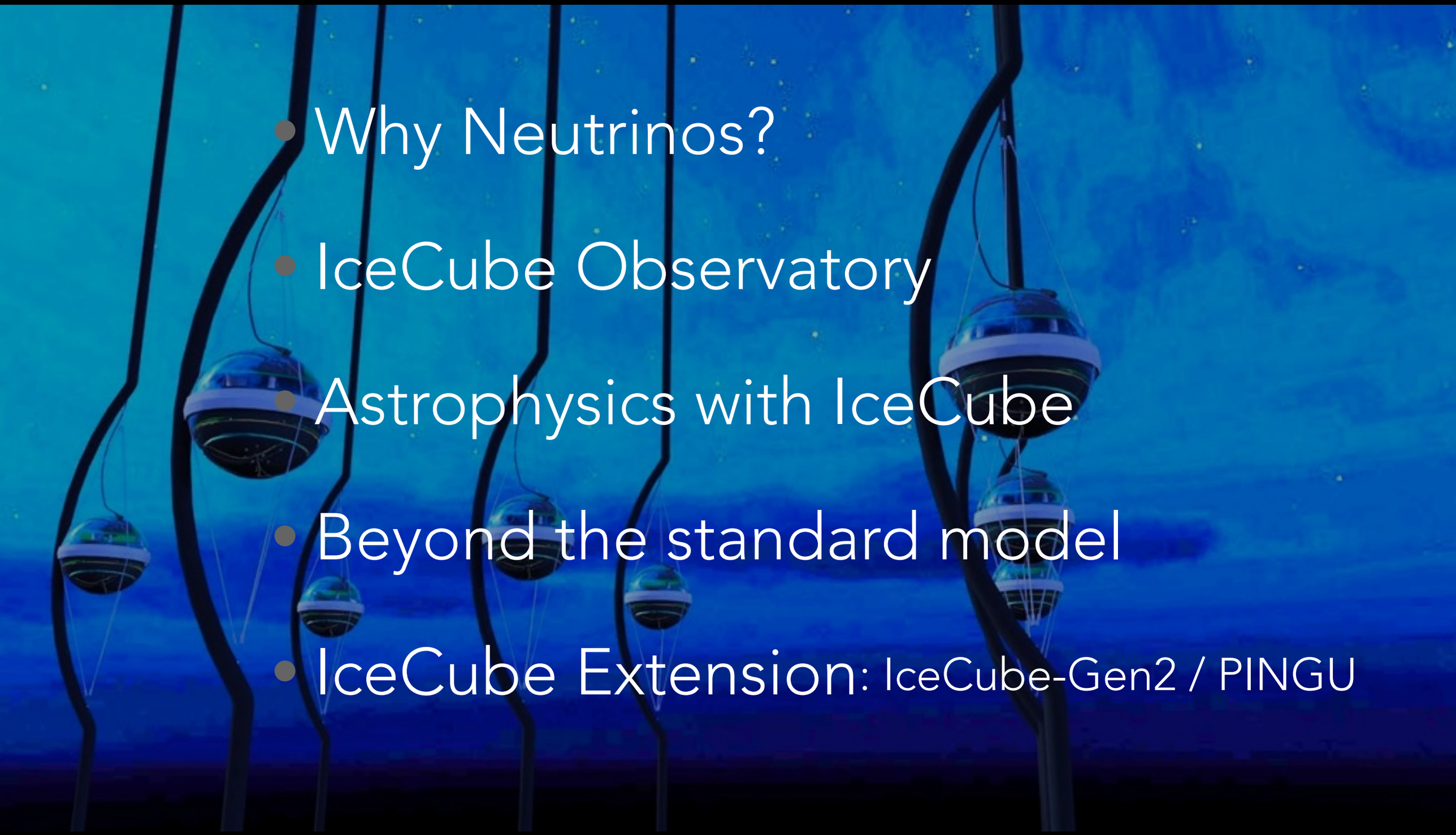
XLVI International Symposium on Multiparticle Dynamics

ASTROPARTICLE PHYSICS @ ICECUBE OBSERVATORY

ON BEHALF OF ICECUBE COLLABORATION
SEONGJIN IN, SKKU

09.02.2016

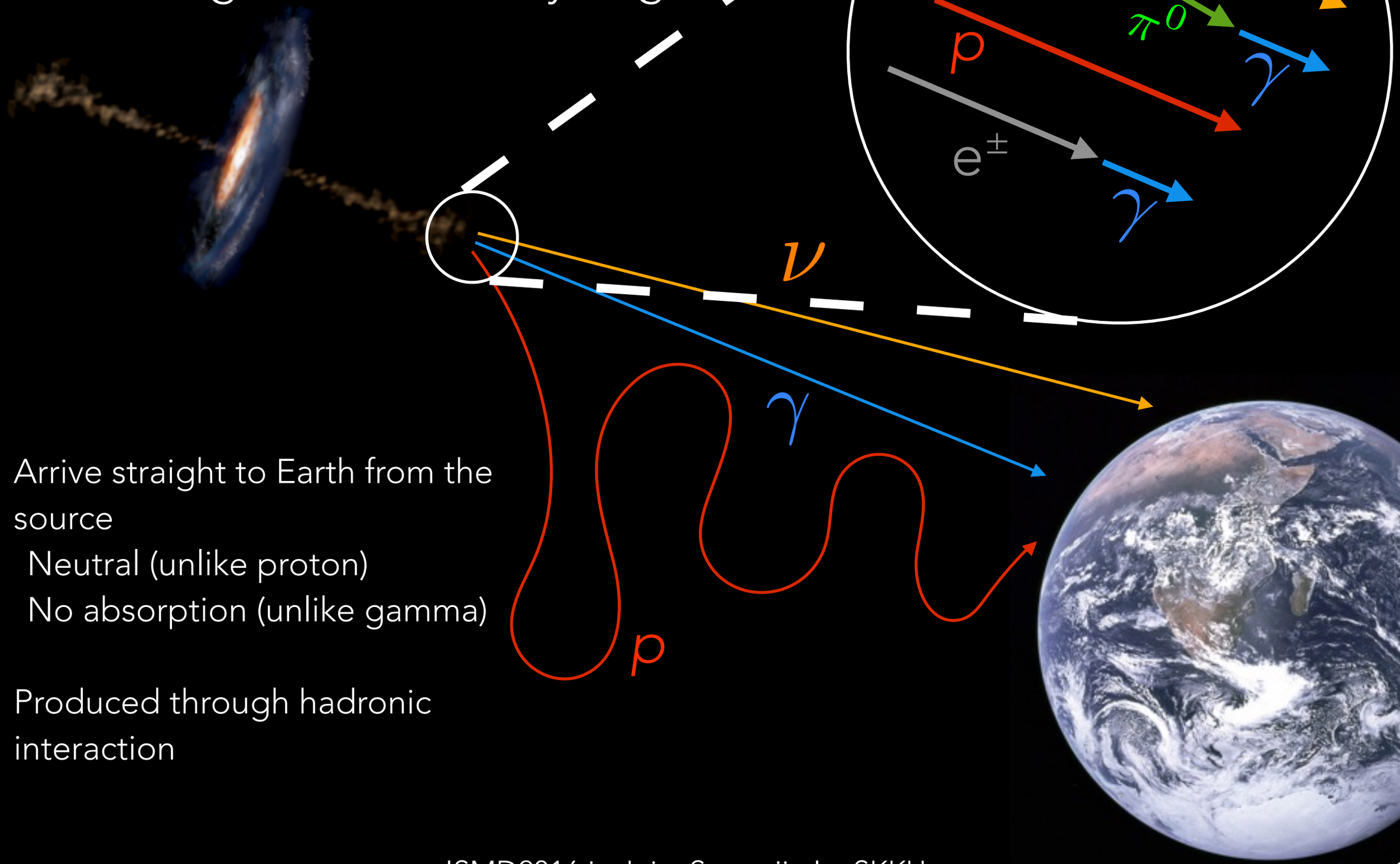
OVERVIEW



- Why Neutrinos?
- IceCube Observatory
- Astrophysics with IceCube
- Beyond the standard model
- IceCube Extension: IceCube-Gen2 / PINGU

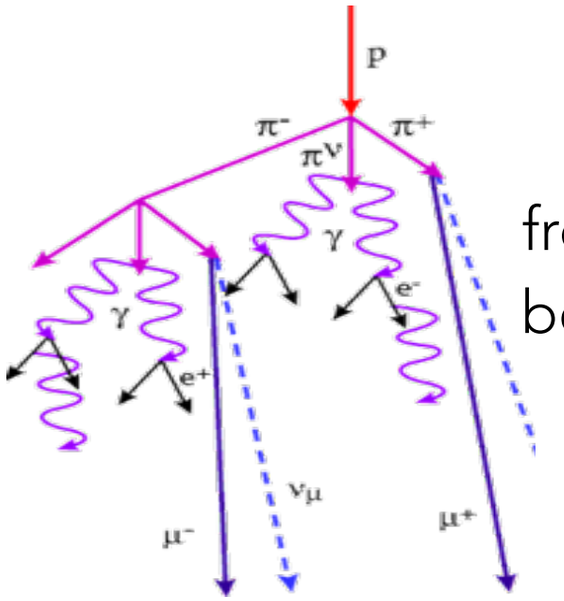
WHY NEUTRINO?

Messenger of cosmic ray origin



- Arrive straight to Earth from the source
  - Neutral (unlike proton)
  - No absorption (unlike gamma)
- Produced through hadronic interaction

