The IceCube Experiment : Current Status and Future Plans

Debanjan Bose

Not on behalf of IceCube collaboration

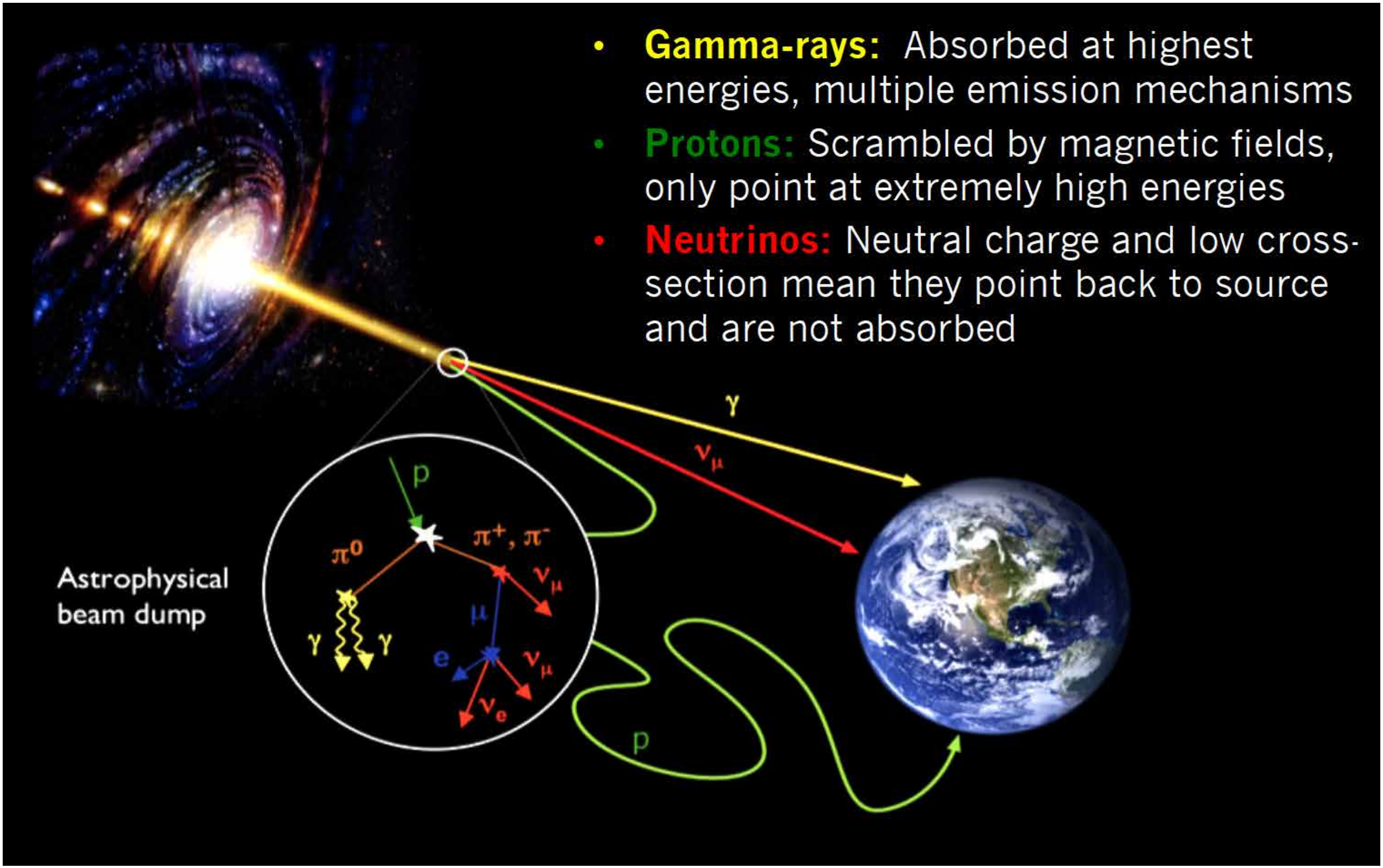
Candles of Darkness, ICTS, Bangalore, 9th June 2017

Plan of Talk

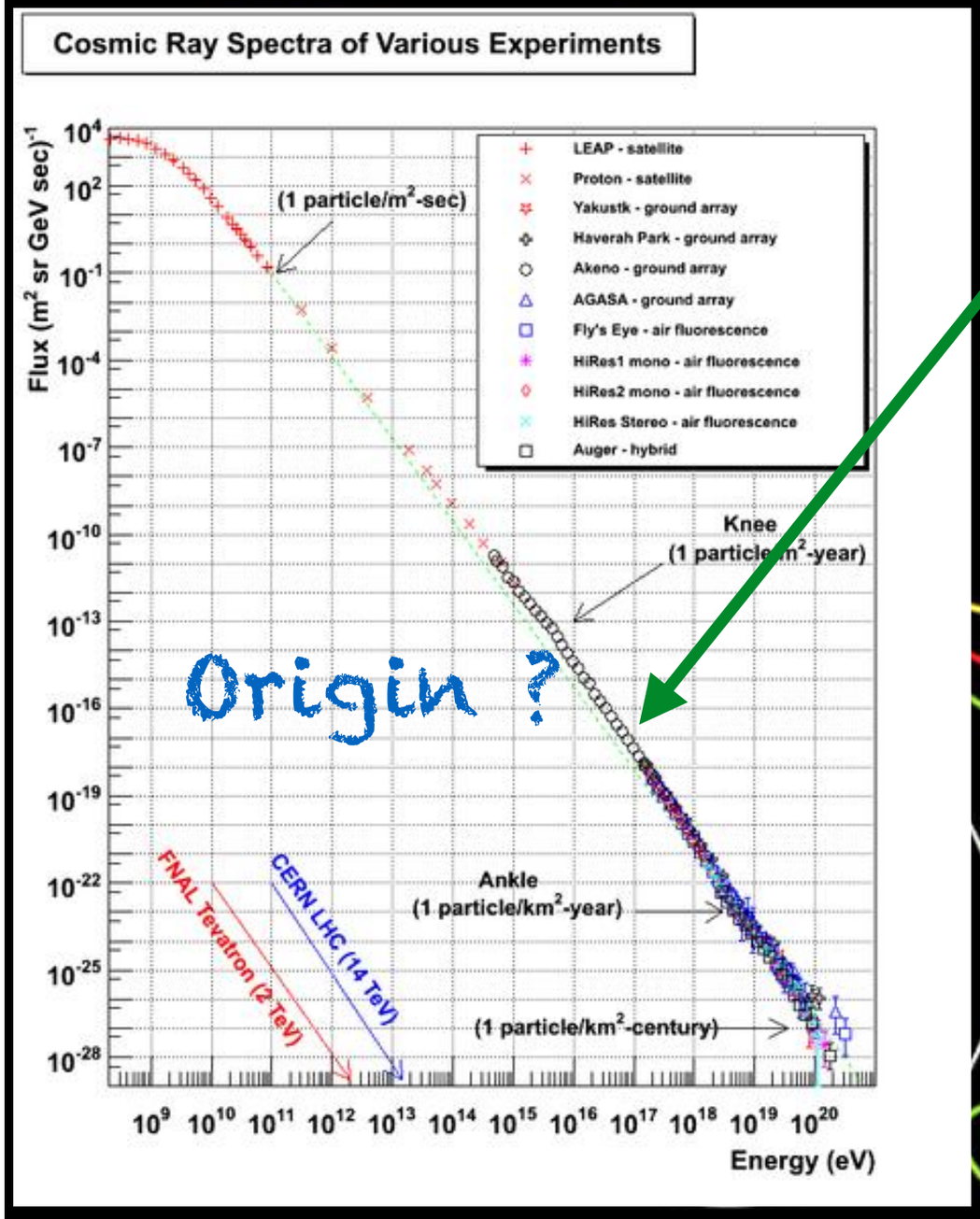
- Motivation to build IceCube
- IceCube Neutrino Telescope : Concept & Design
- Astrophysical Neutrinos ..
- IceCube Gen2 : Future Extensions

Role of Neutrinos @ HE Astrophysics

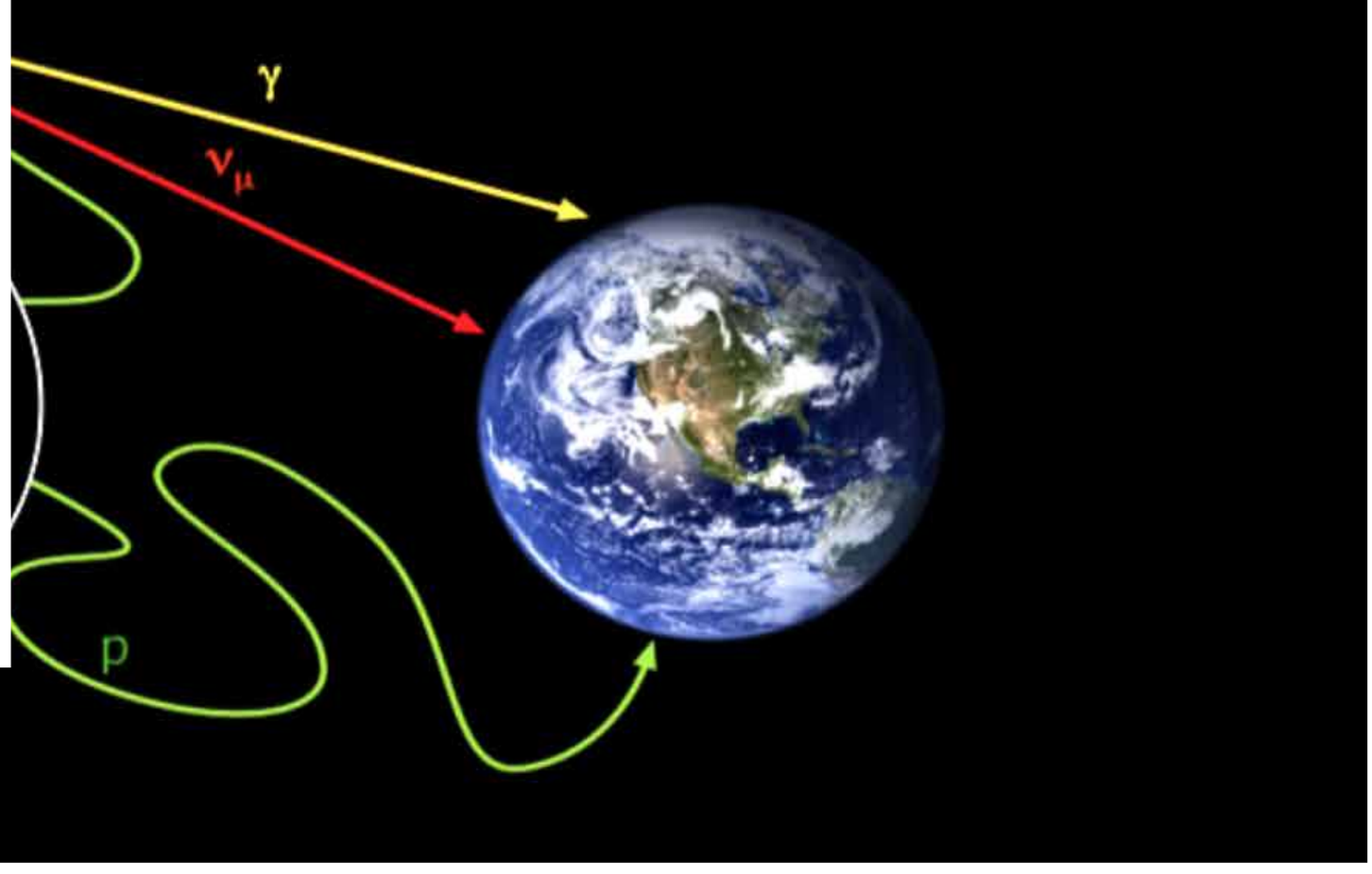
- **Gamma-rays:** Absorbed at highest energies, multiple emission mechanisms
- **Protons:** Scrambled by magnetic fields, only point at extremely high energies
- **Neutrinos:** Neutral charge and low cross-section mean they point back to source and are not absorbed



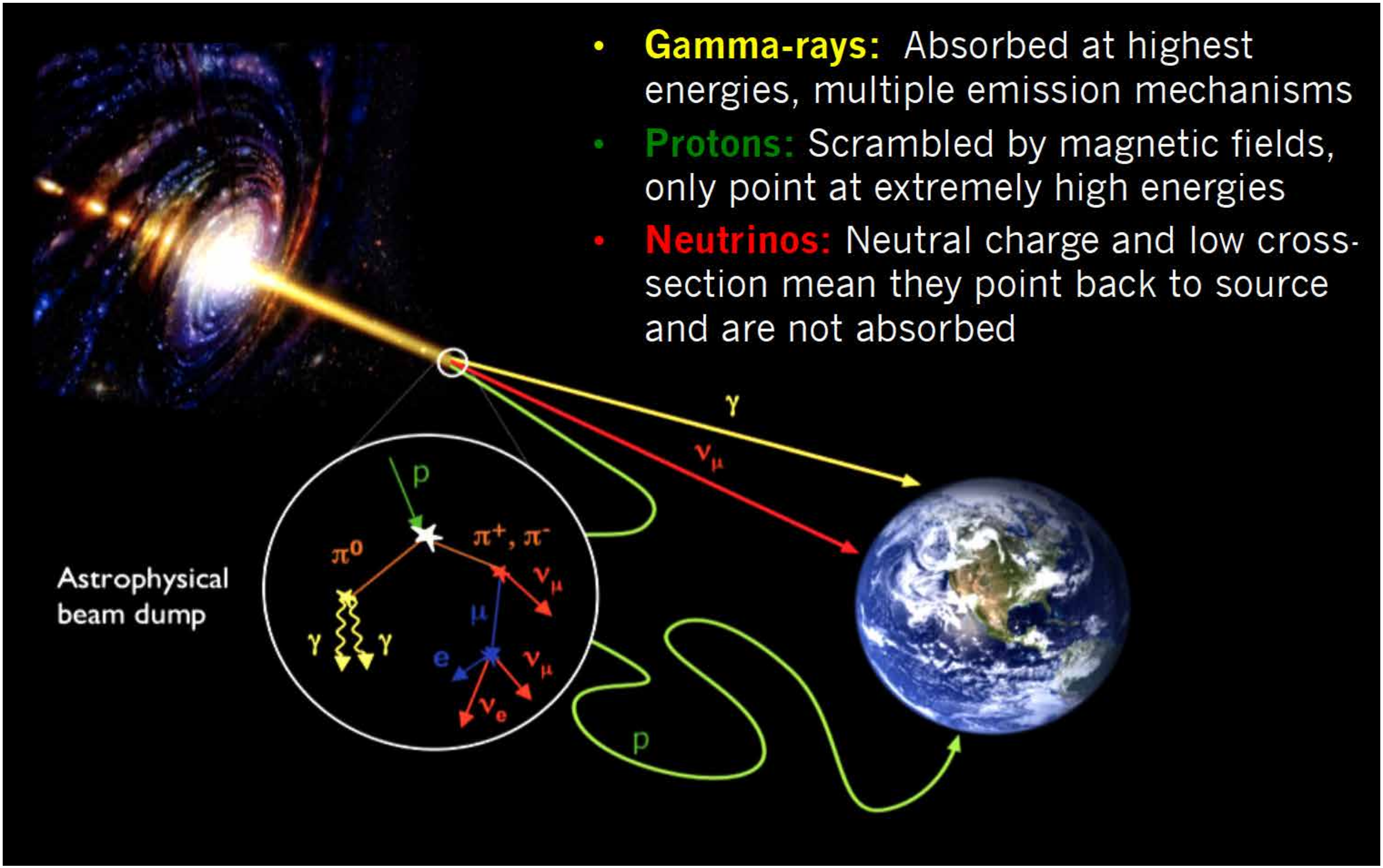
Role of Neutrinos @ HE Astrophysics



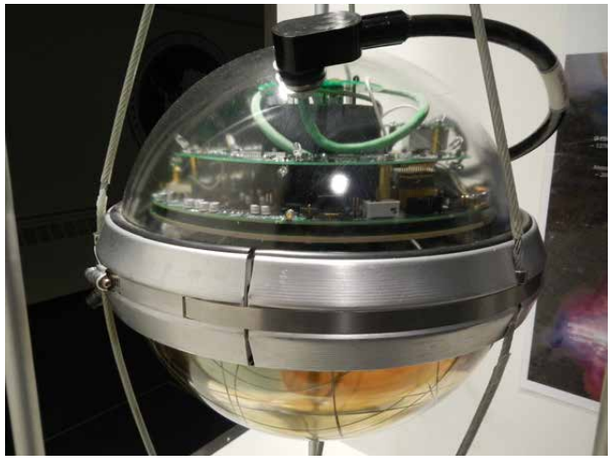
- **Gamma-rays:** Absorbed at highest energies, multiple emission mechanisms
- **Protons:** Scrambled by magnetic fields, only point at extremely high energies
- **Neutrinos:** Neutral charge and low cross-section mean they point back to source and are not absorbed

