over 86 strings
- Completed in December 2010, start of data taking with full detector May 2011
- Data acquired during the construction phase has been analyzed
- Neutrinos are identified through Cherenkov light emission from secondary particles produced in the neutrino interaction with the ice

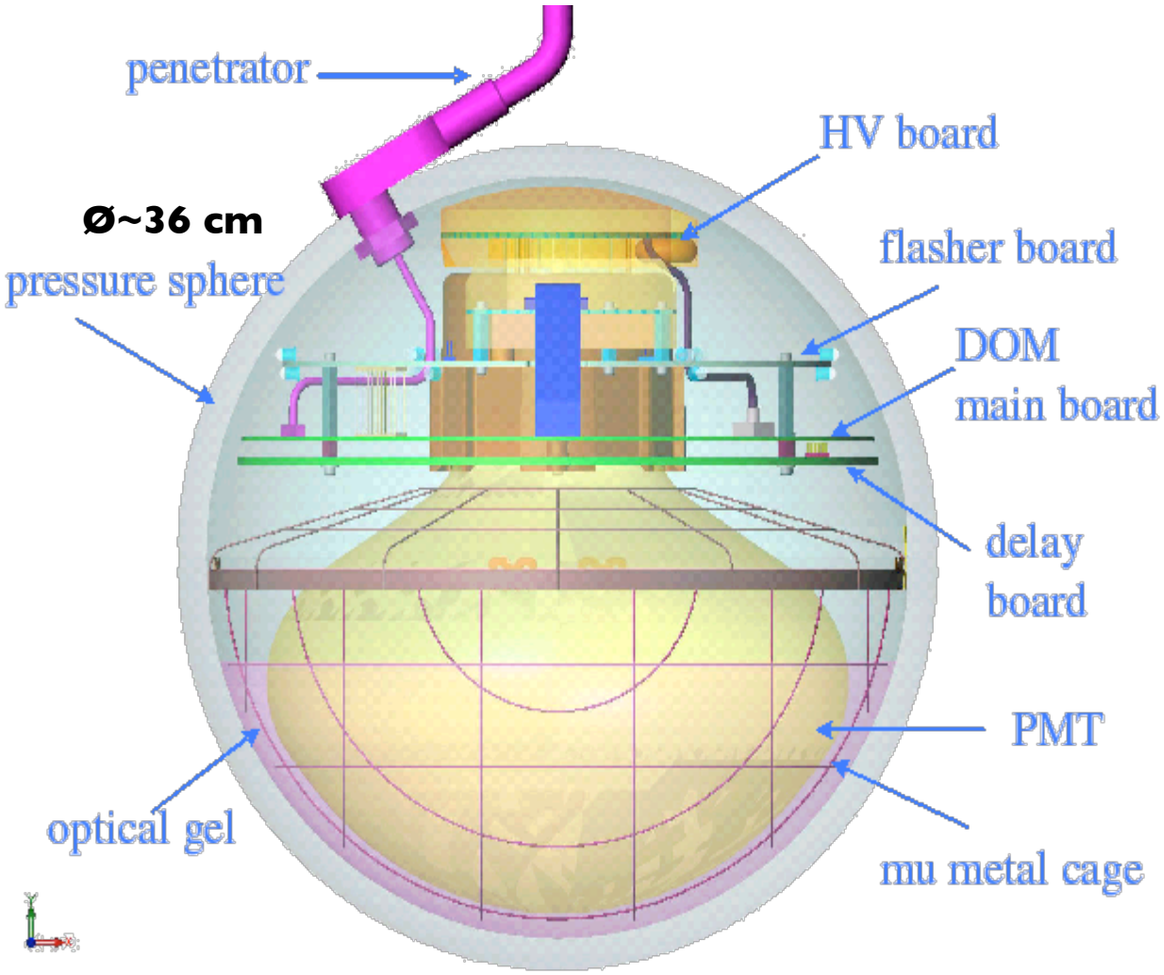


Deploying IceCube Sensors



Digital Optical Module (DOM)

10 inch Hamamatsu PMT (R-7081-02)



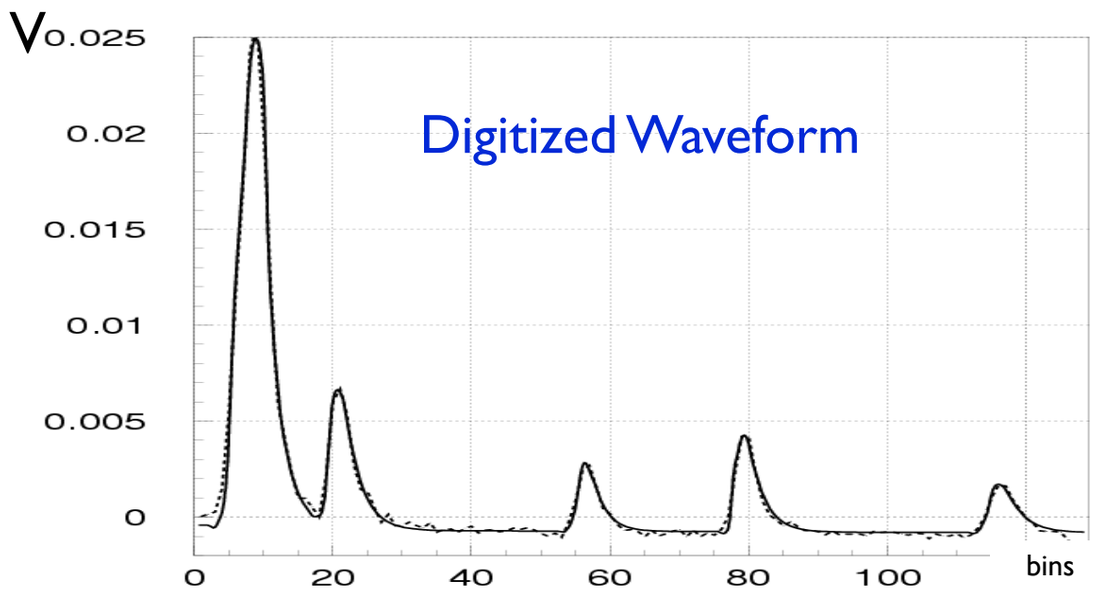
- Dark Noise rate ~ 350 Hz
- Local Coincidence rate ~ 15 Hz
- Deadtime < 1%
- Timing resolution ≤ 2 ns

Measure individual photon arrival time:

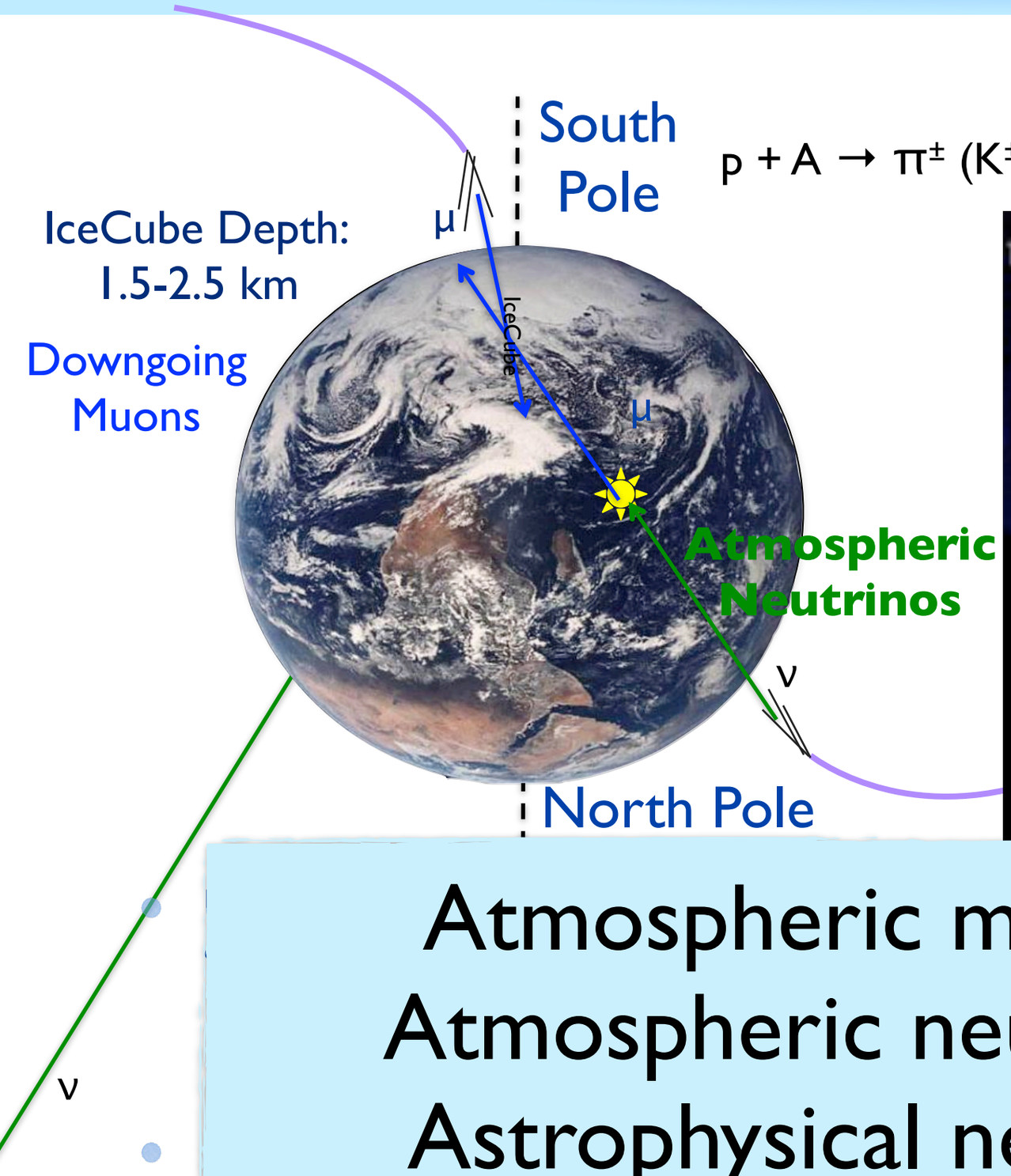
2 ping-ponged four-channel ATWDs:

- Analog Transient Waveform Digitizer
- 200-700 Megasamples/s
- 400 ns range
- 400 pe / 15 ns

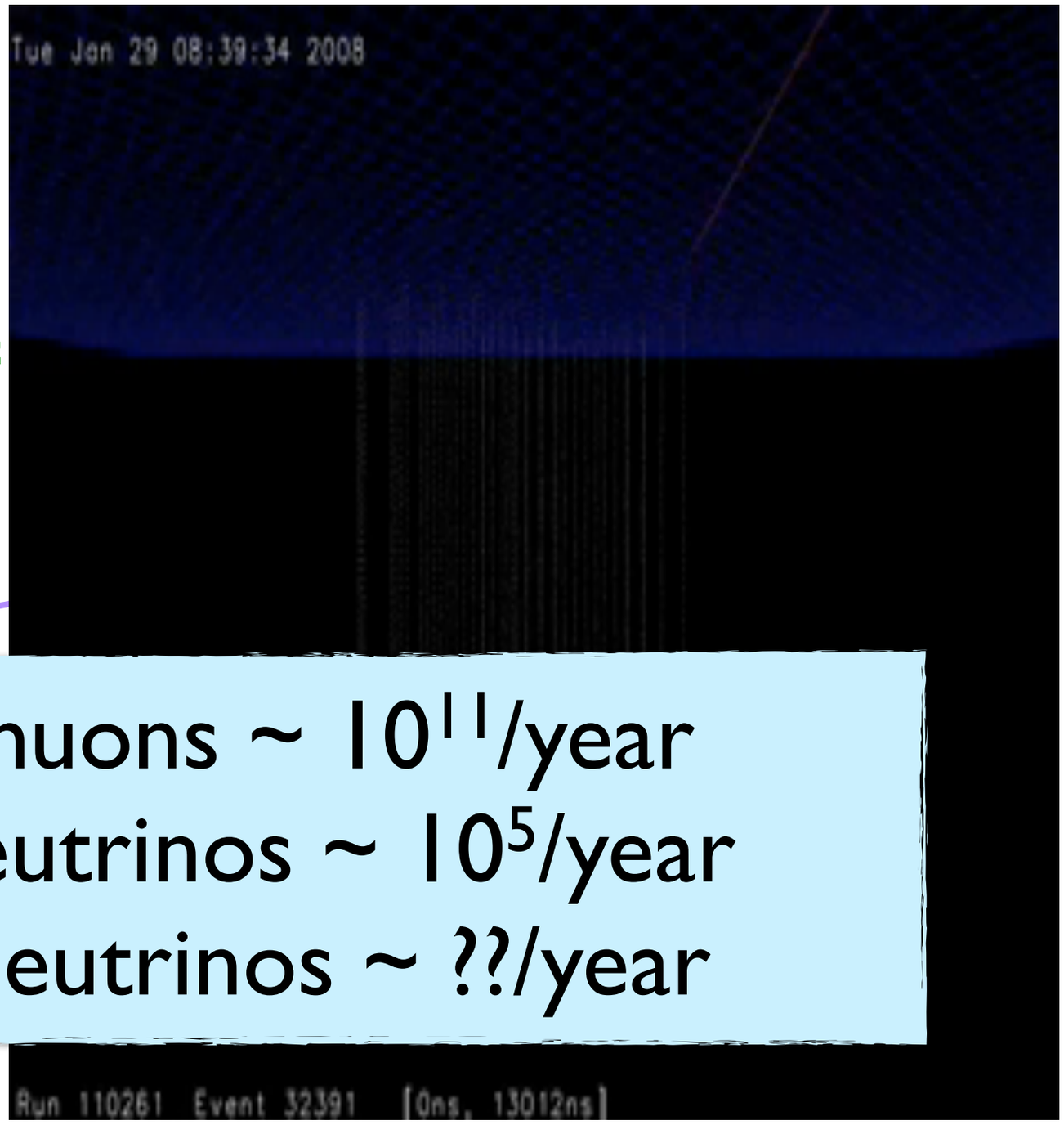
- fADC (fast 'ADC'):
  - 40 Megasamples/s
  - 6.4 μs range



Signals in IceCube



$p + A \rightarrow \pi^{\pm}\,(K^{\pm}) + \text{other hadrons} \quad \ldots \pi^{+} \rightarrow \mu^{+}\nu_{\mu} \rightarrow e^{+}\nu_{e}\nu_{\mu}\nu_{\mu}$