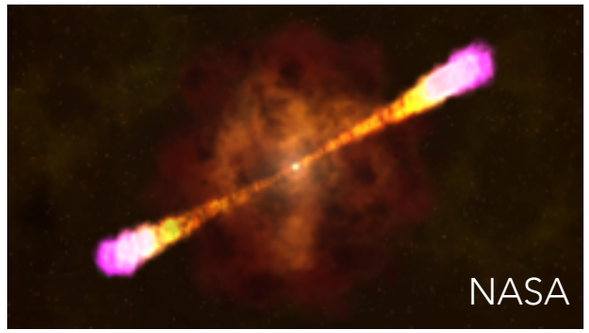
Atmospheric neutrino



from the interaction between cosmic ray and the upper atmosphere

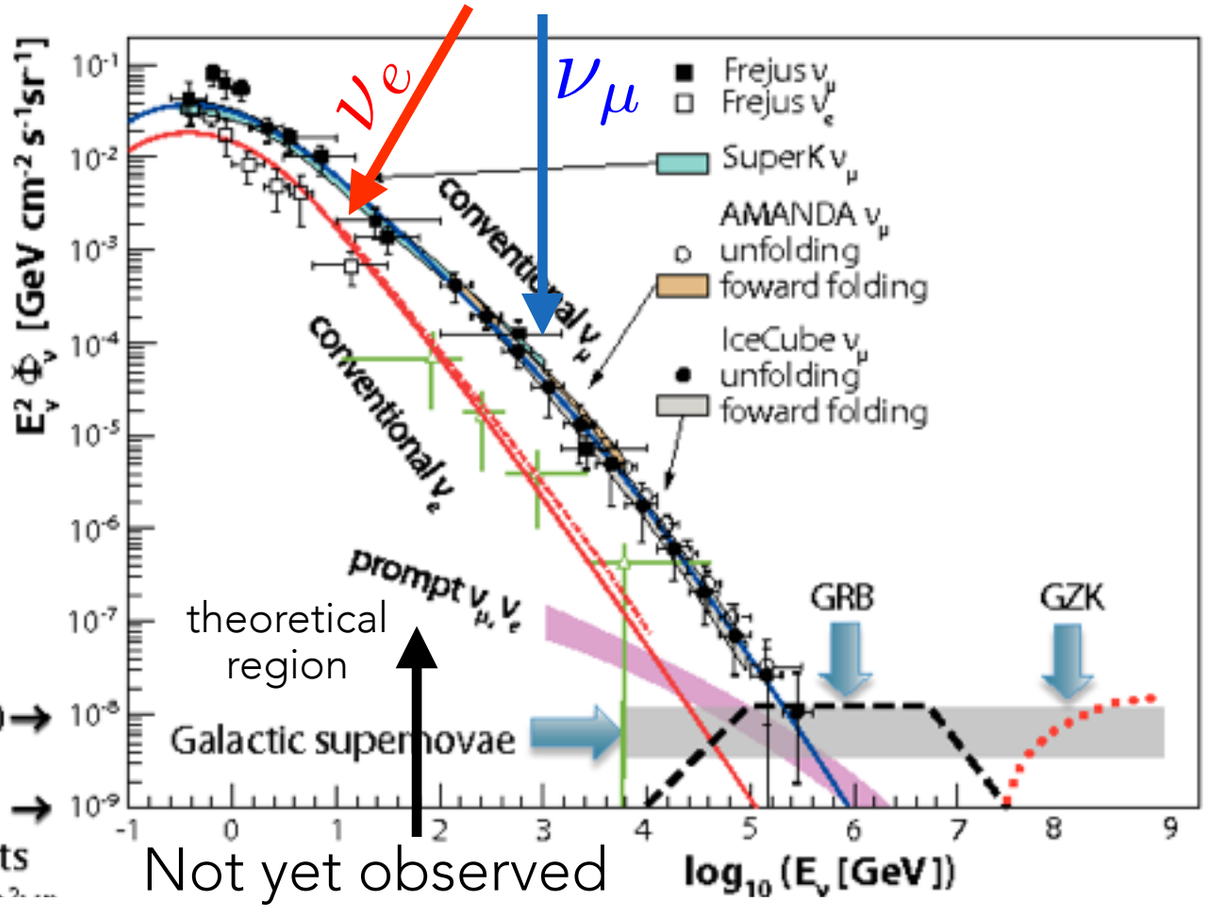
Astrophysical neutrino

Gamma-ray Burst



Active Galactic Nuclei

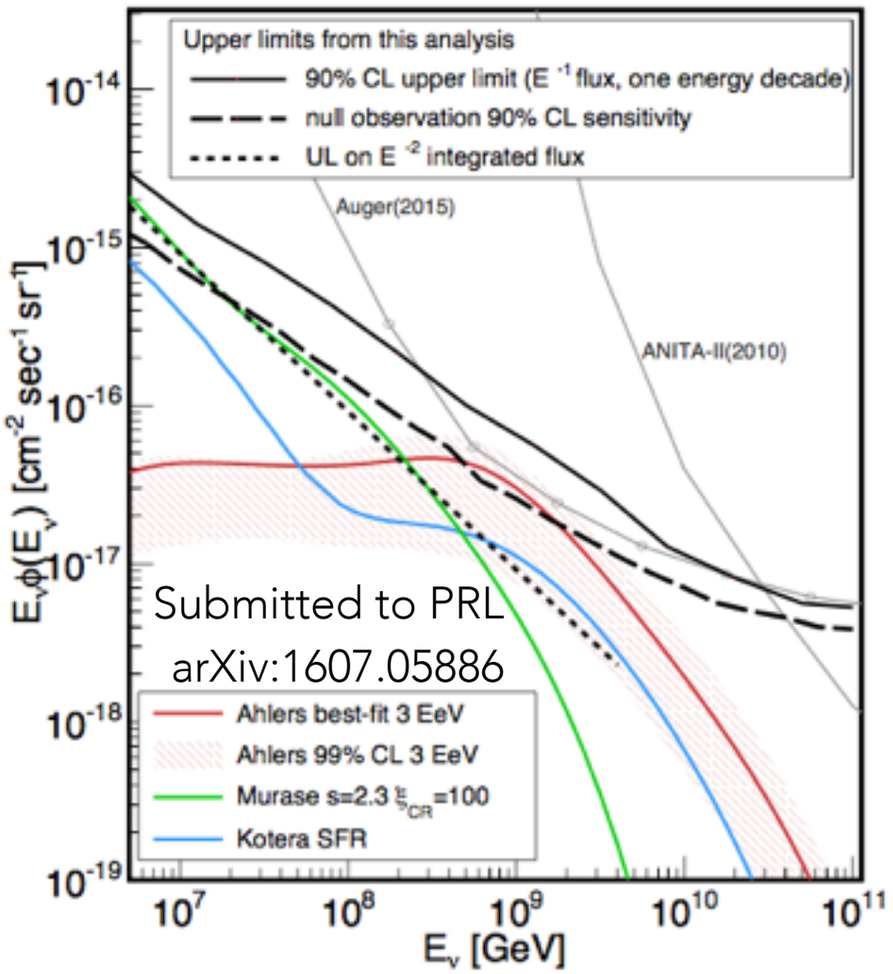
IceCube



Not yet observed

F. Halzen, Astron.Nachr. 335 (2014) 507

Cosmological neutrino

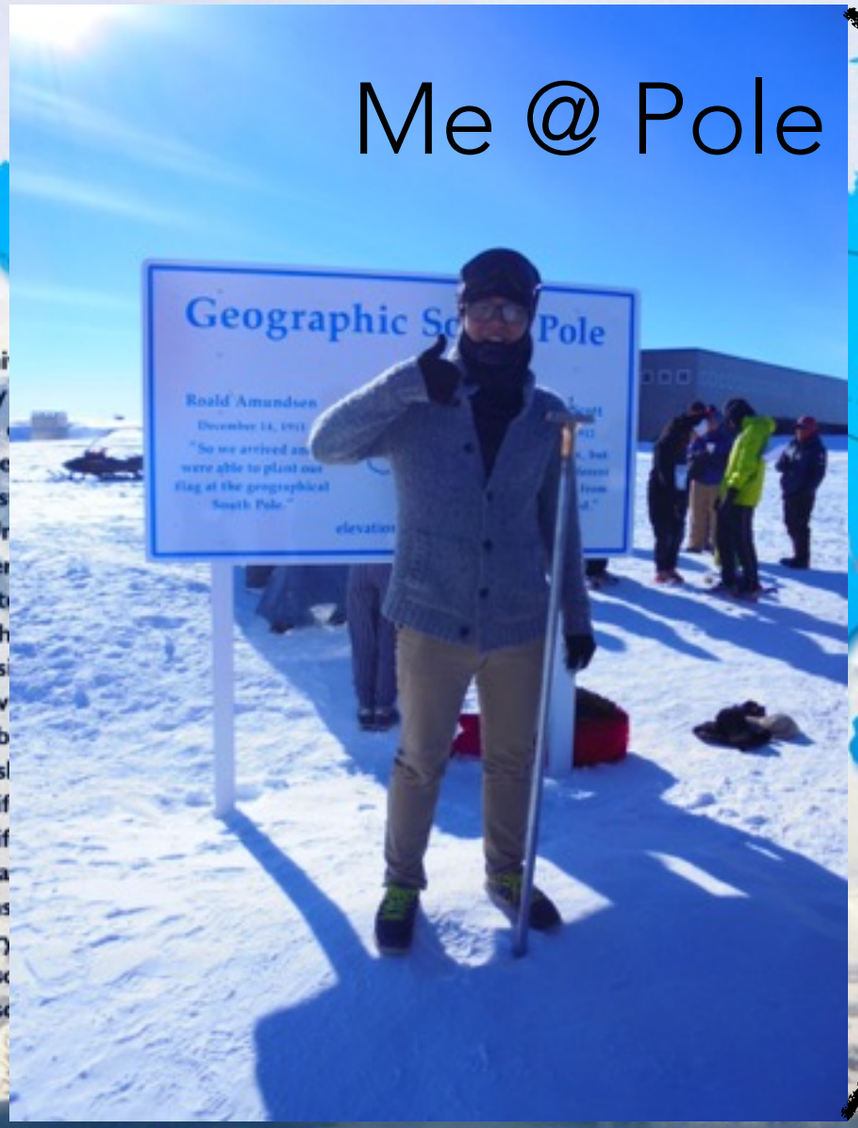


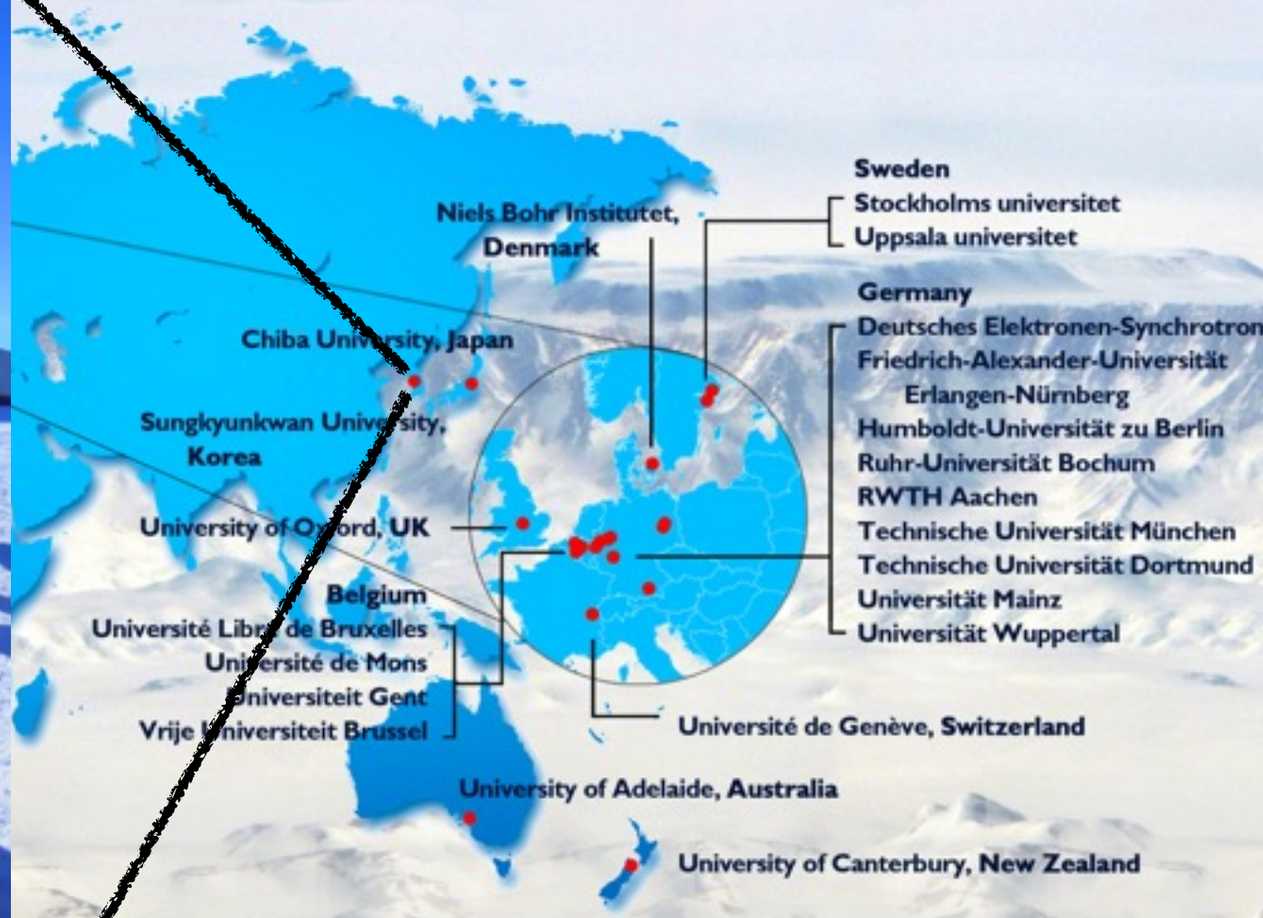
The IceCube Collaboration

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)
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)

The IceCube Collaboration





USA
Clark Atlanta Uni
Drexel University
Georgia Institute
Lawrence Berkele
Massachusetts Ins
Michigan State Un
Ohio State Univer
Pennsylvania Stat
South Dakota Sch
Southern Universi
Stony Brook Univ
University of Alab
University of Alas
University of Calif
University of Calif
University of Dela
University of Kans
University of Mary
University of Wisc
University of Wisc
Yale University