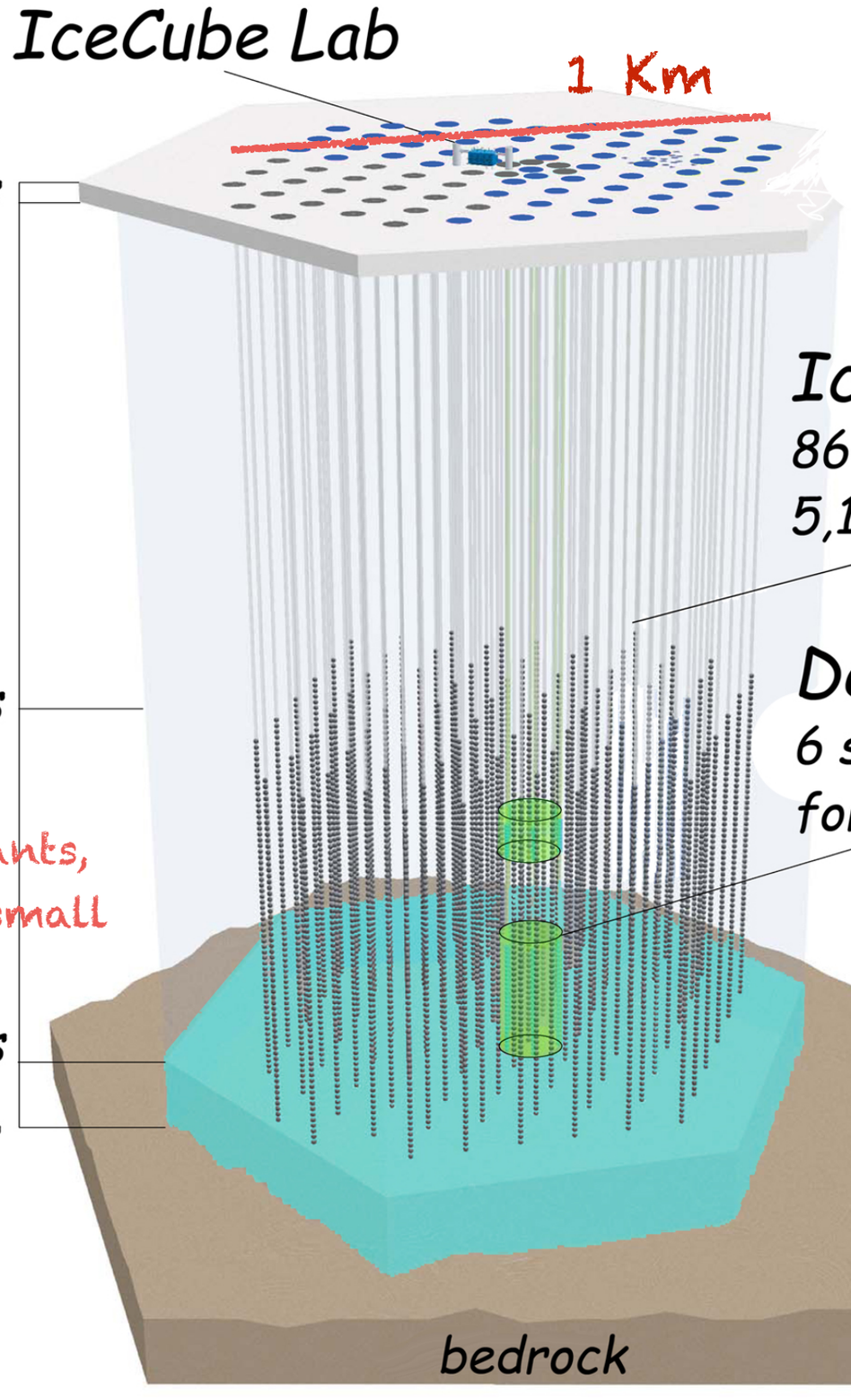


Role of Neutrinos @ HE Astrophysics



IceCube Neutrino Telescope





Absorption Length
tap water 2m
distilled water 10m
ultra pure ice 200m

IceCube Array
86 strings, 60 sensors each
5,160 optical sensors

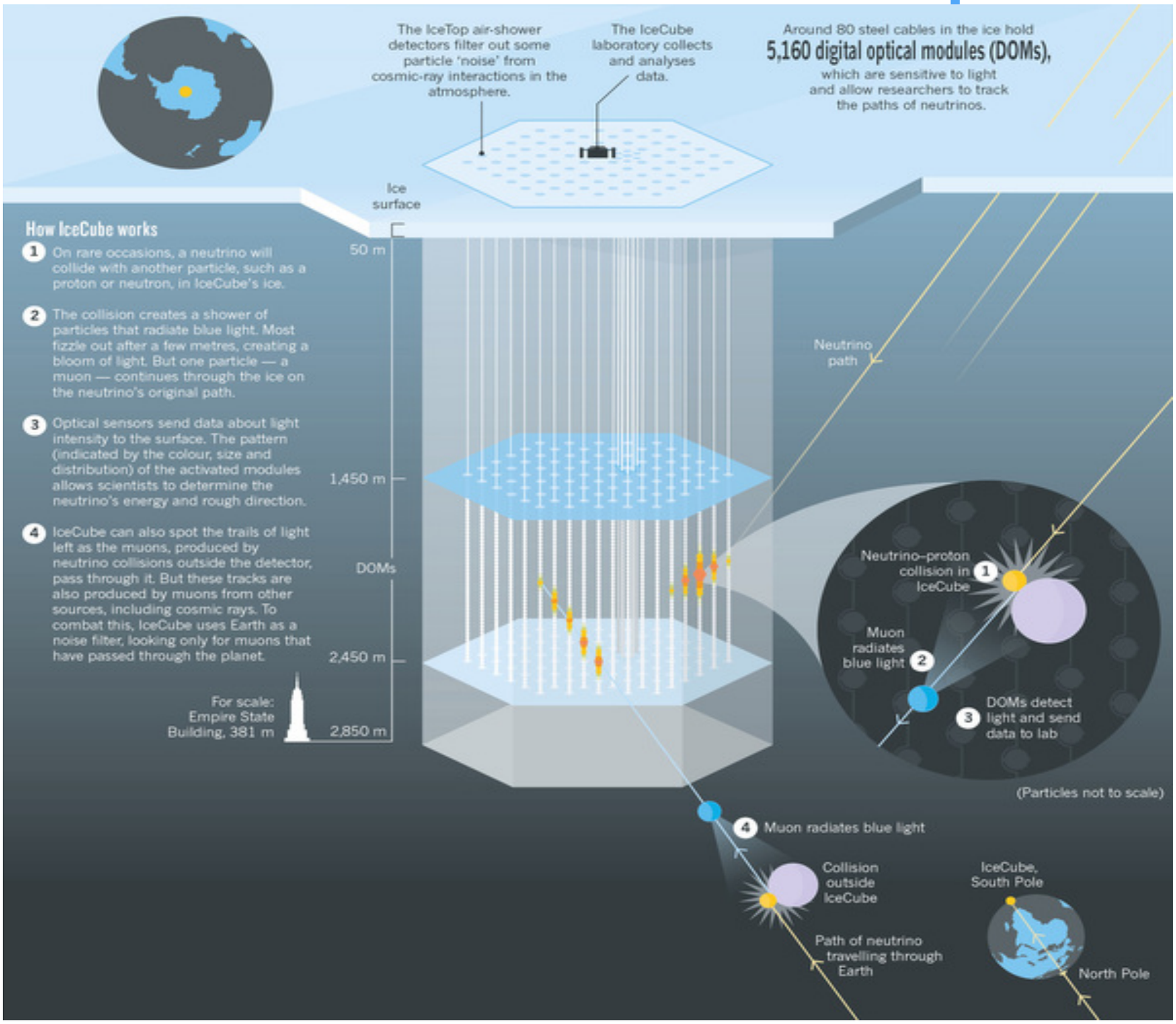
DeepCore
6 strings optimized
for low energies

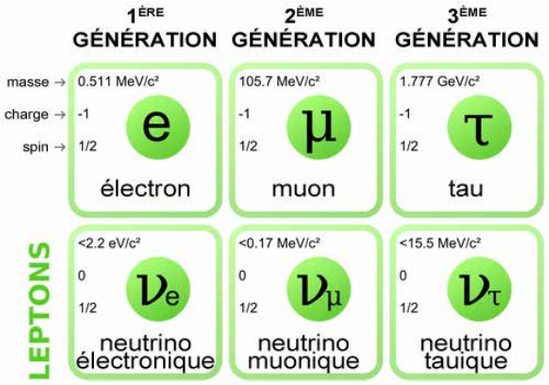
Radioactive contaminants,
thermionic noise very small

Eiffel Tower
324 meters

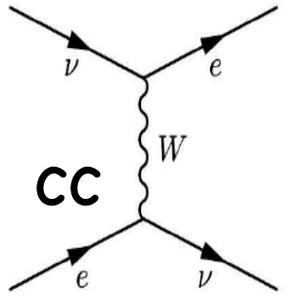
5160 Optical Modules
$1km^3$ = Gton Volume

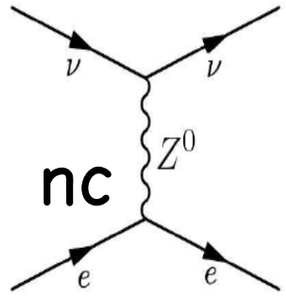
IceCube Neutrino Telescope



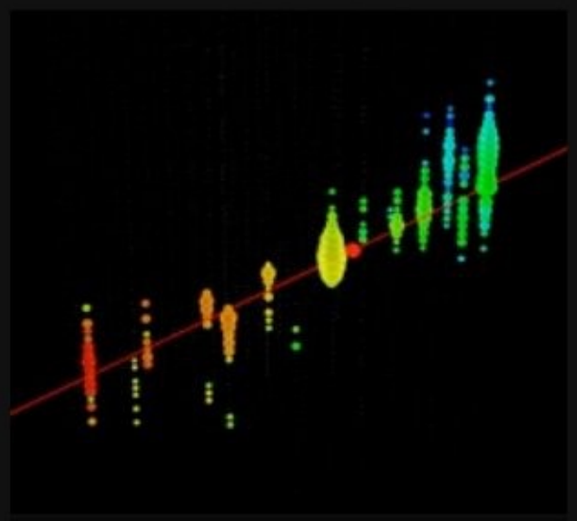


Event Topology





CC Muon Neutrino

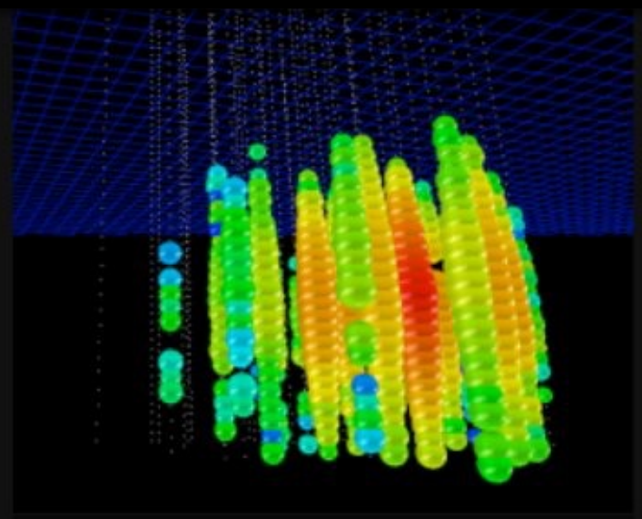


$$\nu_\mu + N \rightarrow \mu + X$$

track (data)

factor of ≈ 2 energy resolution
< 1° angular resolution

NC all types
CC Electron & Tau



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

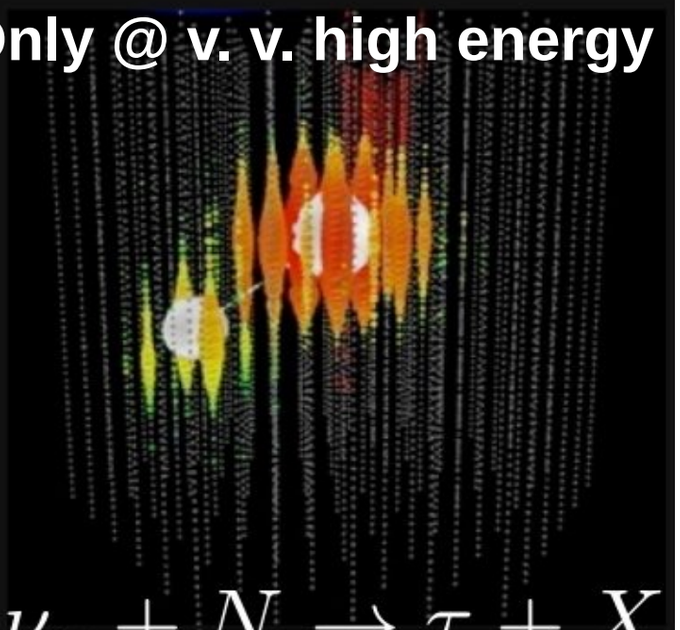
$$\nu_x + N \rightarrow \nu_x + X$$

cascade (data)

≈ ±15% energy resolution
≈ 10° angular resolution
(at energies ≳ 100 TeV)

CC Tau Neutrino

Only @ v. v. high energy

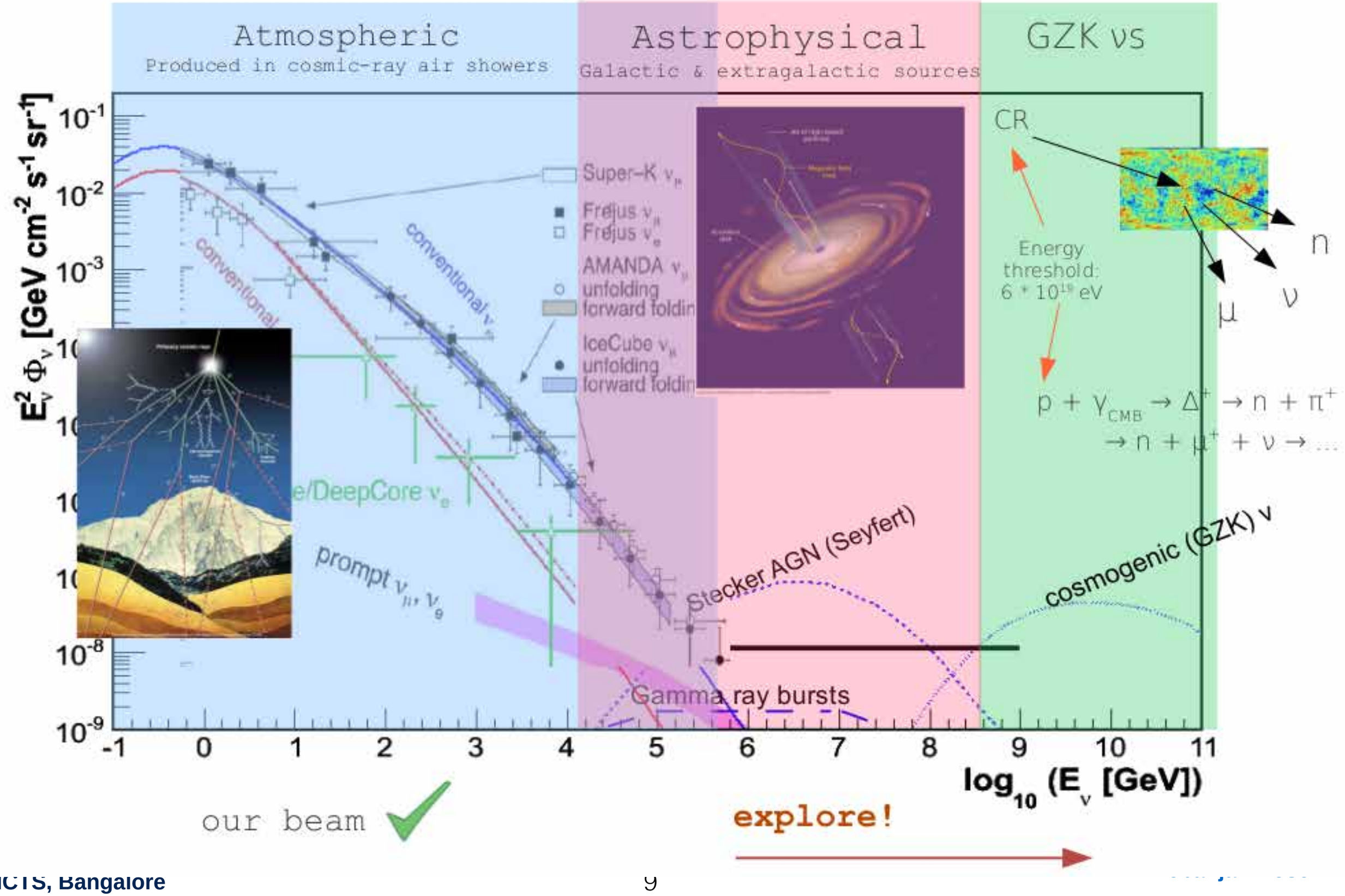


$$\nu_\tau + N \rightarrow \tau + X$$

"double-bang" and other signatures (simulation)

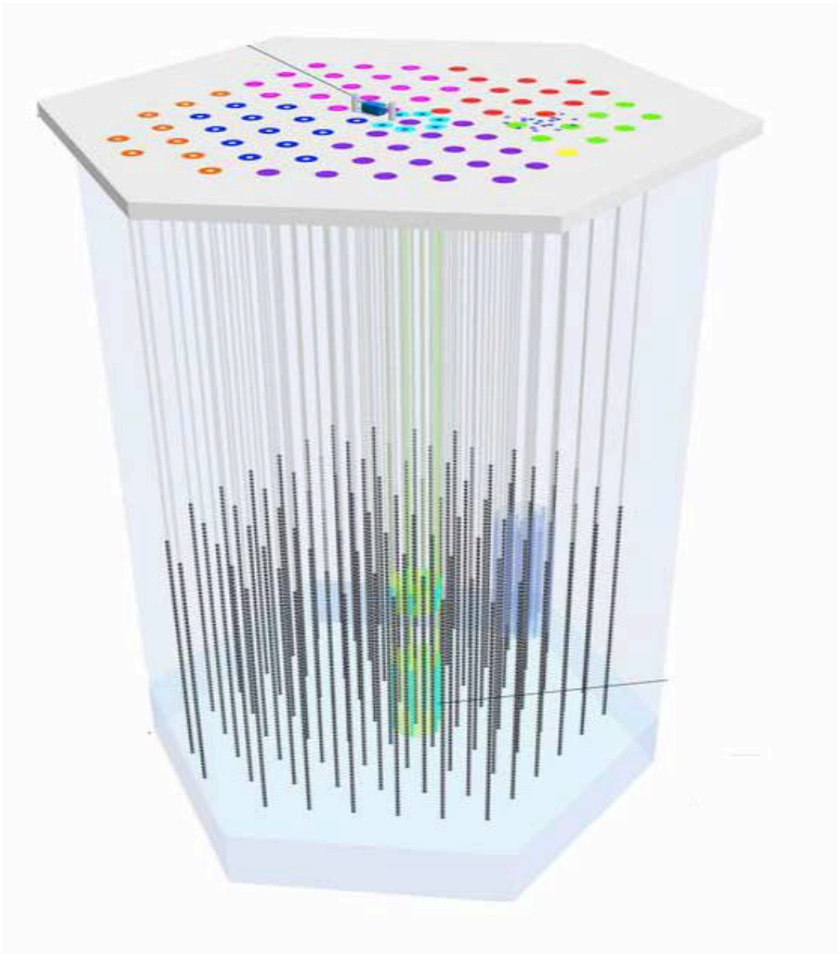
(not observed yet)

