Detecting Astrophysical Neutrinos with the IceCube Observatory

Chad Finley
Oskar Klein Centre
Stockholm University

ICHEP 2010 Paris

2010 July 24

Photo: Patrick Cullis

Why Neutrinos?

Neutrinos, photons, created in decay chain wherever high energy collisions of proton, nuclei occur

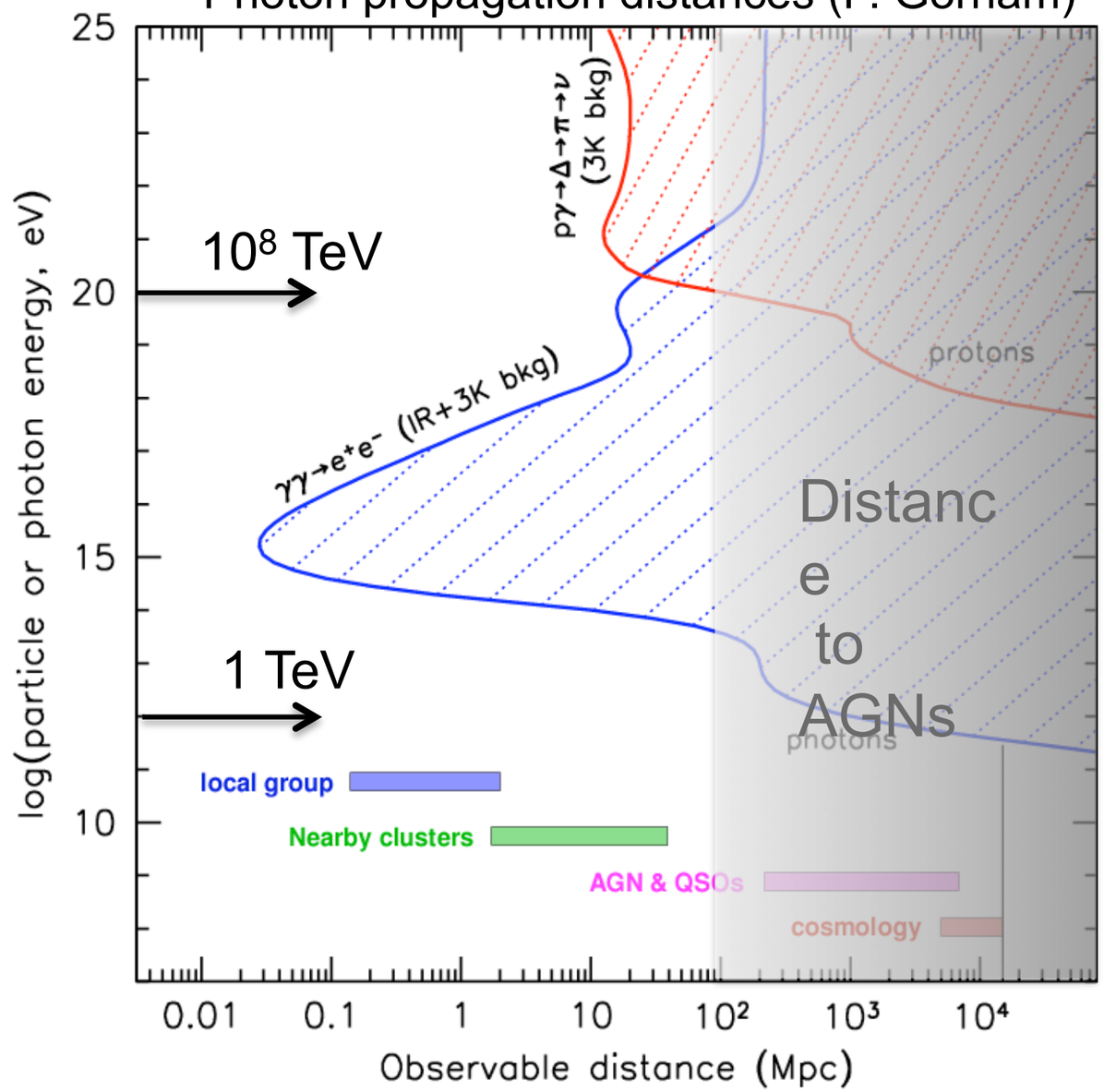
Above 100 TeV, universe is **opaque for photons**, due to pair-production off background radiation fields (CMB, IR)

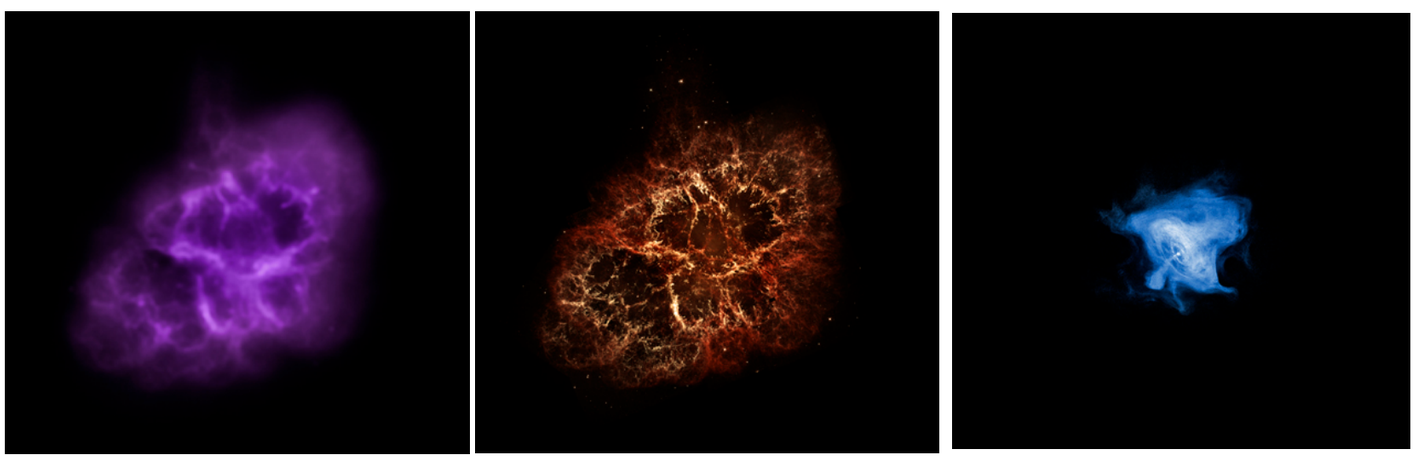
$$\gamma + \gamma_{IR,CMB,radio} \rightarrow e^+ + e^-$$

Cosmic ray sources may be optically thick for gammas but not neutrinos; reveal **"hidden"** sources

Neutrinos are unique and complementary astrophysical probe

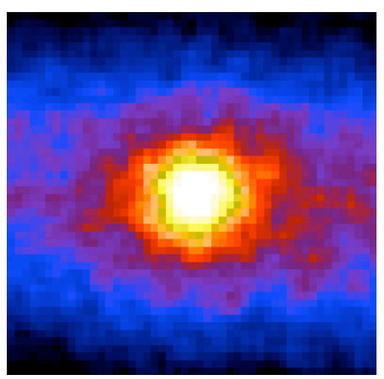
Photon propagation distances (P. Gorham)



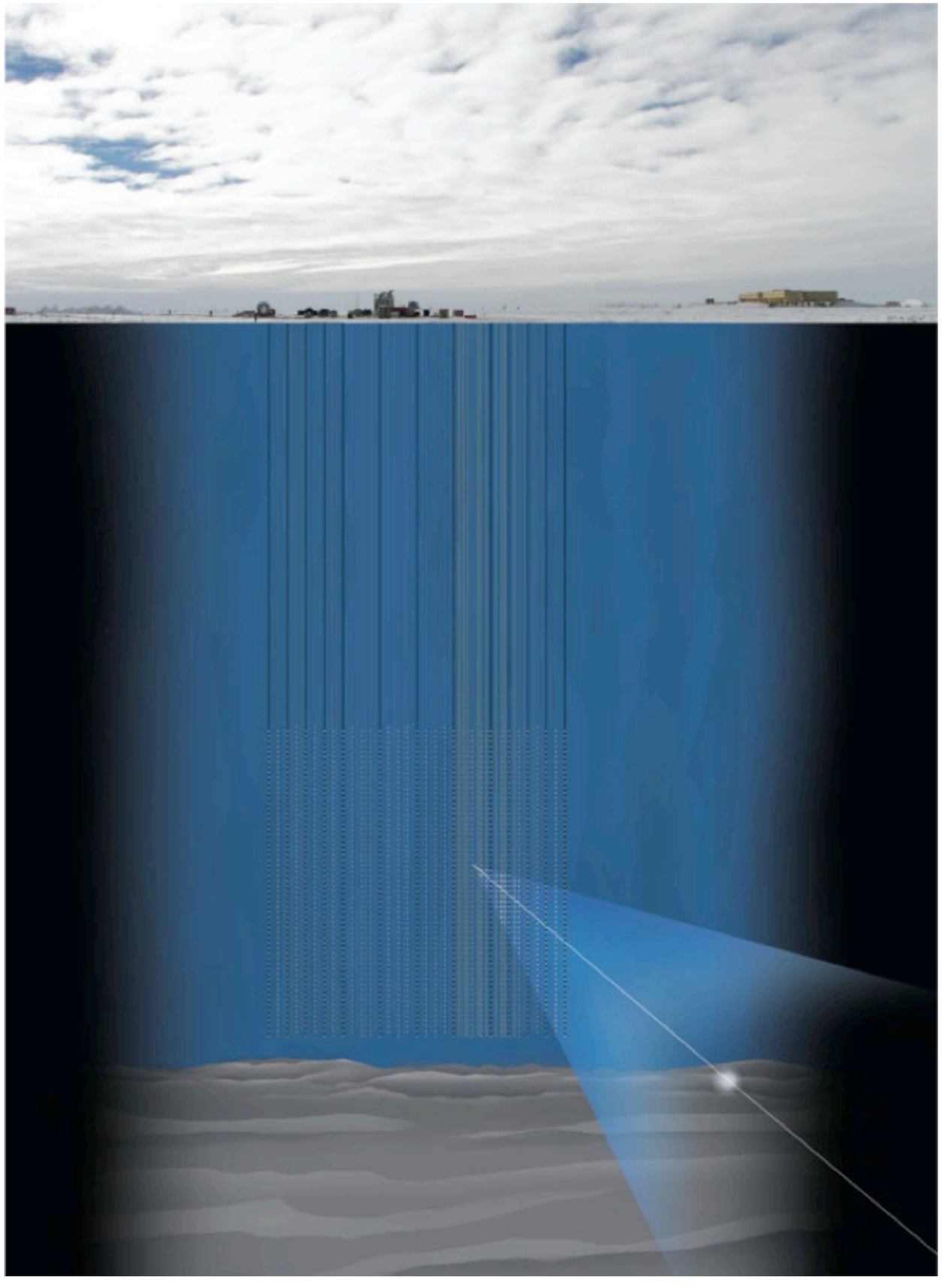


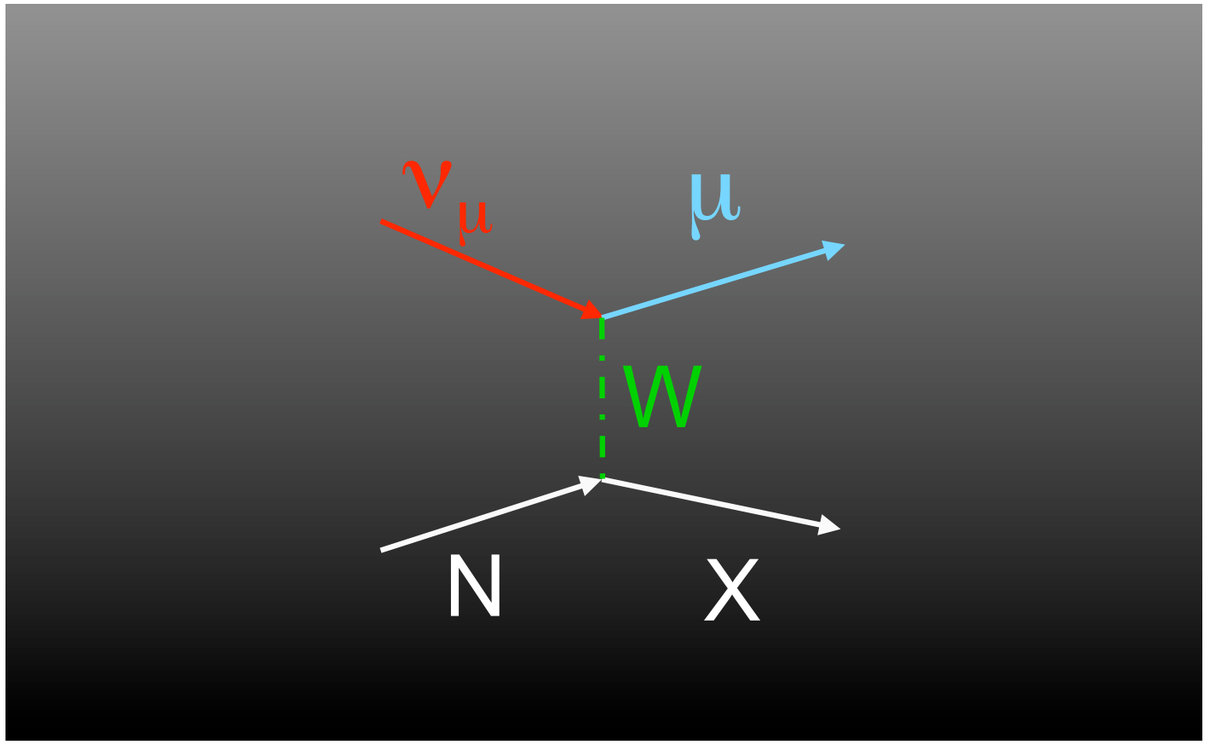
The Crab, in infrared (Spitzer), optical (Hubble), x-ray (Chandra)