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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

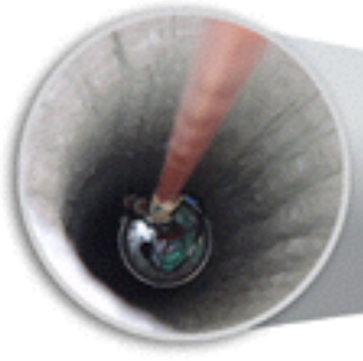
IceCube Laboratory

Data is collected here and sent by satellite to the data warehouse at UW–Madison

50 m

1 gigaton of instrumented ice

1450 m



Digital Optical Module (DOM)

5,160 DOMs deployed in the ice

2450 m

2 nanosecond time resolution

IceCube Lab (ICL) houses data processing and storage and sends 100 GB of data north by satellite daily

86 strings of DOMs, set 125 meters apart

IceCube detector

DeepCore

Antarctic bedrock

Amundsen–Scott South Pole Station, Antarctica

A National Science Foundation-managed research facility

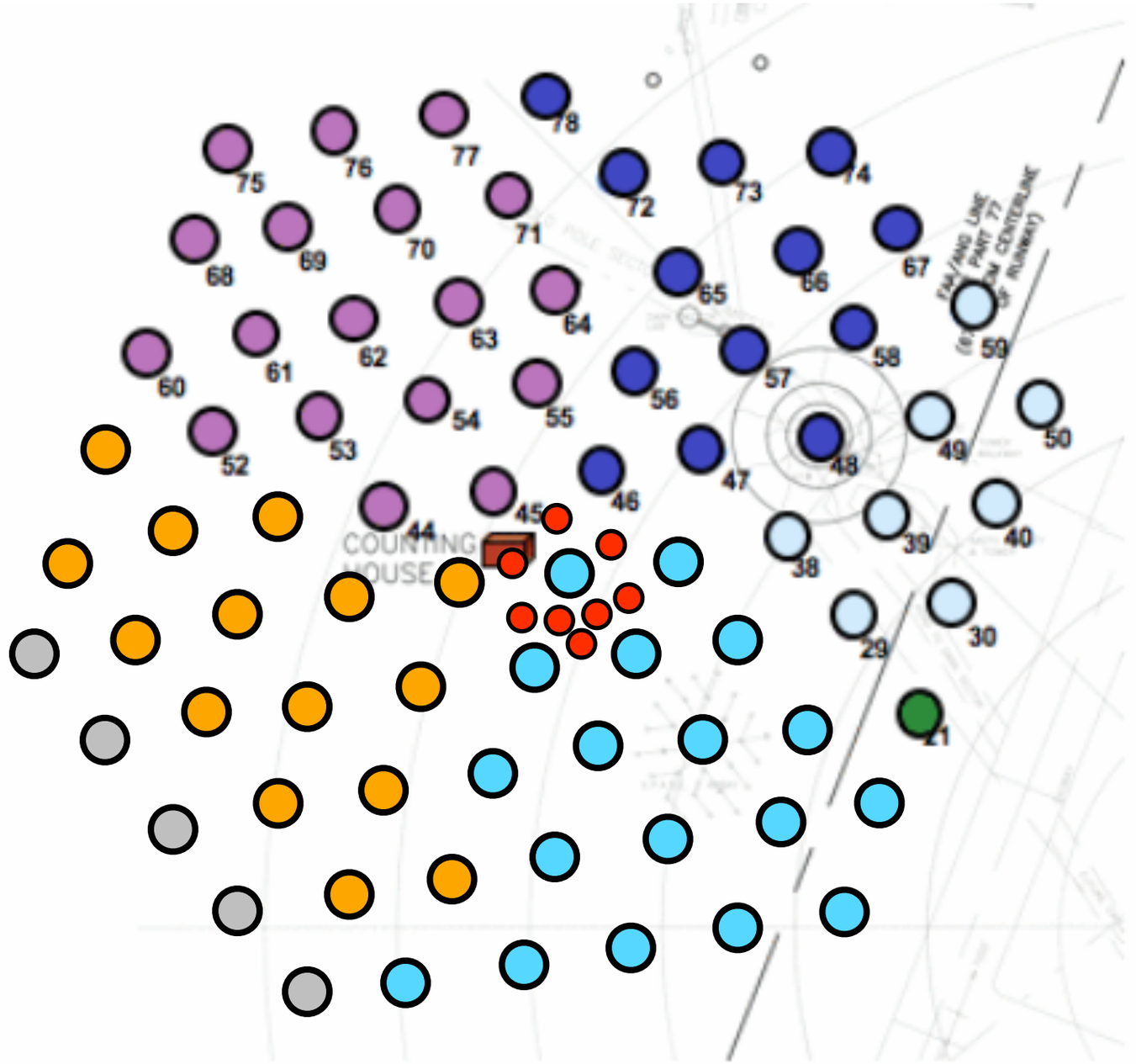
60 DOMs on each string

DOMs are 17 meters apart

The tallest building in Korea

Lotte world tower

CONSTRUCTION



2004-2005
1 string deployed

2005-2006
8 strings deployed

2006-2007
13 strings deployed

IC22

2007-2008
18 strings deployed

IC40

2008-2009
18 strings deployed
+ 1 DeepCore stirngs

IC59

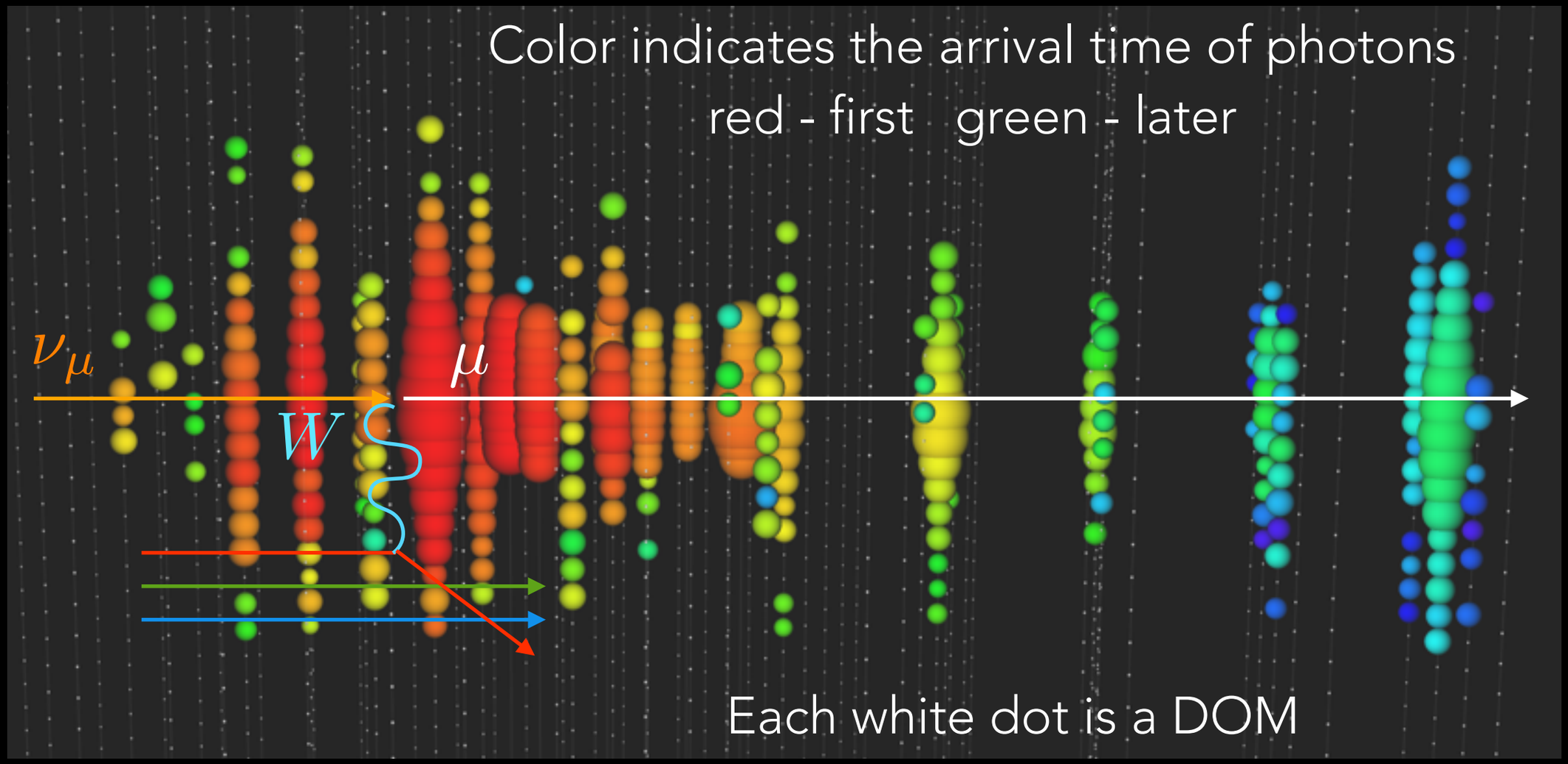
2009-2010
15 strings deployed
+ 5 DeepCore stirngs