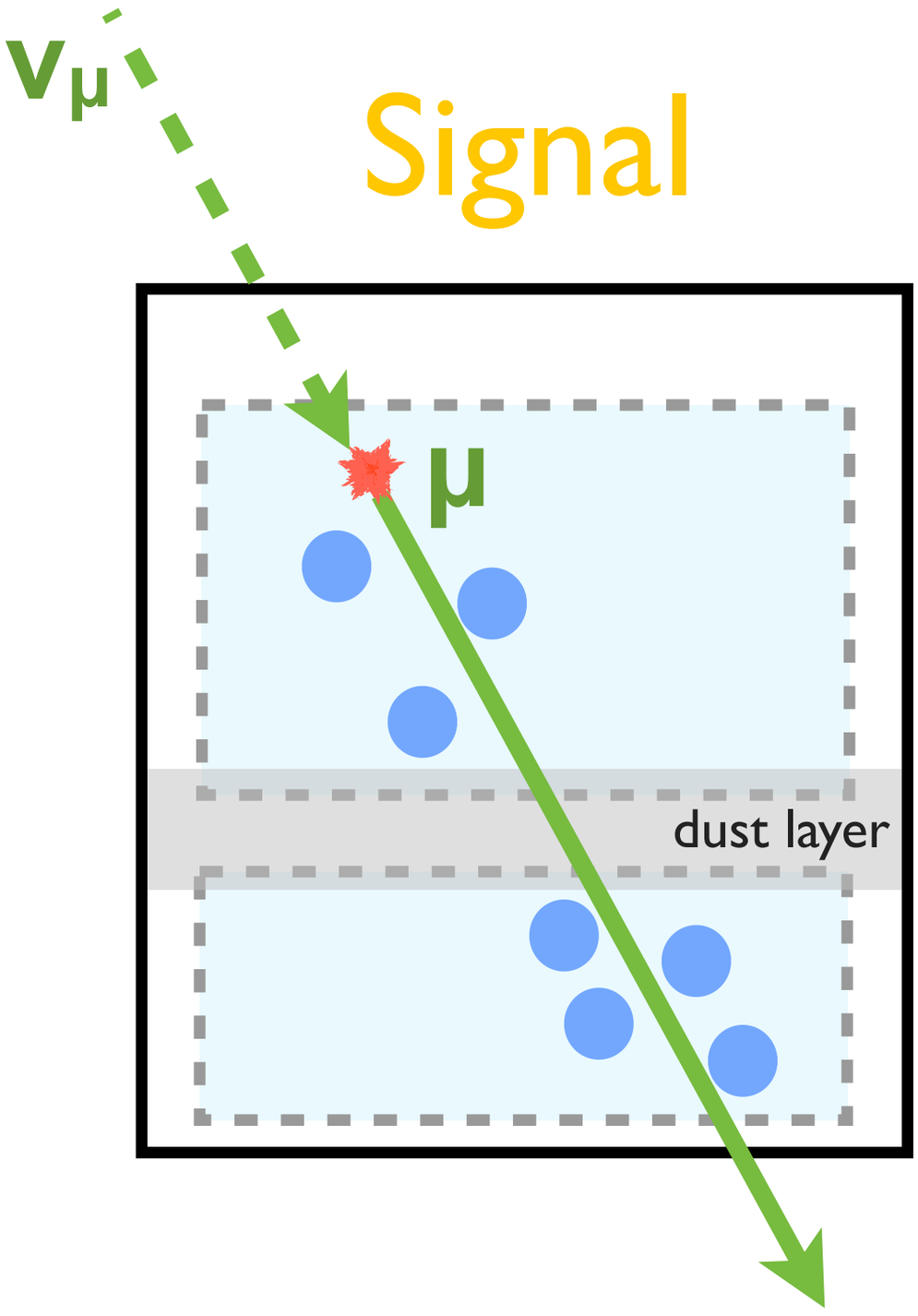


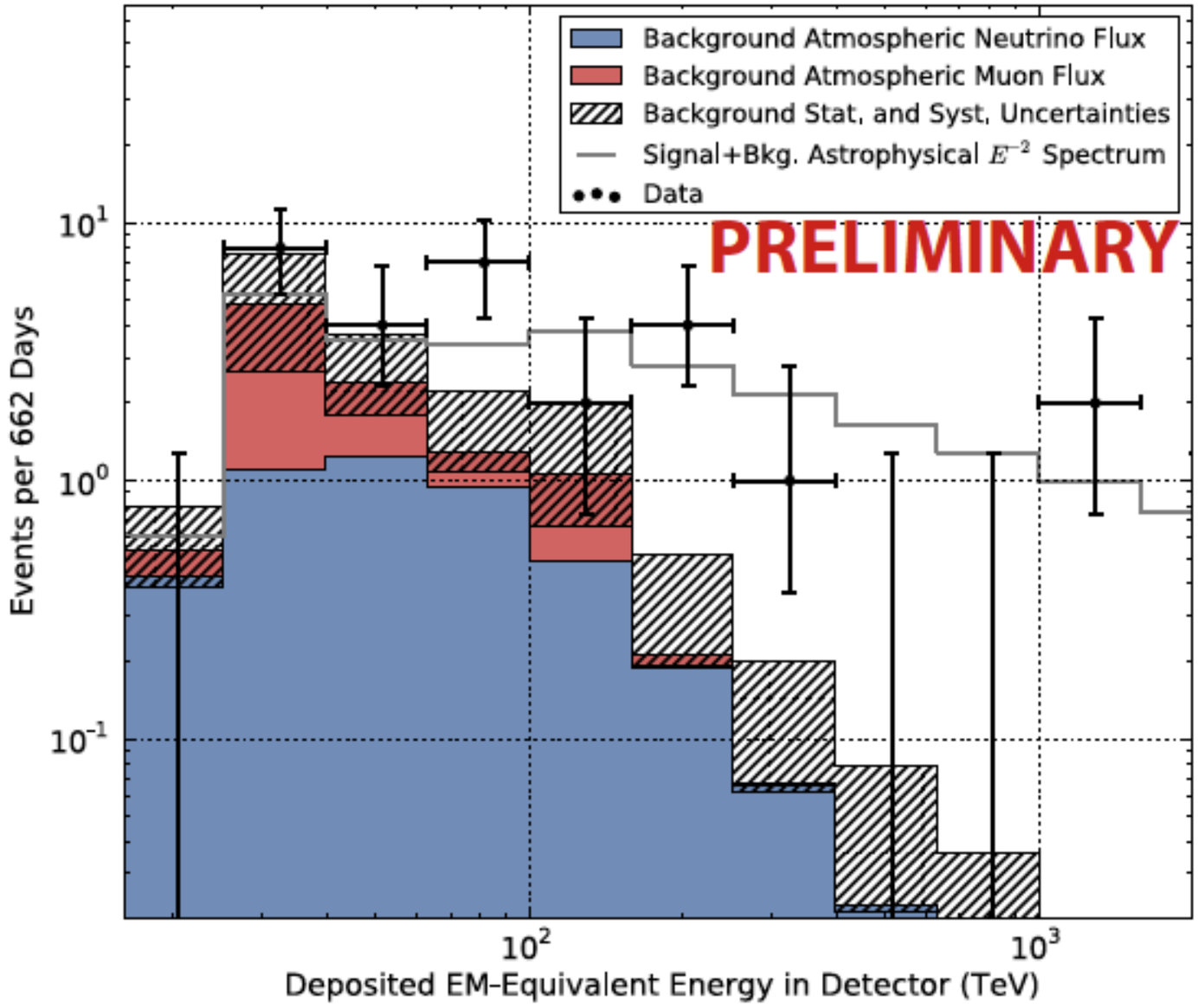
Atmospheric muons ~ 10^{11}/year
Atmospheric neutrinos ~ 10^{5}/year
Astrophysical neutrinos ~ ??/year