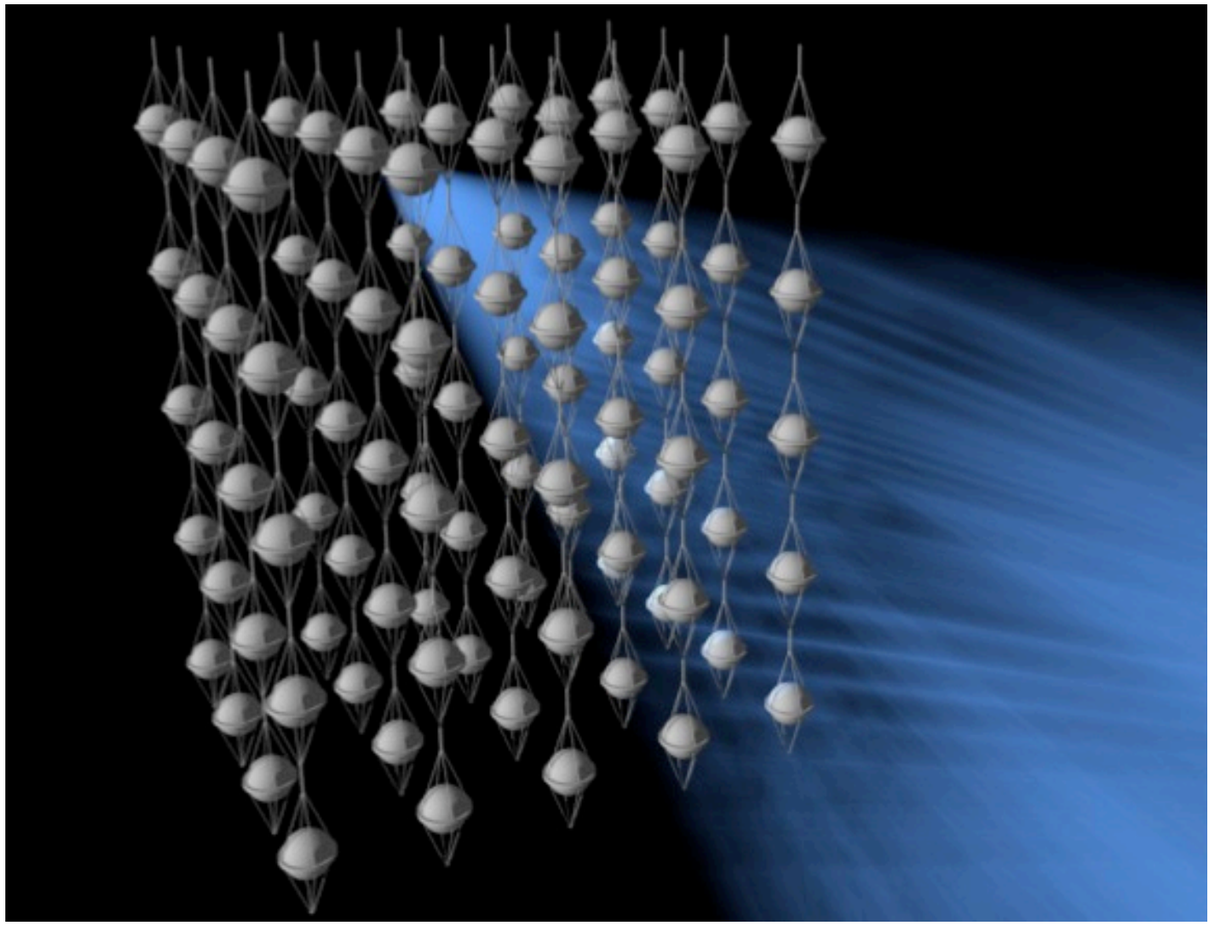
The sun, "seen" in MeV neutrinos by Super-Kamiokande