IC79

2010-2011
5 strings deployed
+ 2 DeepCore stirngs

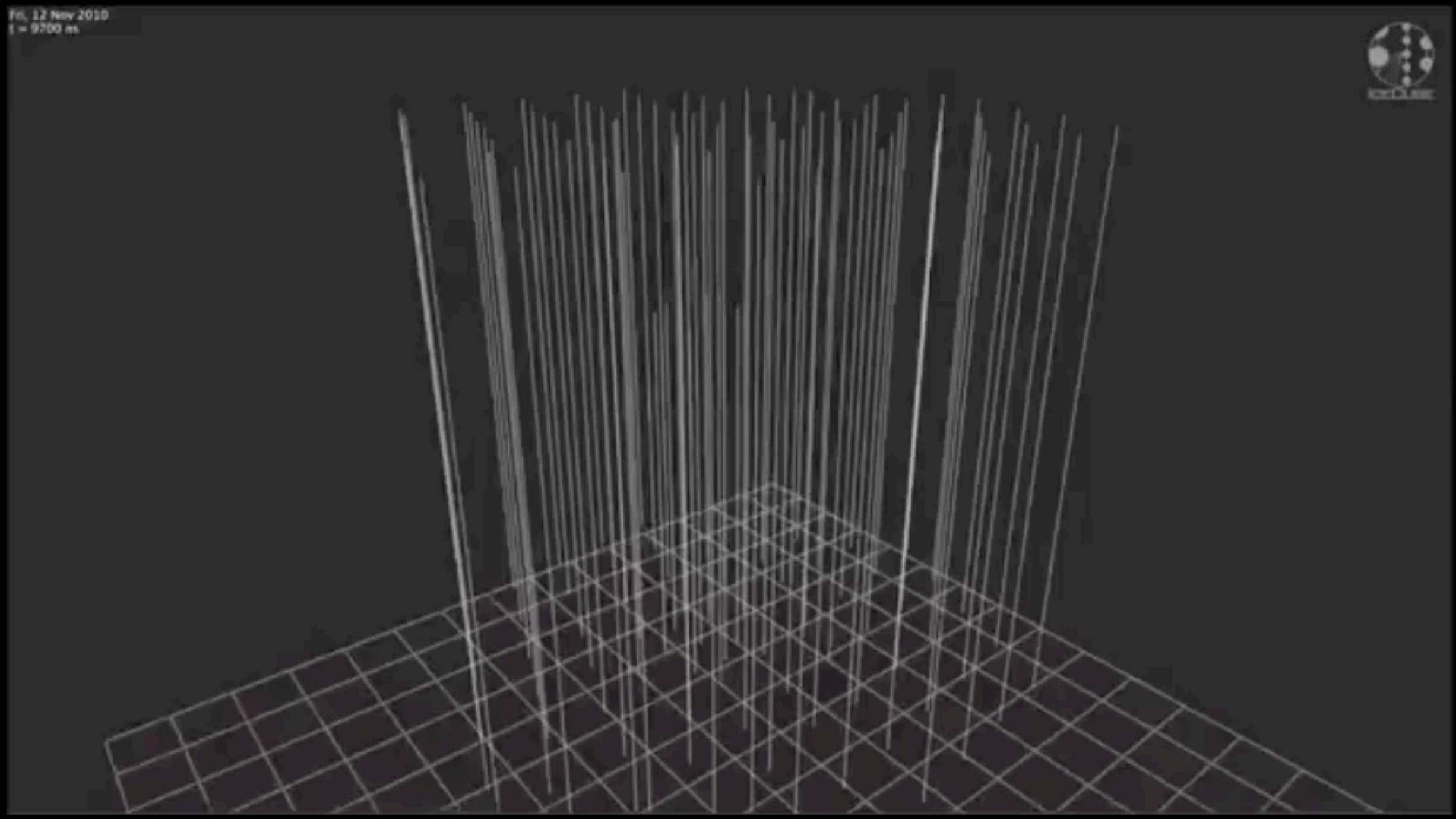
IC86

NEUTRINO DETECTION IN ICECUBE



Nov.12.2010, duration: 3,800 nanosecond, energy: 71.4TeV

NEUTRINO DETECTION IN ICECUBE



Nov.12.2010, duration: 3,800 nanosecond, energy: 71.4TeV

Ernie (~1.1 PeV) at Backrokdam

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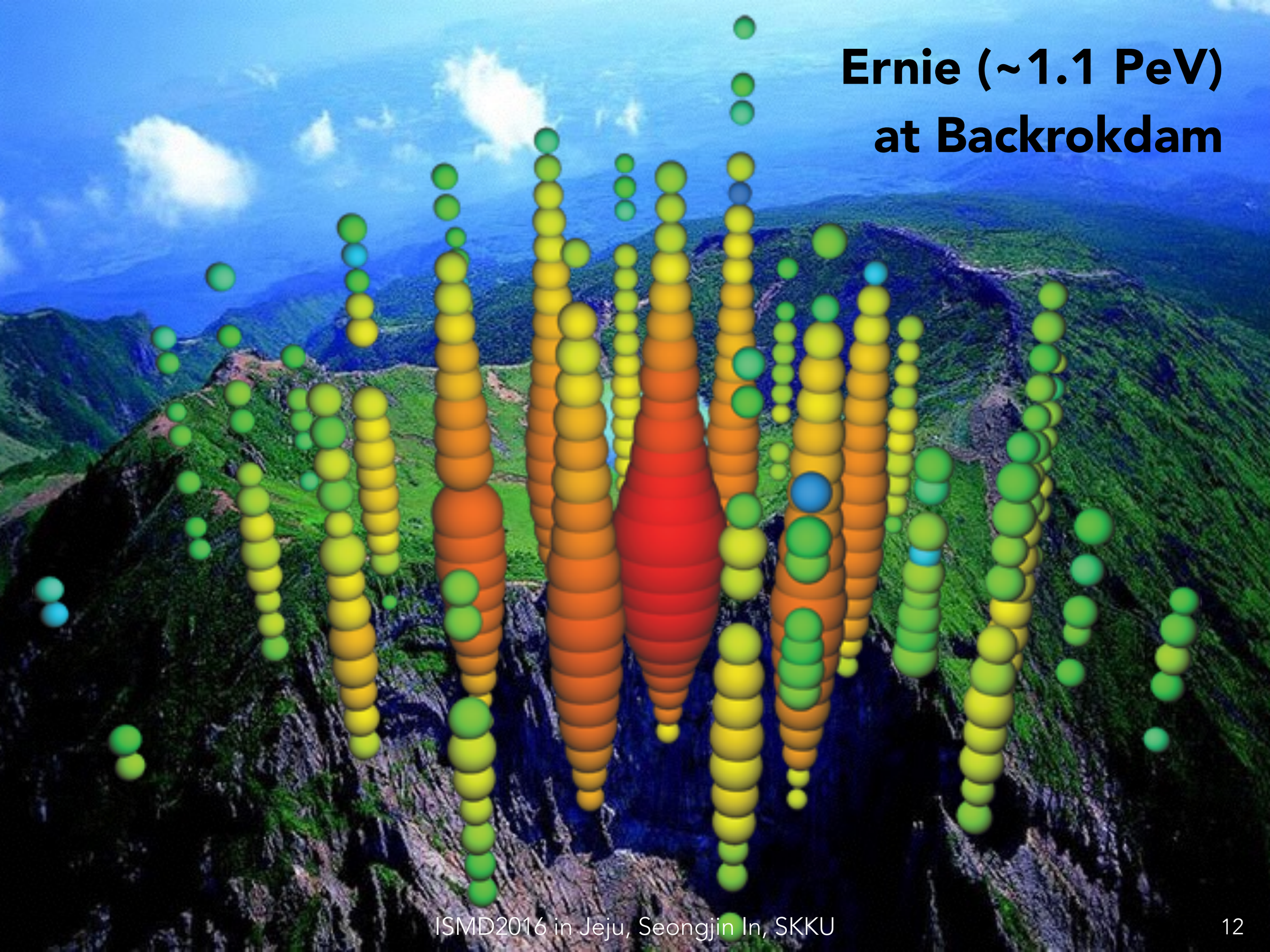
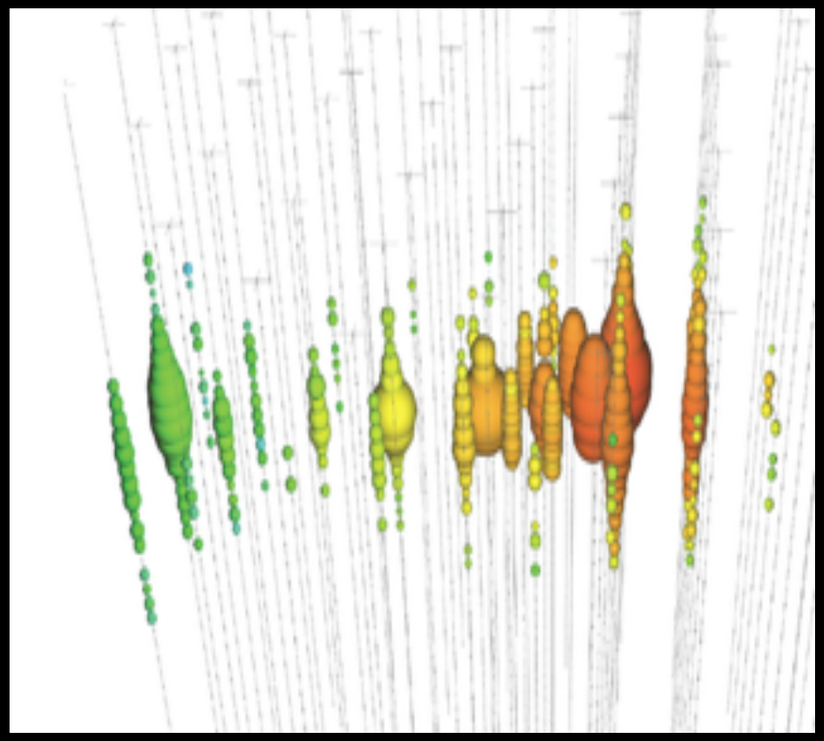


NEUTRINOS IN ICECUBE

Charged Currunt (CC) Muon Neutrino



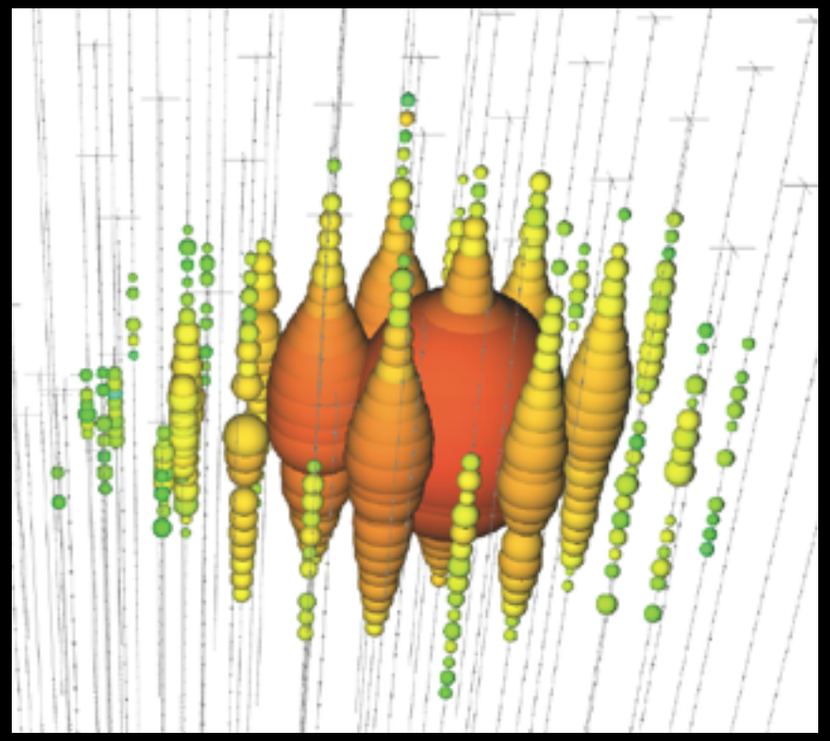
Track

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

factor of ≈ 2 energy resolution

<1° angular resolution at high energy

Neutral Currunt / CC Electron Neutrino



Cascade

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

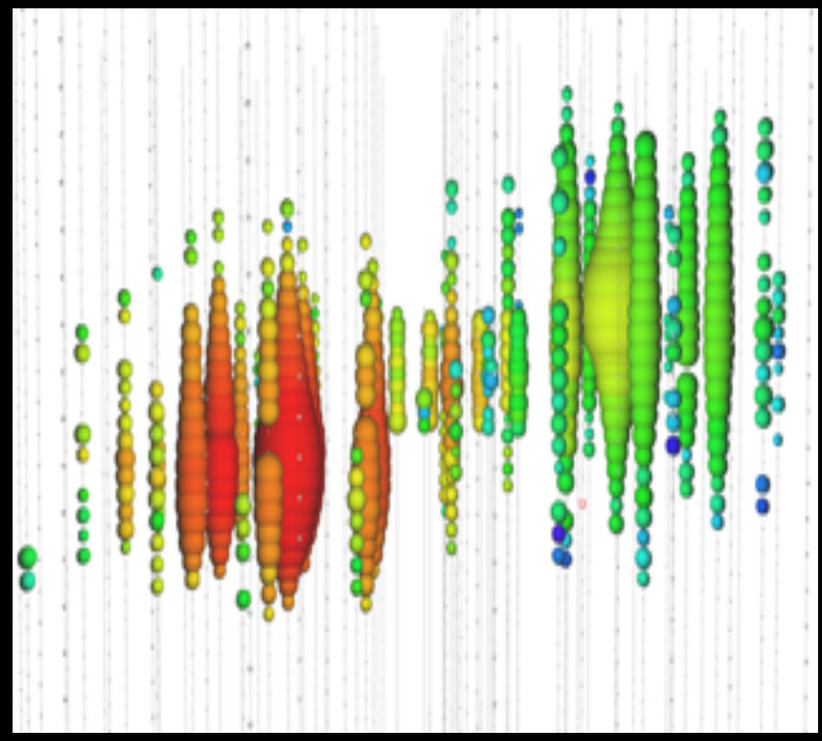
$$\nu_x + N \rightarrow \nu_x + X$$

≈15% energy resolution

≈10° angular resolution

(at energy ≳ 100 TeV)