irreducible neutrino background to extra terrestrial neutrino fluxes

Selected Results

High-energy neutrino search

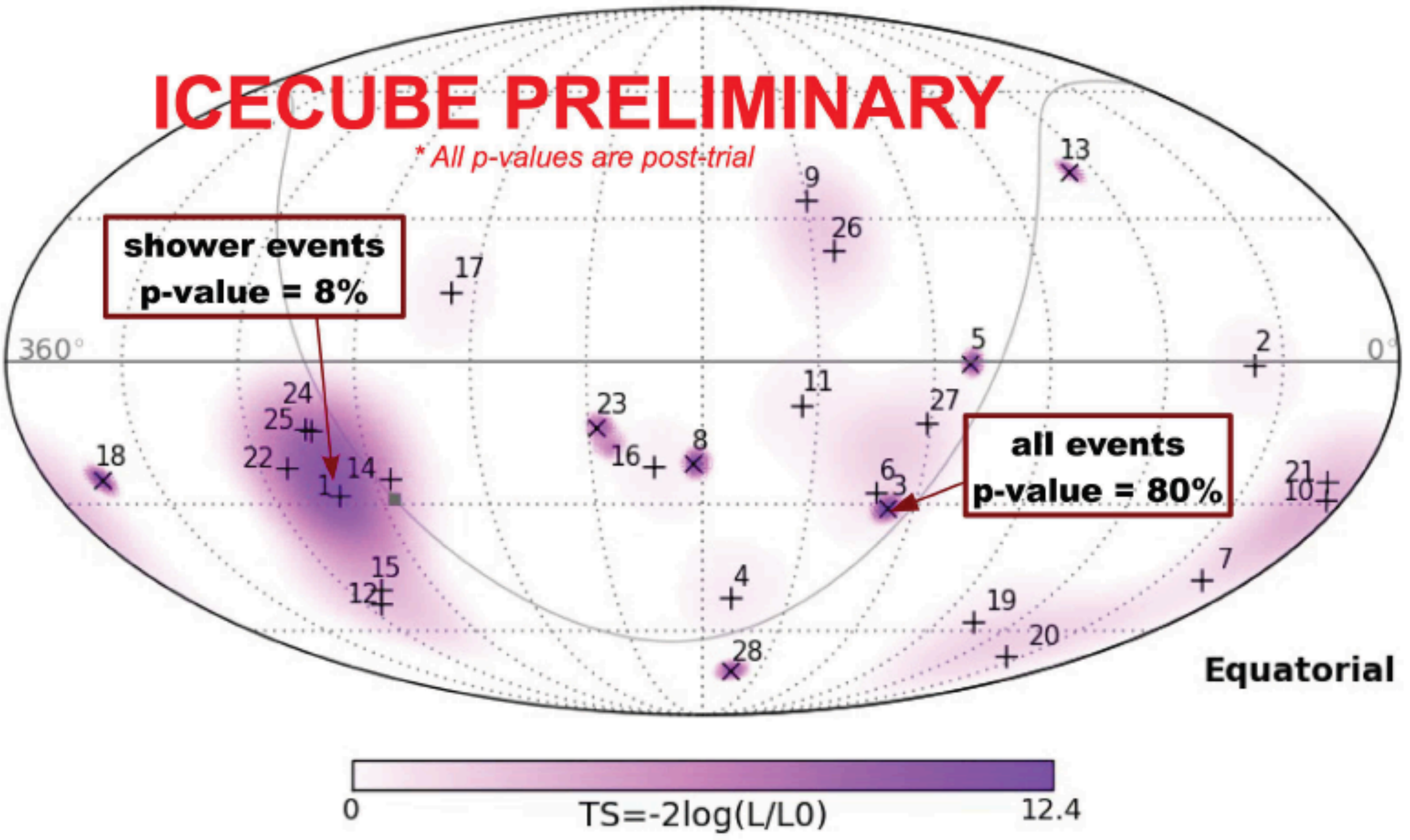




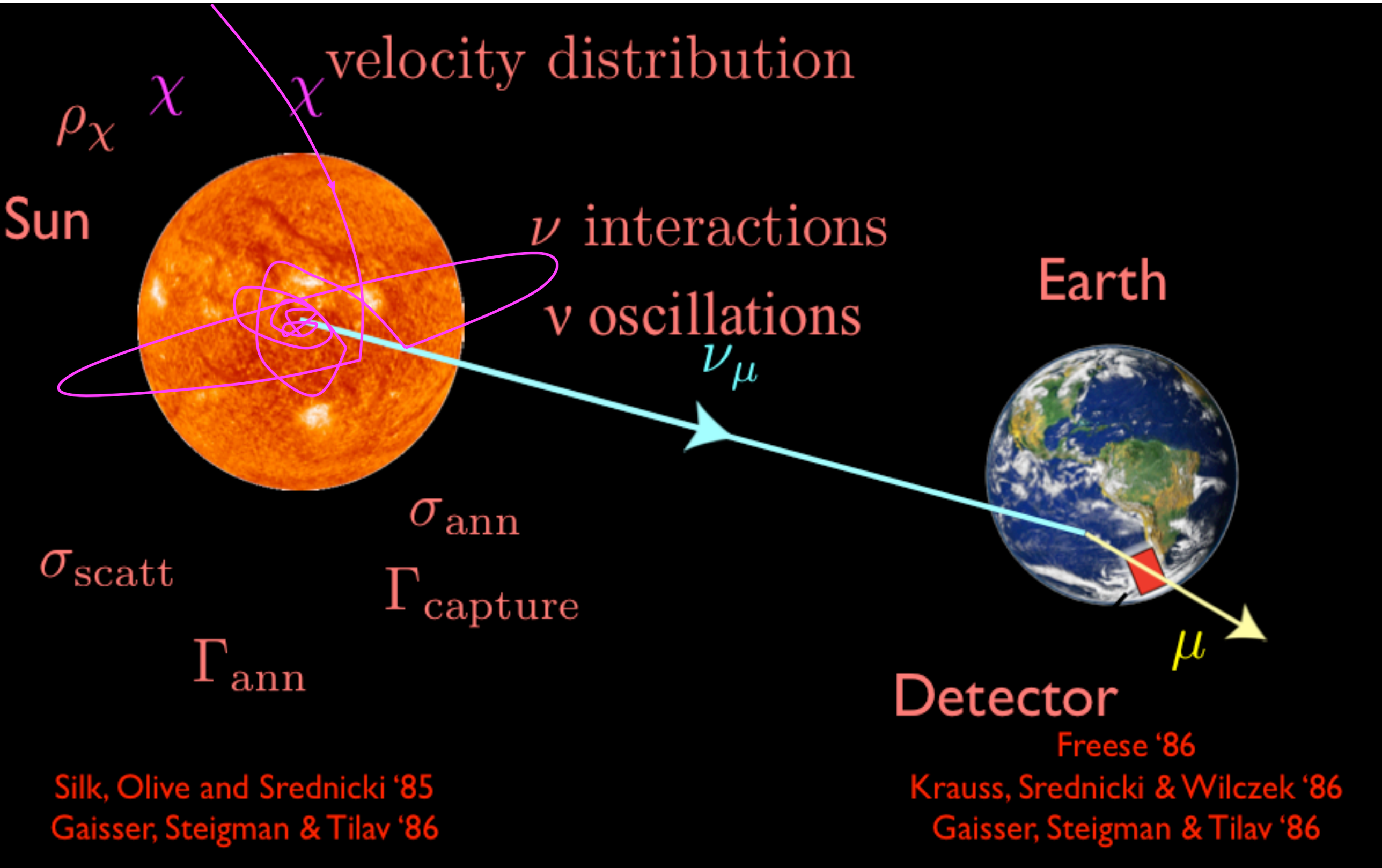
28 events (7 track-like, 21 showers) observed