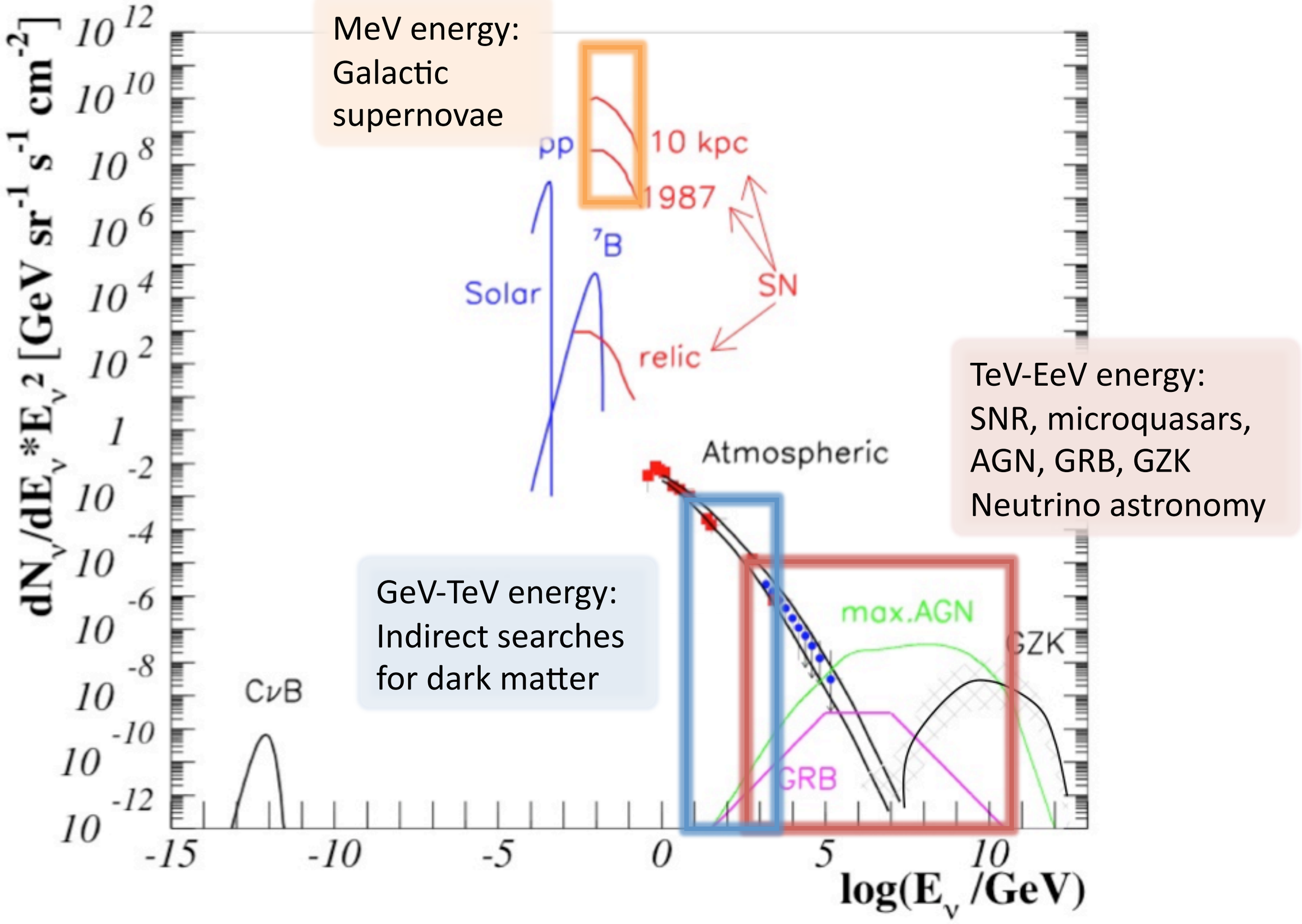
Neutrino Detection Principles



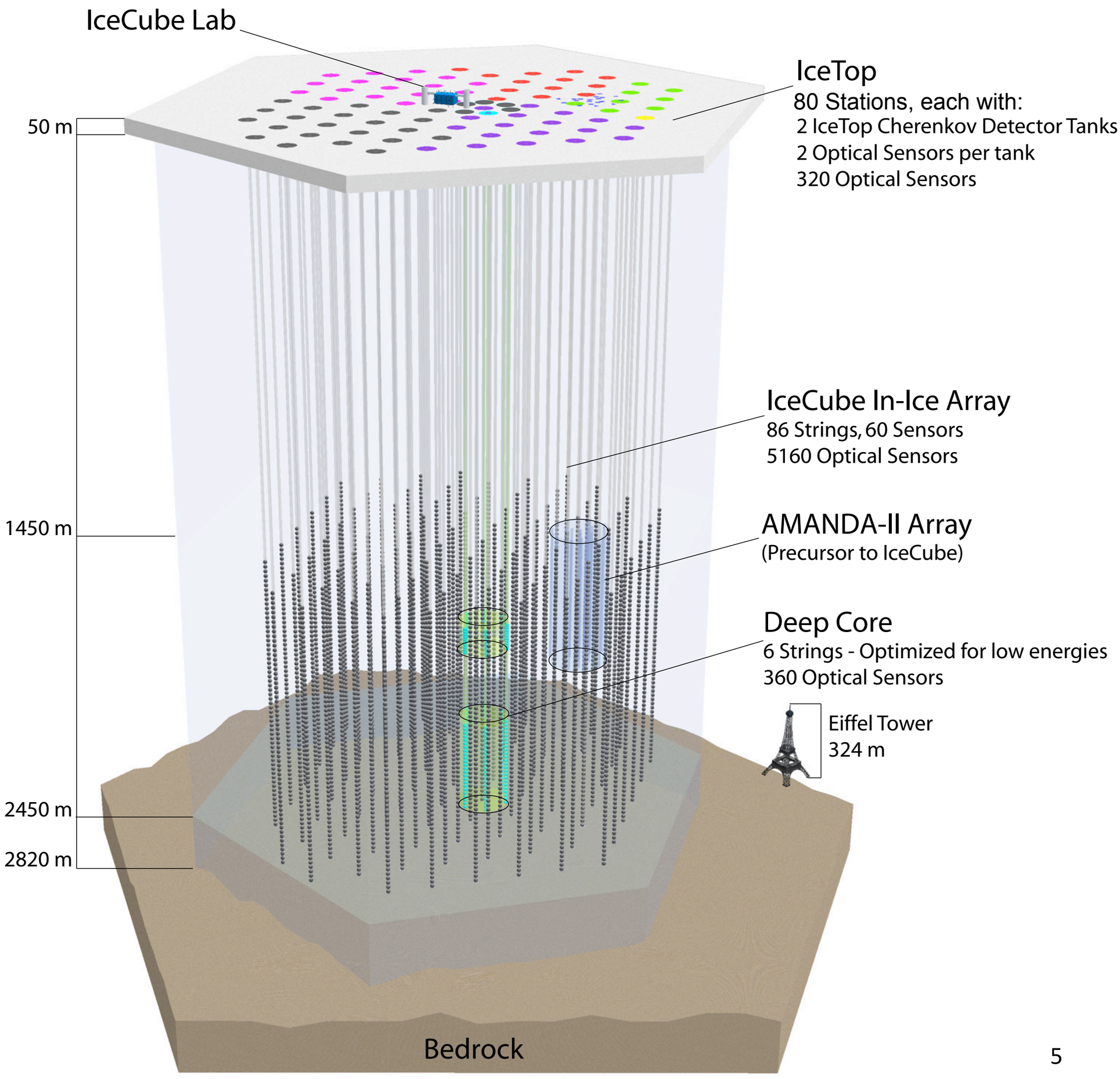




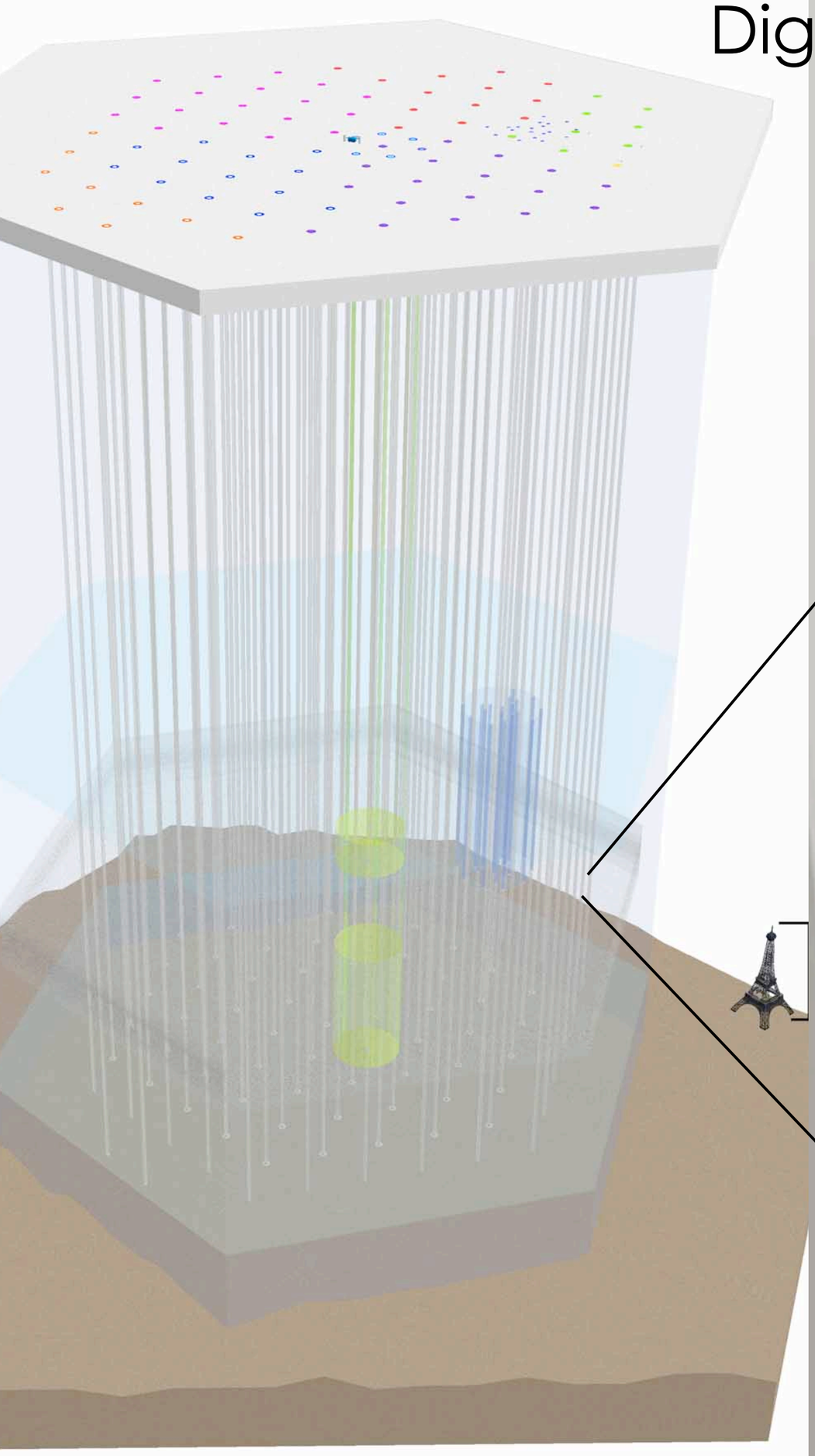
IceCube Search Regimes for Neutrinos

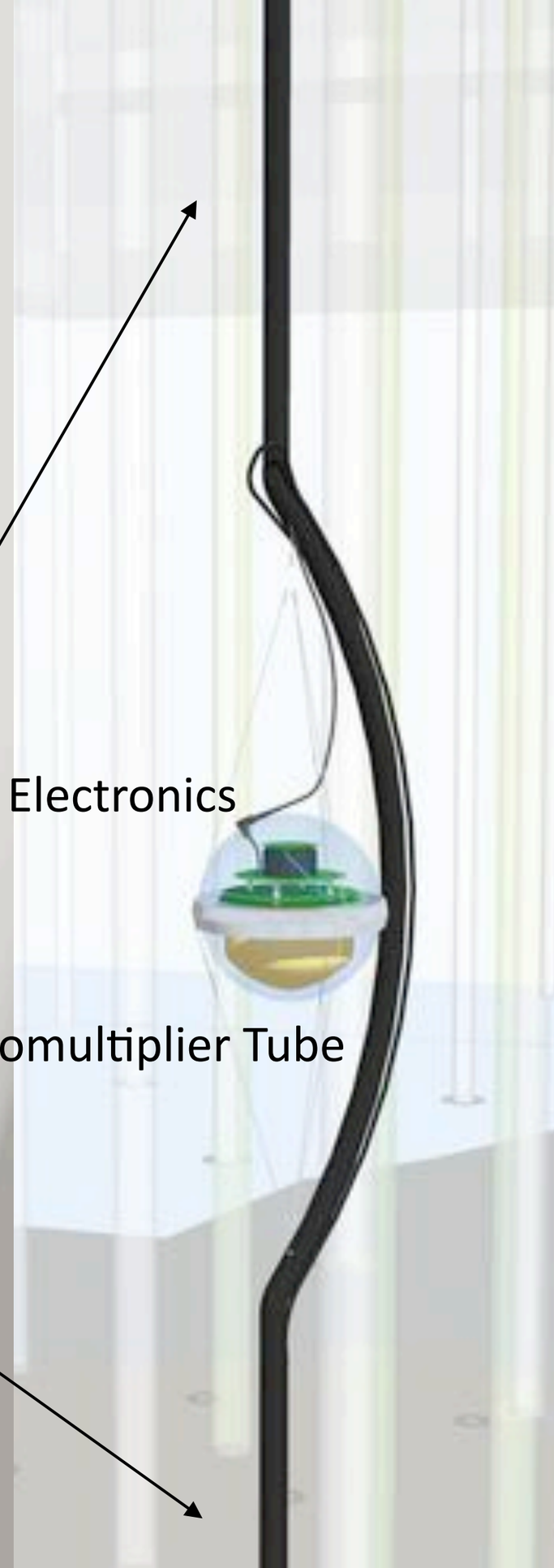


- 86 strings
- 1.5 km - 2.5 km deep
- typically 125 m spacing between strings
- 60 Modules per string
- 1 km^3 -- 1 Gton instrumented volume



Digital Optical Module

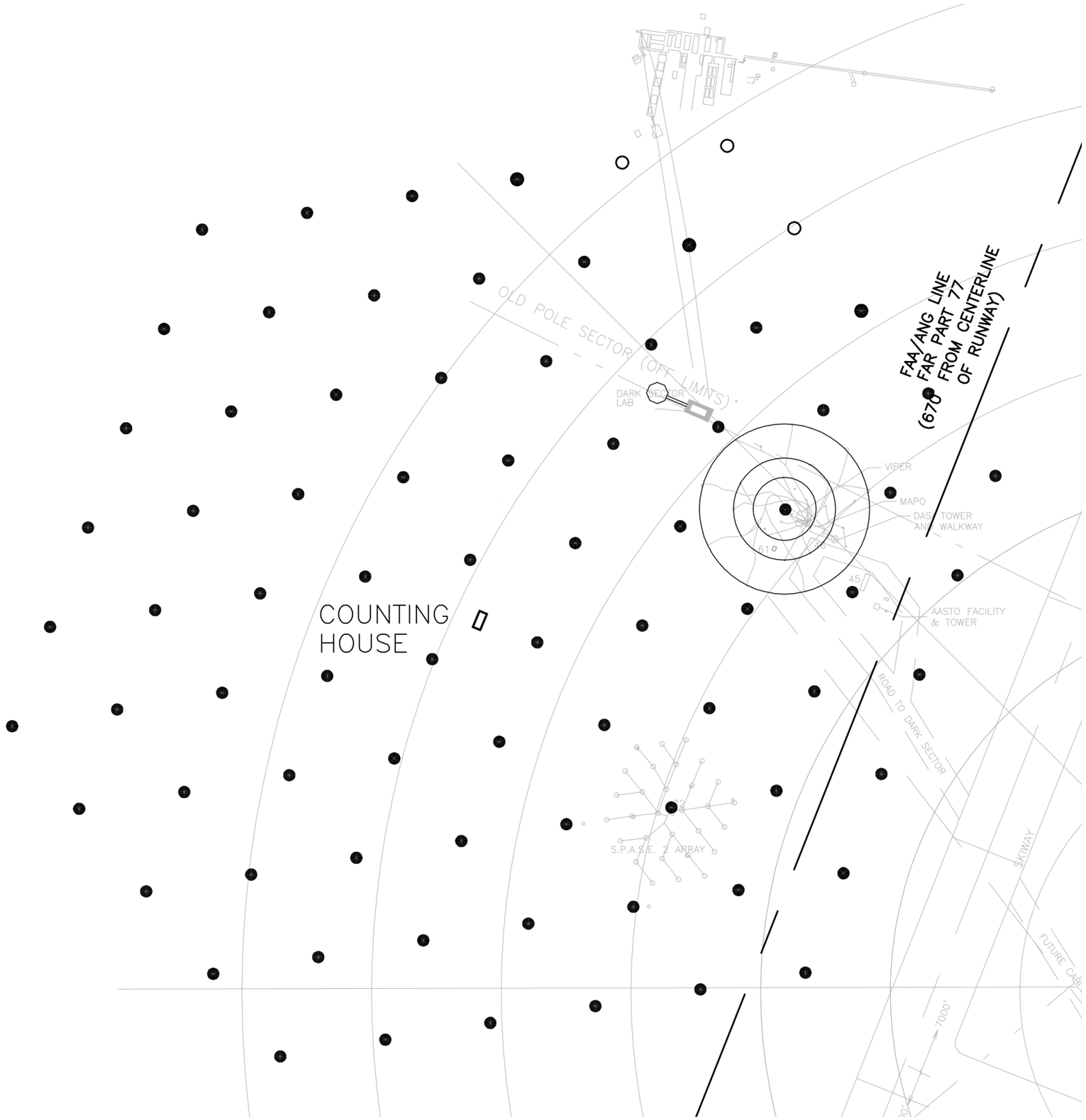




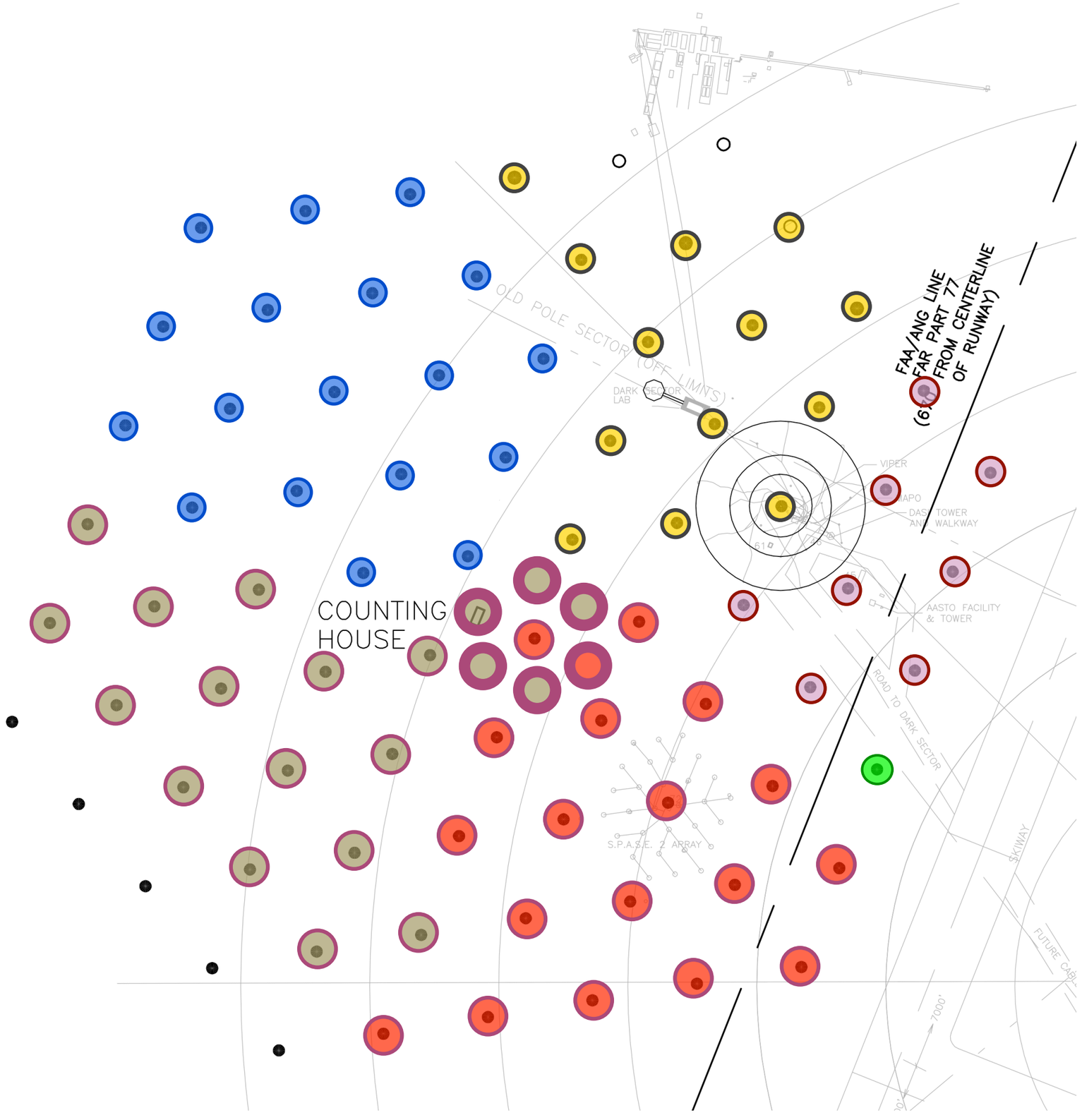
Electronics

Photomultiplier Tube

IceCube Current Status:



IceCube Current Status: 79-Strings Taking Data



2004 – 2005

2005 – 2006

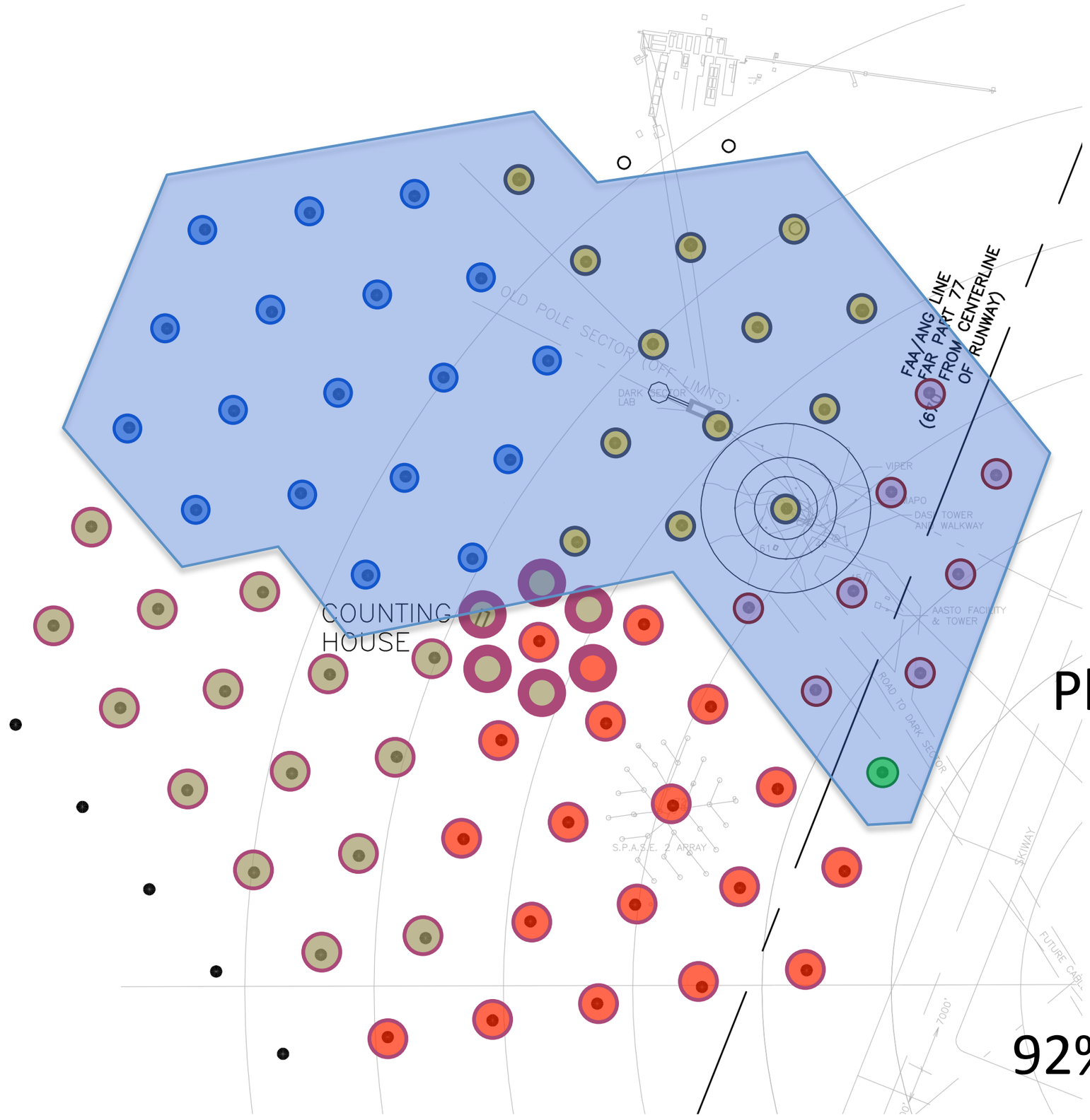
2006 – 2007

2007 – 2008

2008 – 2009

2009 – 2010

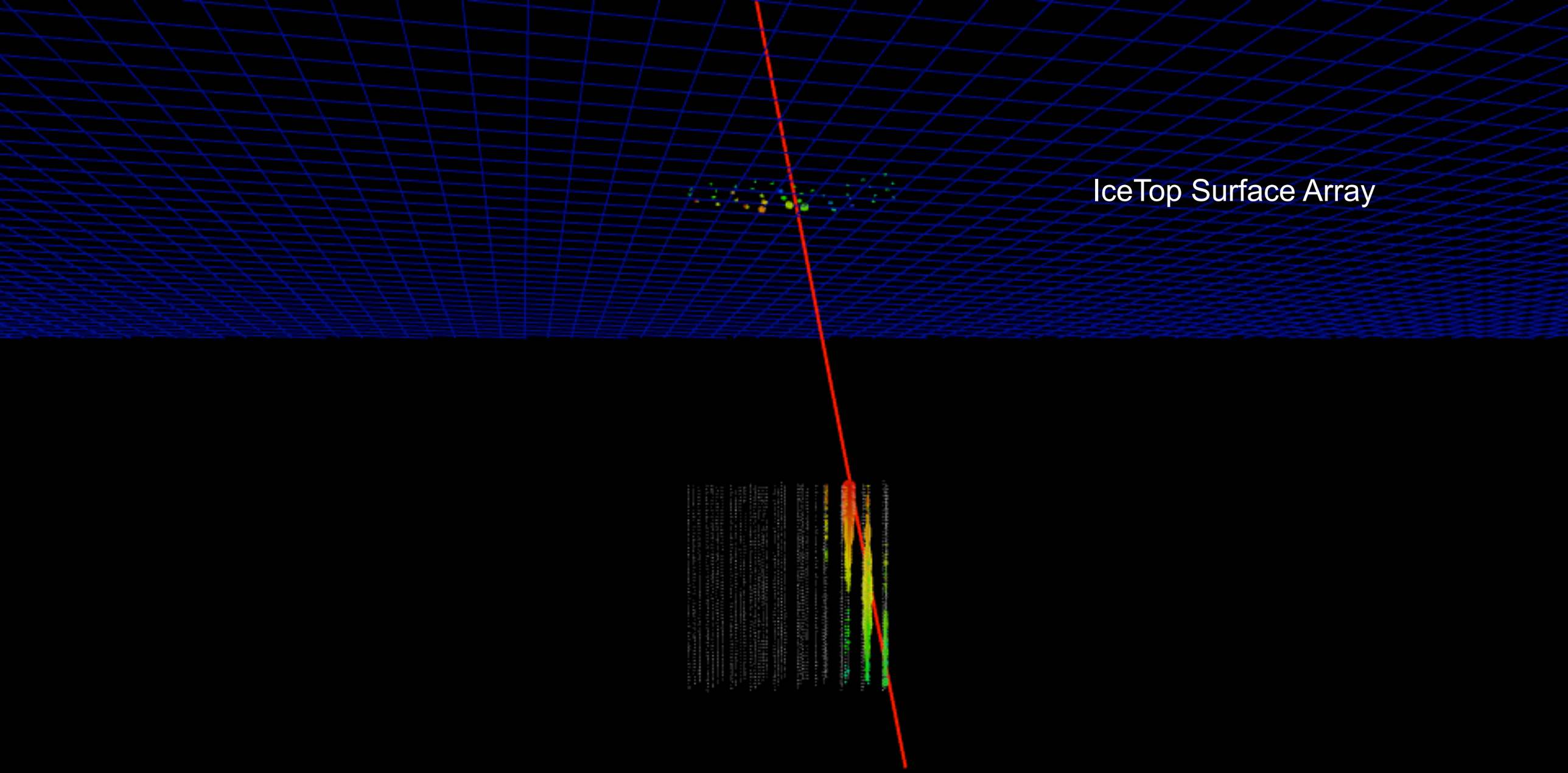
IceCube 40-String Data (2008-09) Fully Processed