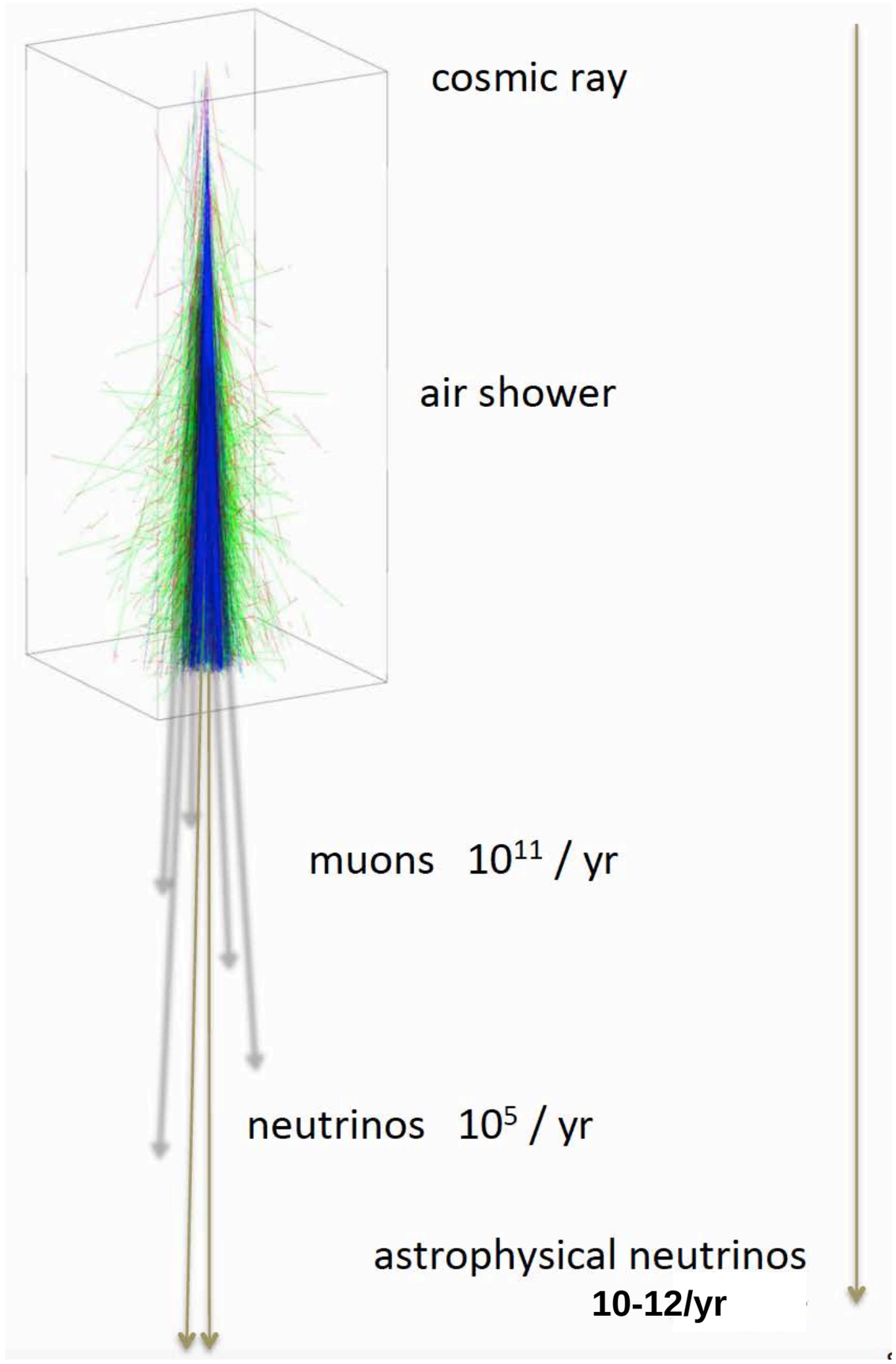
Neutrino Spectrum



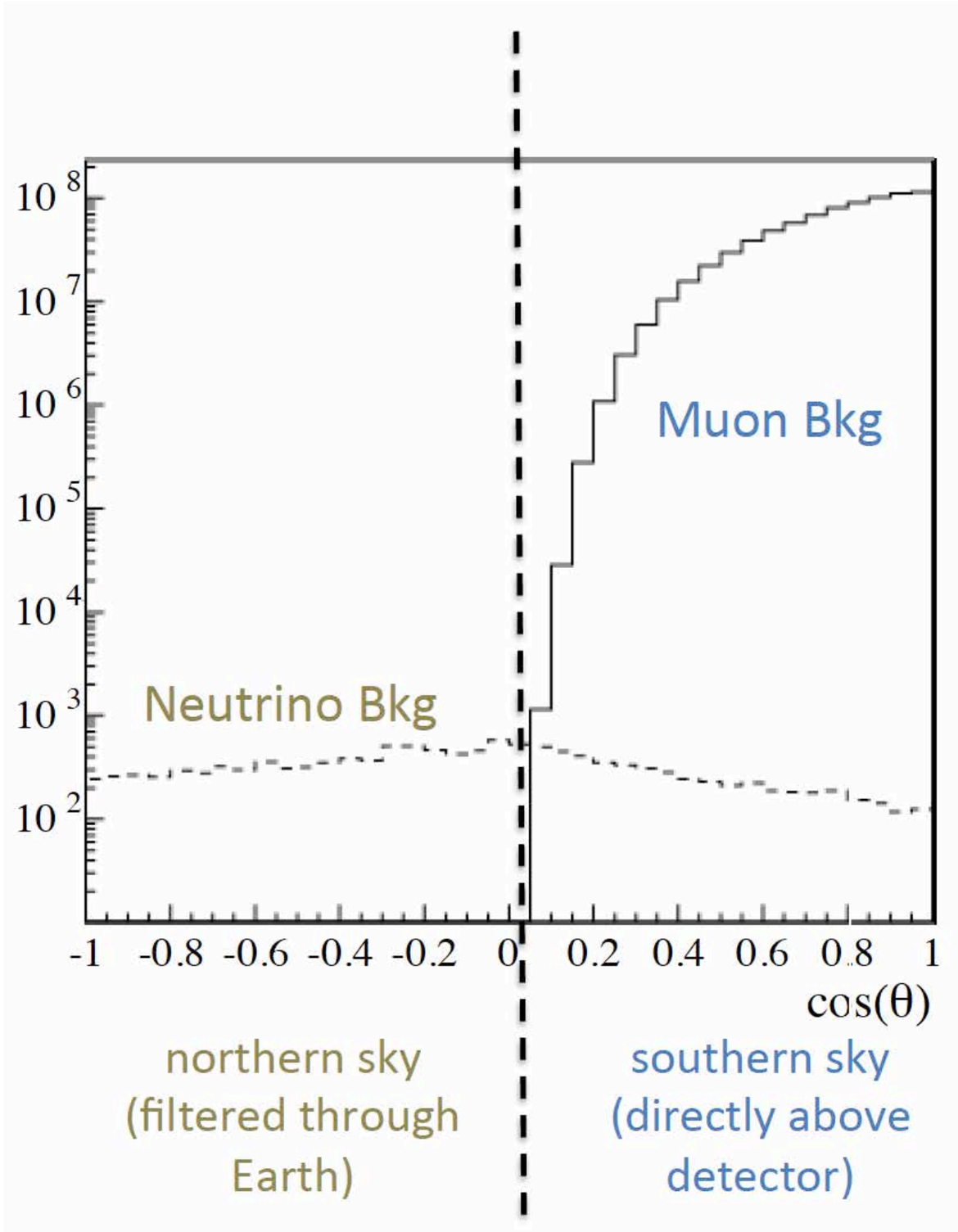
IceCube Events

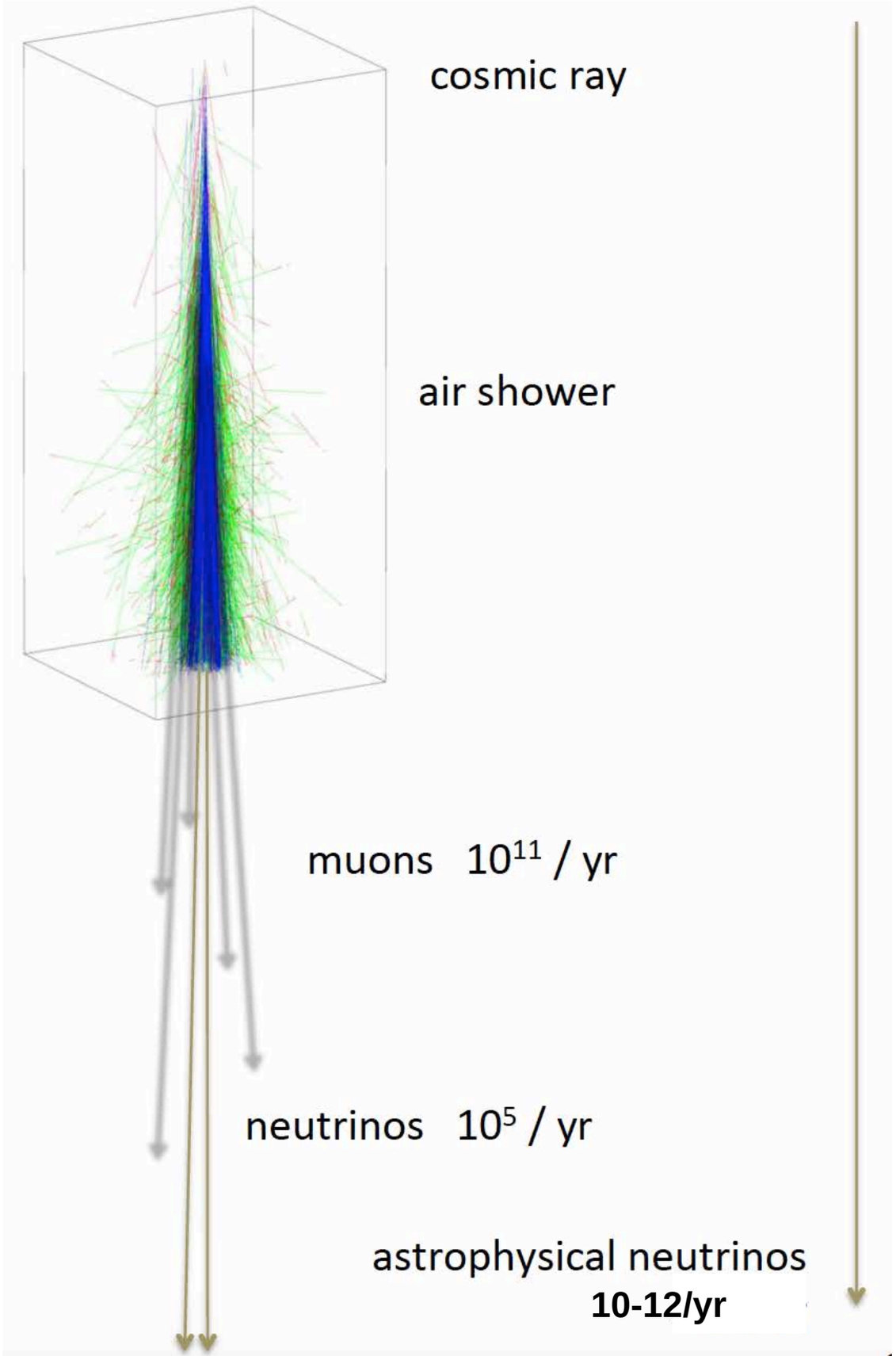
Muon Trigger Rate 3 kHz



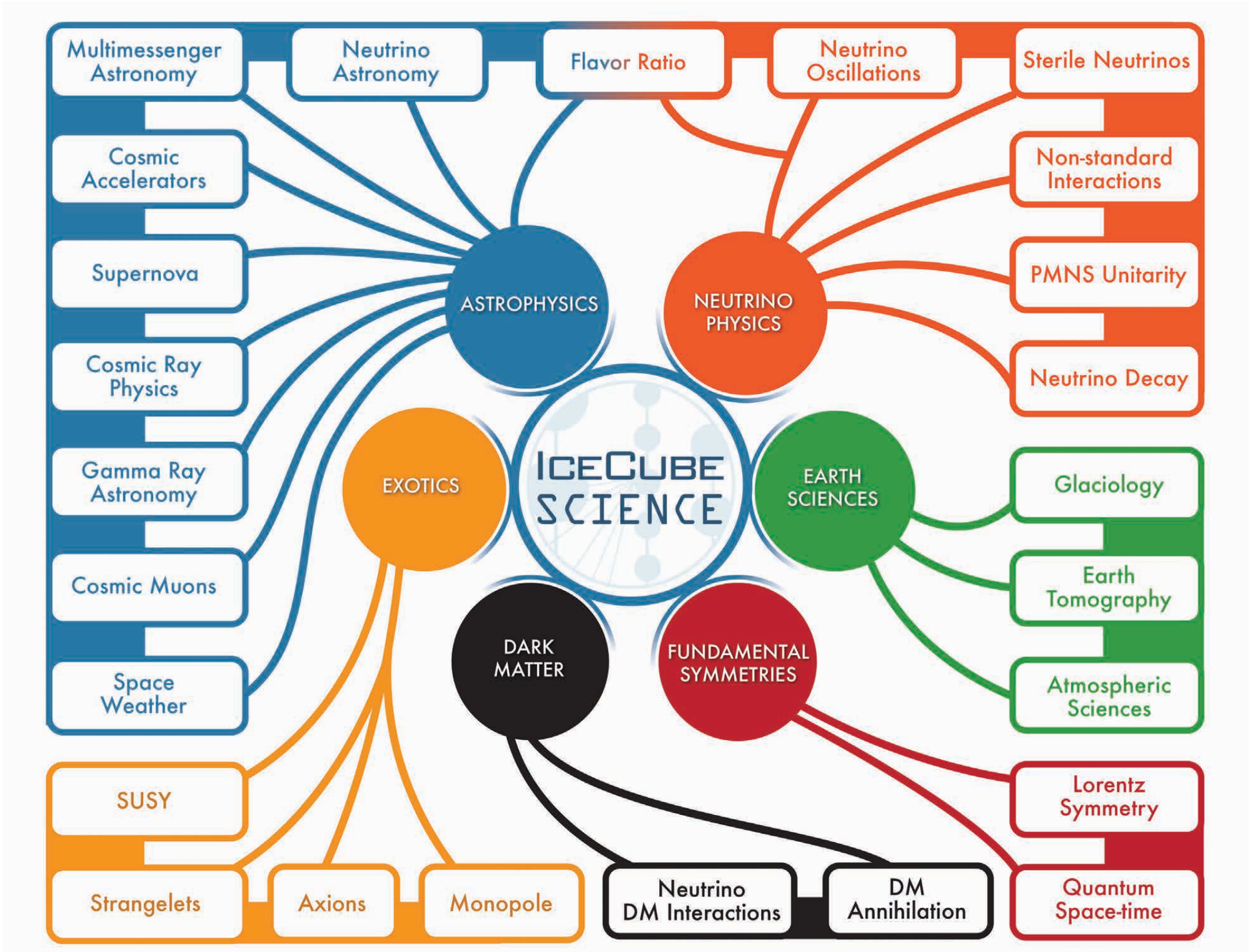


IceCube Events





Science with IceCube



THE ICECUBE COLLABORATION

AUSTRALIA
University of Adelaide

BELGIUM
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel

CANADA
SNOLAB
University of Alberta–Edmonton

DENMARK
University of Copenhagen

GERMANY
Deutsches Elektronen-Synchrotron
Friedrich-Alexander-Universität Erlangen-Nürnberg
Humboldt–Universität zu Berlin
Ruhr-Universität Bochum
RWTH Aachen
Technische Universität Dortmund
Technische Universität München
Universität Münster
Universität Mainz
Universität Wuppertal

JAPAN
Chiba University

NEW ZEALAND
University of Canterbury

REPUBLIC OF KOREA
Sungkyunkwan University

SWEDEN
Stockholms Universitet
Uppsala Universitet

SWITZERLAND
Université de Genève

UNITED KINGDOM
University of Oxford

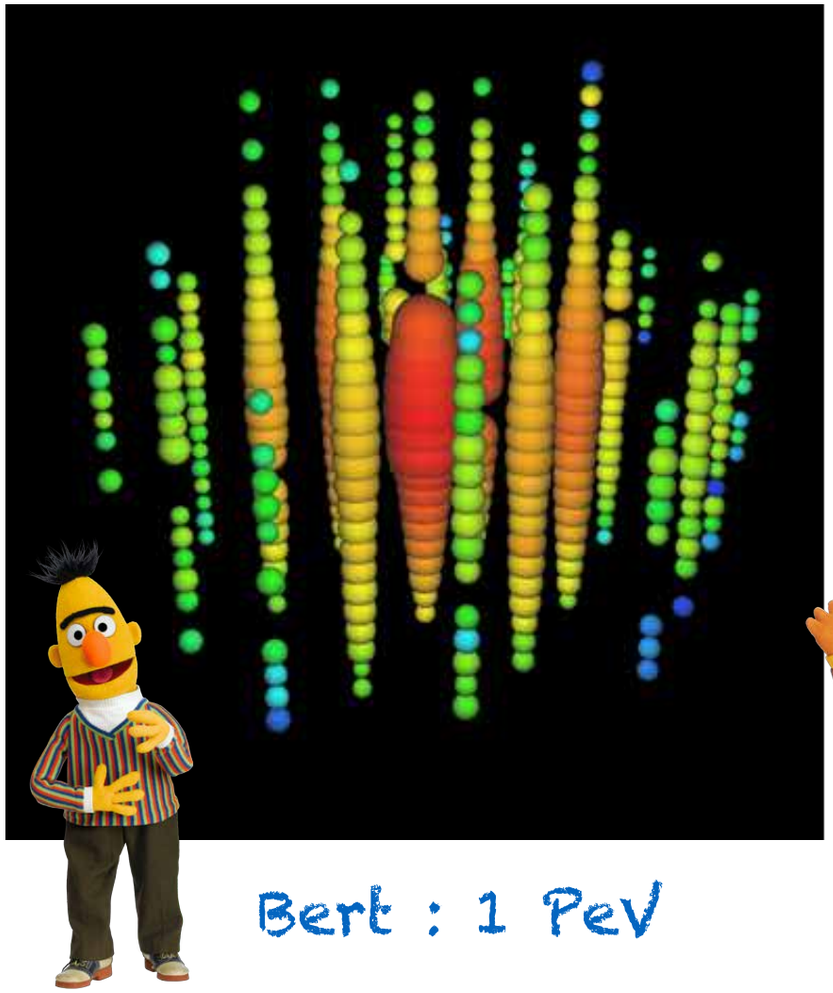
UNITED STATES
Clark Atlanta University
Drexel University
Georgia Institute of Technology
Lawrence Berkeley National Lab
Marquette University
Massachusetts Institute of Technology
Michigan State University
Ohio State University
Pennsylvania State University
South Dakota School of Mines and Technology
Southern University and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
University of California, Berkeley
University of California, Irvine
University of Delaware
University of Kansas
University of Maryland
University of Rochester
University of Texas at Arlington
University of Wisconsin–Madison
University of Wisconsin–River Falls
Yale University

FUNDING AGENCIES

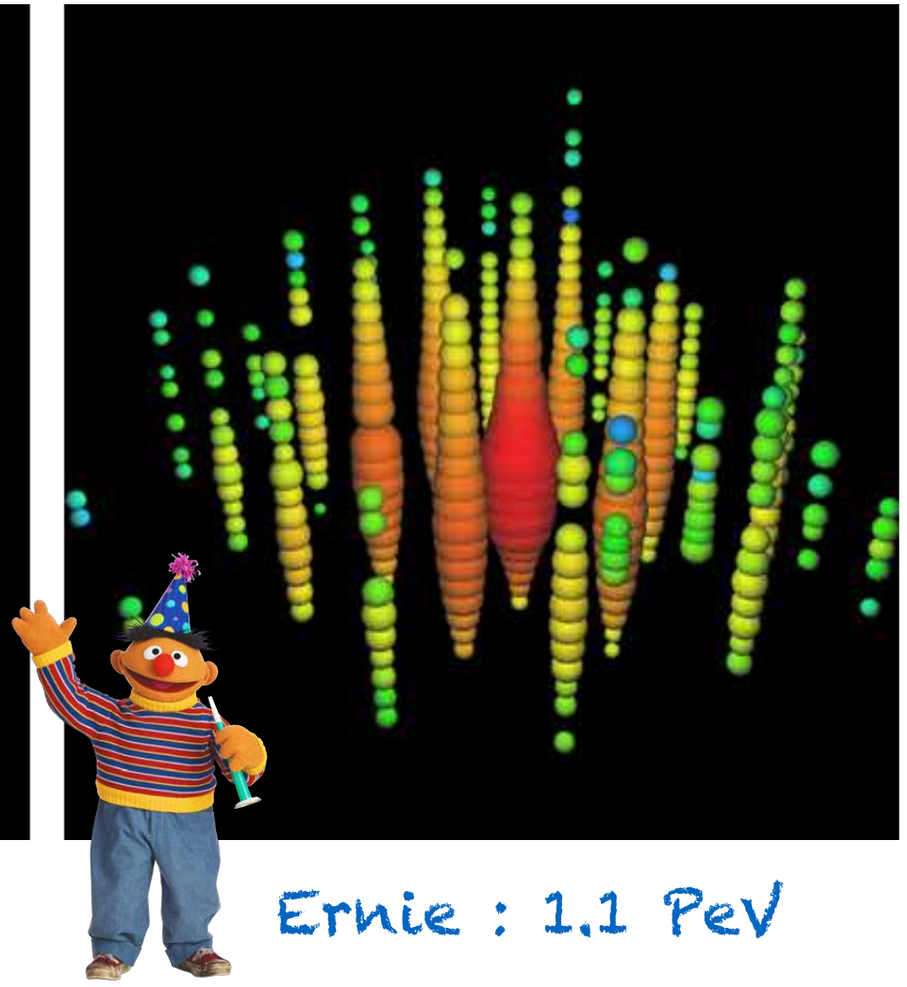
Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education and Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg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