Expectation from conventional atm. neutrinos $10.6\,^{+5.0}_{-3.6}$

High-energy neutrino search



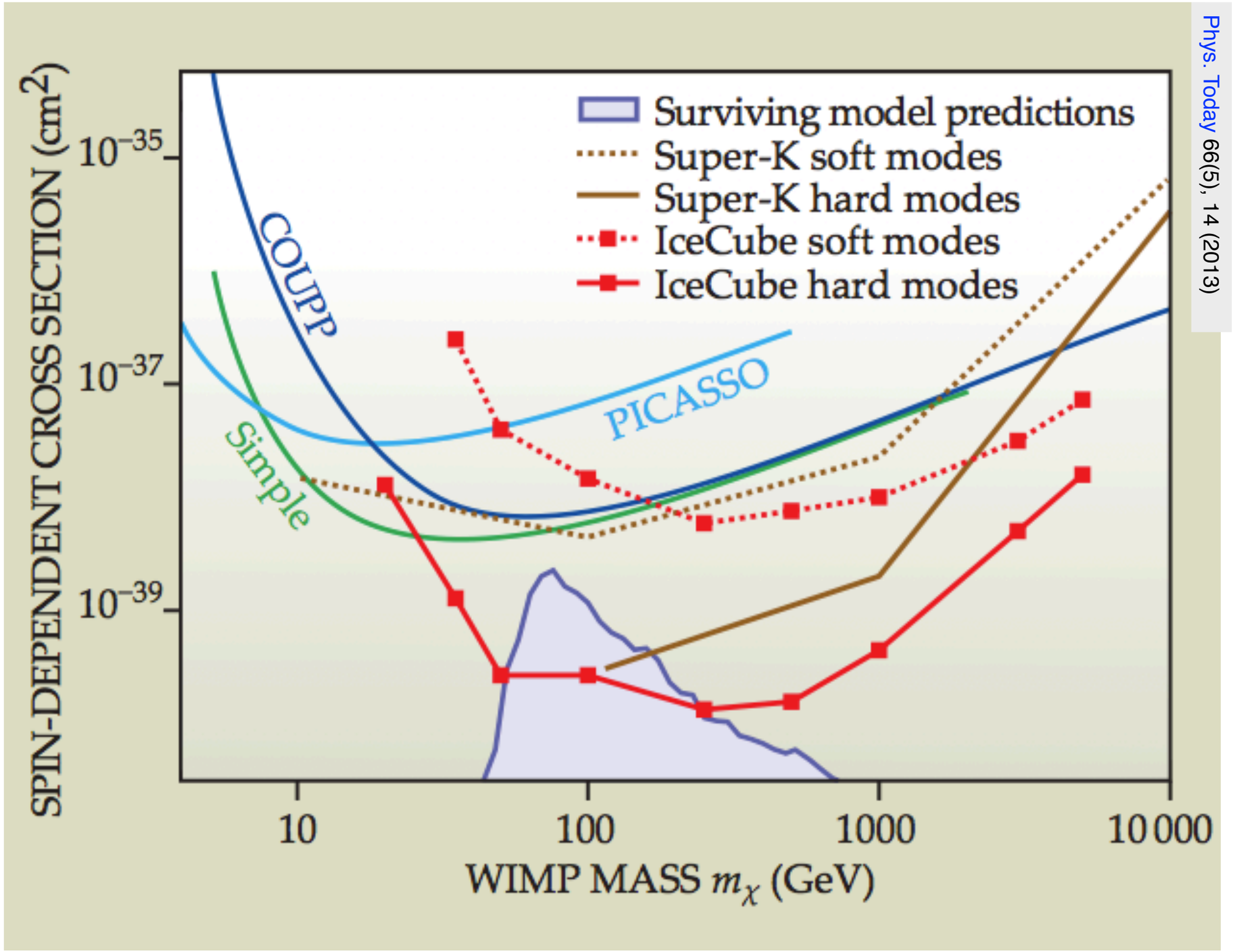
Dark Matter Search



Silk, Olive and Srednicki '85
Gaisser, Steigman & Tilav '86

Freese '86
Krauss, Srednicki & Wilczek '86
Gaisser, Steigman & Tilav '86

IceCube Dark Matter Search

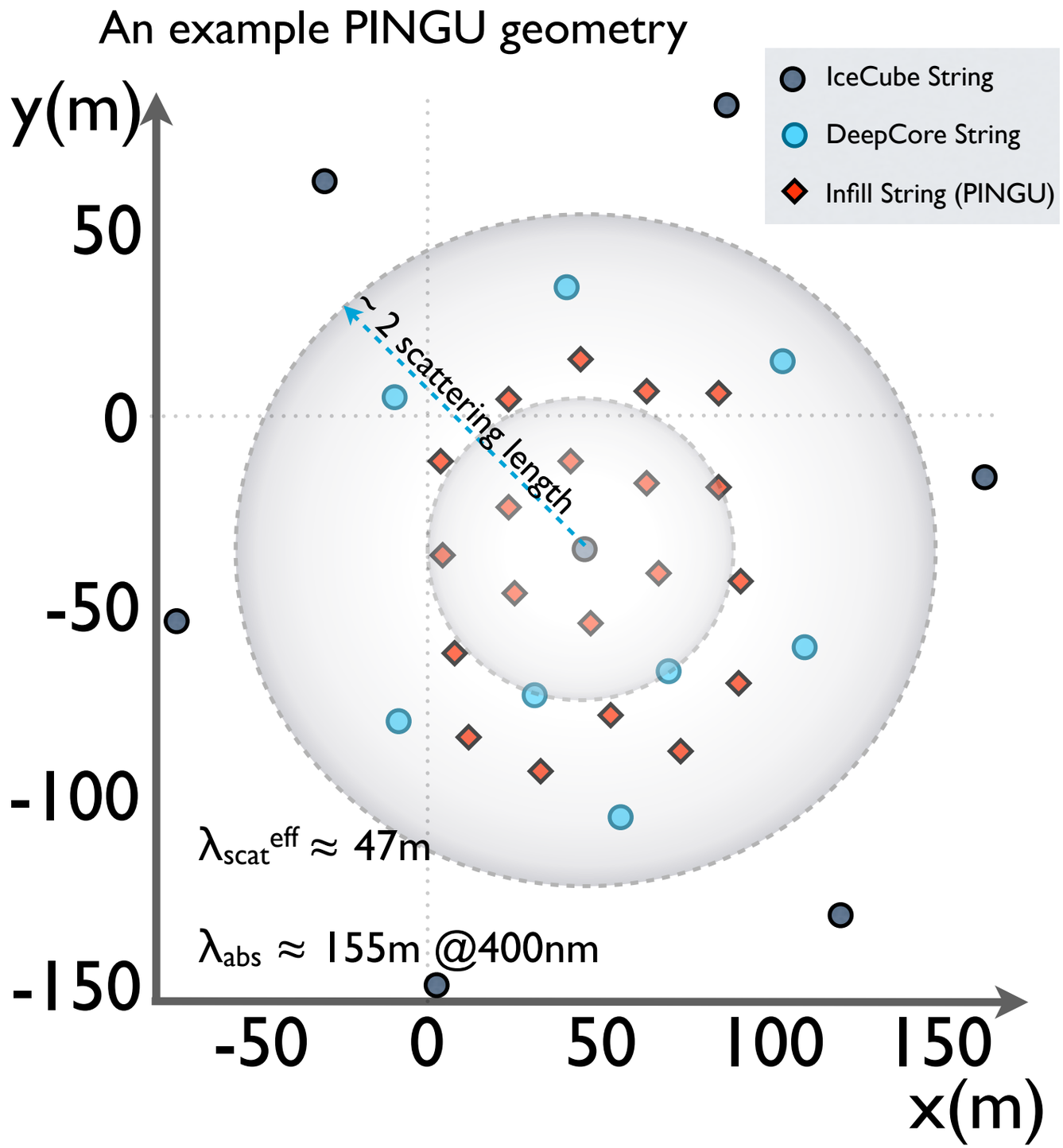


Phys. Today 66(5), 14 (2013)

Future Plans

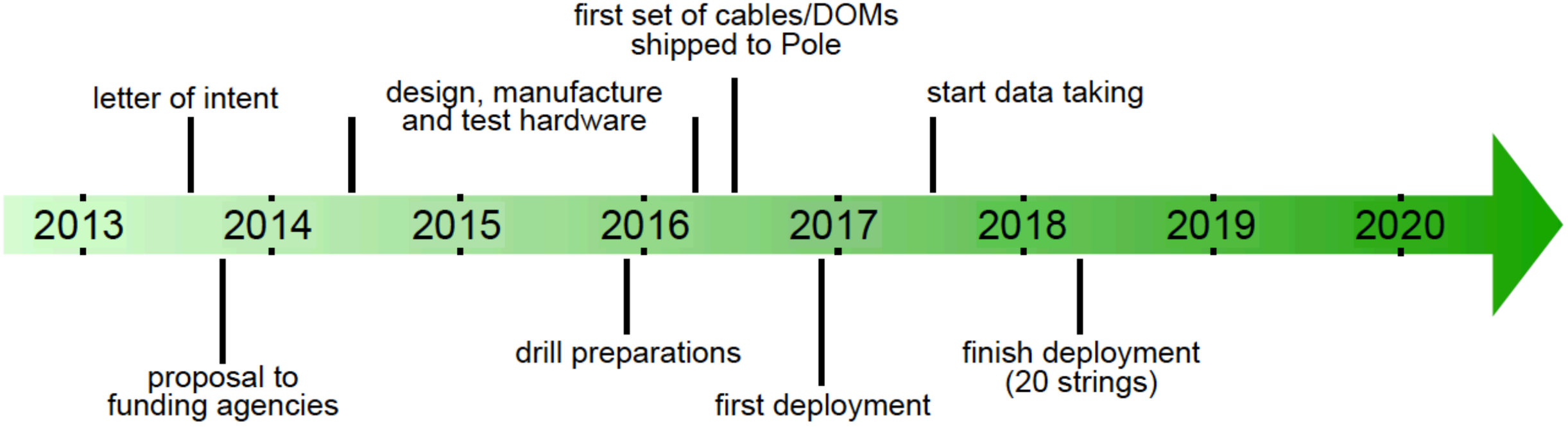
PINGU - Precision IceCube Next Generation Upgrade