IceCube 40-String Physics Run completed in May 2009

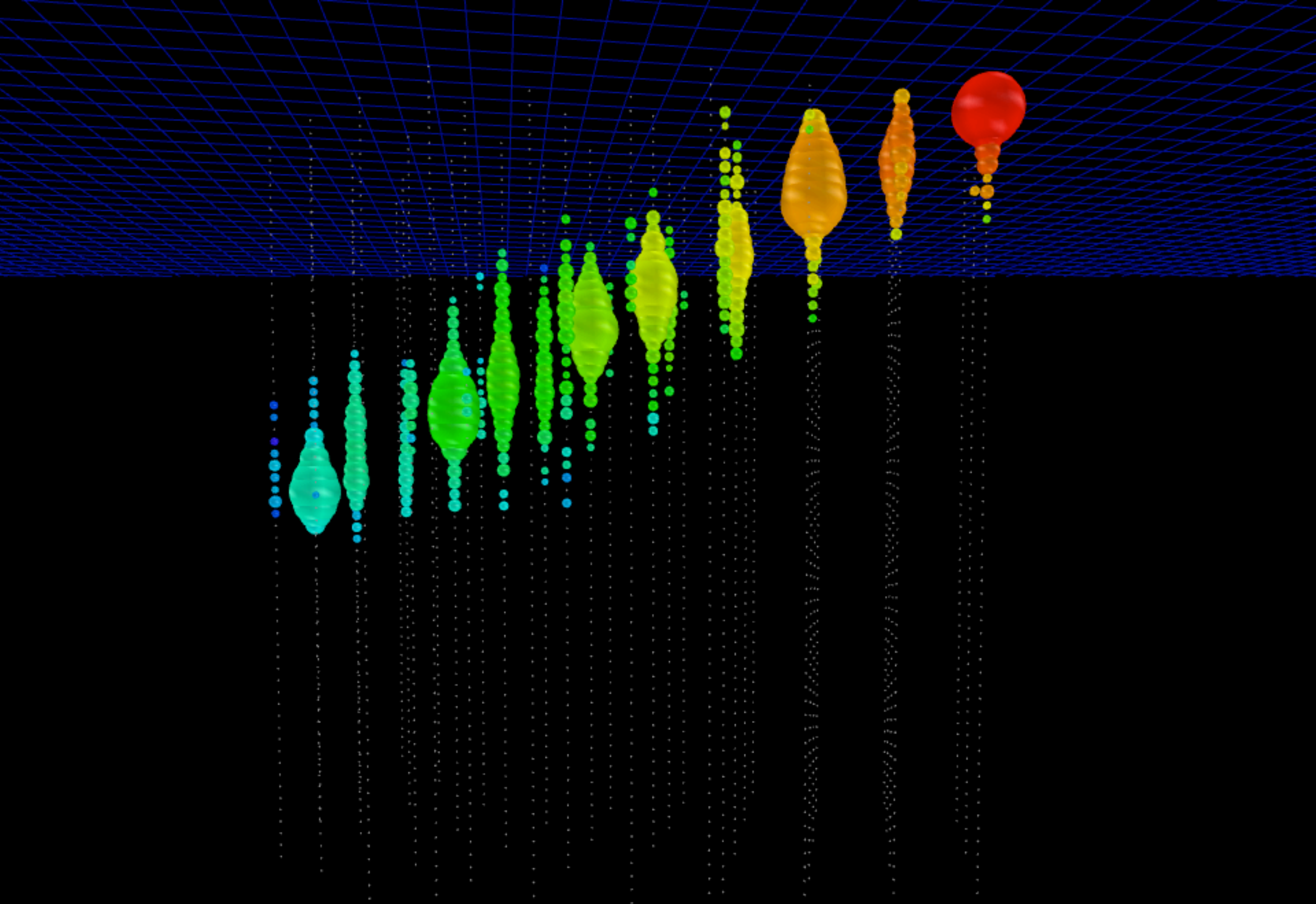
Livetime = 375.5 days

92% duty cycle *including* construction season



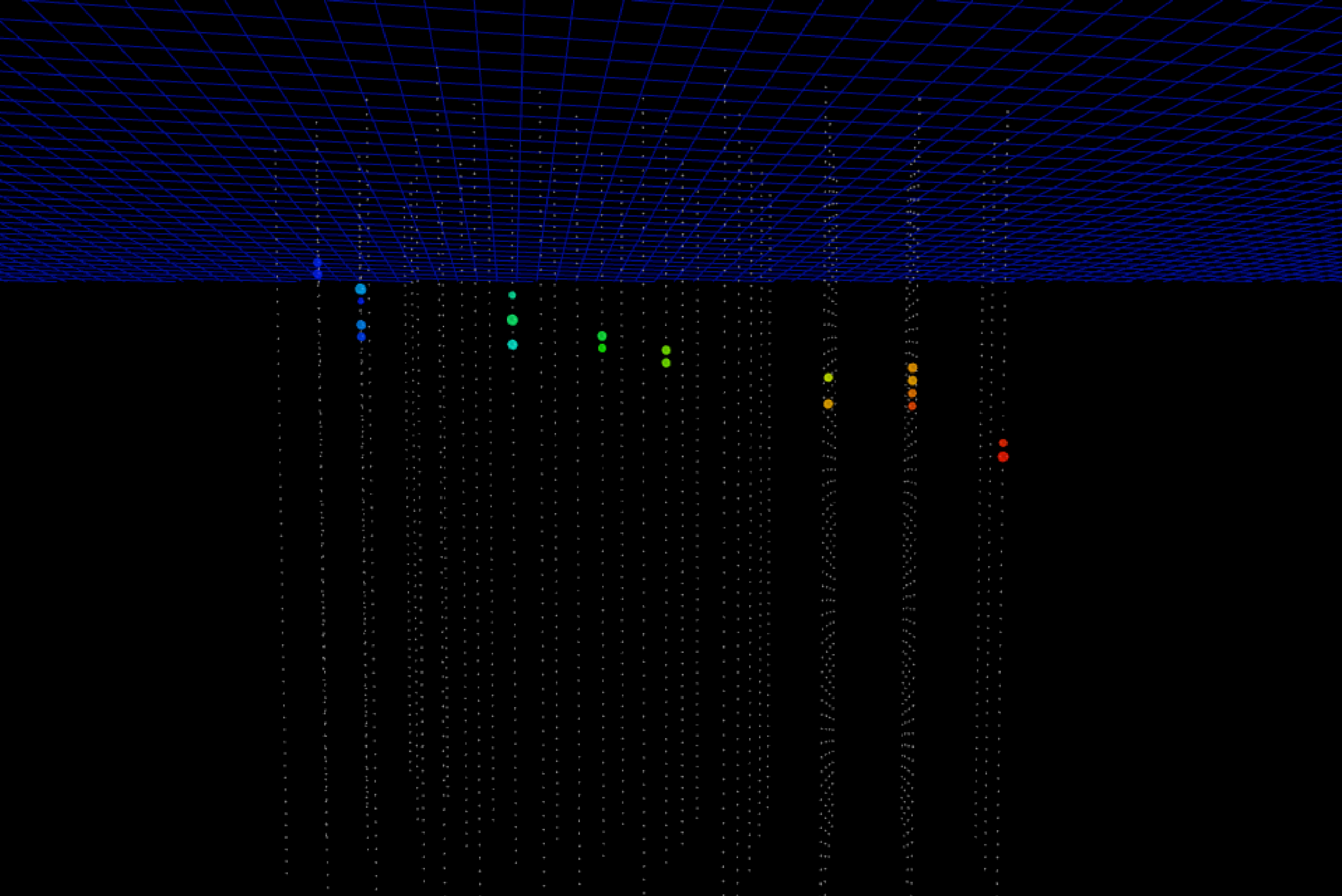
IceCube 40-string Data

~ 1000 TeV cosmic ray muon bundle



IceCube 40-string Data

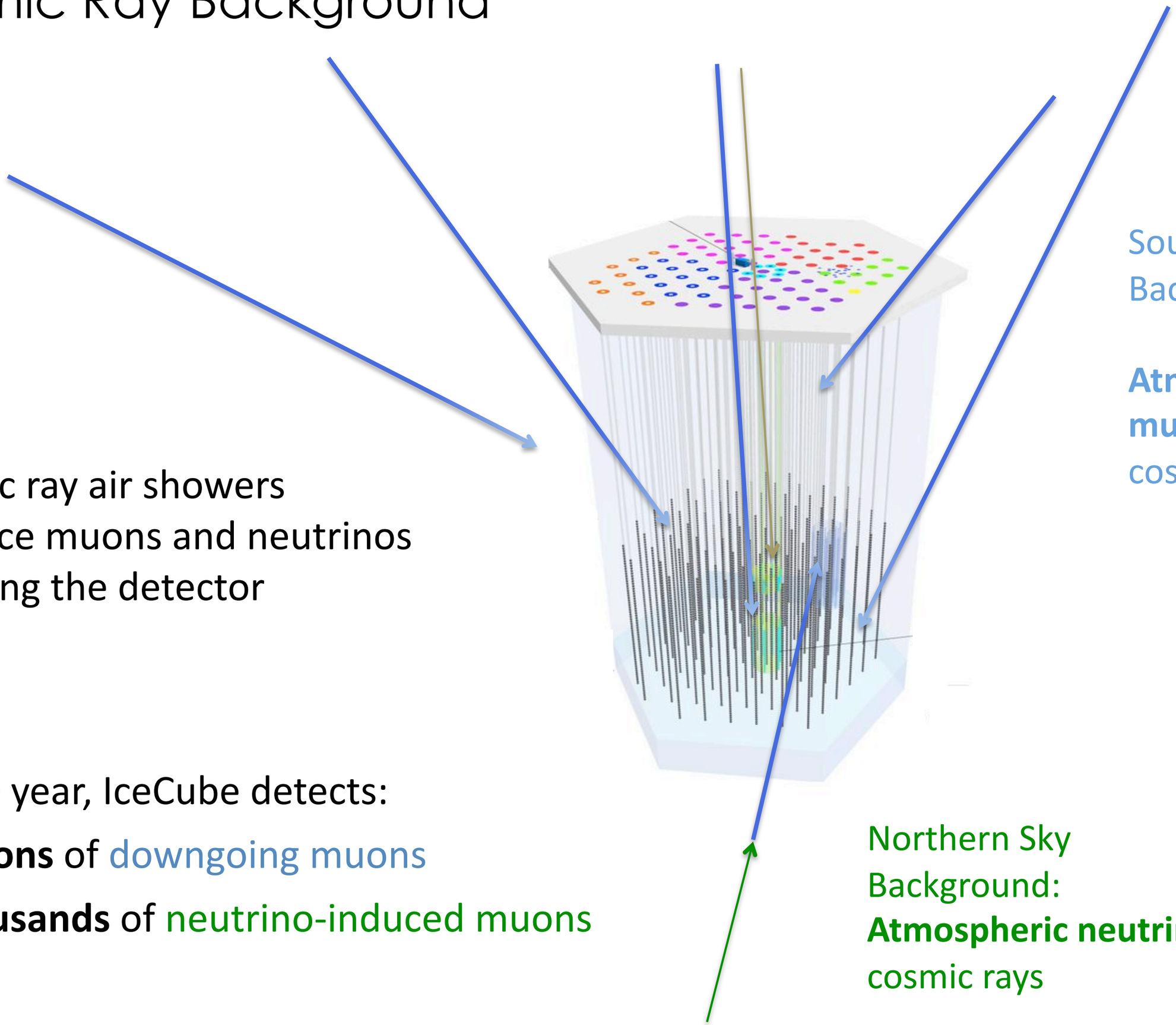
~ 300 TeV cosmic ray muon bundle



IceCube 40-string Data

~ 1 TeV neutrino-induced muon

Cosmic Ray Background



Cosmic ray air showers produce muons and neutrinos reaching the detector

Southern Sky Background:

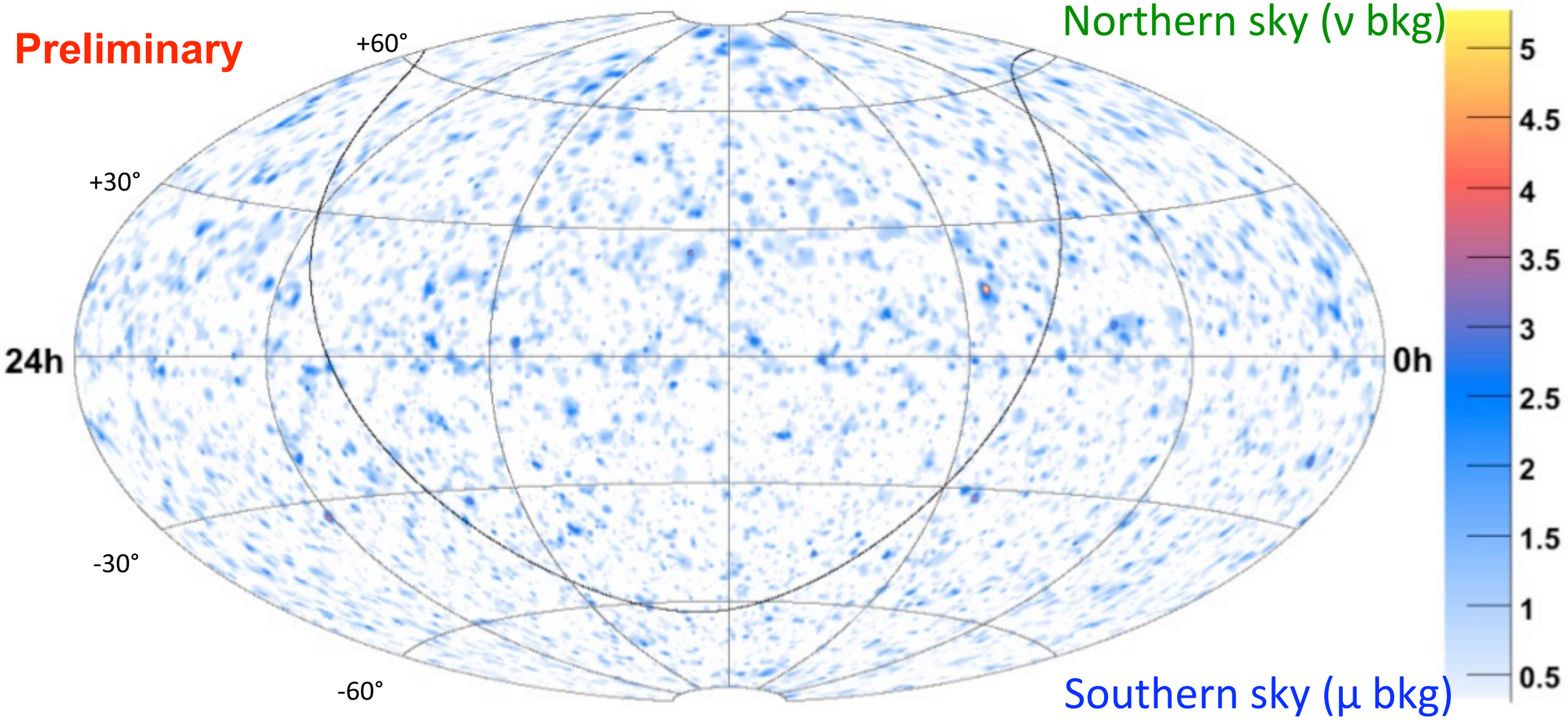
Atmospheric muons from cosmic rays

In one year, IceCube detects:

- **billions** of downgoing muons
- **thousands** of neutrino-induced muons

Northern Sky Background:
Atmospheric neutrinos from cosmic rays

IceCube 40-String (2008-09)



Median PSF for E^{-2} spectrum:

0.8° in northern sky

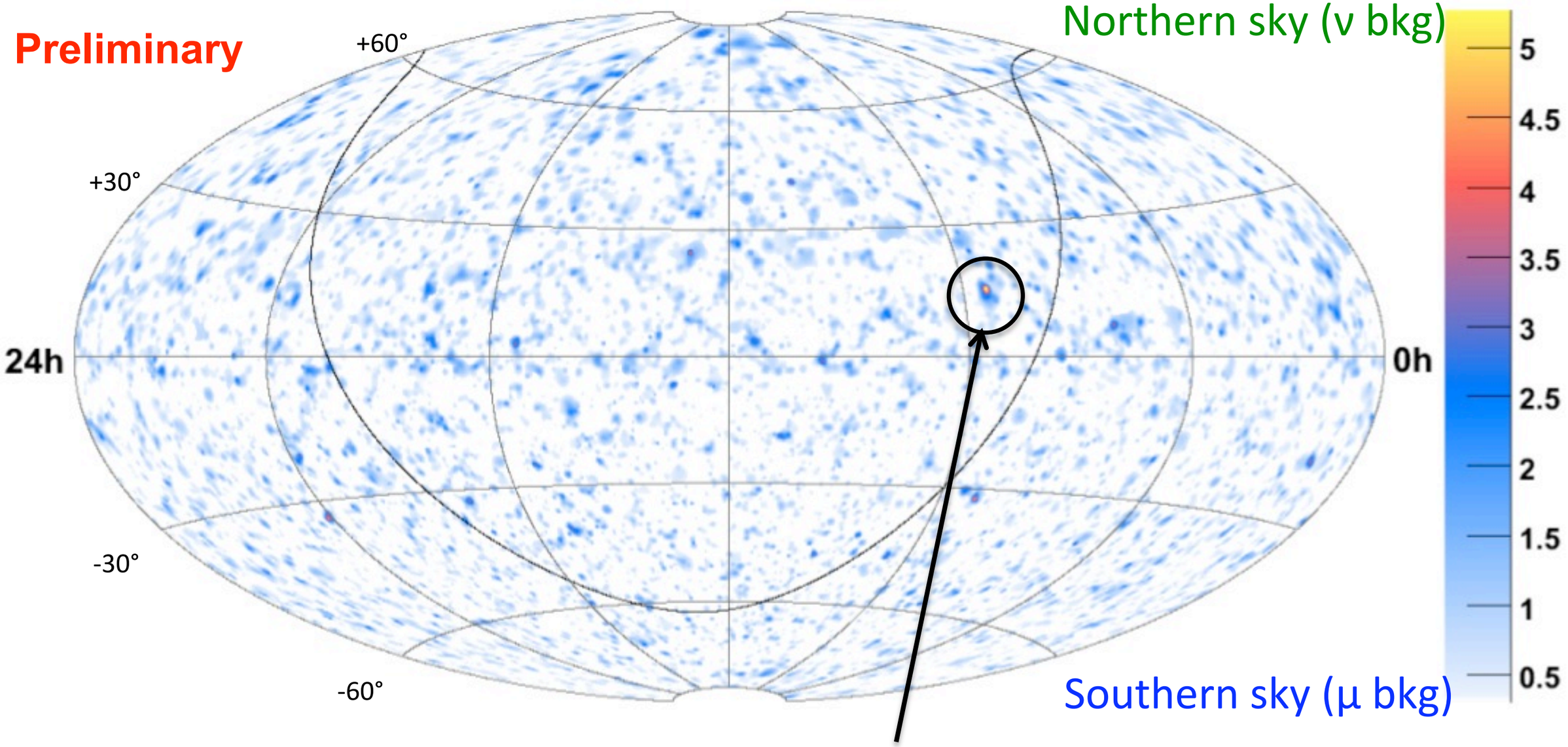
0.6° in southern sky

36 900 events:

14 121 **up-going** (neutrino candidates)

22 779 **down-going** (high energy muons)

IceCube 40-String (2008-09)

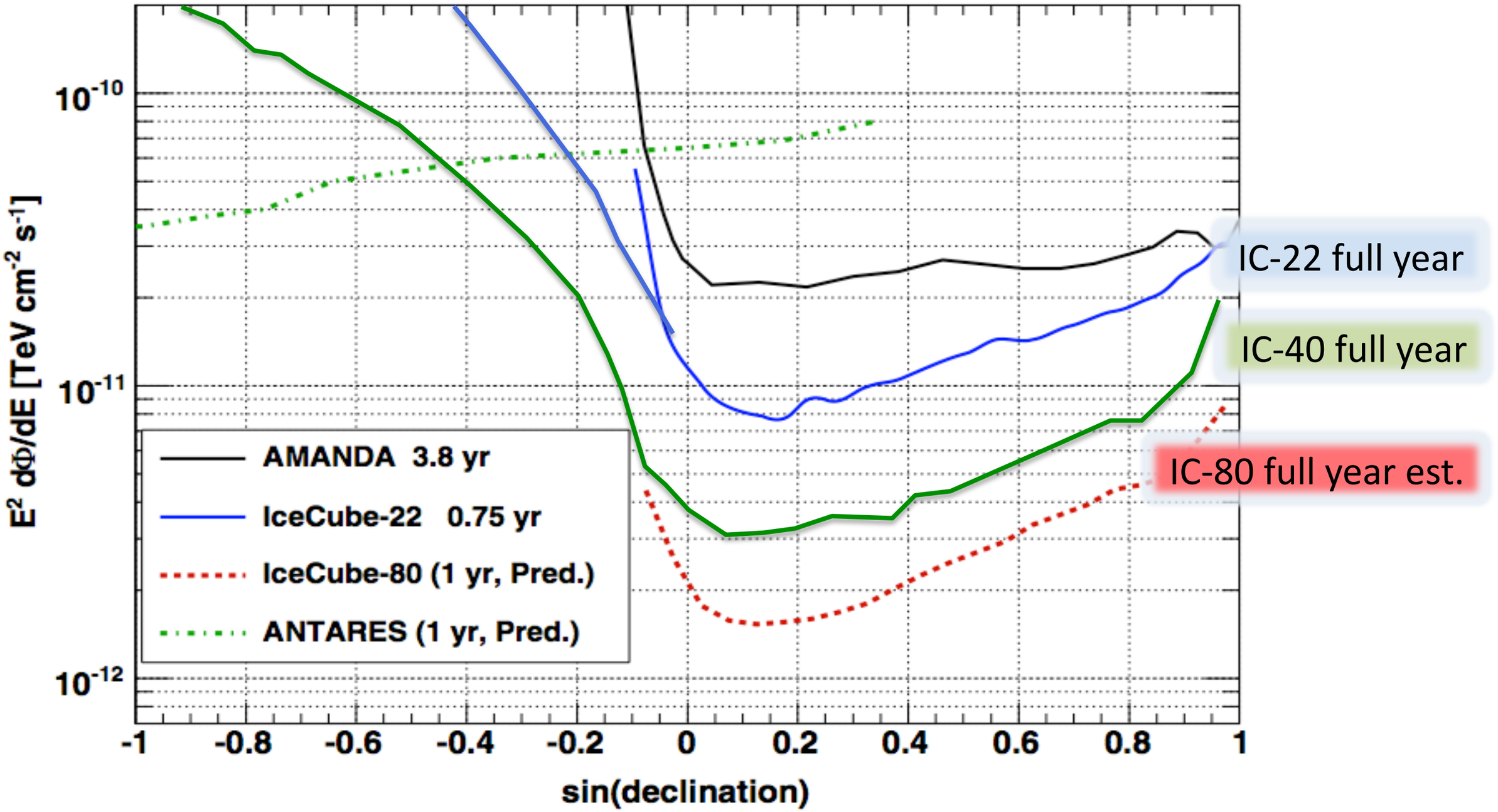


Hottest location in the all-sky search is: R.a. = 115° , Dec. = +15°

18% of simulated background sets (scrambling data in r.a.) have an equal or greater excess occurring by chance. **Not significant.**