IceCube
South Pole Neutrino Observatory

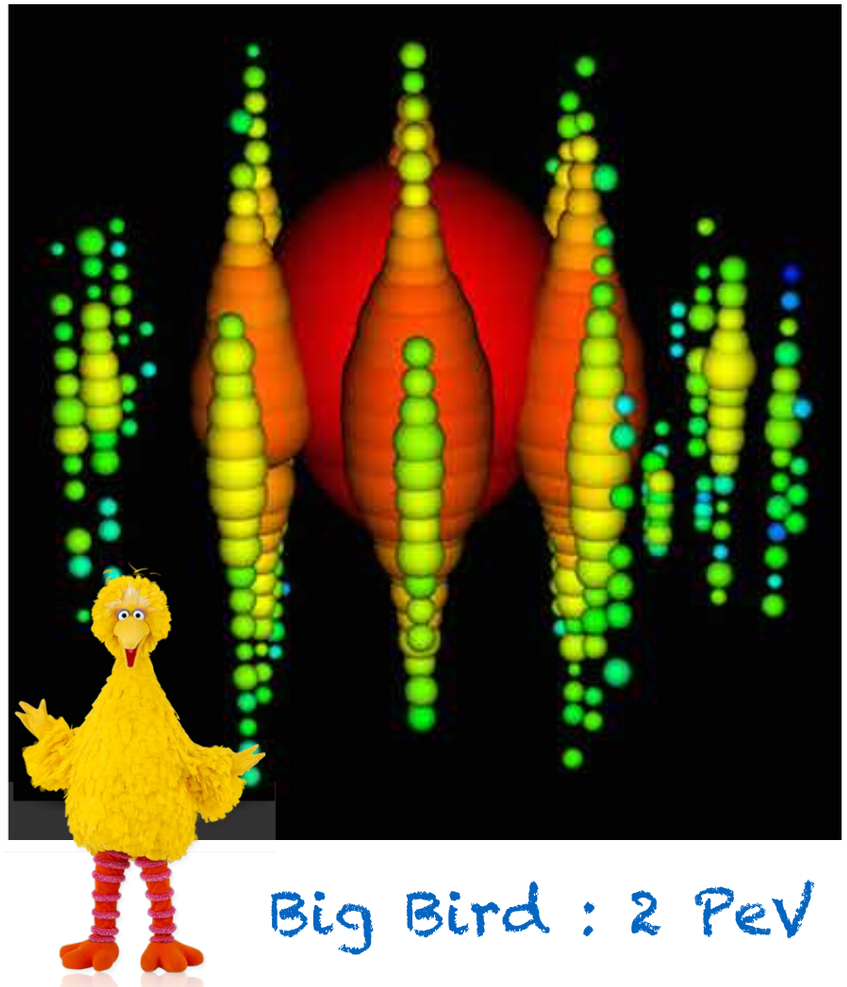
Big Three



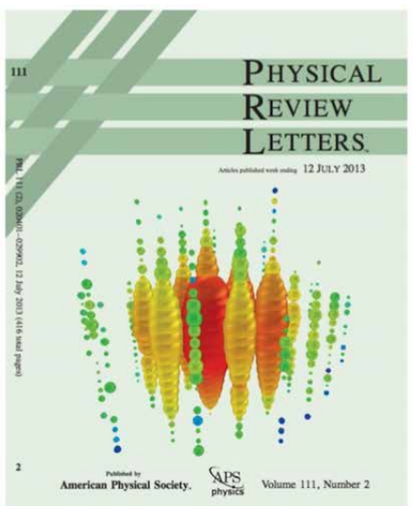
Bert : 1 PeV

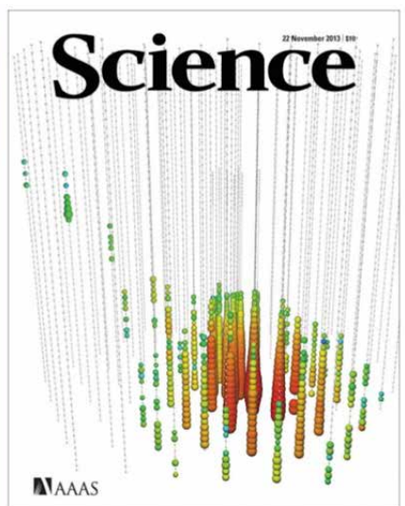


Ernie : 1.1 PeV



Big Bird : 2 PeV



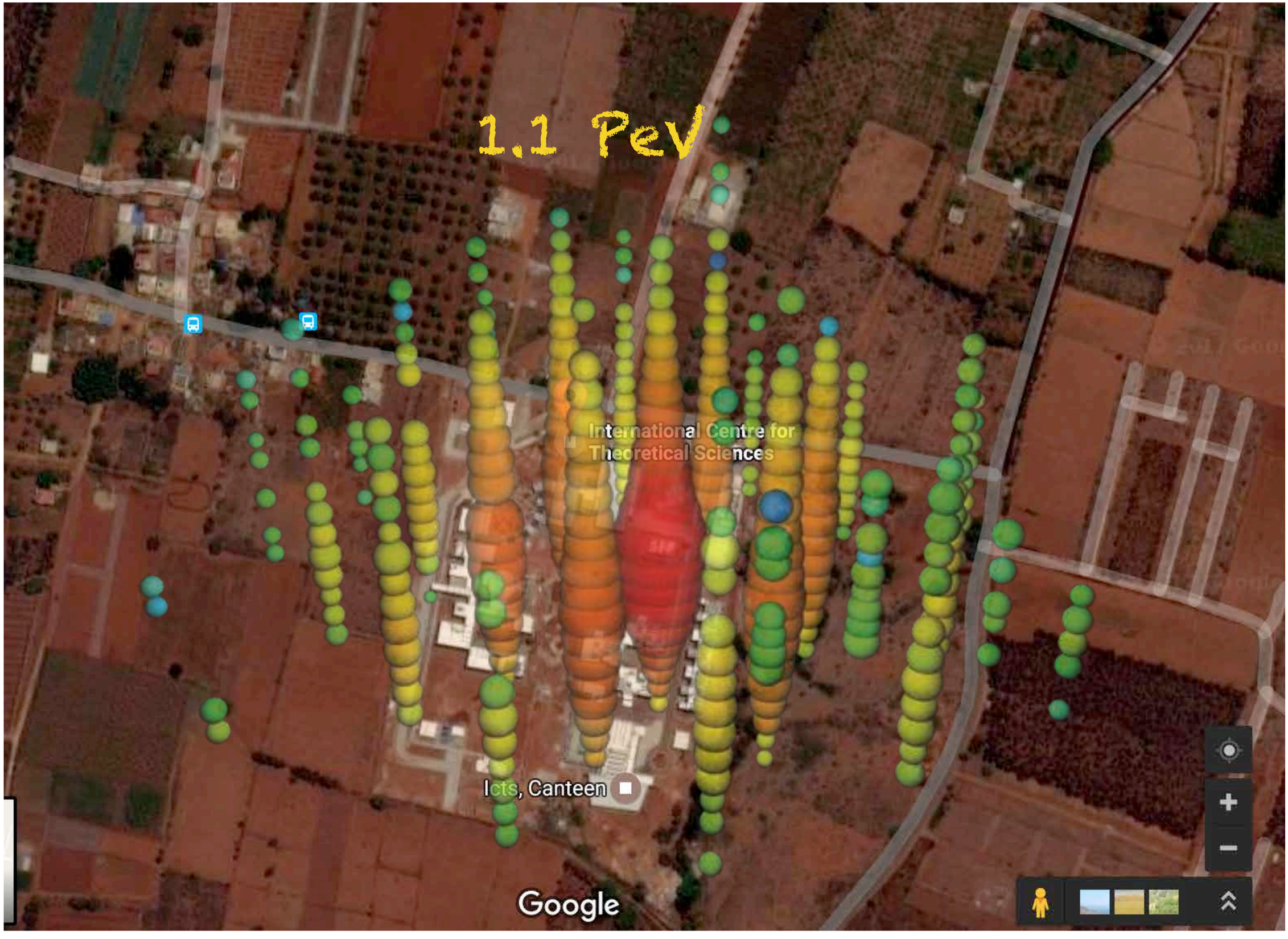


PRL 111, 021103 (2013)

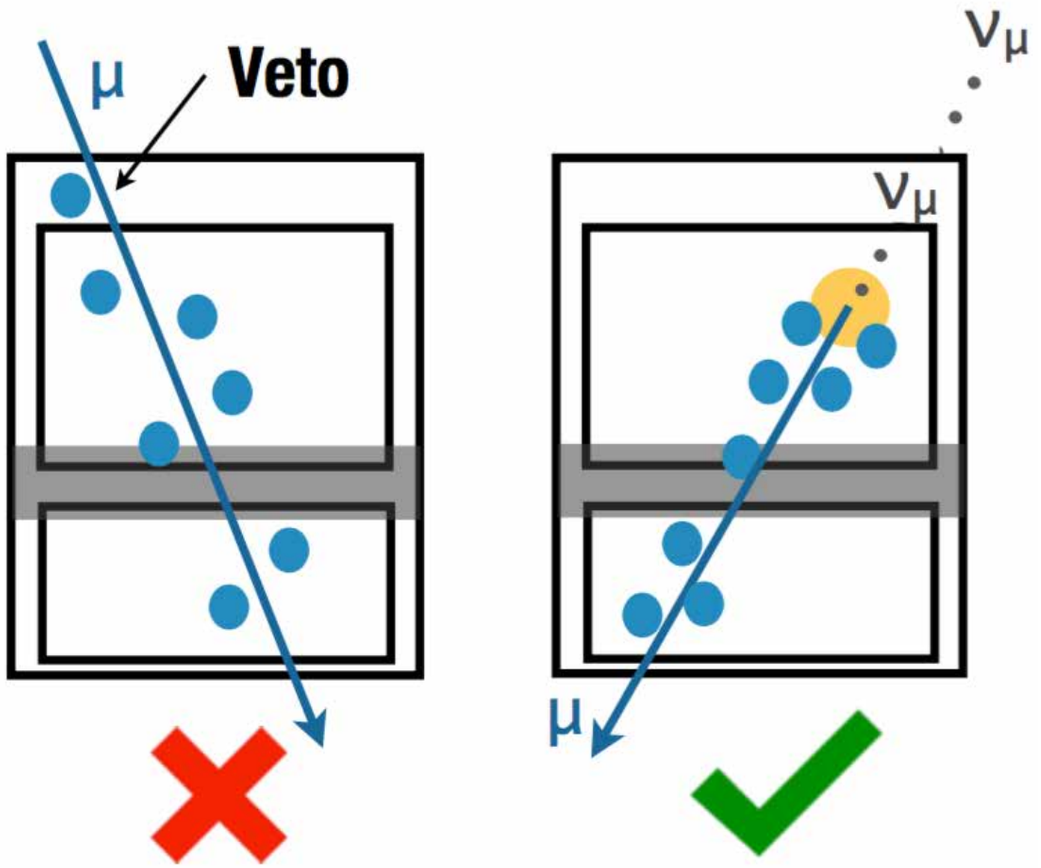
Science 342, 1242856 (2013)

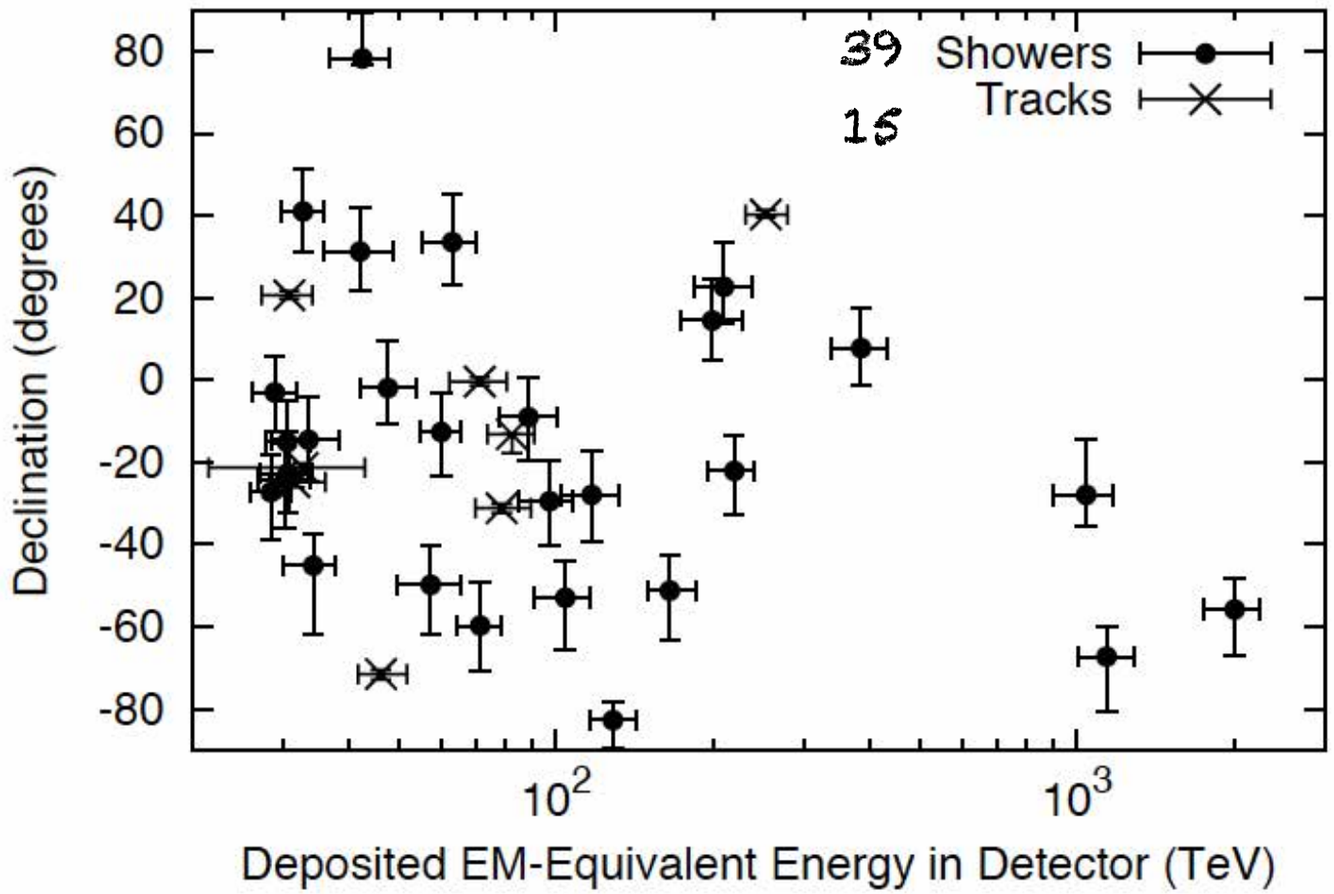
PRL 113, 101101 (2014)

http://icecube.wisc.edu/pubs


1.1 PeV
International Centre for
Theoretical Sciences
Icts, Canteen
Google

High Energy Starting Event Search



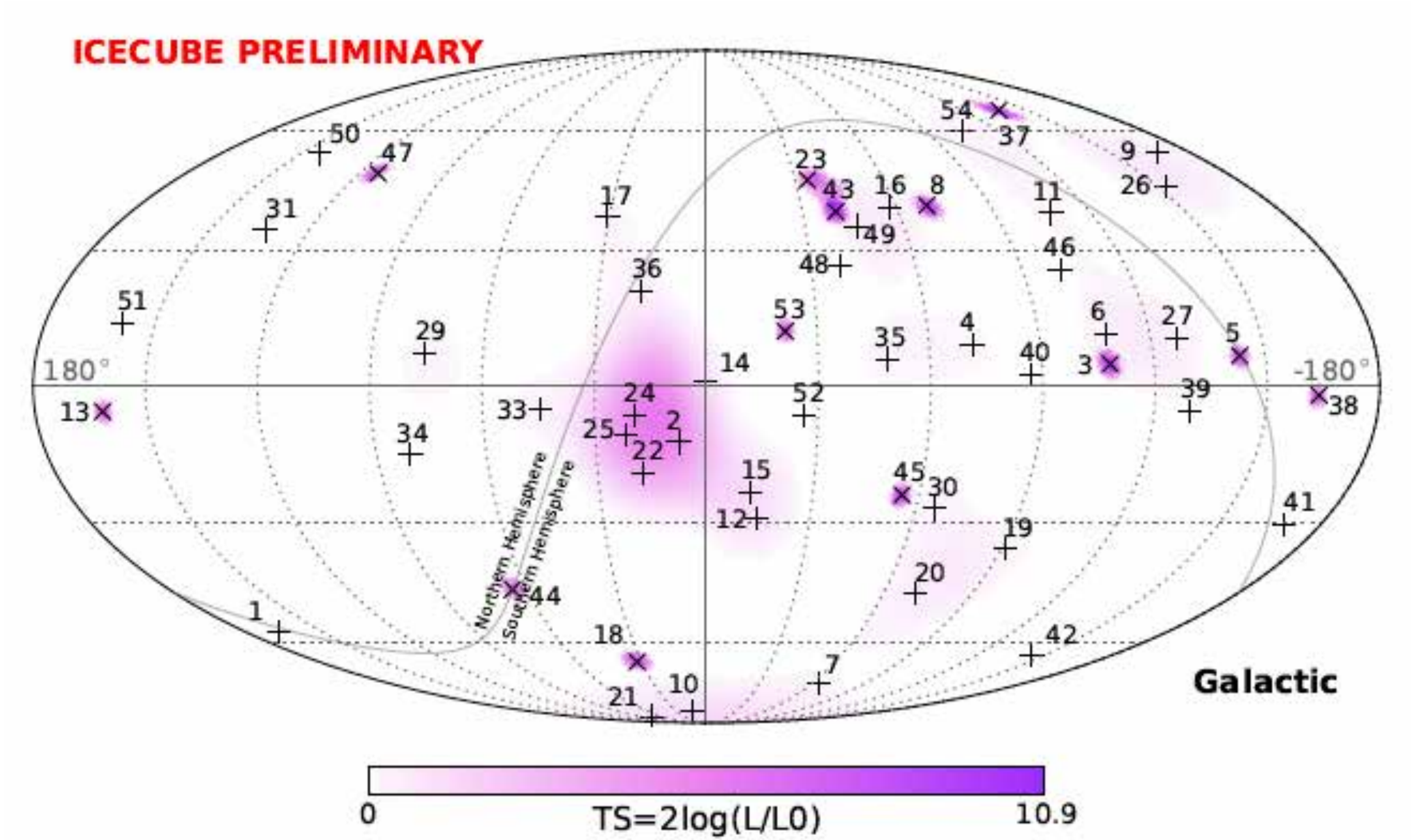


- Veto layer excludes atmospheric muons and some atmospheric neutrinos
- Sensitive to all flavors, all directions