- Developing a proposal to further in-fill DeepCore, called PINGU
  - Instrument a volume of about 10MT with ~20 strings each containing 50-60 optical module
  - Rely on well established drilling technology and photo sensors
  - Create platform for calibration program and test technologies for future detectors
- Physics Goals:
  - Precision measurements of neutrino oscillations (mass hierarchy, ...)
  - Test low mass dark matter models



PINGU Time Line

- Moderate timeline of ~10 years (data taking could start in 2017)
- Overall low risk for construction and operation (IceCube experience)
- Costs: ~10 M$ for startup (includes drill reactivation) + 1.25 M$ per string



Low-cost on-board cameras for PINGU

- Low-cost on-board camera system
  - complementary to the more sophisticated camera systems.
  - The merit of the system:
    - can be deployed on a large fraction or all of PINGU Sensors
  - determine the exact positioning of individual DOMs with respect to the drill hole and refrozen ice
  - understand local ice properties after freeze in

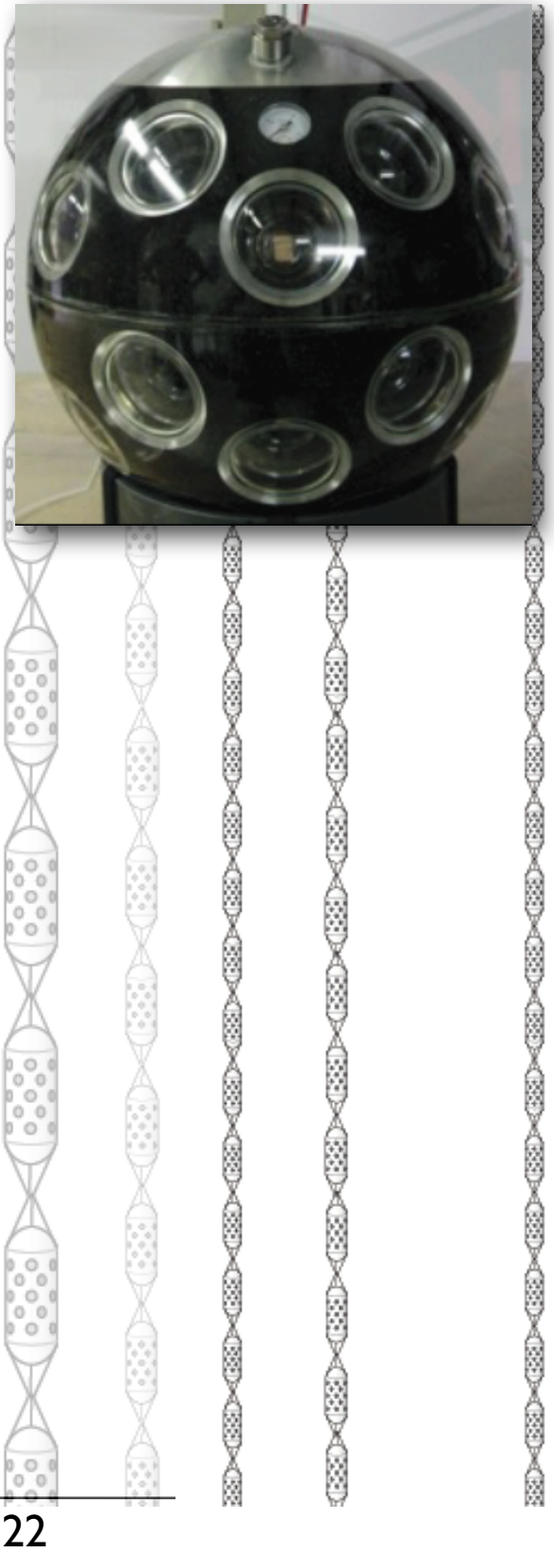
Conclusions

- IceCube has reigned in a new era in astro-particle physics
- Neutrinos offer new and complementary ways to study the cosmos
- Great prospect for future upgrades
  - Neutrino telescopes evolve towards precision detectors

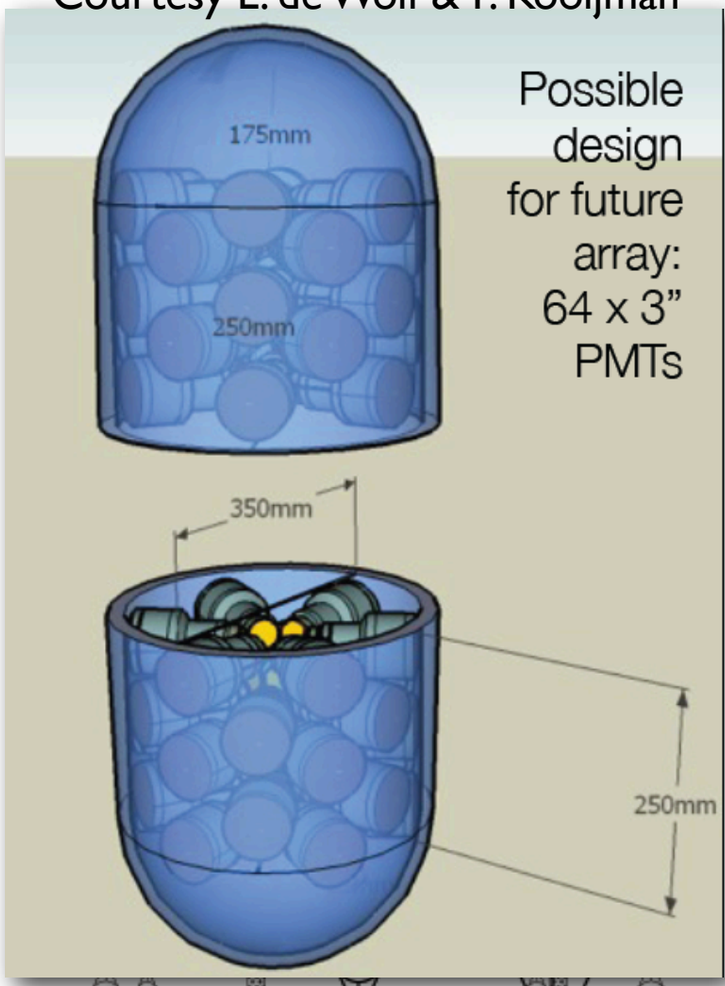
Backup

MICA -Megaton Ice Cherenkov Array

- In-fill of a few hundred strings
  - String spacings ~5 m, sensors spaced by ~1 m on a string
  - The Medium is the support structure
- An ambitious vision worth working towards:
  - Fiducial volume > 1MTon
  - Photo coverage ~10%
  - O(10 MeV) threshold for bursts
  - O(100 MeV) for single events
- IceCube and DeepCore provide active veto
  - No excavation is necessary, drilling/ deployment has been refined to an industrial process – deployment costs would be well below 10% of total
- Physics extraction from Cherenkov ring imaging in the ice