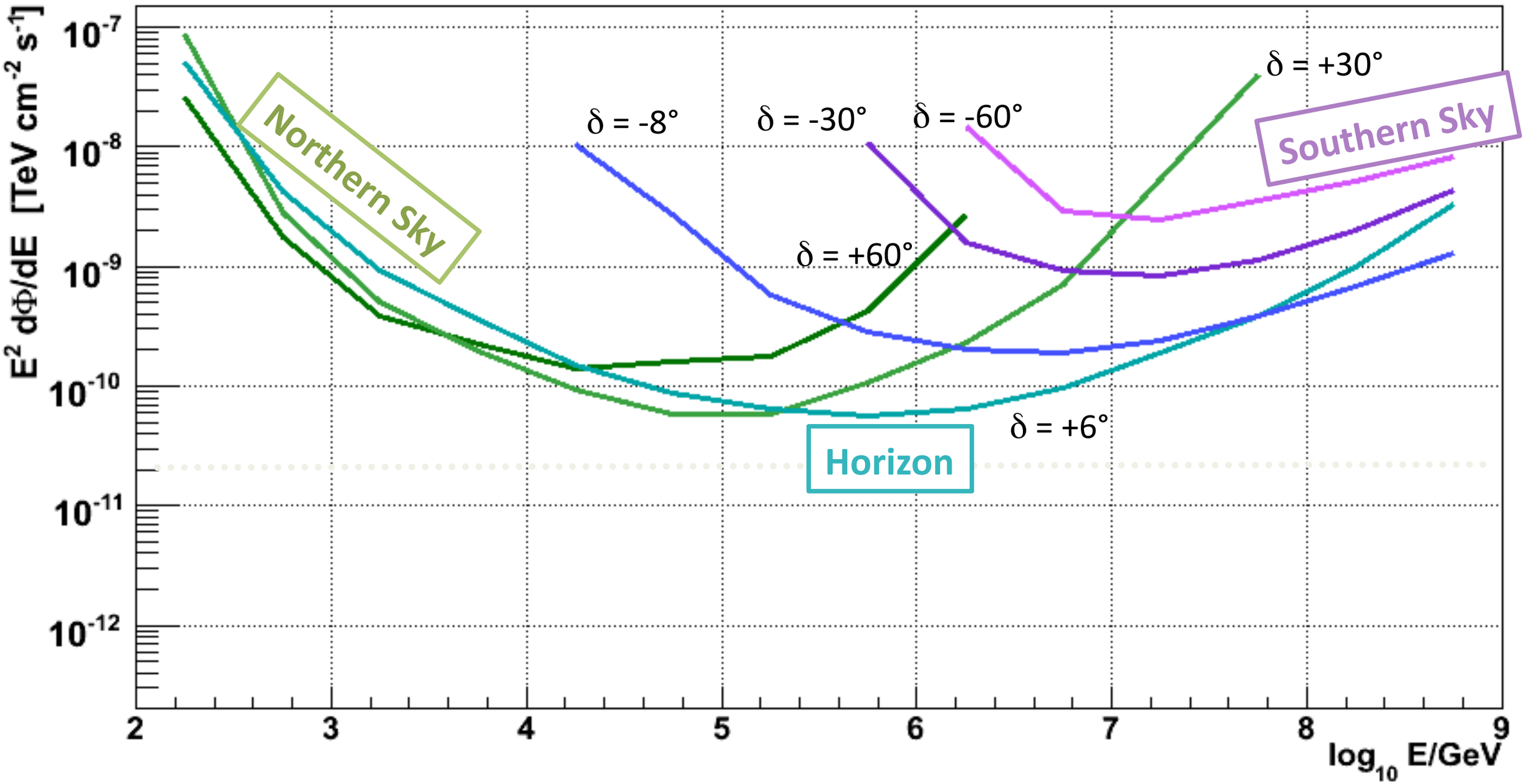
Median Upper Limits: E^{-2} Neutrino Point Source Fluxes

Preliminary

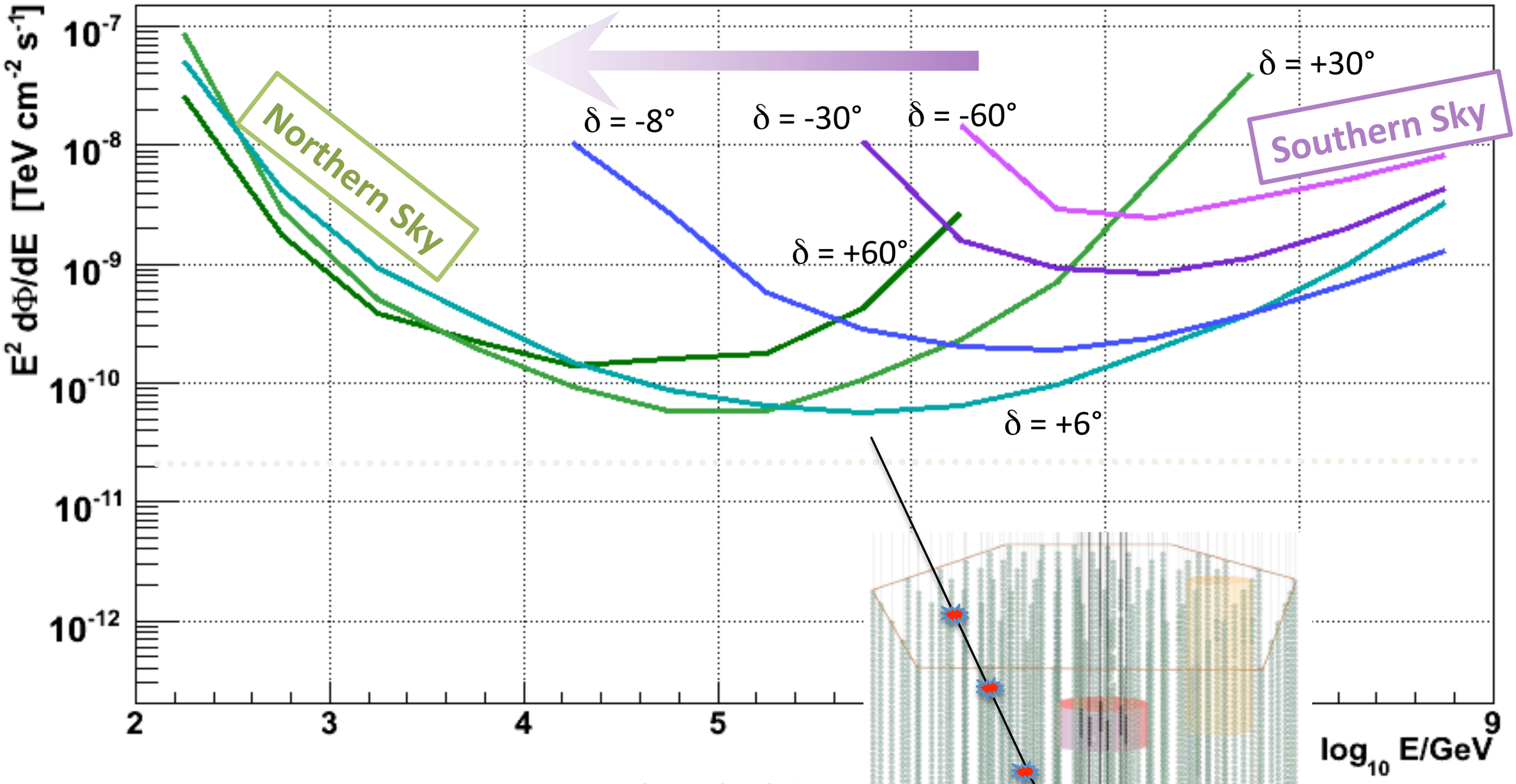


Preliminary

Differential Sensitivity – Declination Dependence

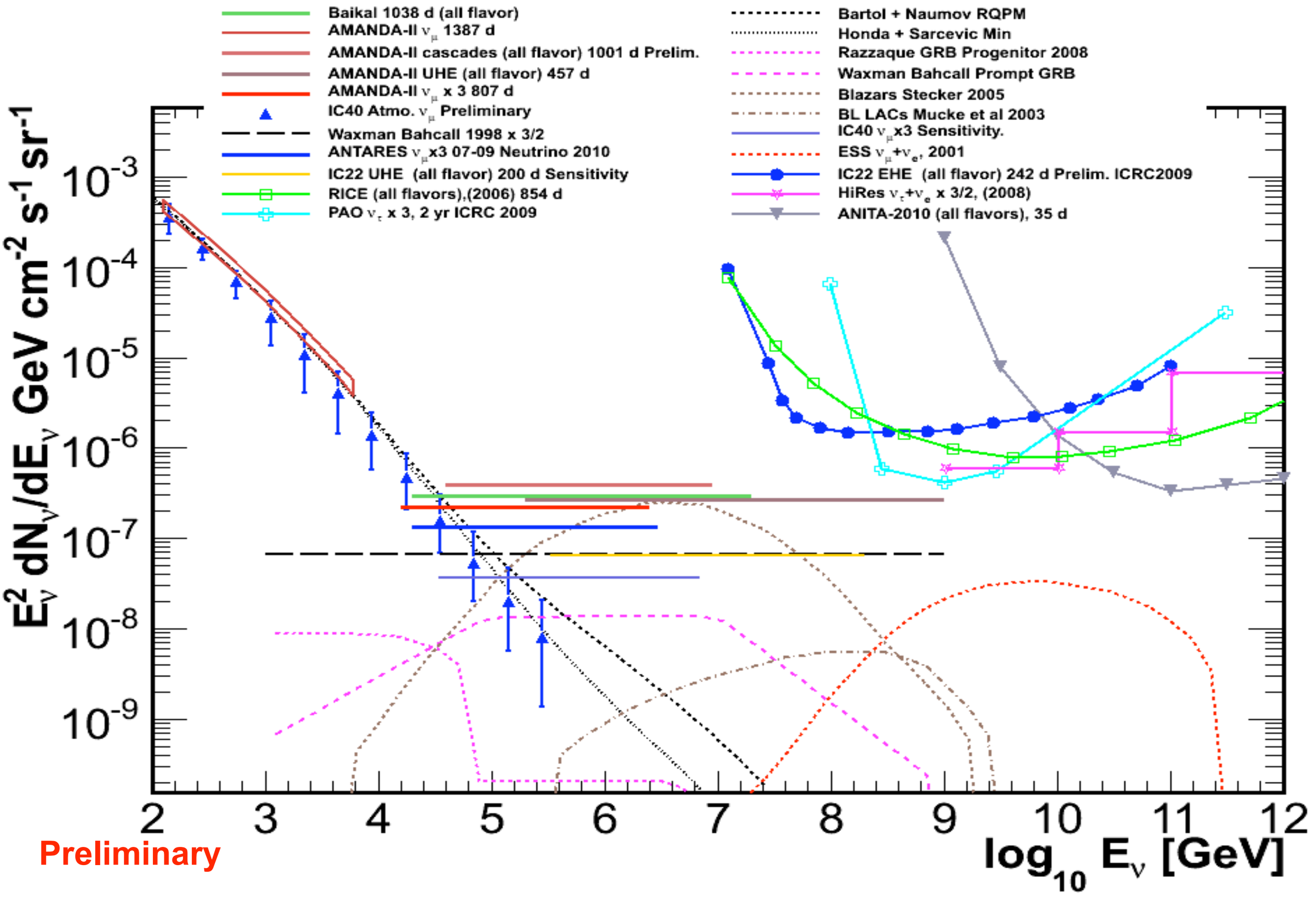


Outer-string Veto for Cosmic Ray Muons



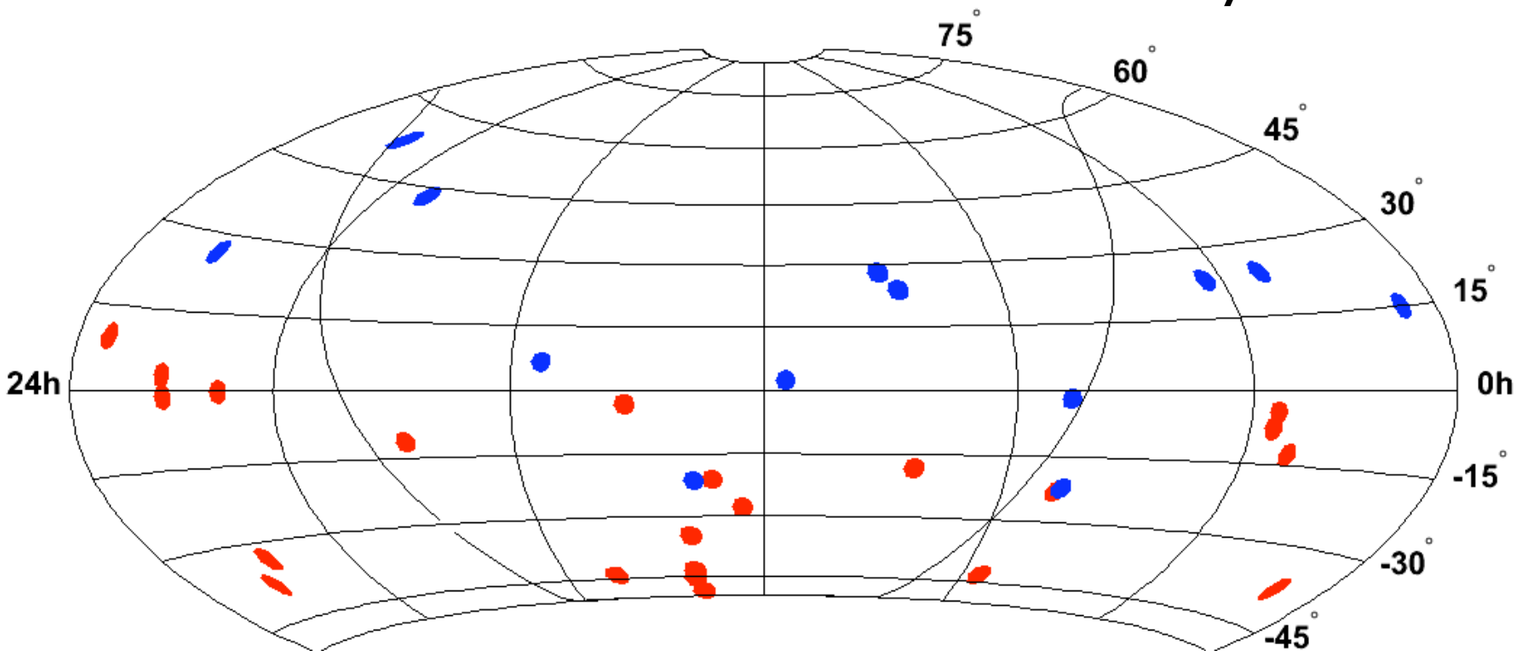
Outer-String Veto = Lower energy threshold in southern hemisphere, galactic center and all-year Sun visibility for dark matter searches