- 54 events in 1347 days (2010 to 2014)
- Expected Background : 21
- Significance : **7σ**

PoS (ICRC2015) 1081

Skymap - High Energy Starting Event



No Significant Clustering Found Including Around Galactic Plane

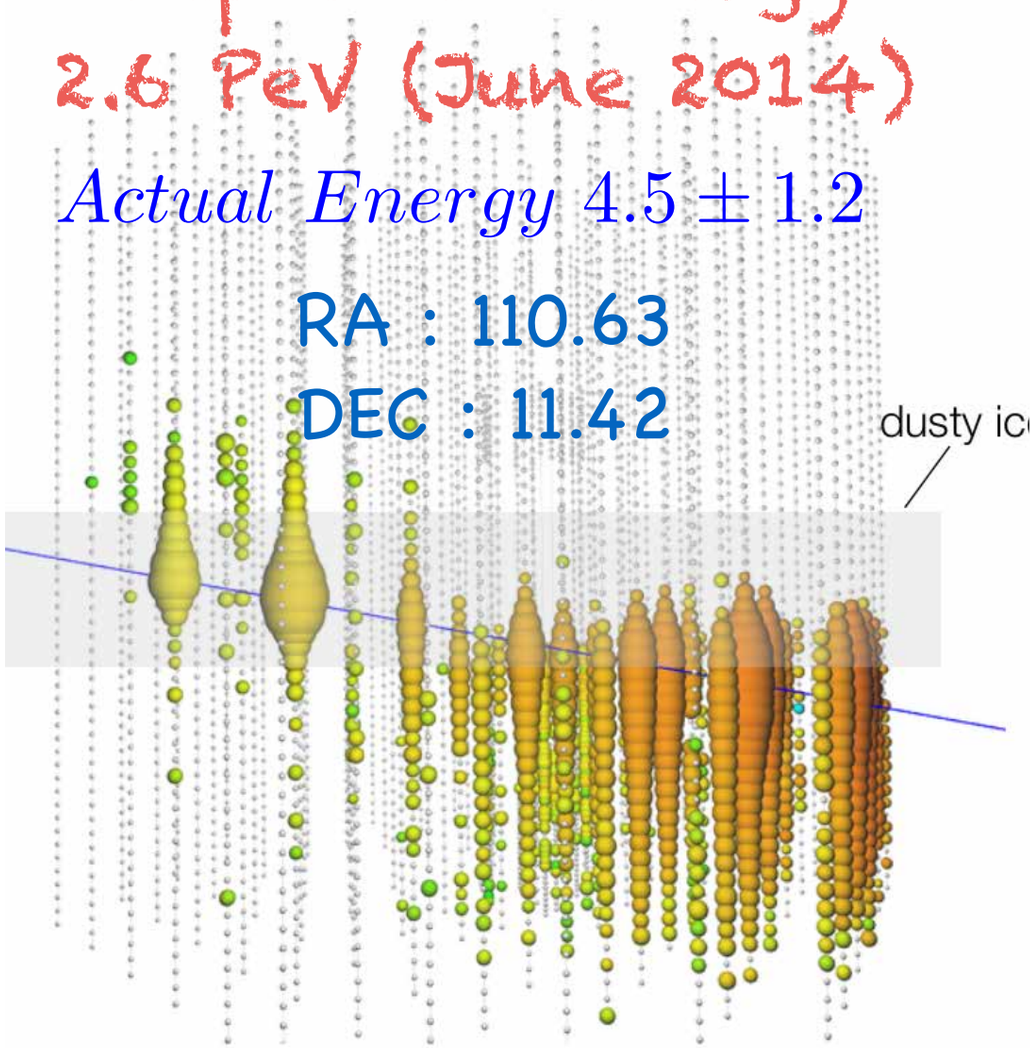
Through Going Muons

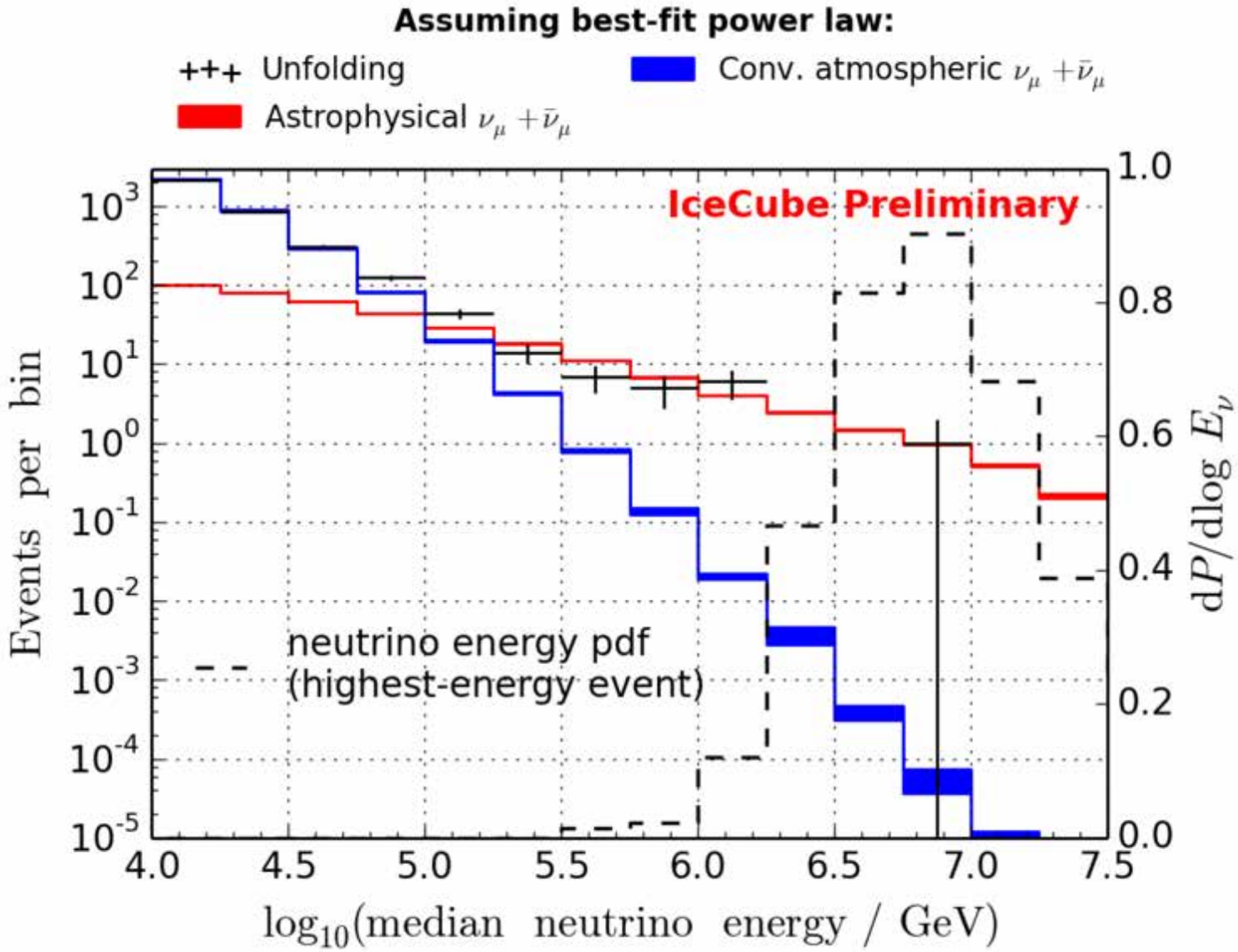
Deposited energy
2.6 PeV (June 2014)

Actual Energy 4.5 ± 1.2

RA : 110.63

DEC : 11.42





Atmospheric origin rejected at 5.6σ
Dominant above 200 TeV
Spectral Index $E^{-2.13}$

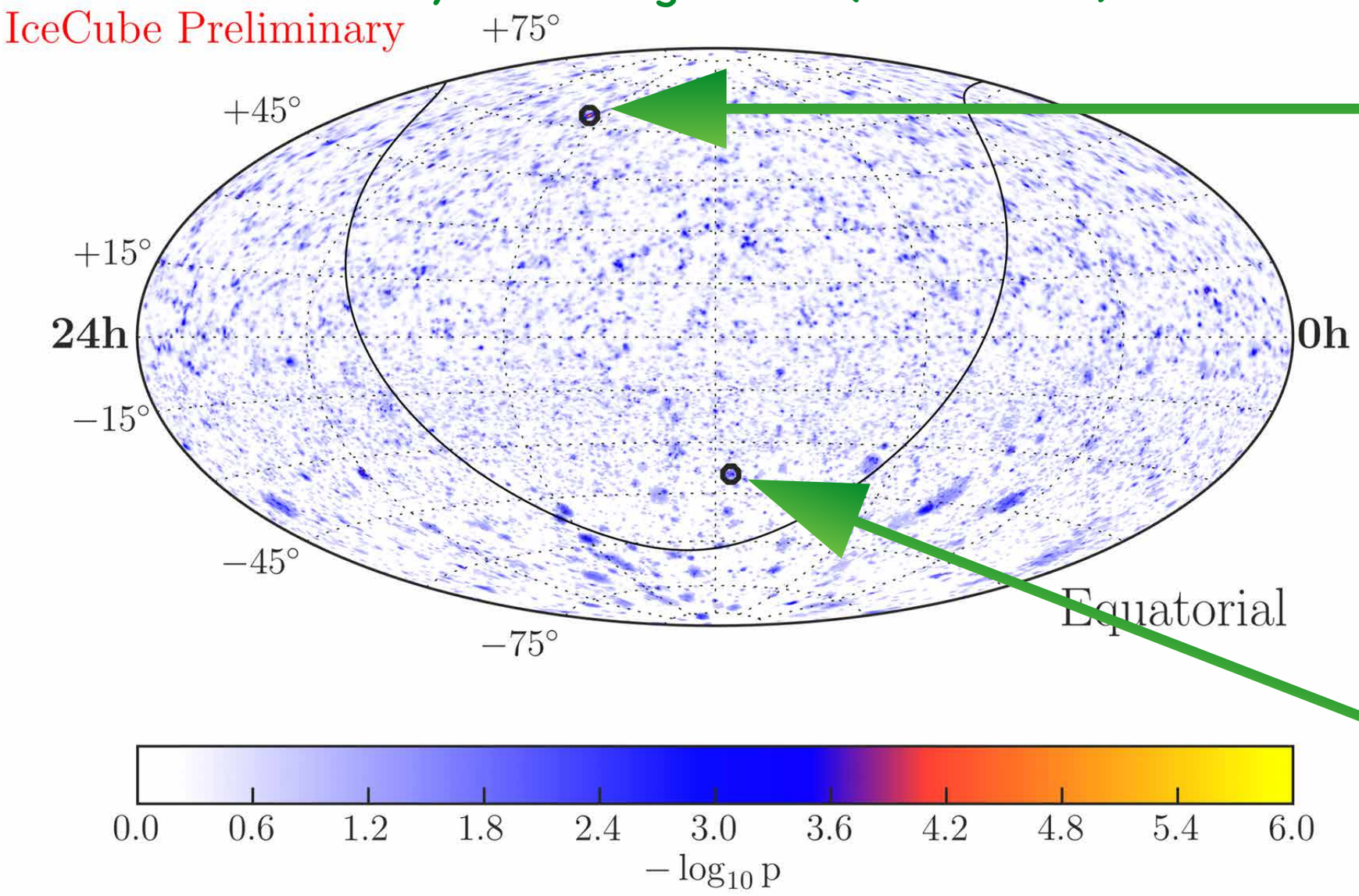
Up going or Horizontal track = Earth-filtered (99.7% pure muon neutrino sample)

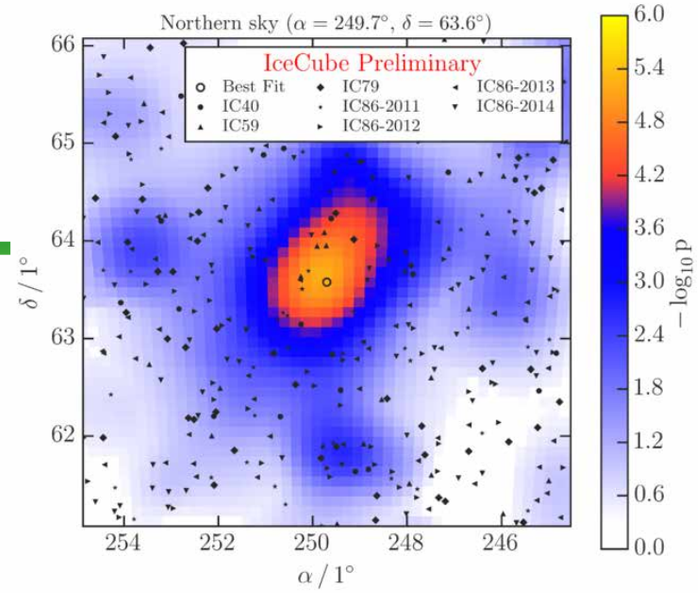
Point Source Search All Sky

Full Sky scan of local significance : Likelihood method

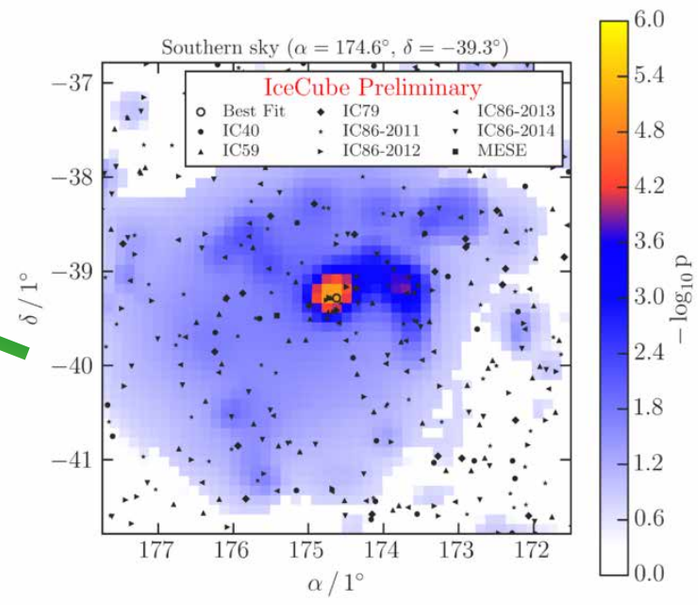
7 yrs through-going tracks (2008-2015)

5 yrs starting tracks (2010-2015)





p-value : 44%

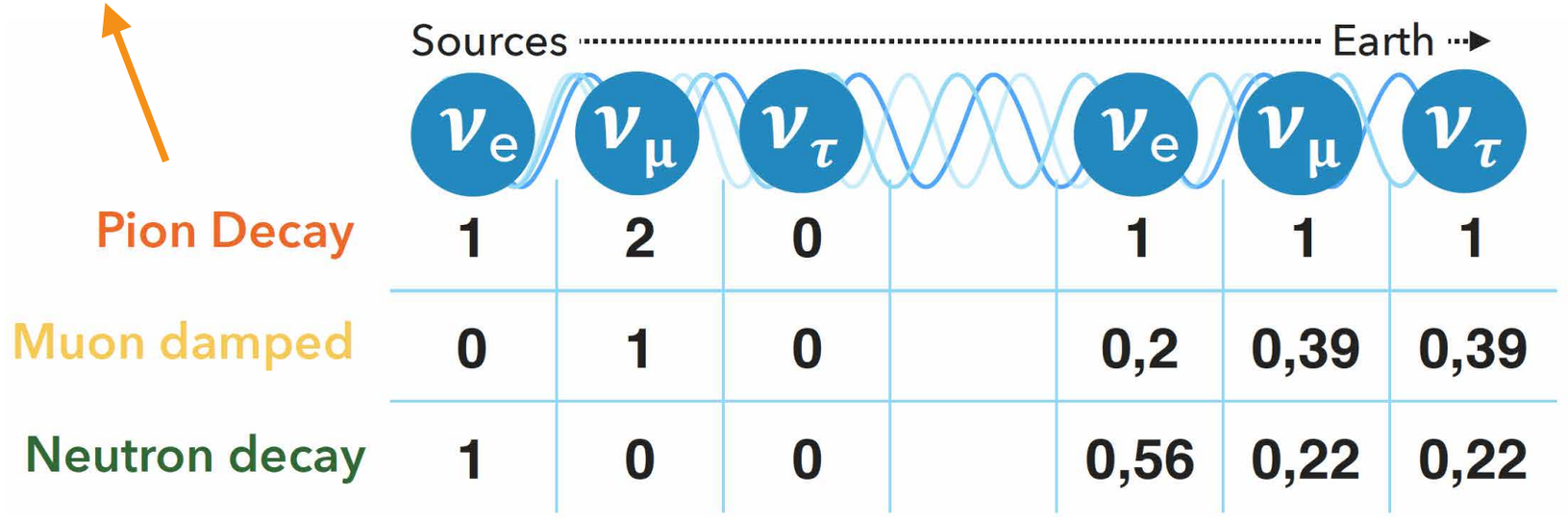


p-value : 39%

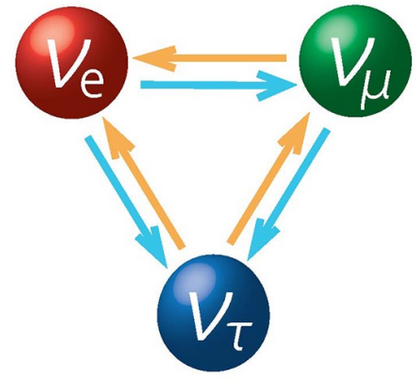
No significant point source found

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\downarrow$$
$$e^+ + \nu_e + \bar{\nu}_\mu$$