Tau Neutrino



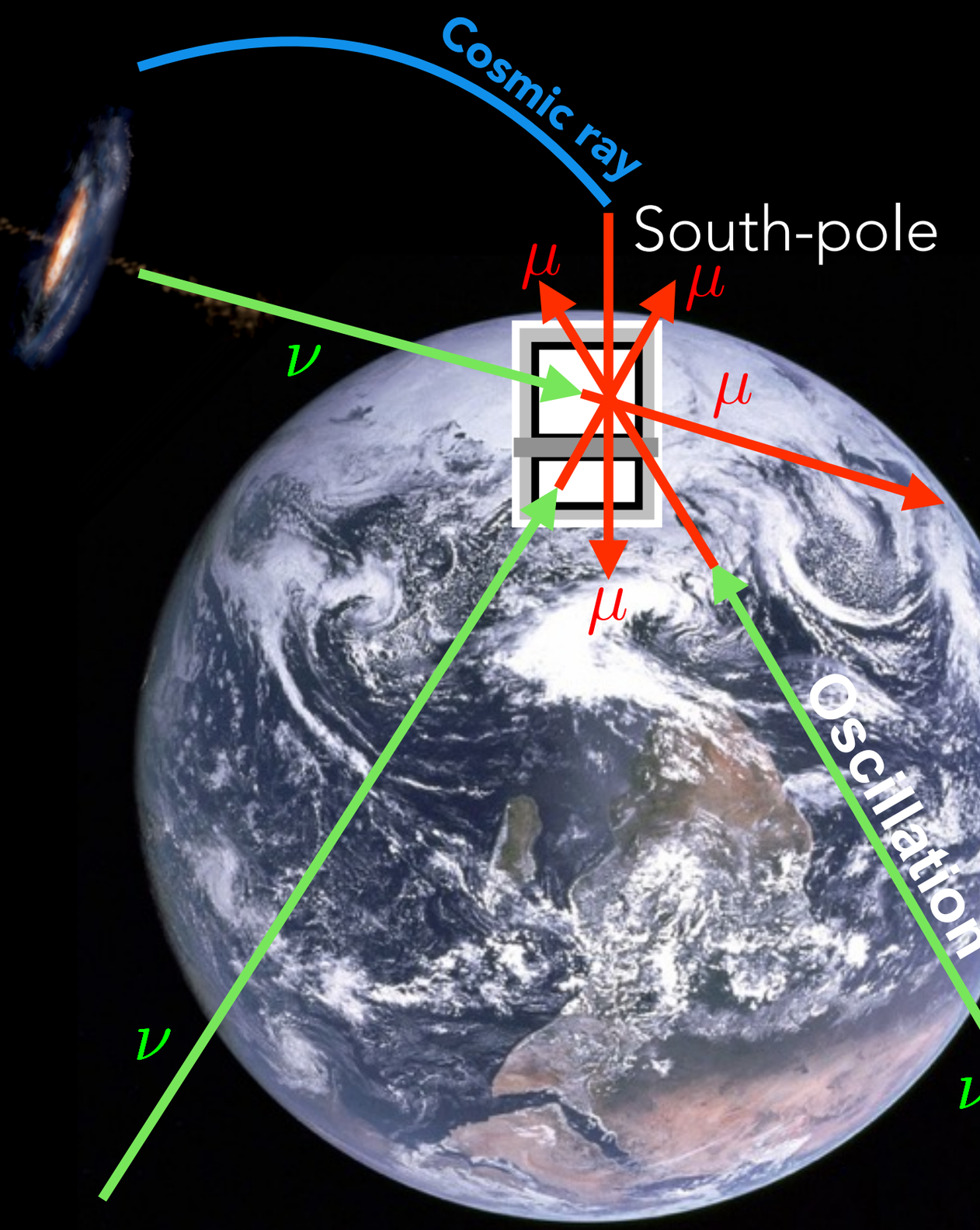
Double-Bang

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

$$\tau\ decay$$

Not yet observed

IceCube Events

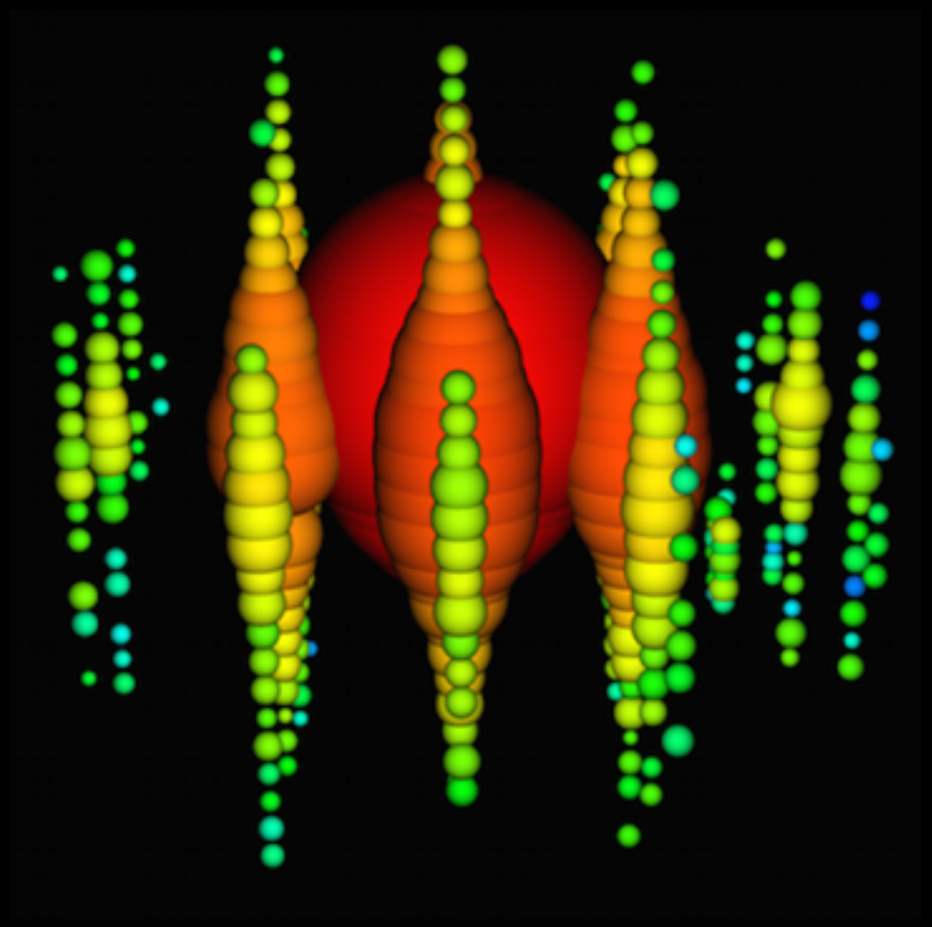


Atmospheric muons ~ 10^{11} / year

Atmospheric neutrinos ~ 10^{5} / year

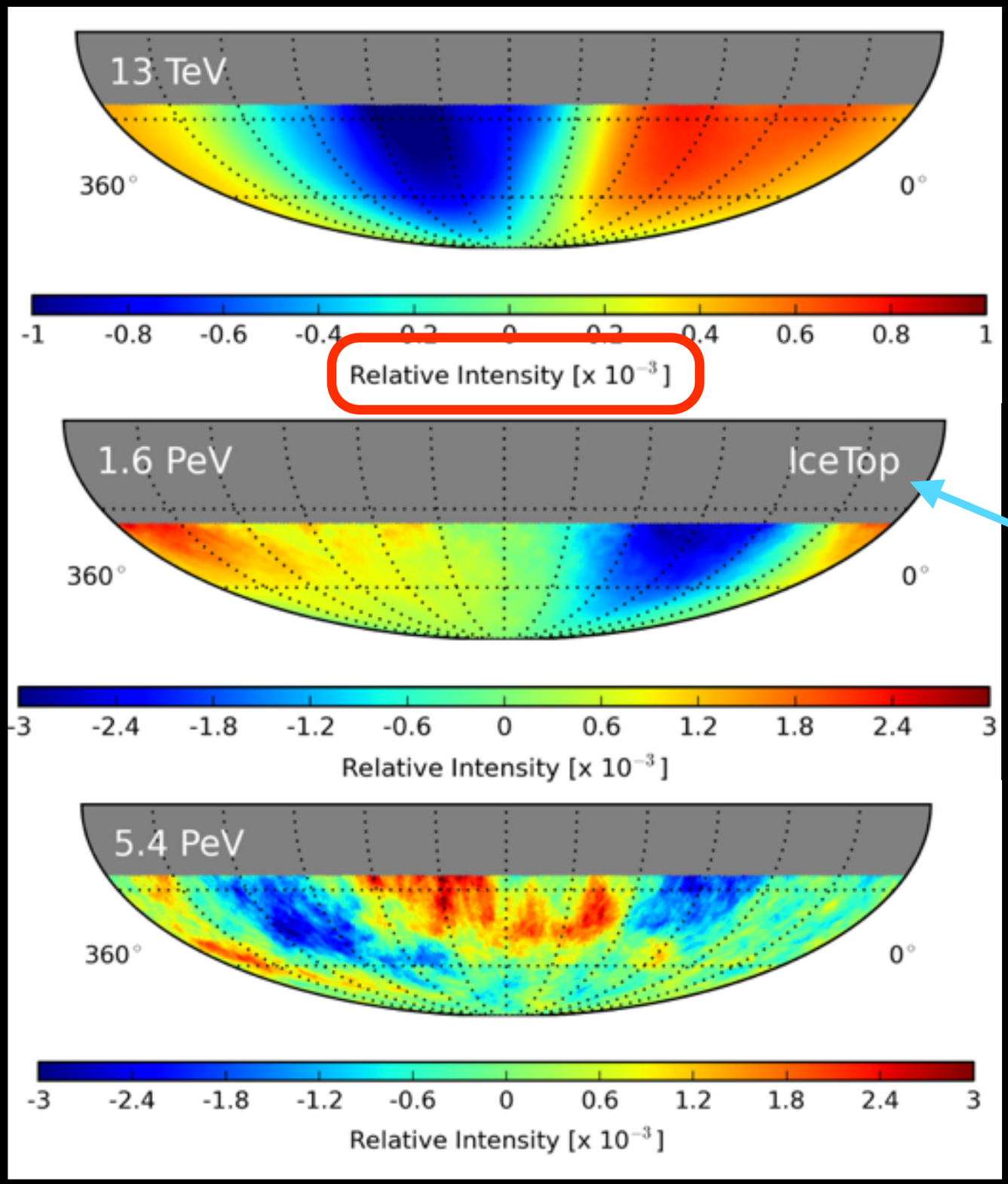
Astrophysical neutrinos ~ 100 / year

Up-going event can be used to obtain "clean" neutrino sample (Earth is working as muon filter)