Courtesy E. de Wolf & P. Kooijman



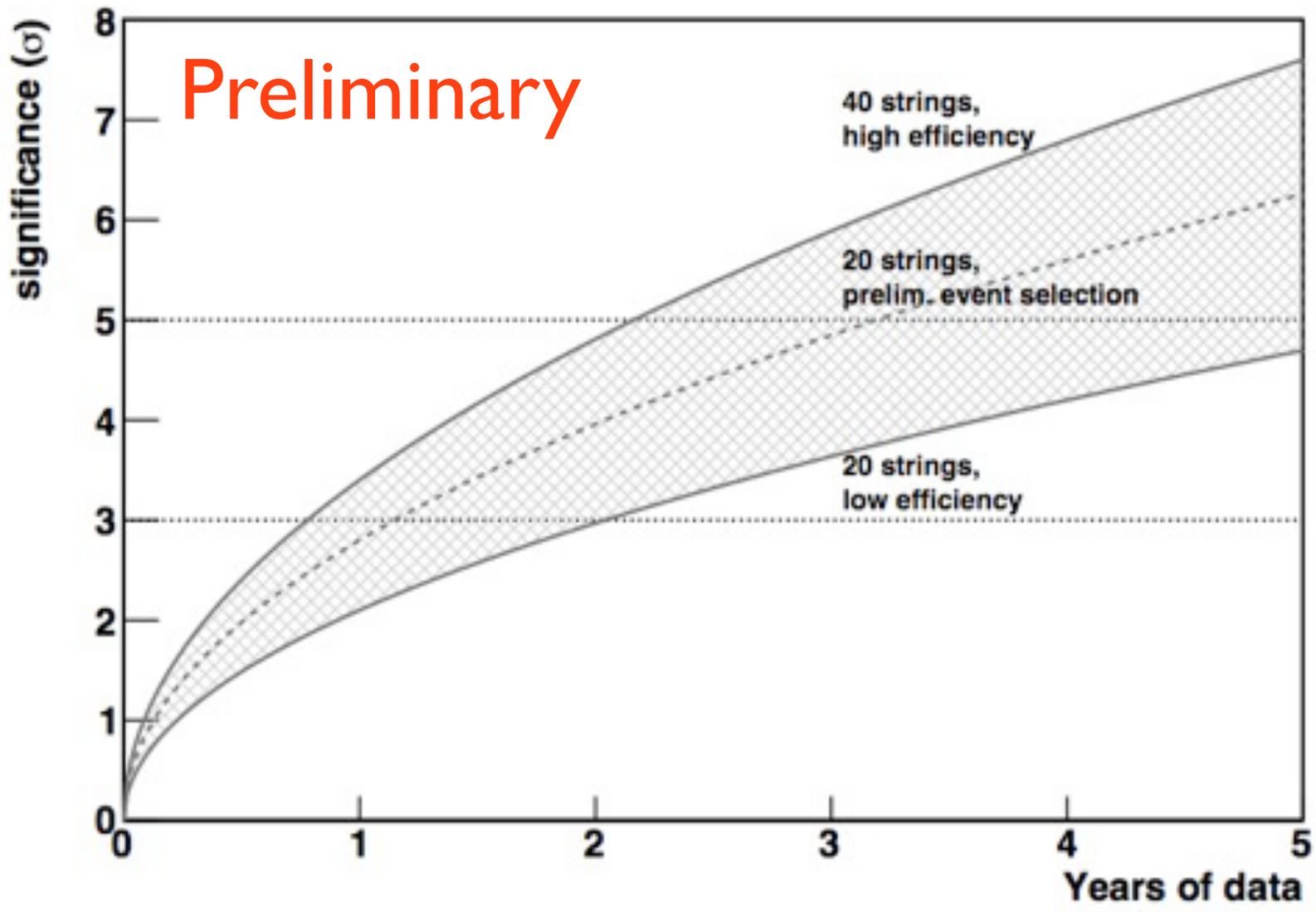
Possible design for future array: 64 x 3" PMTs

pixelization

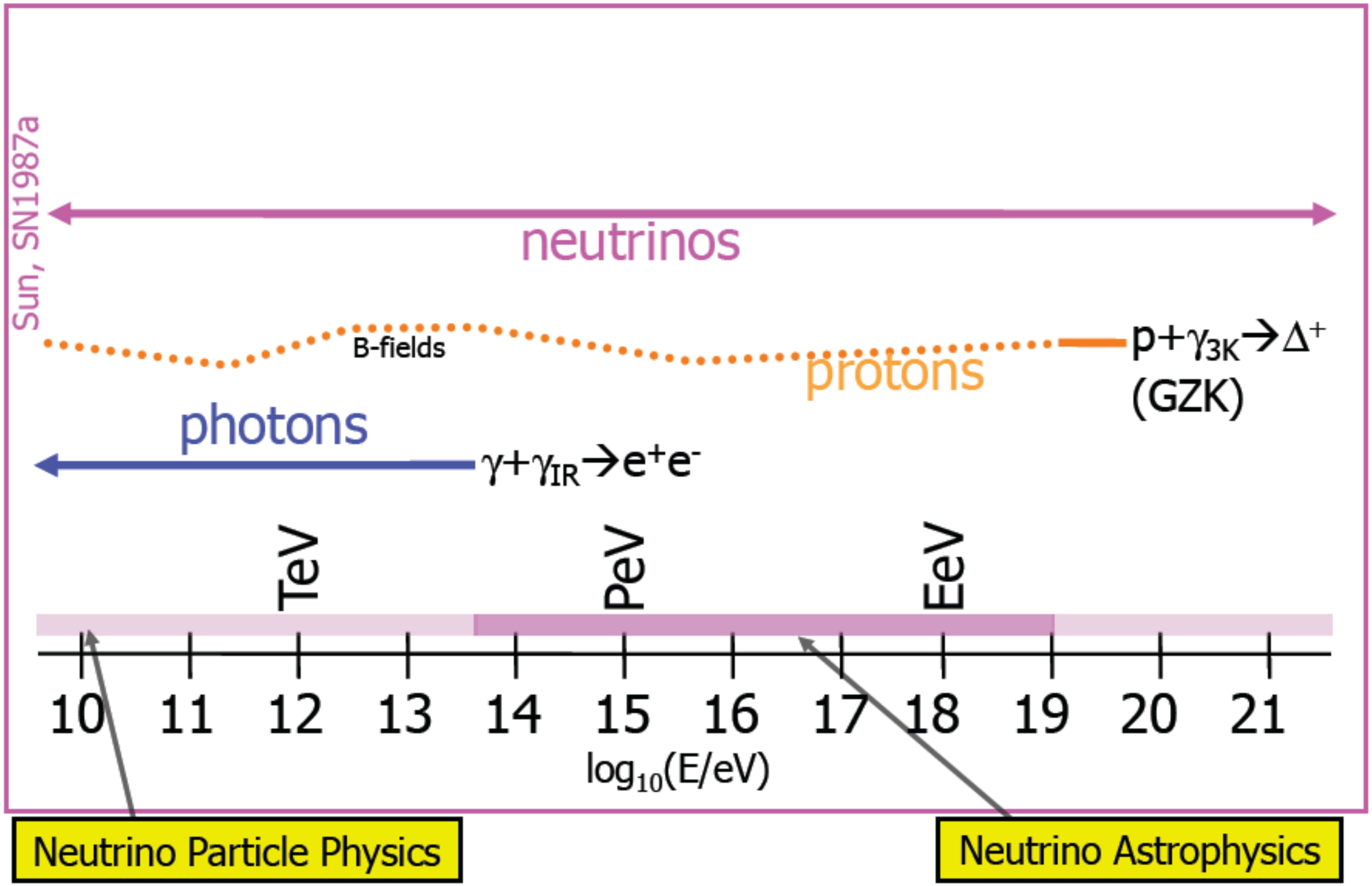
"isotropic" light acceptance

Neutrino Mass Hierarchy

- One of the last unmeasured parameters of the neutrino sector
  - Ordering of neutrino mass eigenstates
- Preliminary Sensitivity of PINGU for neutrino mass hierarchy