Flavour Ratio



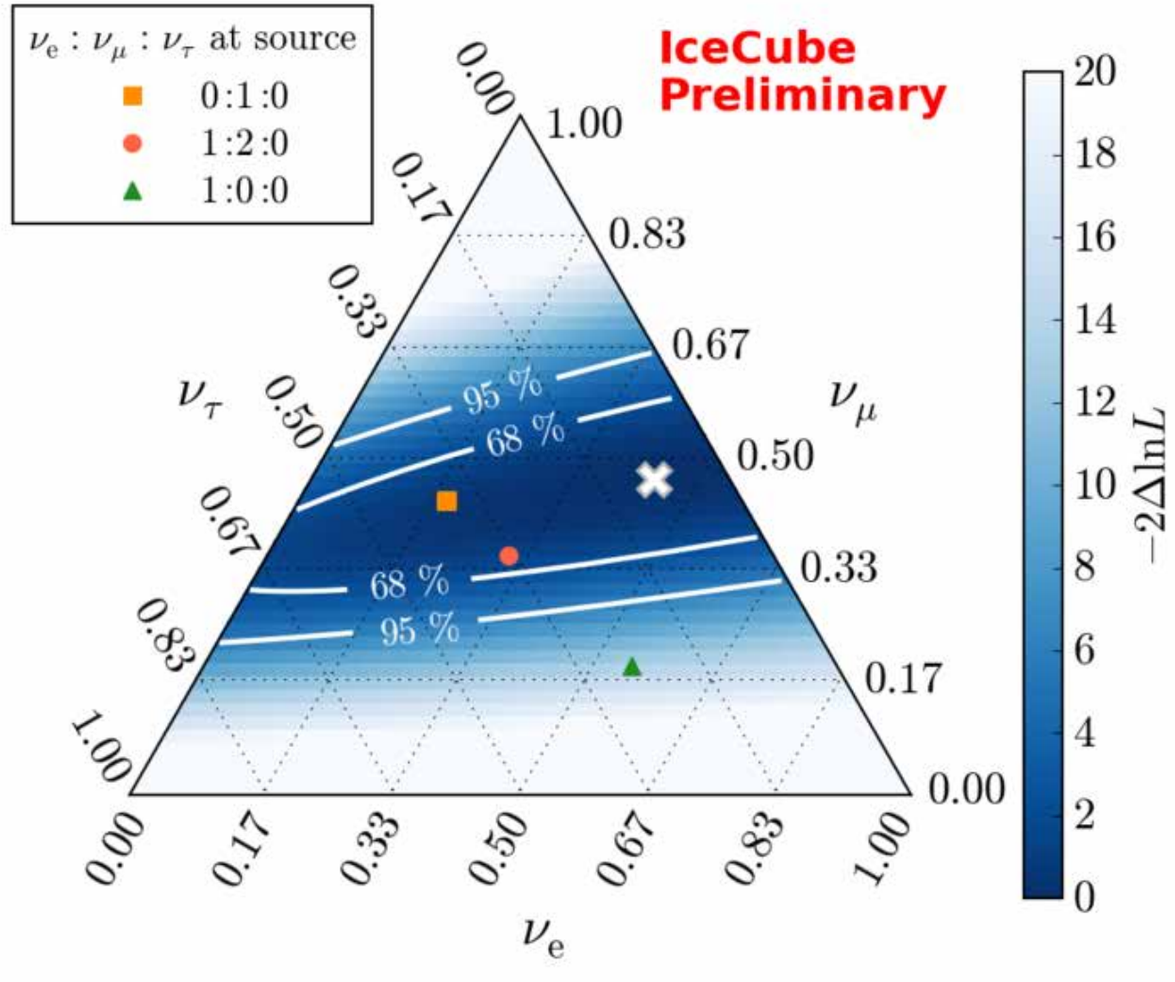
Pion Decay	1	2	0	1	1	1
Muon damped	0	1	0	0,2	0,39	0,39
Neutron decay	1	0	0	0,56	0,22	0,22



pion decay & muon damped allowed

neutron decay excluded (3.7σ)

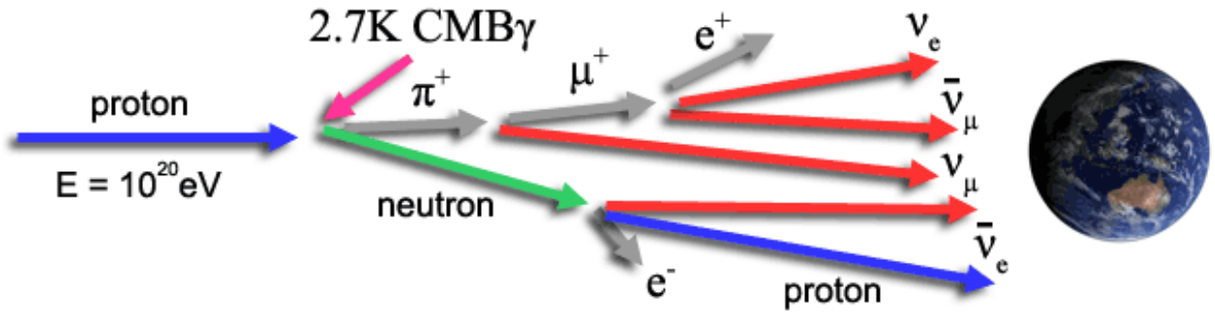
From flavour ratio study we get an idea about the surroundings of the cosmic sources

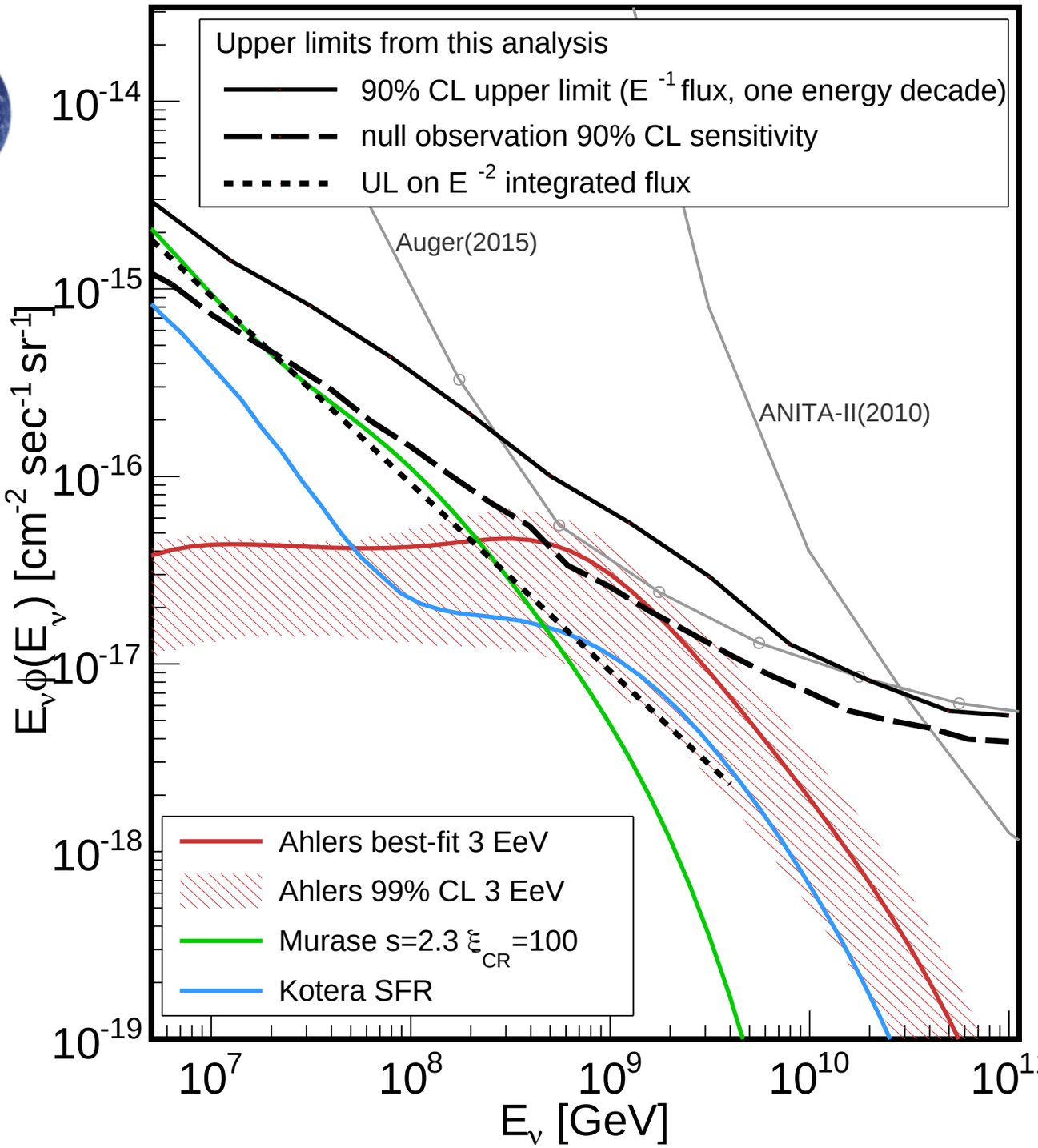


ApJ 809, 98 (2015)

PoS(ICRC2015) 1066

GZK - Neutrinos

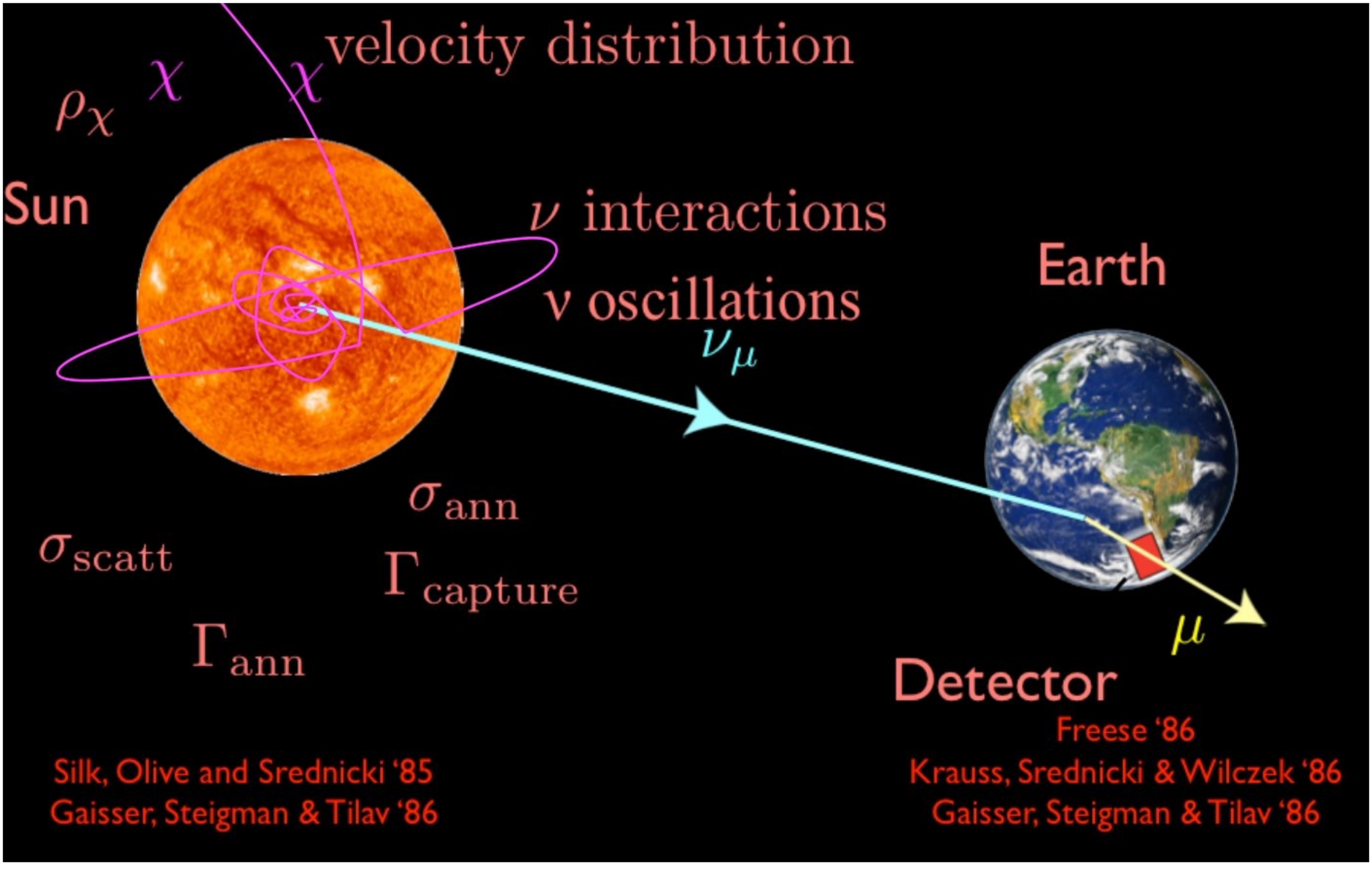




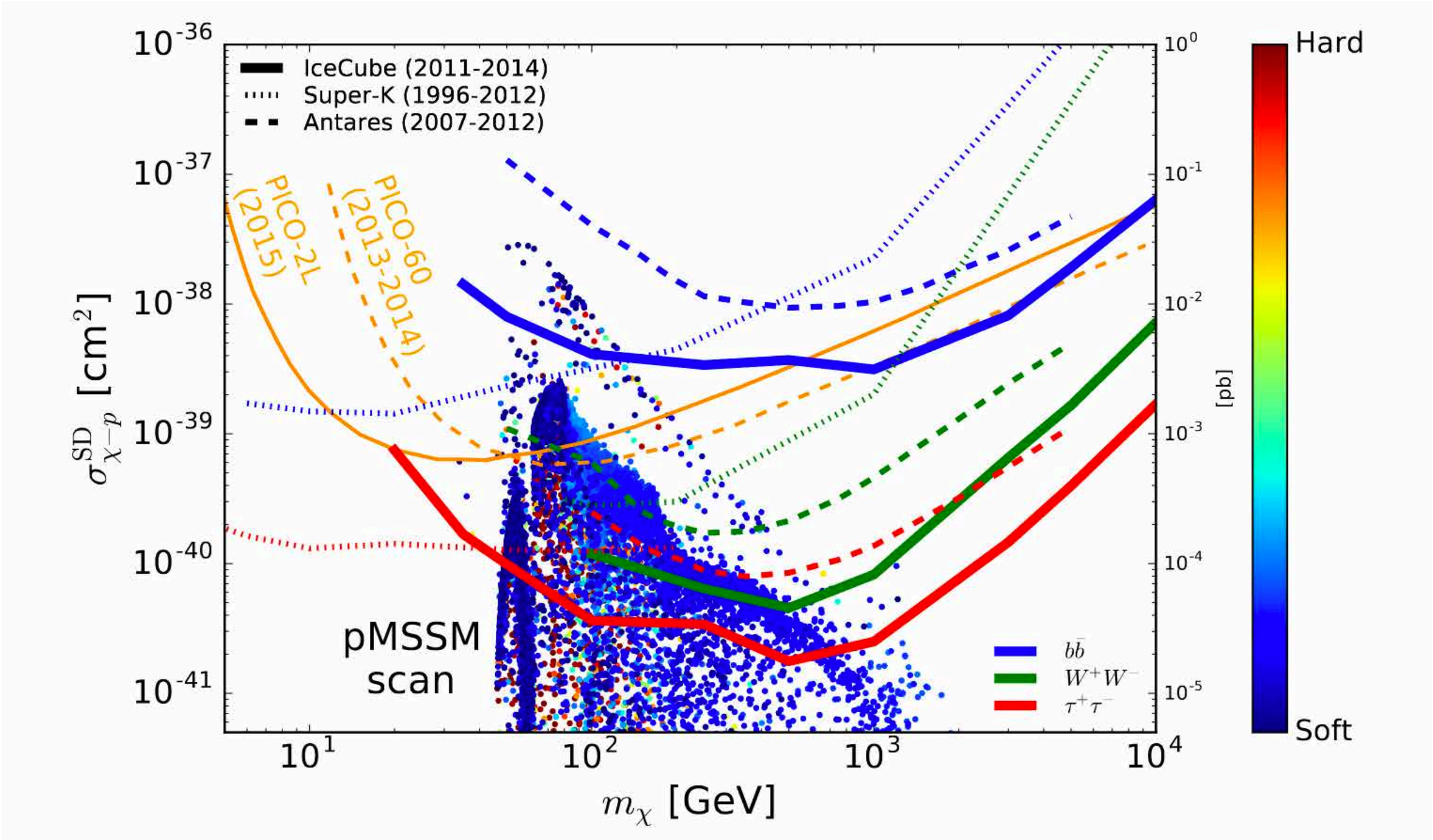
- 7 years of IceCube data PeV to EeV range
- No cosmogenic candidate neutrinos found
- Placed tight limits on GZK models

PRL 117, 241101 (2016)