ASTROPHYSICS IN ICECUBE

Cosmic ray anisotropy

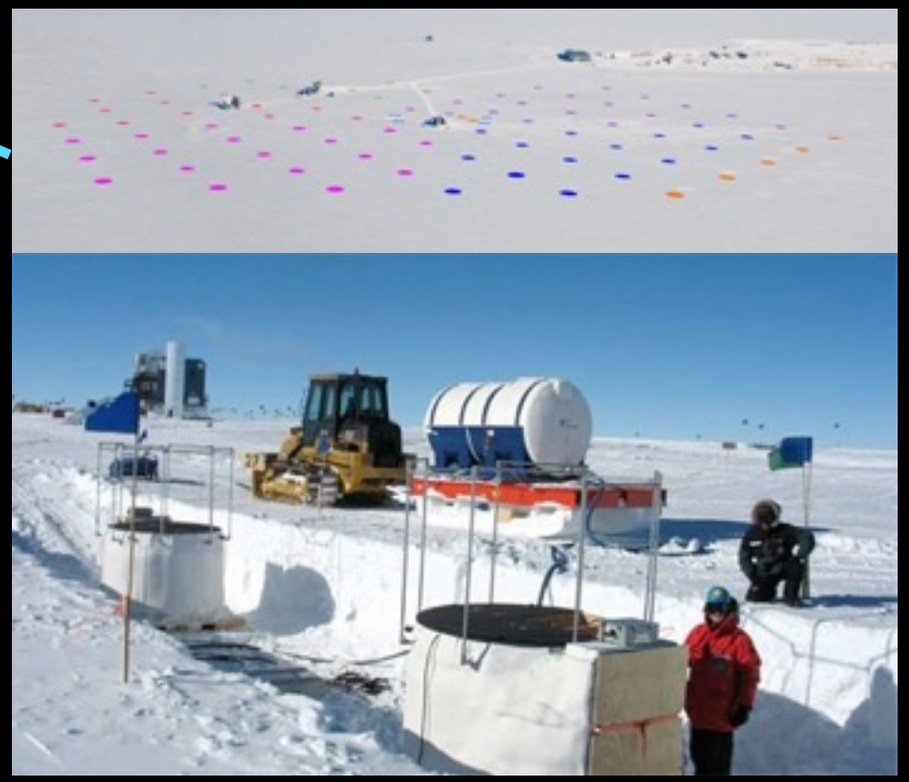


Southern Hemisphere

$3.179*10^{11}$ events

Blue: Underrepresent

Red: Overrepresent

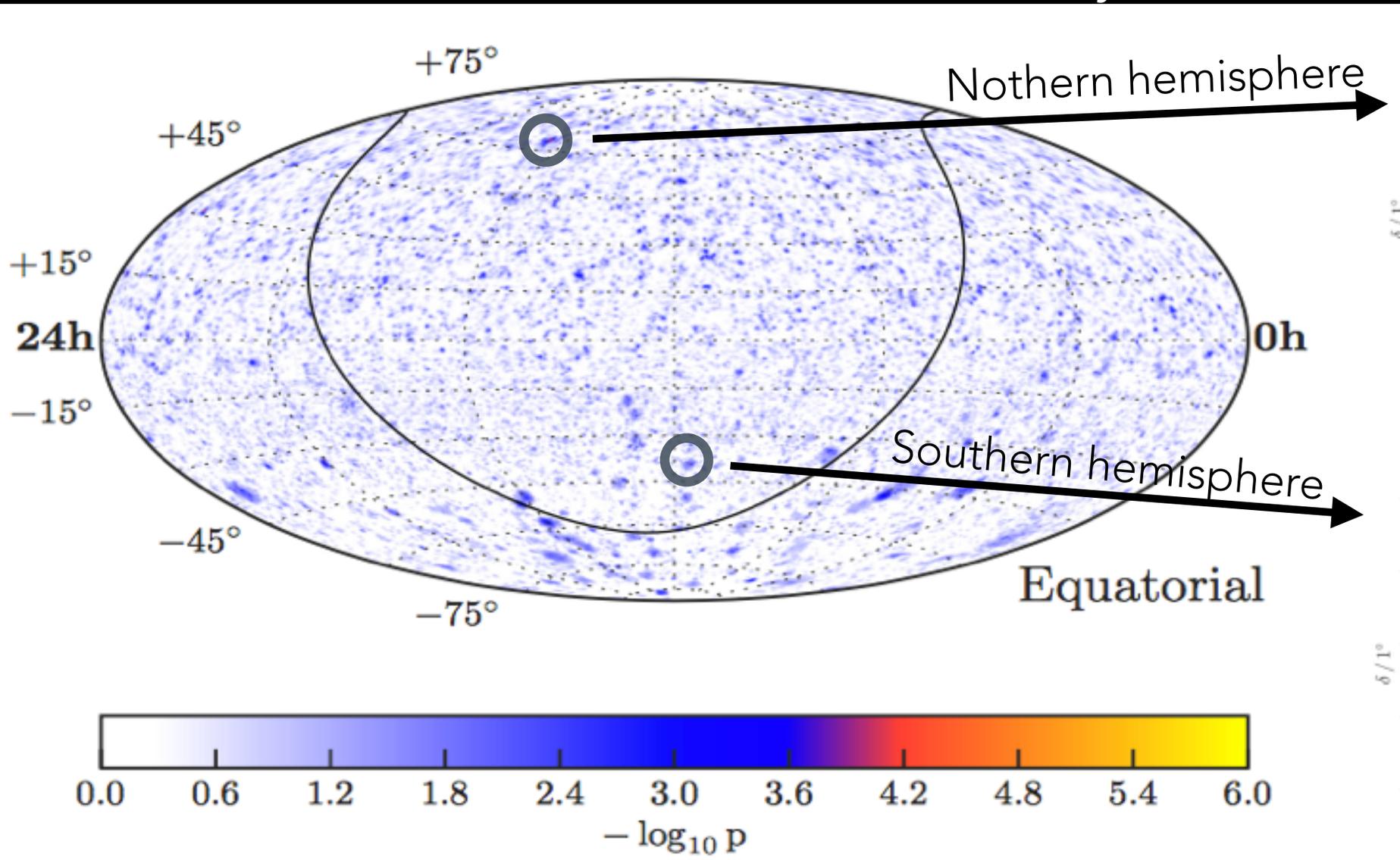


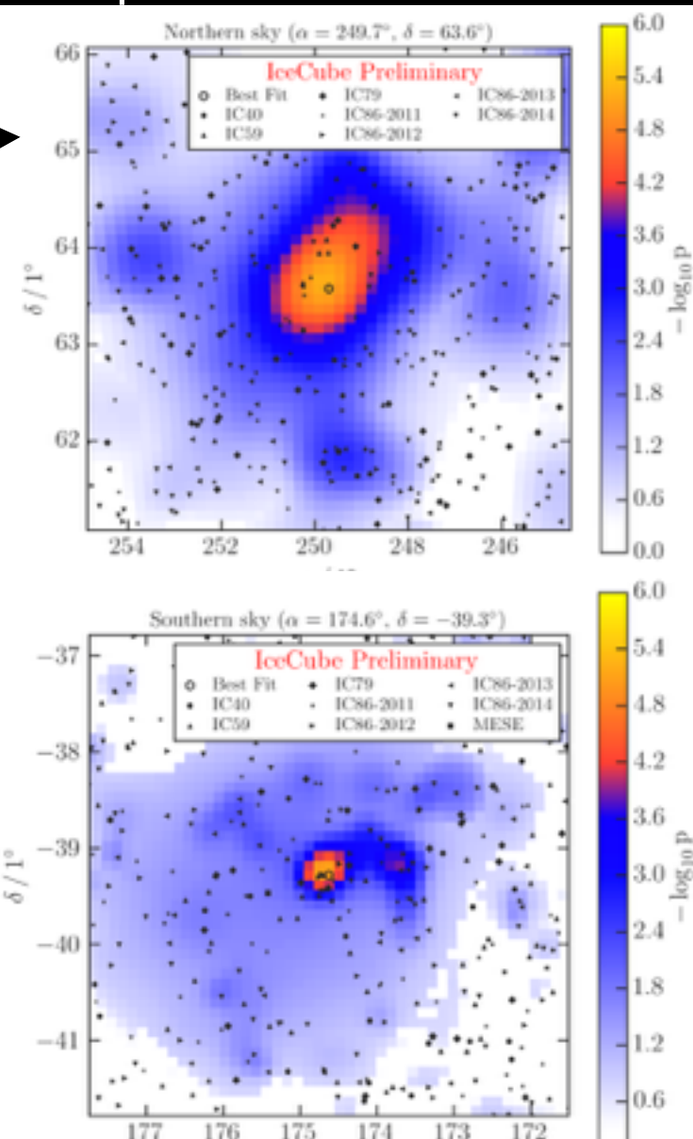
Astrophys. J. 826 (2016) no.2, 220
arXiv:1603.01227