Diffuse Astrophysical Neutrino Flux: IceCube-40 Analysis



Preliminary

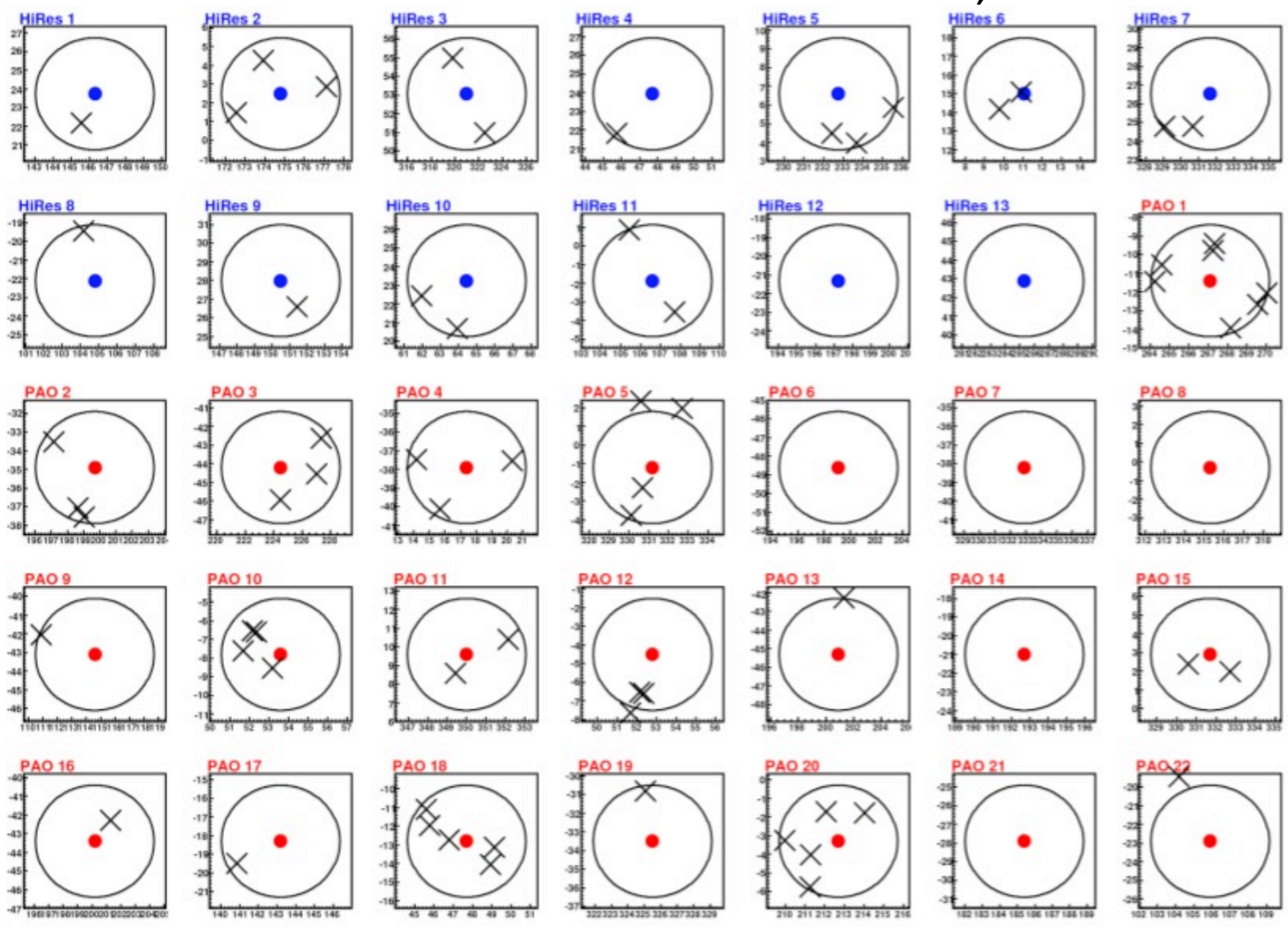
IceCube-22 Correlation Analysis with UHECR (Auger, HiRes)



13 HiRes and 22 Auger events
> 57 EeV
in IceCube-22 UHE field of view

3° search bin selected *a priori*
(allow mag. deflection offset between UHECR and source)

R. Lauer, Ph.D. Thesis



Result:
- 60 events observed
- 43.7 events bkg. expectation

At 2.3 sigma significance (1% p-value), no evidence claimed for association.

Follow-up:
- updated Auger data set
- IceCube-40 data set

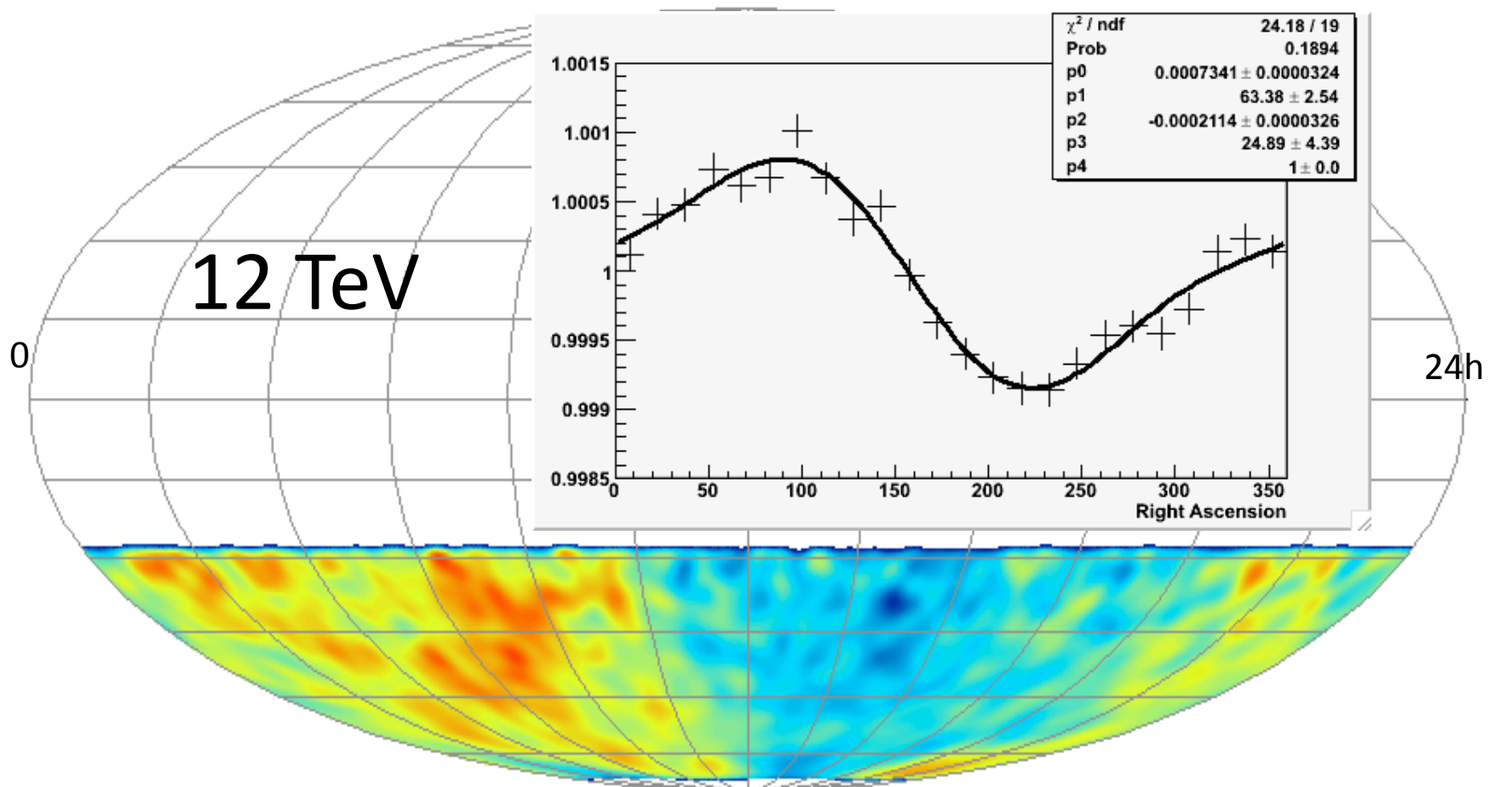
Each has ~ 2x more events

Large Scale Anisotropy of Cosmic Rays

Data: IceCube-22 strings, 4.3×10^9 events.

Median angular Resolution: 3^o degrees.

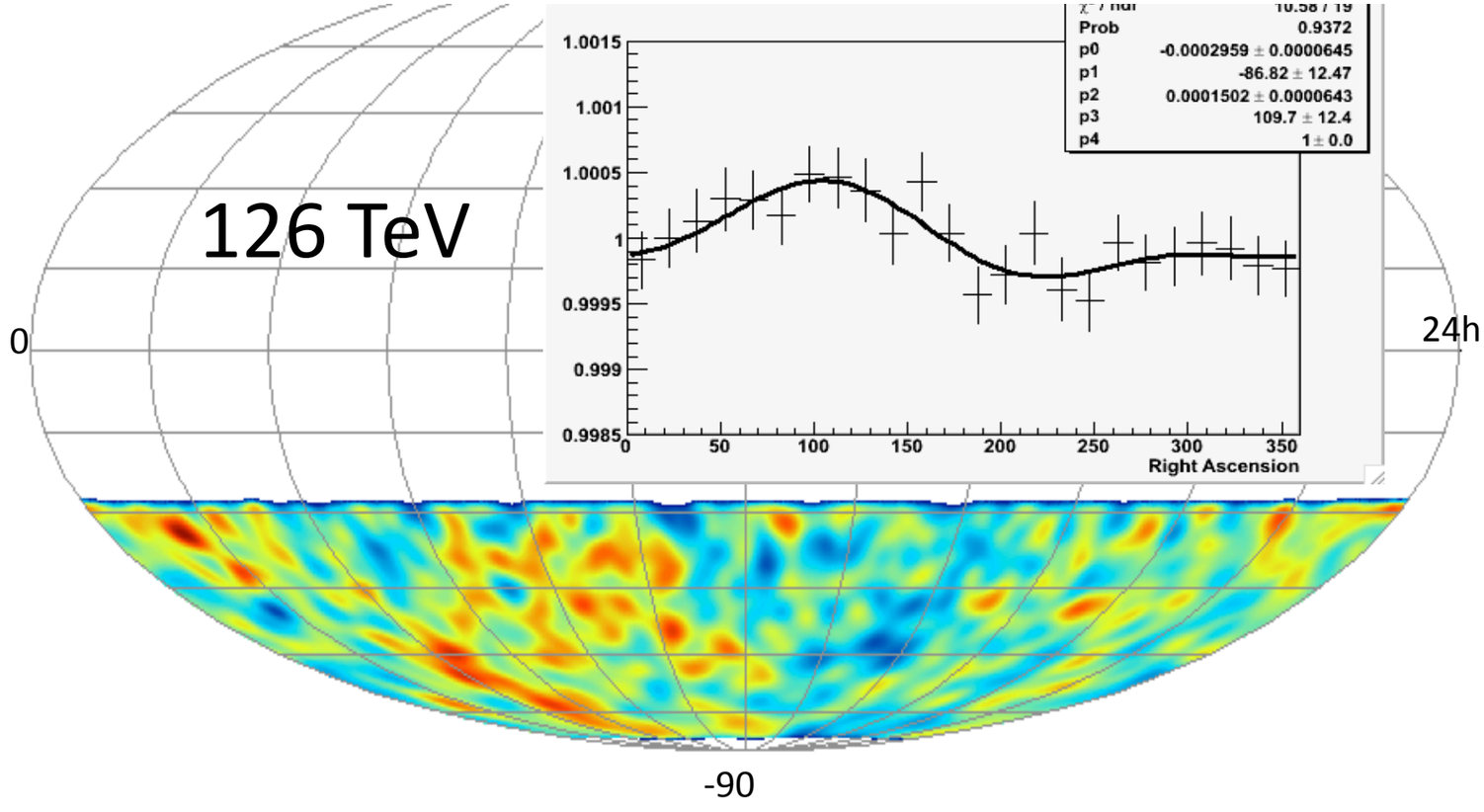
Median energy per cosmic ray particle: ~12 TeV.