Indirect Dark Matter Search

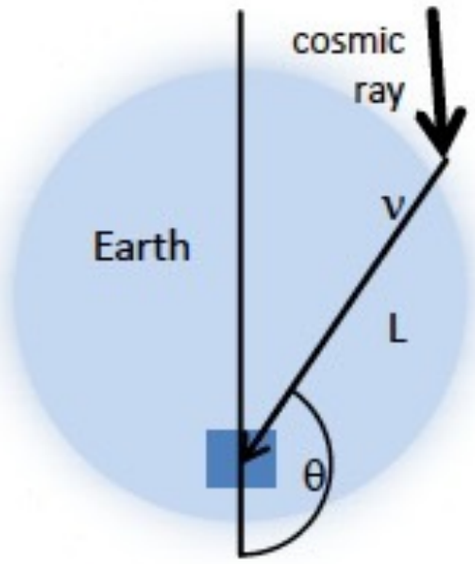


Indirect Dark Matter Search

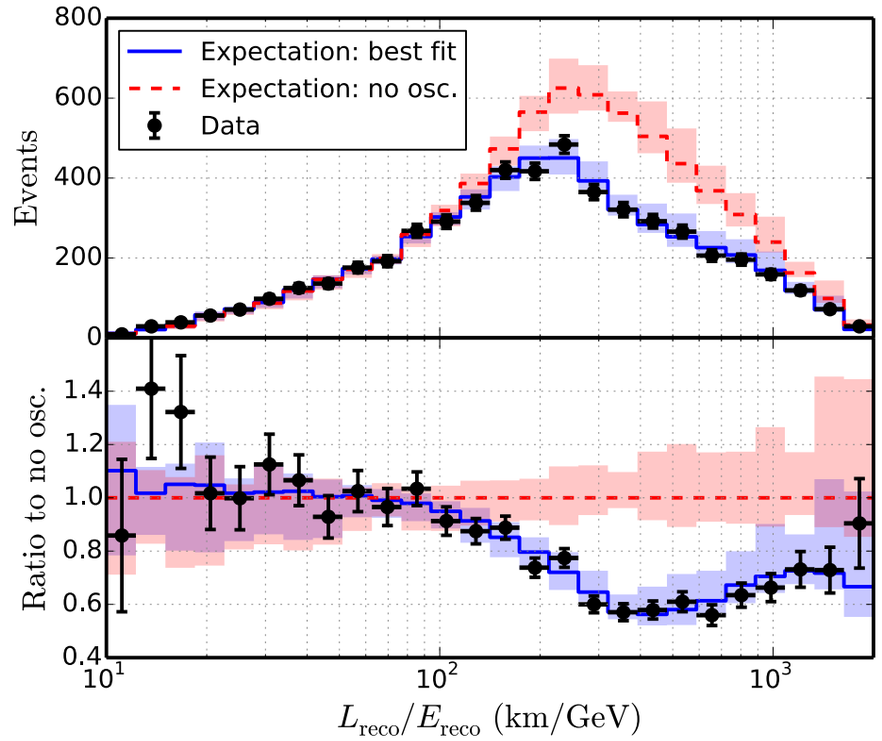


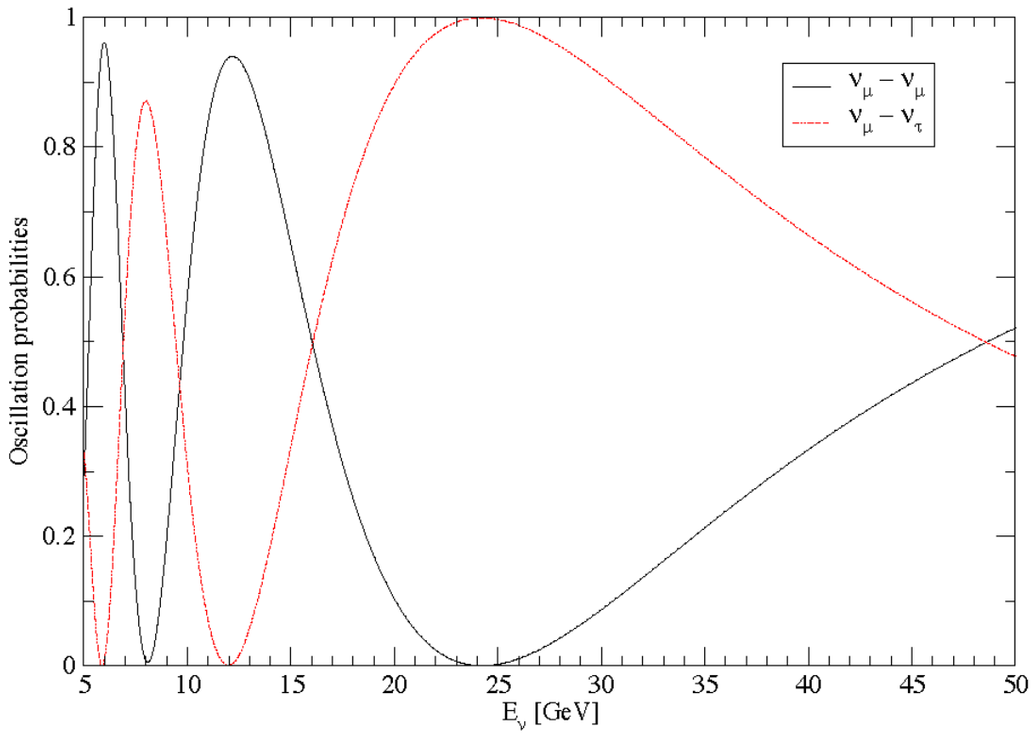
arxiv.org/1612.05949

Neutrino Oscillations

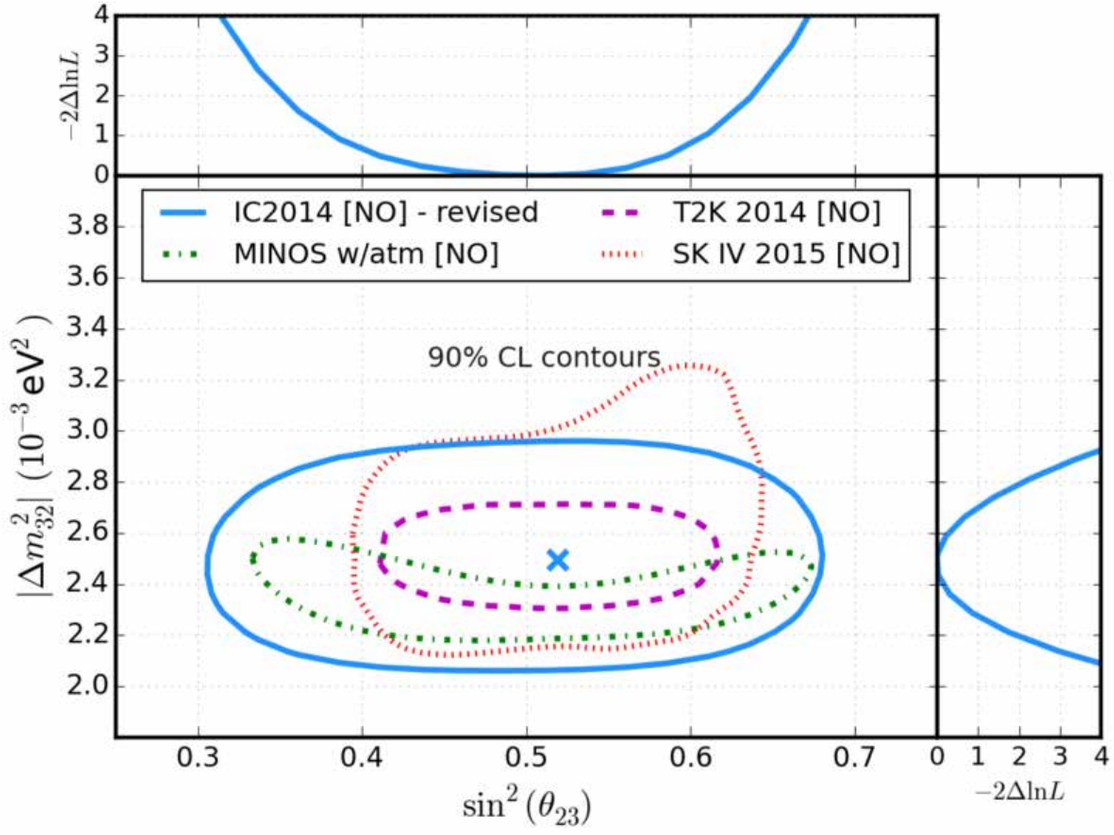


$$P_{\nu_\mu \to \nu_\mu} \approx 1 - sin^2 2\theta_{23} sin^2[1.27 \Delta m^2_{32} L/E]$$

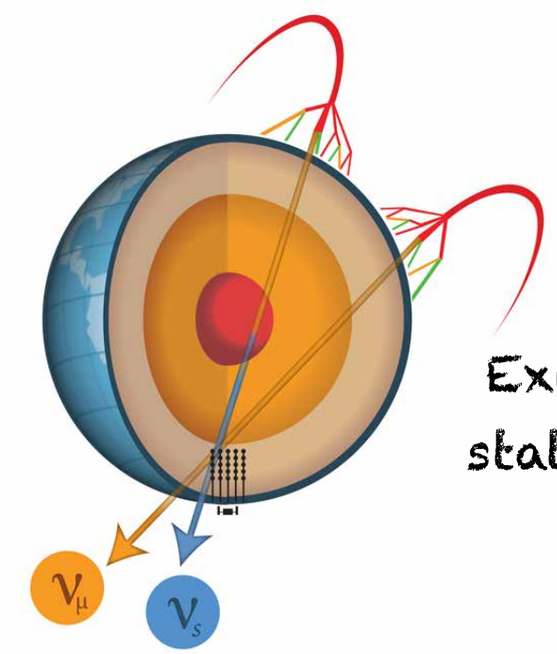




PRD 91, 072004 (2015)



Sterile Neutrino Search

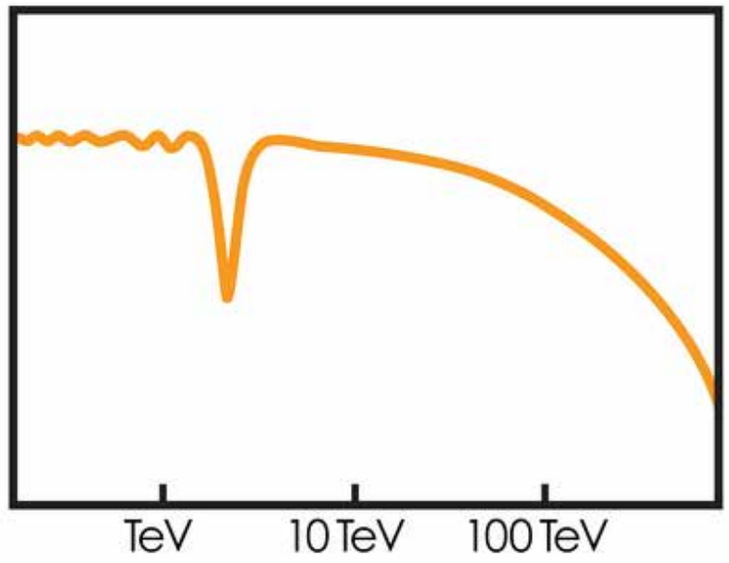


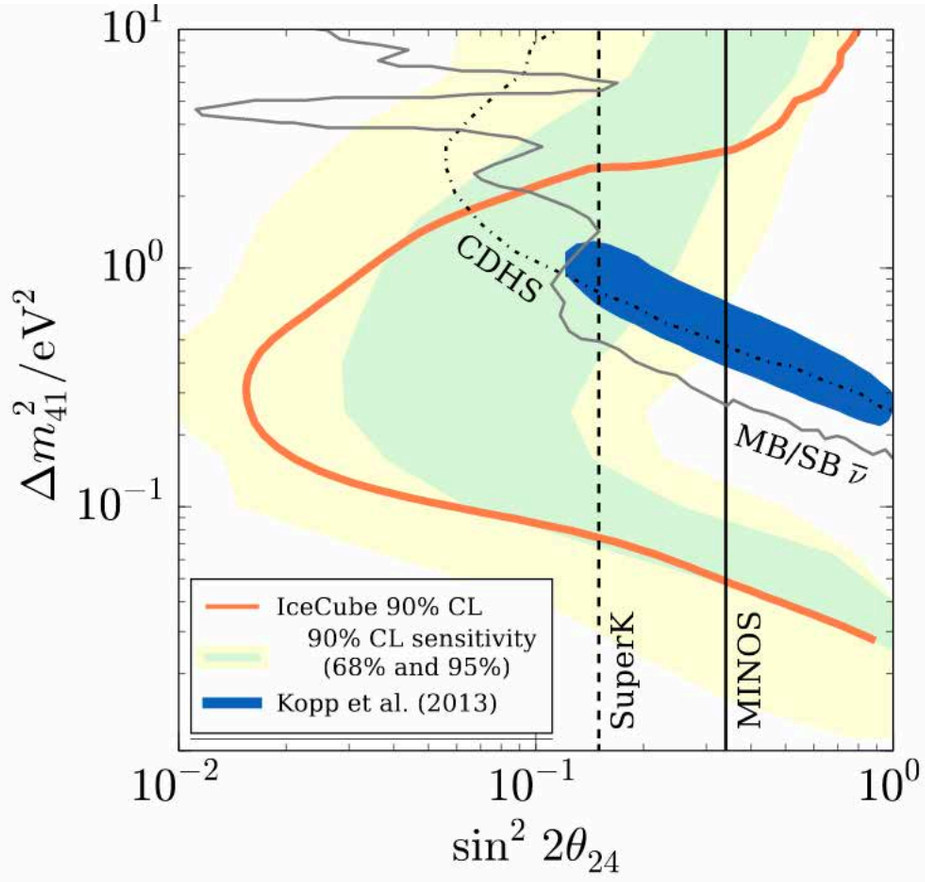
Existence of sterile neutrino state produces resonance like disappearance

Preferred range around $1eV^2$ leads to resonance in TeV scale

Strong constraints on θ_{24} for Δm^2 around 0.1–2eV^2

PRL 117, 071801 (2016)

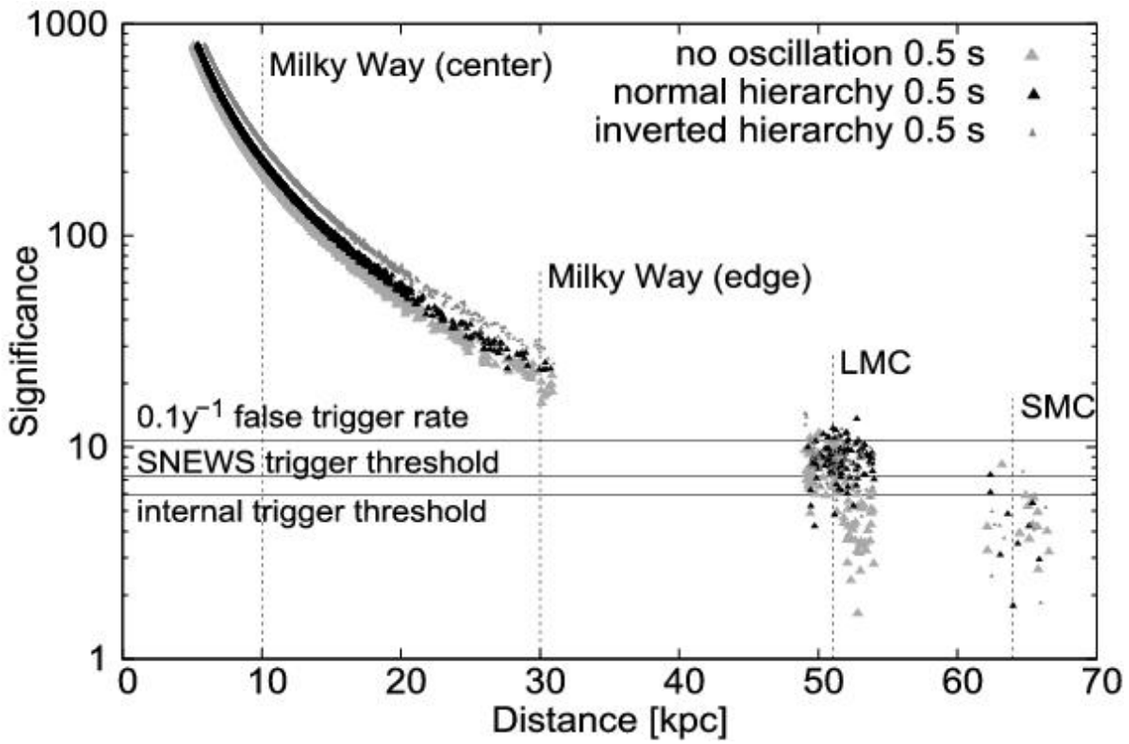




Supernova Search with IceCube

A Giant neutrino factory :

A supernova radiates 10 times more neutrinos than there are particles, protons, neutrons and electrons in the sun.



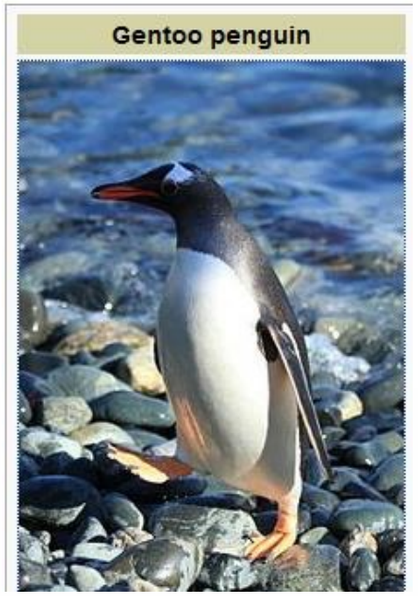
Core Collapse Supernova

- SN1987A, only neutrino source detected outside solar system
- Detailed features of gravitational collapse can only be studied with neutrinos, they carry almost 99% energy soon after collapse
- IceCube can detect large number of MeV neutrinos by observing rise in all PMT rates over dark noise rates

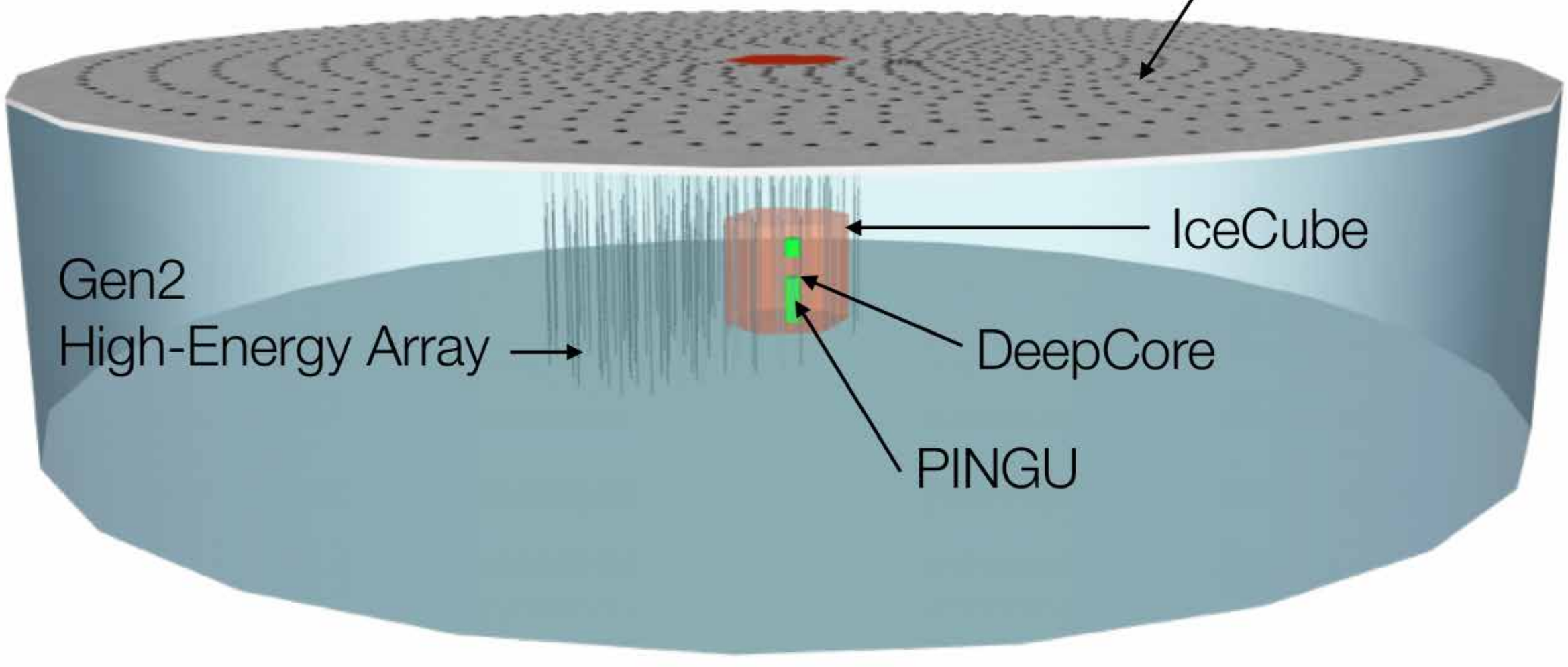
Astronomy & Astrophysics 535, A109 (2011)

Road Ahead ..