Point Source Search

neutrinos ~ 10^5 / year

p-value = 44%

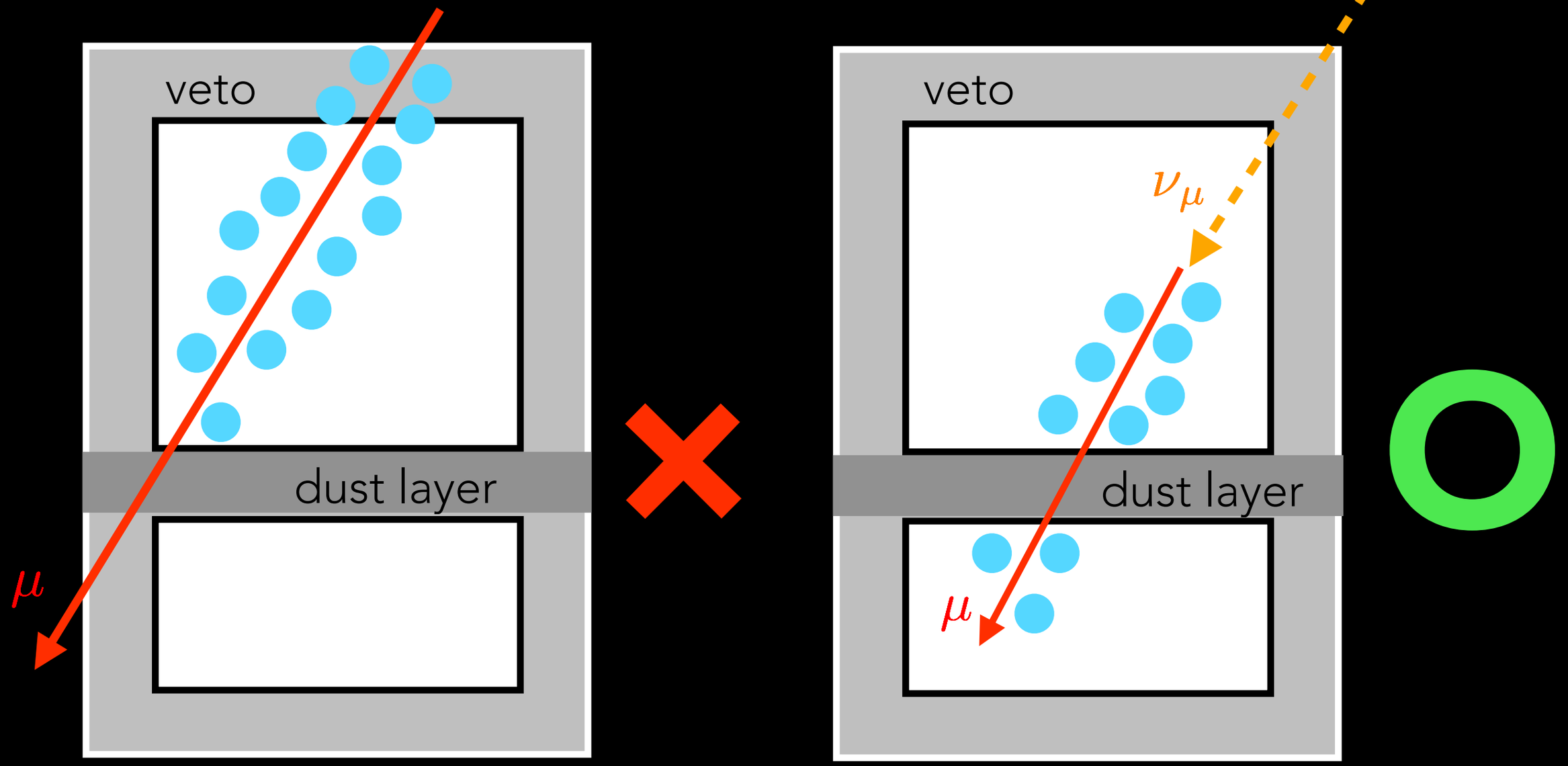




712830 events

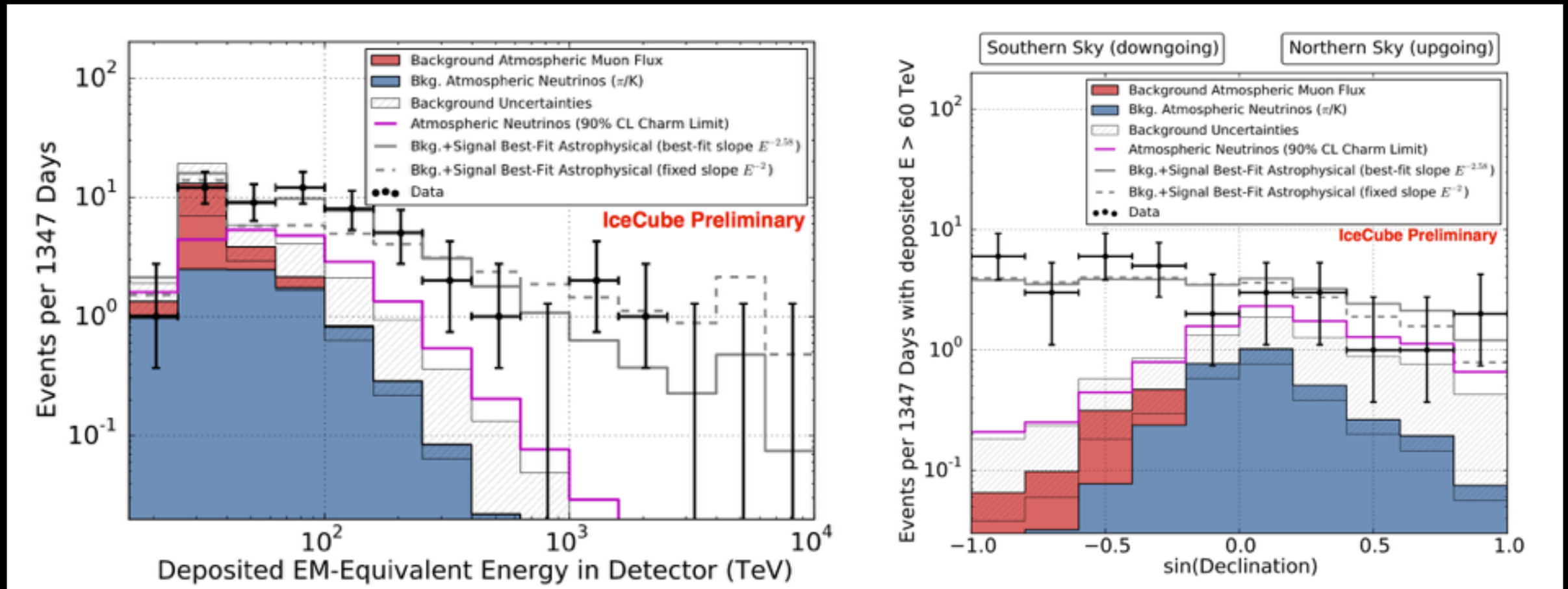
p-value = 39%

High Energy Starting Event search



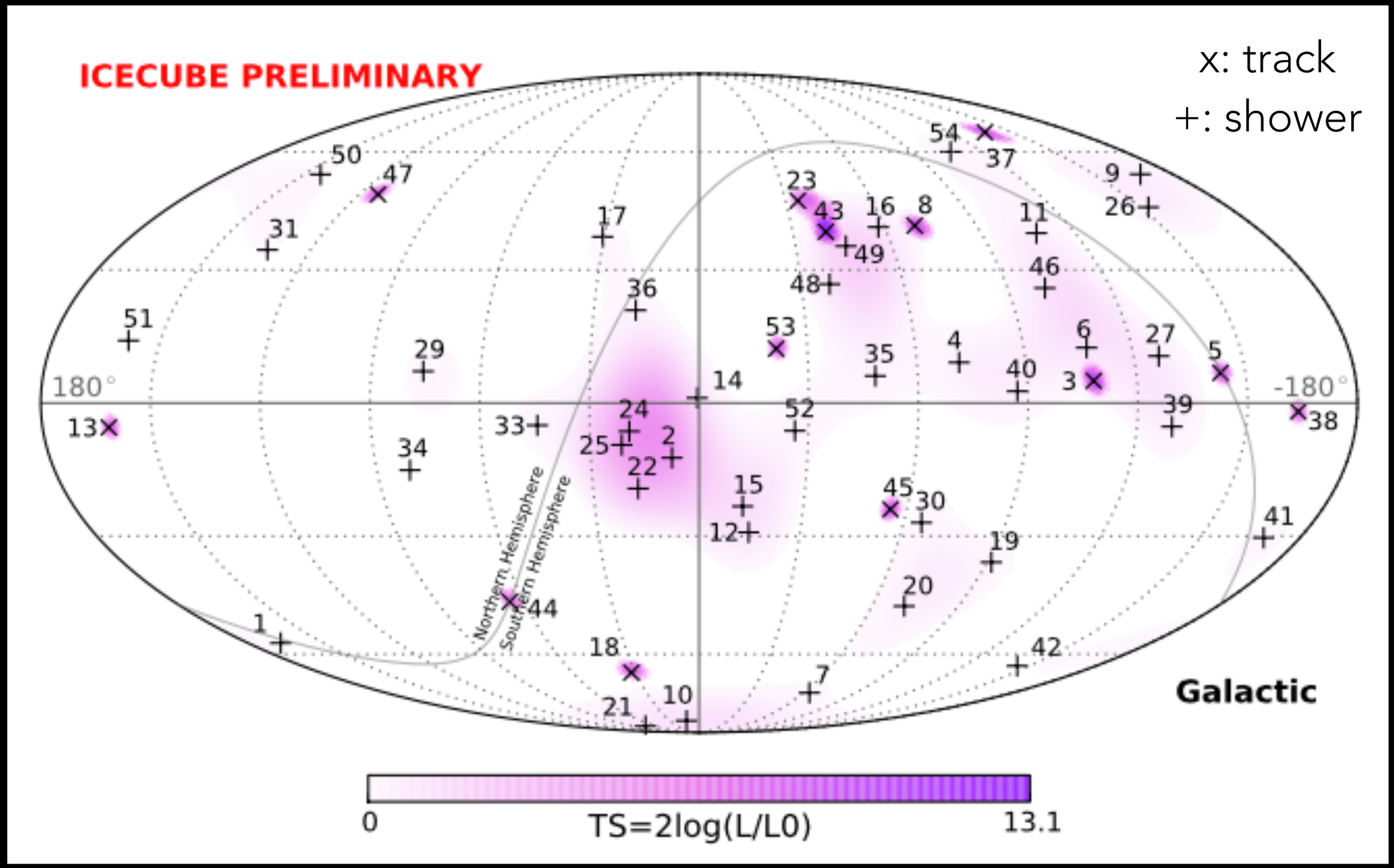
- Outer layers are working as a veto for atmospheric muons
- Sensitive to all flavors, all directions
- Energy threshold ~ 30 TeV

High Energy Starting Event search



- 54 events in 1347 days
- Atmospheric neutrinos ~ $9^{+8.0}_{-2.2}$
  Atmospheric muon ~ 12.6±5.1
- Background only scenario rejected with ~ 7σ

Arrival Direction



No significant clustering was found

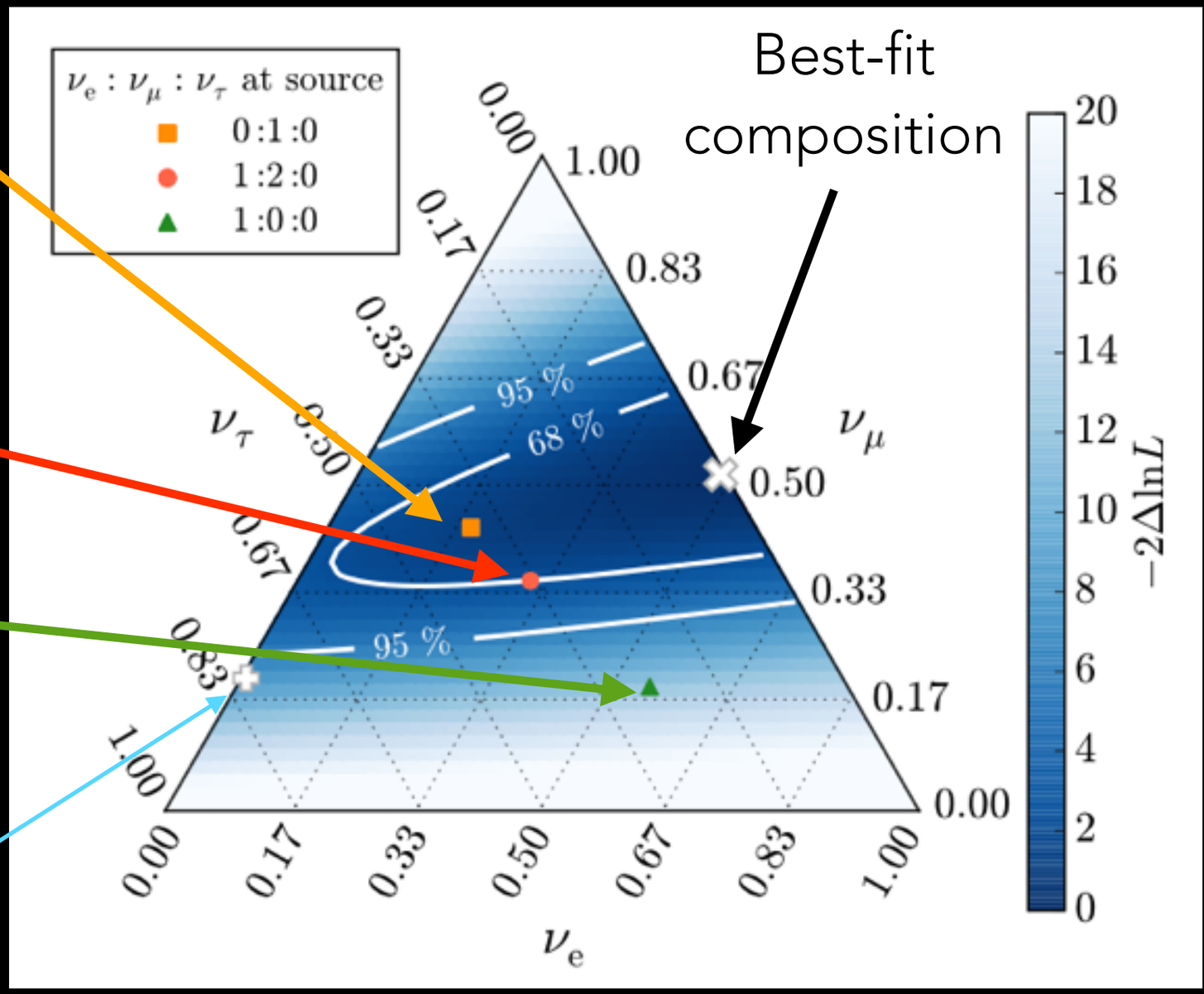
Flavor ratio

Likelihood scan of the flavor composition

Muon-damped
Acceptable

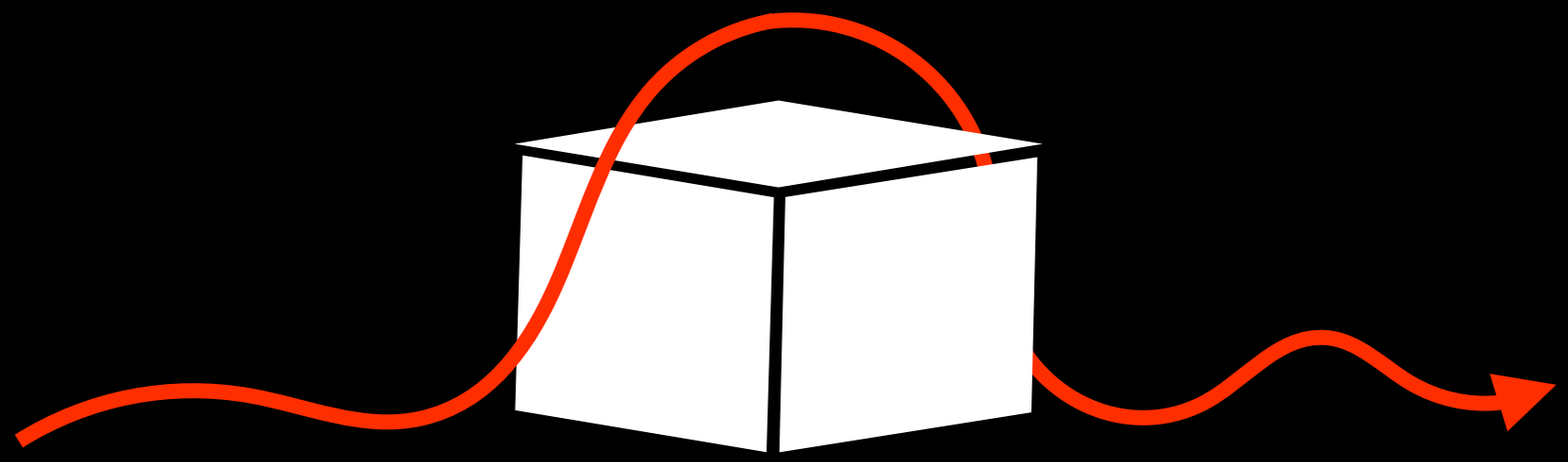
Pion decay
Acceptable

Nucleon decay
rejected at 3.6σ



IceCube Collaboration, Astrophys. J. 809 (2015) 1, 98

Previous analysis for exclusion region
IceCube Collaboration
Phys.Rev.Lett. 114 (2015) 17, 171102