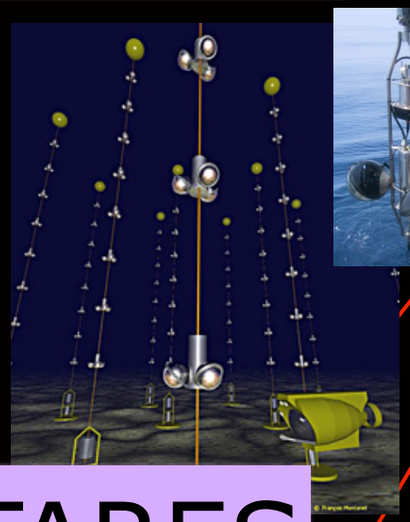
Astronomical Messengers



Optical Neutrino Telescopes / Detectors

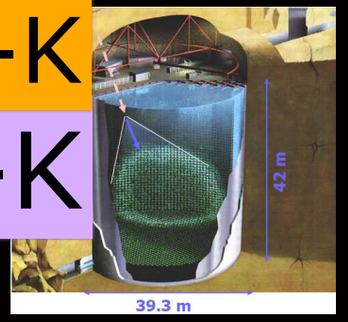
…Dumand

Nemo



Hyper-K

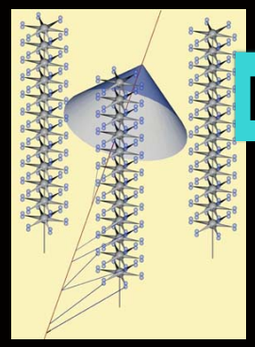
Super-K



Lake Baikal

GVD

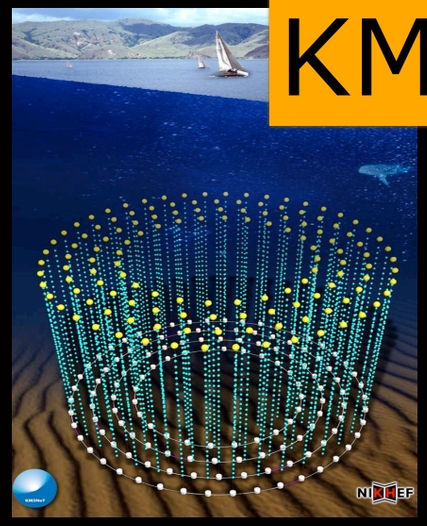
ANTARES



Nestor

ORCA

KM3Net



Active

Retired

Prototype

Planned

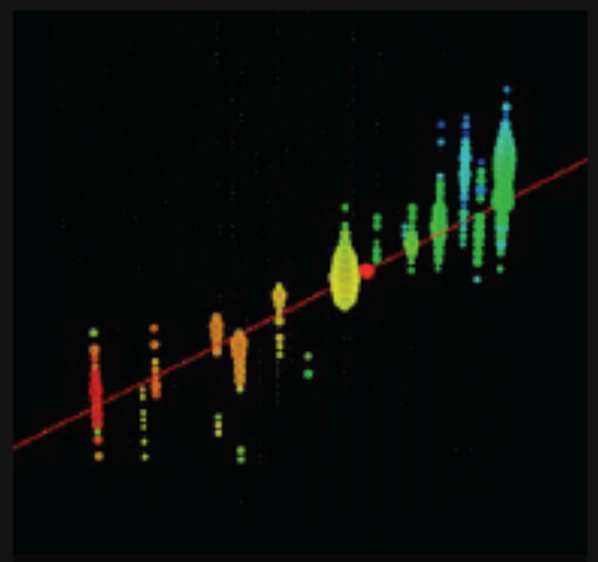
IceCube

AMANDA

PINGU

Neutrino Event Signatures

CC Muon Neutrino

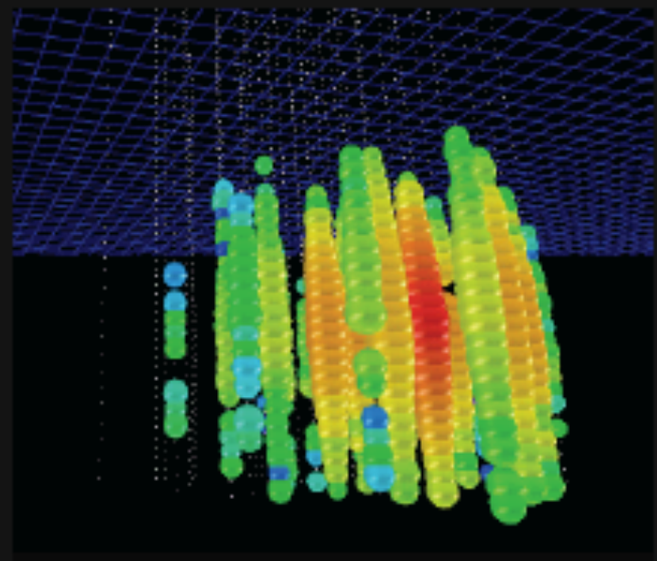


$$\nu_\mu + N \rightarrow \mu + X$$

track (data)

factor of ≈ 2 energy resolution
$< 1°$ angular resolution

Neutral Current /Electron Neutrino



$$\nu_e + N \rightarrow e + X$$
$$\nu_x + N \rightarrow \nu_x + X$$

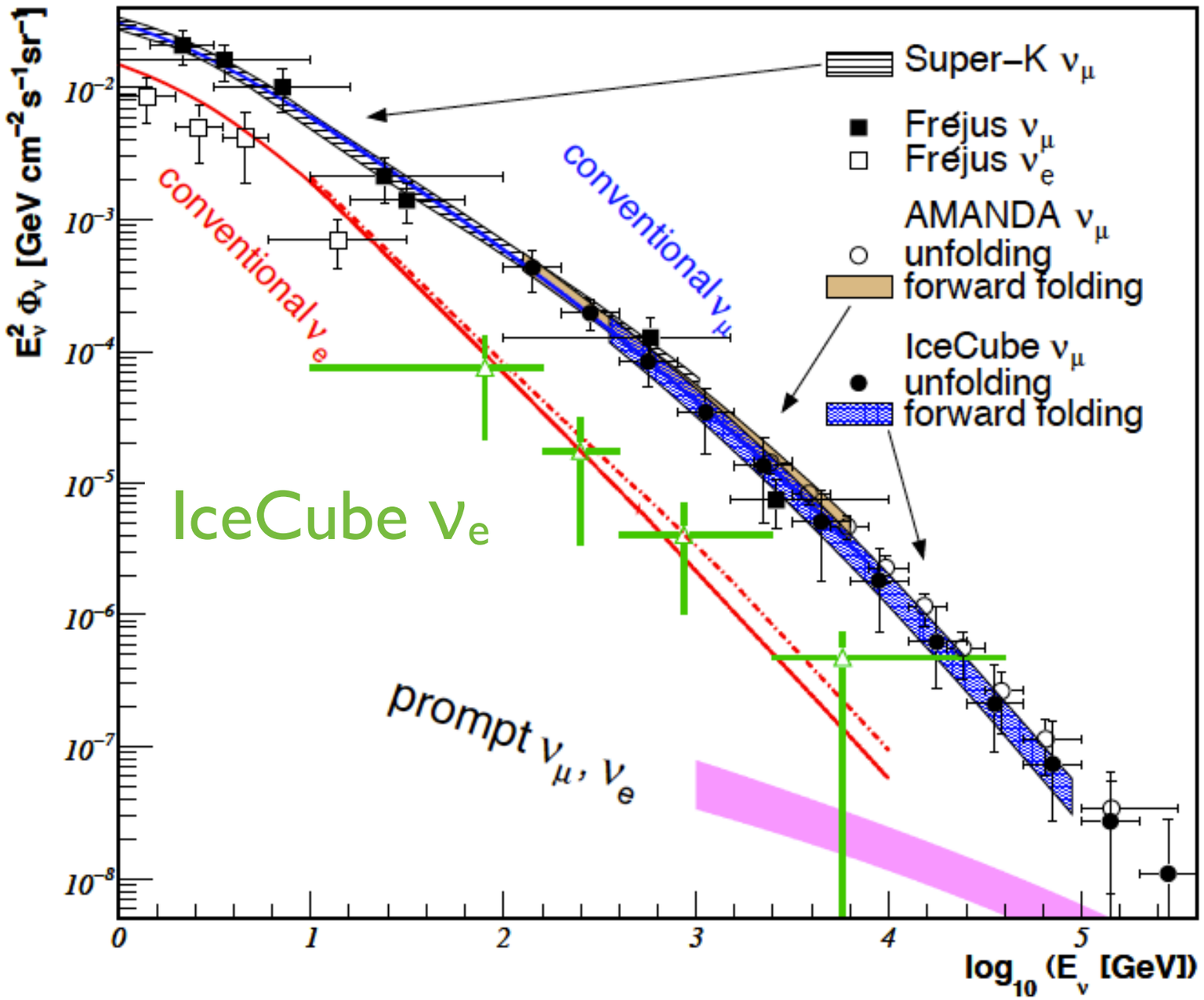
cascade (data)

$\approx \pm 15\%$ deposited energy resolution
$\approx 10°$ angular resolution
(at energies $\approx$ 100 TeV)

Known Neutrino Sources

- Collisions of cosmic-rays with nuclei in the Earth's atmosphere produce neutrinos
  - pions, kaons→ν's
  - 4π
  - Neutrino energies extend up to ~100 TeV
- Higher energy contribution from "prompt" ν's from charm decays not yet observed
  - $(D_0, D_\pm, D_{s\pm}, \Lambda_{c\pm}) \rightarrow \nu$'s

IceCube Collaboration arXiv:1212.4760v2



Performance

arXiv:1305.6811