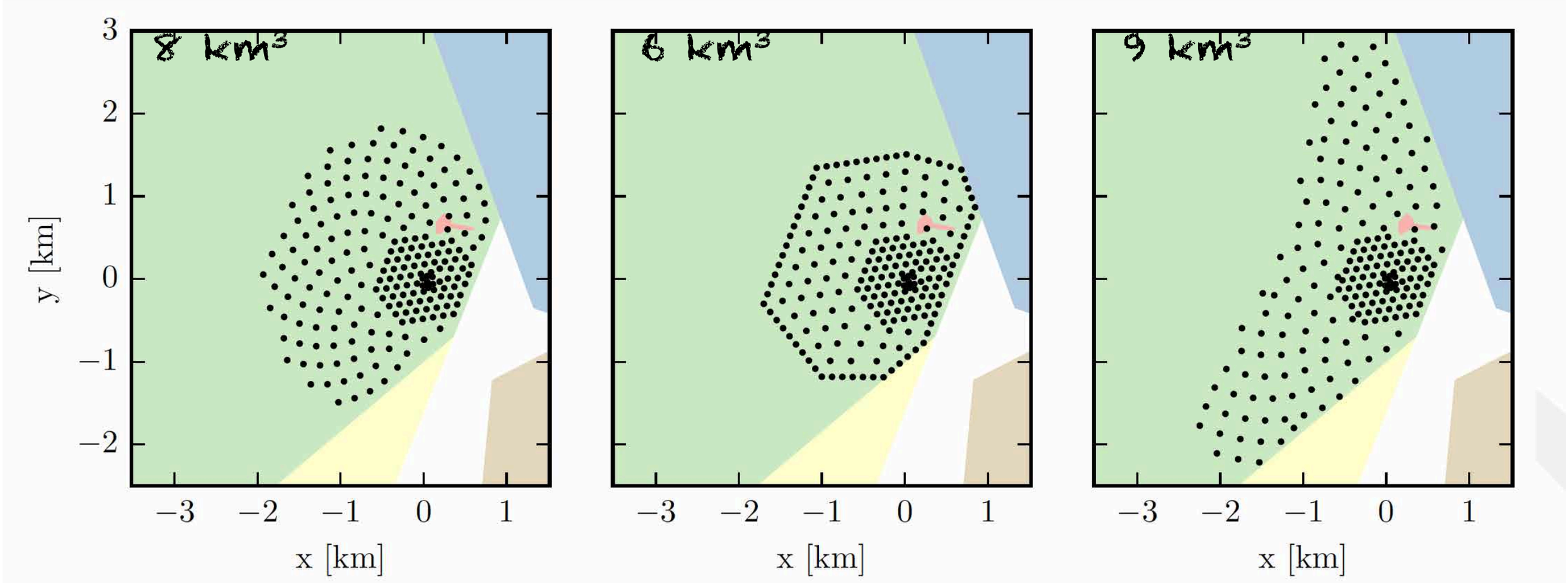
IceCube Gen2



- Gen2 high energy array
- PINGU low energy extension
- Surface air shower/veto array
- Sub-surface radio Cherenkov array



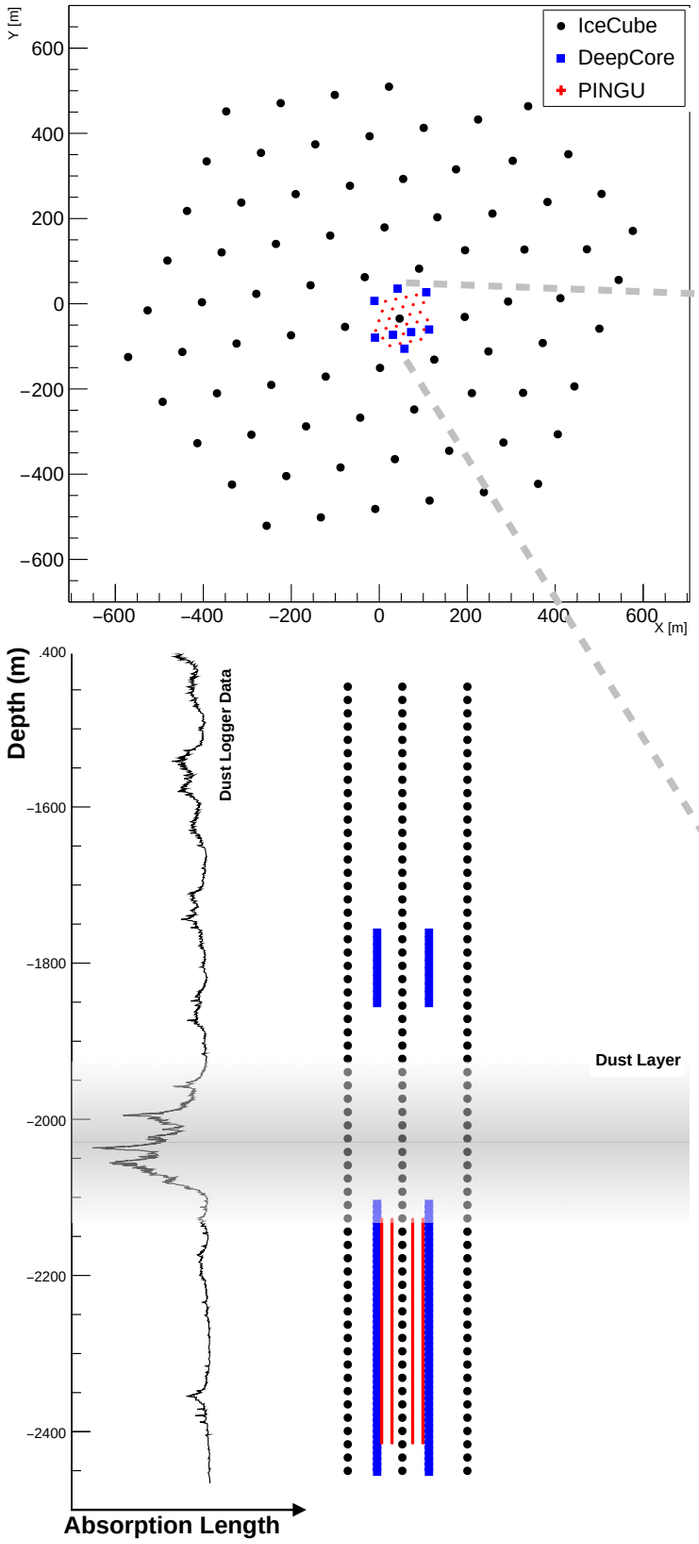
High Energy Extension

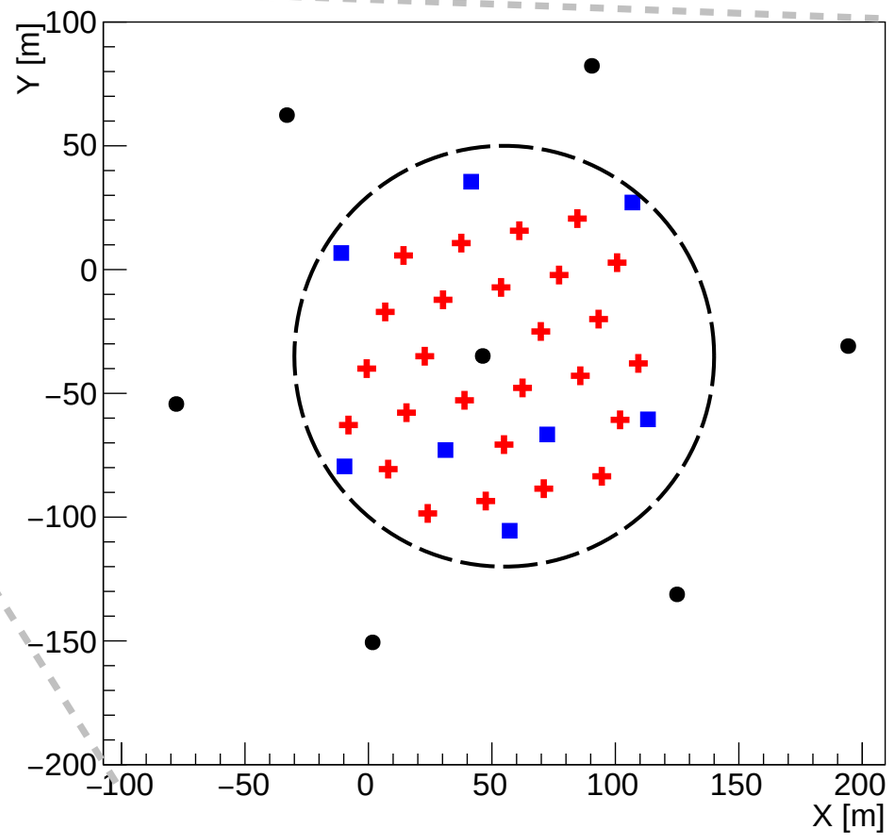


- Resolving the sources of astrophysical neutrinos
- Neutrinos from highest energy cosmic rays
- Are there signature of new physics at >= PeV energies ?
- Number of observed cosmic neutrinos will be ten times

arXiv : 1412.5106

PINGU - Low Energy Extension





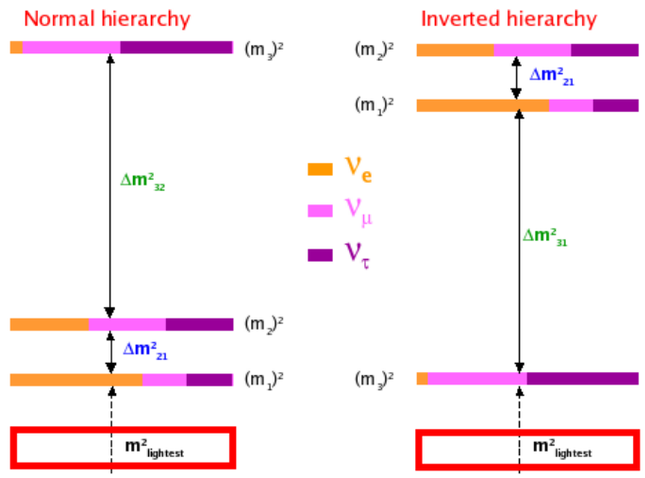
26 Strings
192 DOMs/String
1.5m DOM-DOM Spacings

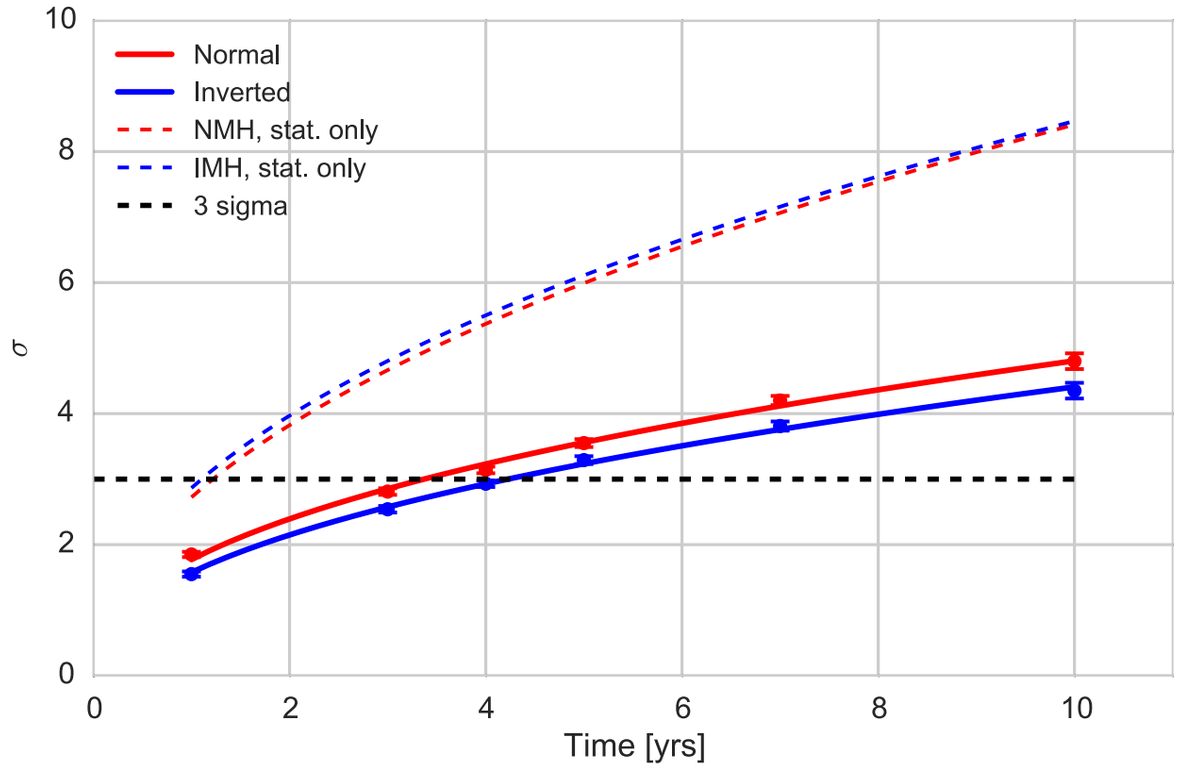
Journal of Physics, G44, 054006, 2017

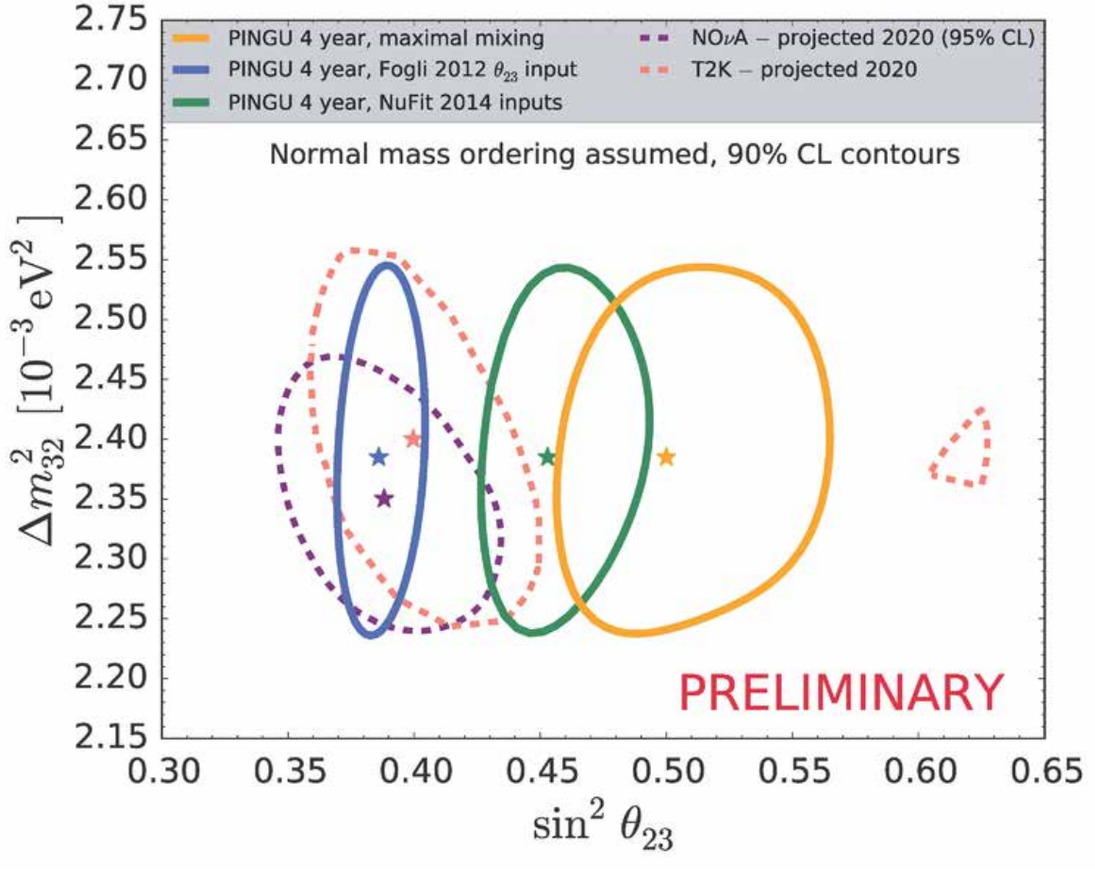
PINGU - Low Energy Extension

Neutrino Physics with atmospheric neutrinos

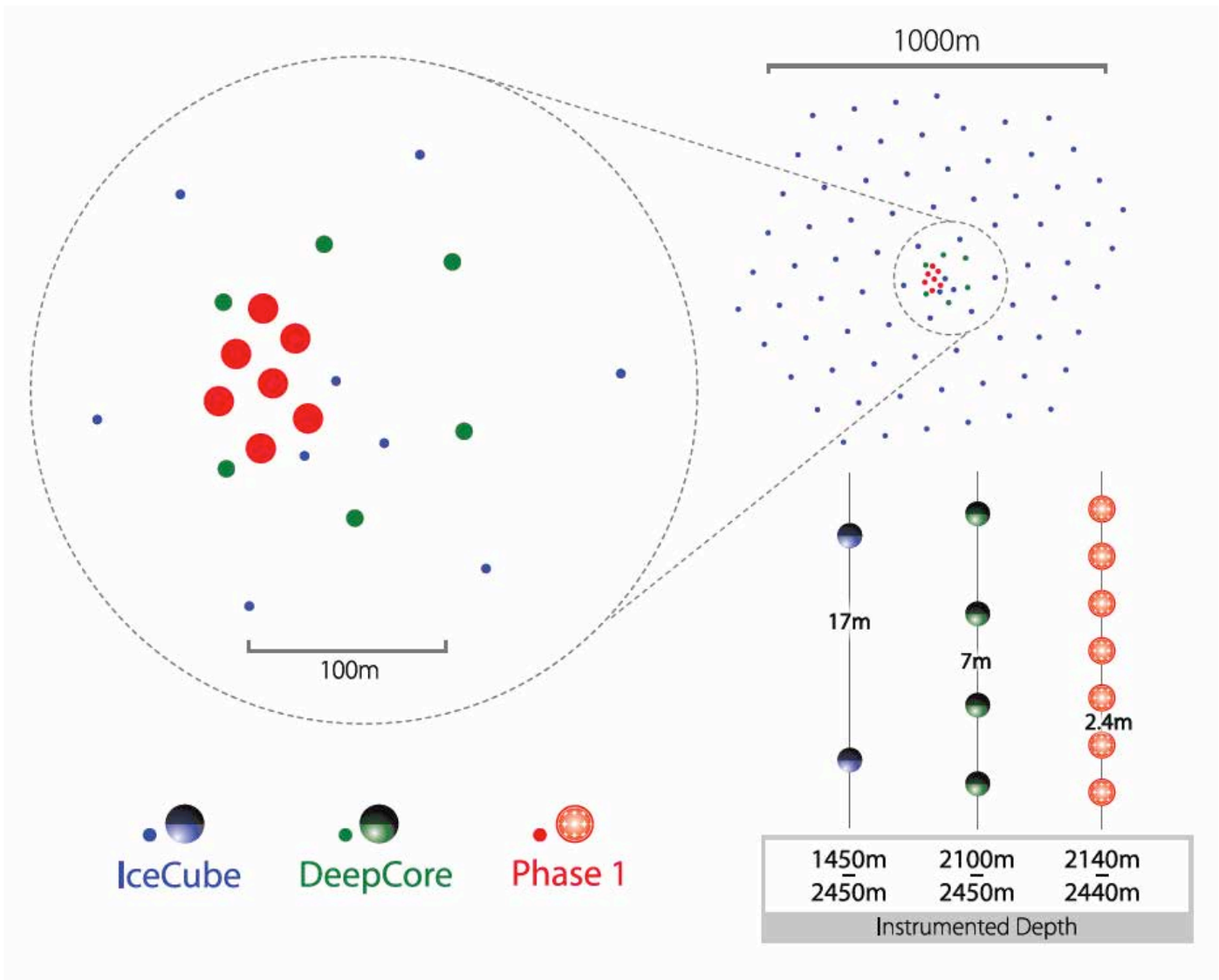
- Neutrino mass ordering
- Tau neutrino appearance
- SN neutrinos
- Dark matter Searches
- Geophysics







IceCube Gen 2 Phase 1



mDOM - 24 3inch PMTs
Better directionality
Double photocathode area

125 sensors per string
22m horizontal / 2.4m vertical DOM spacing

Summary

- IceCube has begun a new era in astro-particle physics
- Increasing evidence for high energy neutrinos beyond the atmospheric spectrum, though origins not known
- Other exciting physics being done by IceCube : cosmic ray, supernova, dark matter, neutrino oscillations ..
- Good prospects for future upgrades
- Exciting time for multi-messenger astronomy

IceCube Gen2 Timeline