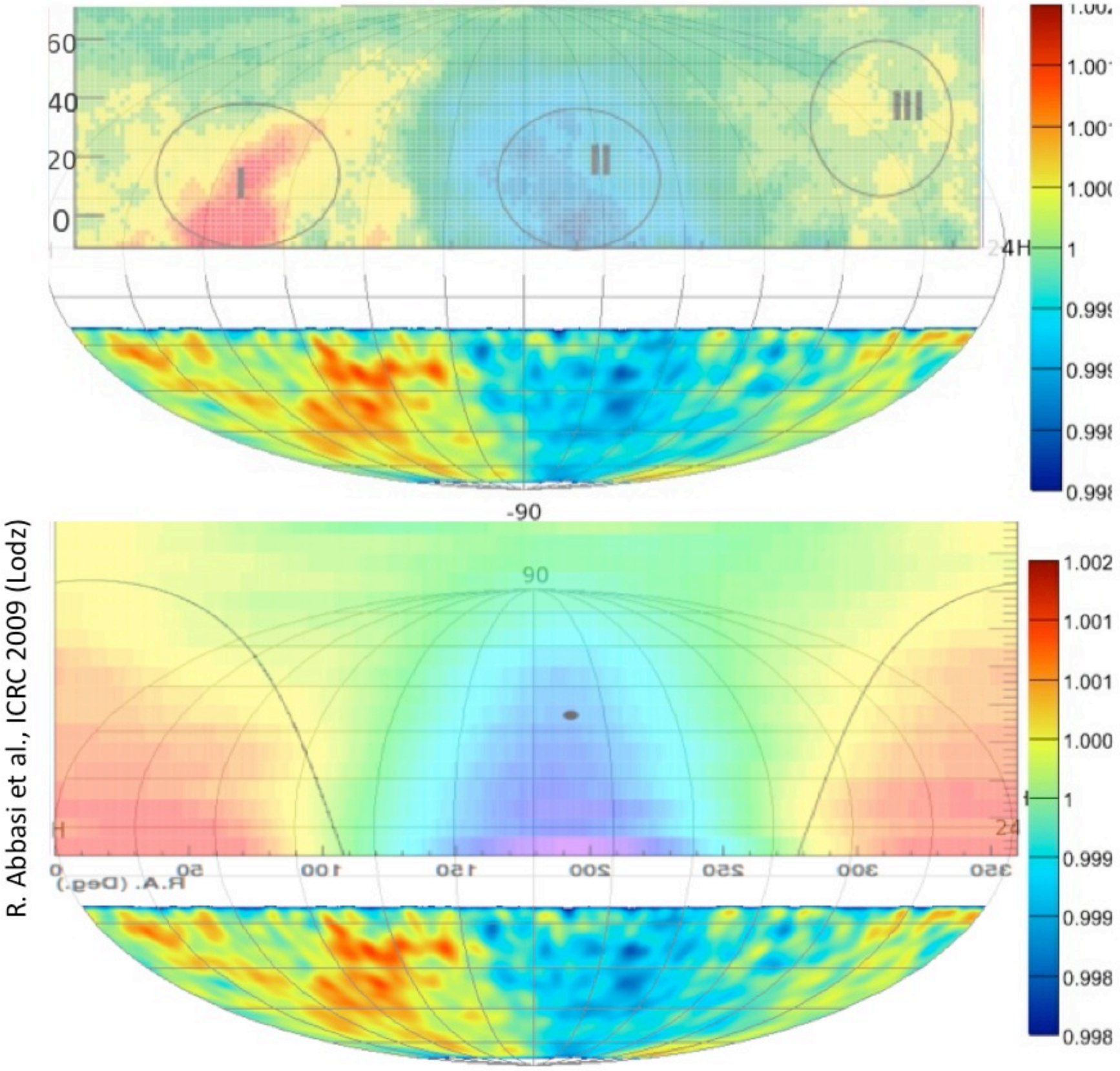
Observe large scale anisotropy.

Amplitude diminishes with increasing cosmic ray energy.

Abbasi et al., ApJL, in press



Large Scale Anisotropy of Cosmic Rays



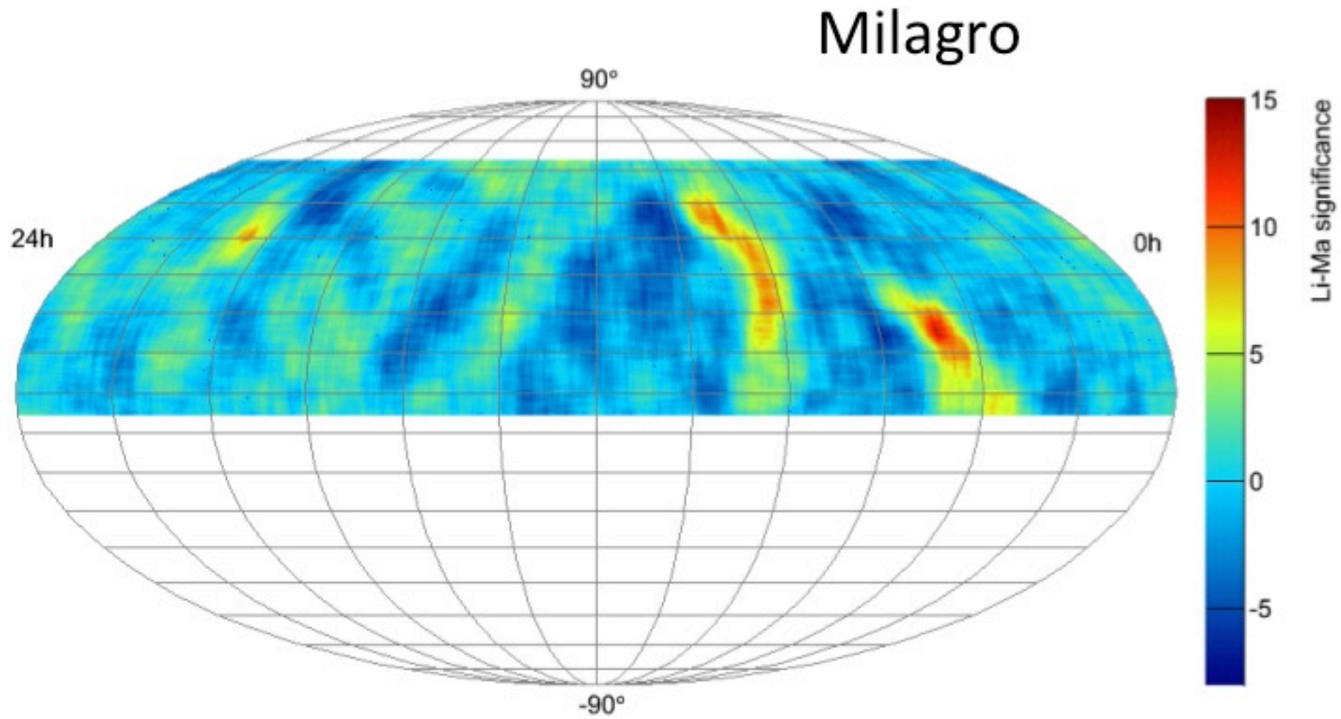
Tibet Array

IceCube Southern Sky consistent with large scale anisotropy observed in Northern hemisphere

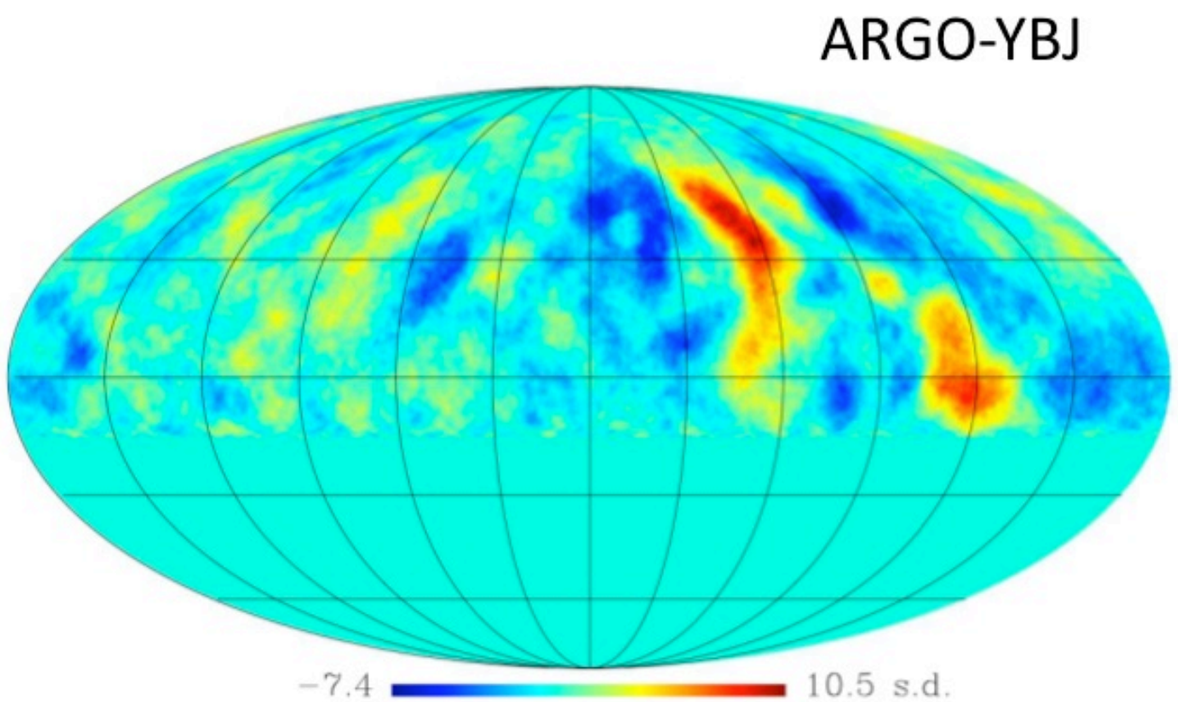
Milagro

Medium Scale Anisotropy of Cosmic Rays

Analyses on ~ 10° scale have also revealed anisotropies of unknown origin in Northern sky

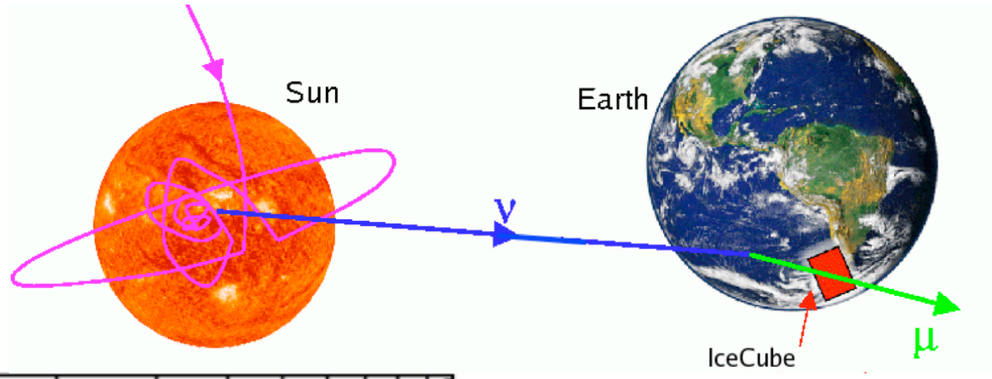


Together with upcoming IceCube analysis of 40-string data, **complete picture of sky** may help understand origin of structures



Indirect Dark Matter Detection: Annihilation in Sun

IC22 result from
Abbasi et al., *Phys. Rev. Lett.* **102**, 201302 (2009)



$0.05 < \Omega_\chi h^2 < 0.20$

Neutralino-proton SD cross-section (cm^2)

$\sigma_{SI} < \sigma_{SI}^{lim}$ CDMS(2008)+XENON10(2007)

$\sigma_{SI} < 0.001 \times \sigma_{SI}^{lim}$ CDMS(2008)+XENON10(2007)

IceCube/AMANDA ($b\bar{b}$)

IceCube/AMANDA (W^+W^-, $\tau^+\tau^-$ for 50GeV)

IC80+DC6 sens. (W^+W^-, $\tau^+\tau^-$ for 50GeV)

CDMS (2008)

COUPP (2008)

KIMS (2007)

SUPER-K 1996-2001

AMANDA

DeepCore

IceCube-22

IceCube-86

Neutralino mass (GeV)

Outlook

- IceCube is on schedule: all 86 strings to be operational next year
(and planned 20 year lifetime)

- IceCube is detecting neutrinos: ~ 20 000 neutrinos already observed in two seasons of partially built detector (consistent with expected rate of atmospheric neutrinos)

- *Likely* to already be extra-terrestrial neutrinos in this data
(but still to be identified by: direction, energy, or timing)

Outlook

- To maximize potential, continue to push detector design and search agenda
  - Lower energy thresholds (Dark Matter)
  - Veto cosmic ray background (All sky searches, DM Halo)
  - Transient, multi-messenger searches (SNe, GRBs, “hidden” bursts)

- IceCube is the first of a new class of km^3 detectors

- A long list of potential new sources and science objectives

- Most interesting result may be something unexpected

Stockholm University
Uppsala University

University of Alberta

University of Oxford

EPFL, Lausanne

RWTH Aachen
Humboldt Univ., Berlin
Ruhr-Universität Bochum
Universität Bonn
Universität Dortmund
MPI Heidelberg
Universität Mainz
Universität Wuppertal
DESY, Zeuthen

Chiba University

U. of West Indies, Barbados

Univ Alaska, Anchorage
Clark-Atlanta University
Georgia Tech
Southern University, Baton Rouge
UC Berkeley
Lawrence Berkeley National Lab
University of Maryland
The Ohio State University
UC Irvine
University of Kansas
University of Wisconsin-Madison
U Delaware / Bartol Research Inst
University of Wisconsin-River Falls
Univ Alabama, Tuscaloosa
Pennsylvania State University

Universite Libre de Bruxelles
Vrije Universiteit Brussel
Universiteit Gent
Université de Mons

Univ. of Canterbury, Christchurch

The IceCube Collaboration

36 Institutions, ~250 members