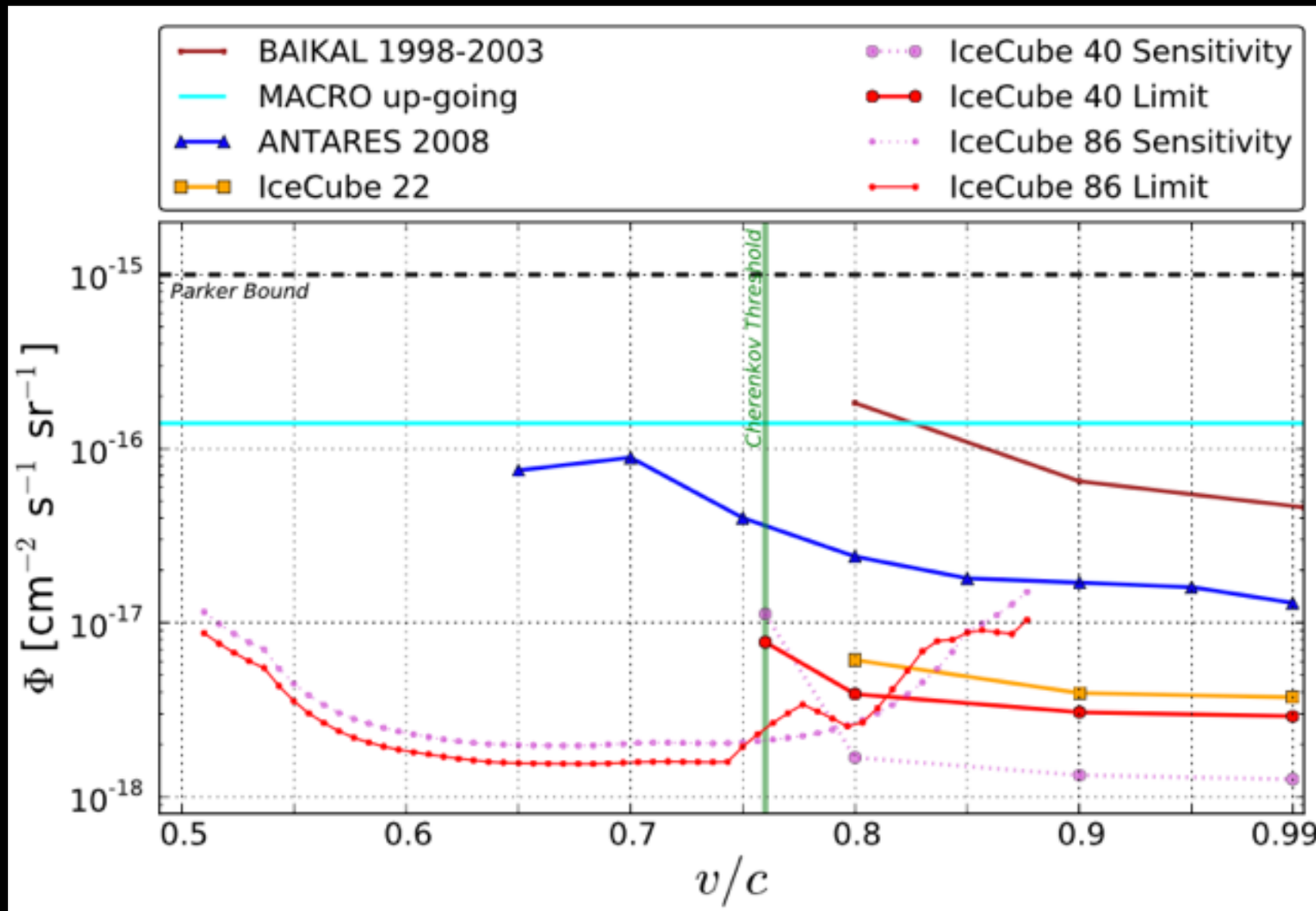


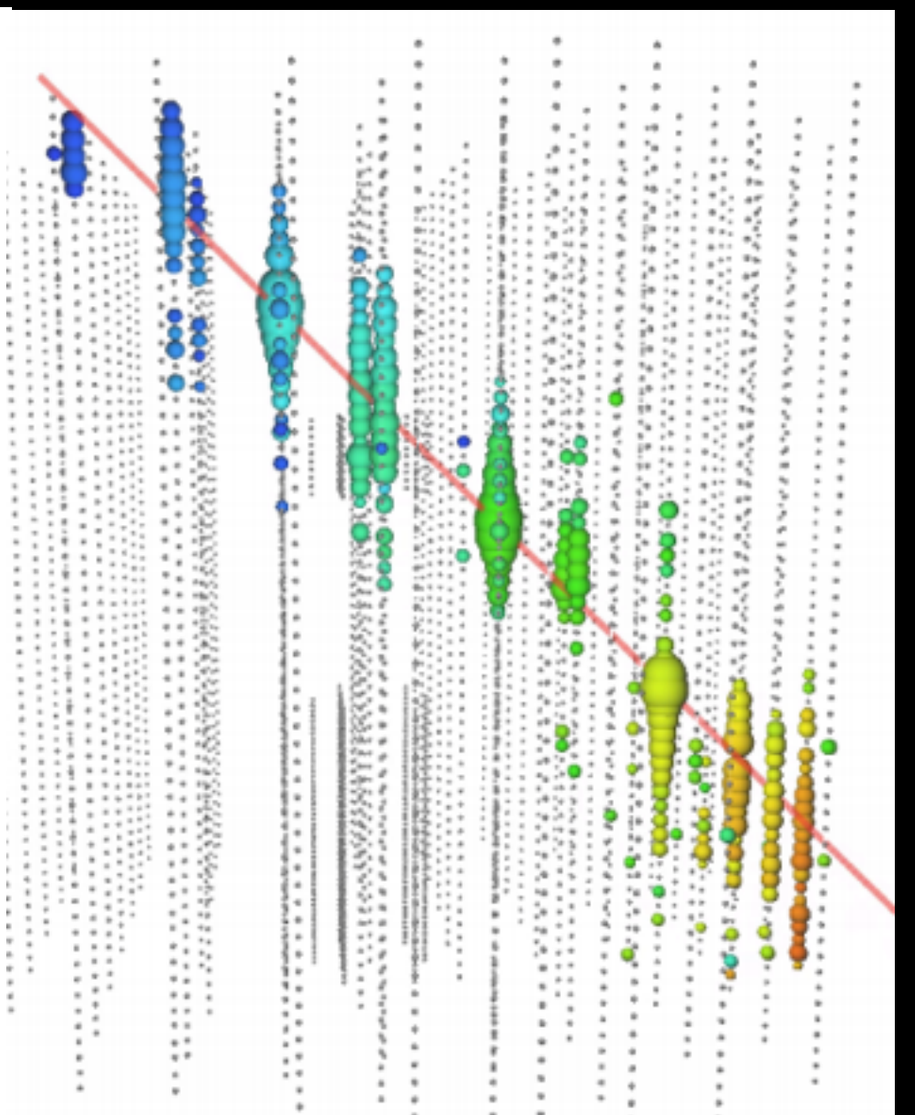
BEYOND THE STANDARD MODEL

BEYOND STANDARD MODEL

-MONOPOLE SEARCH

EPJ C76 (2016) 133



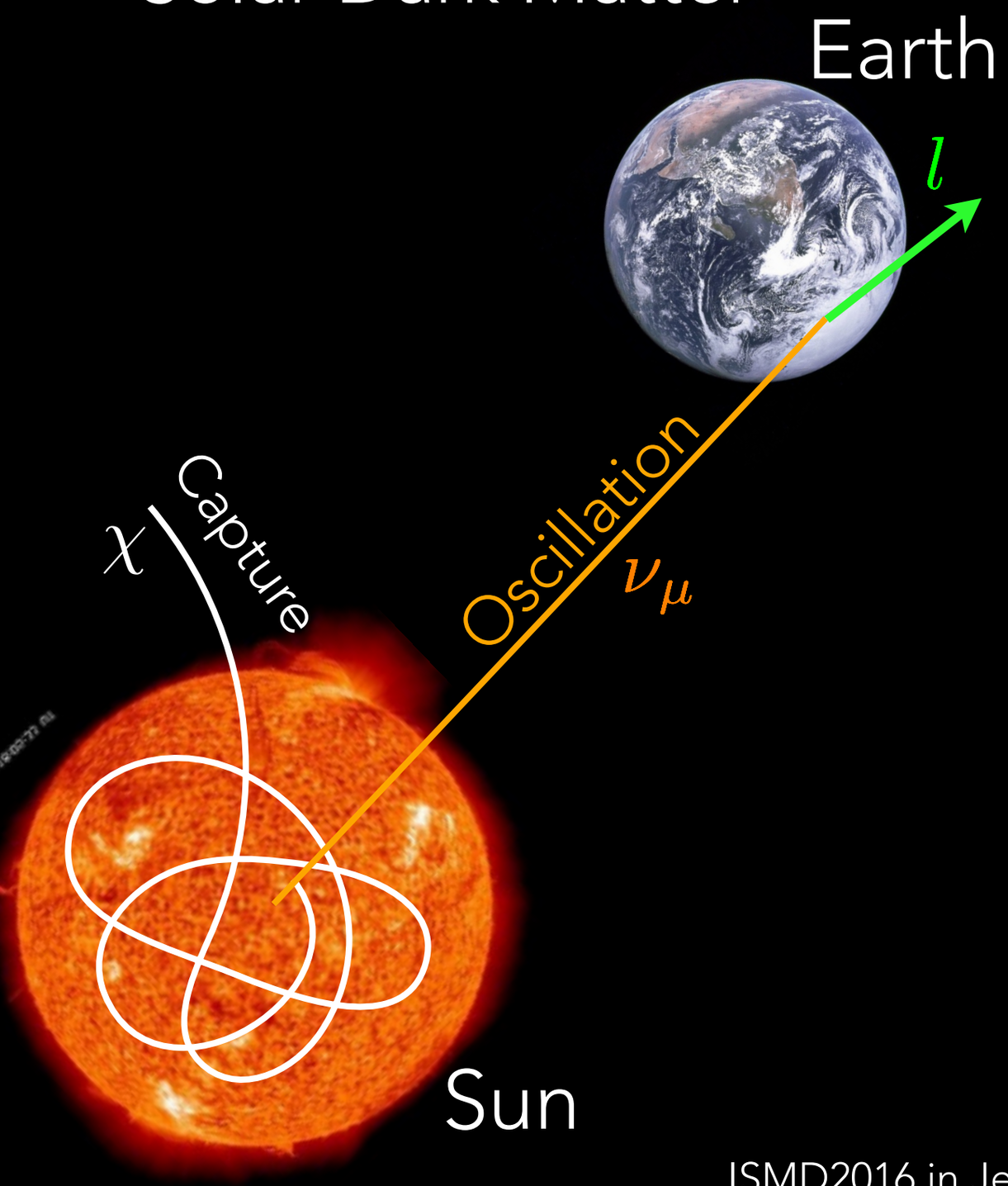


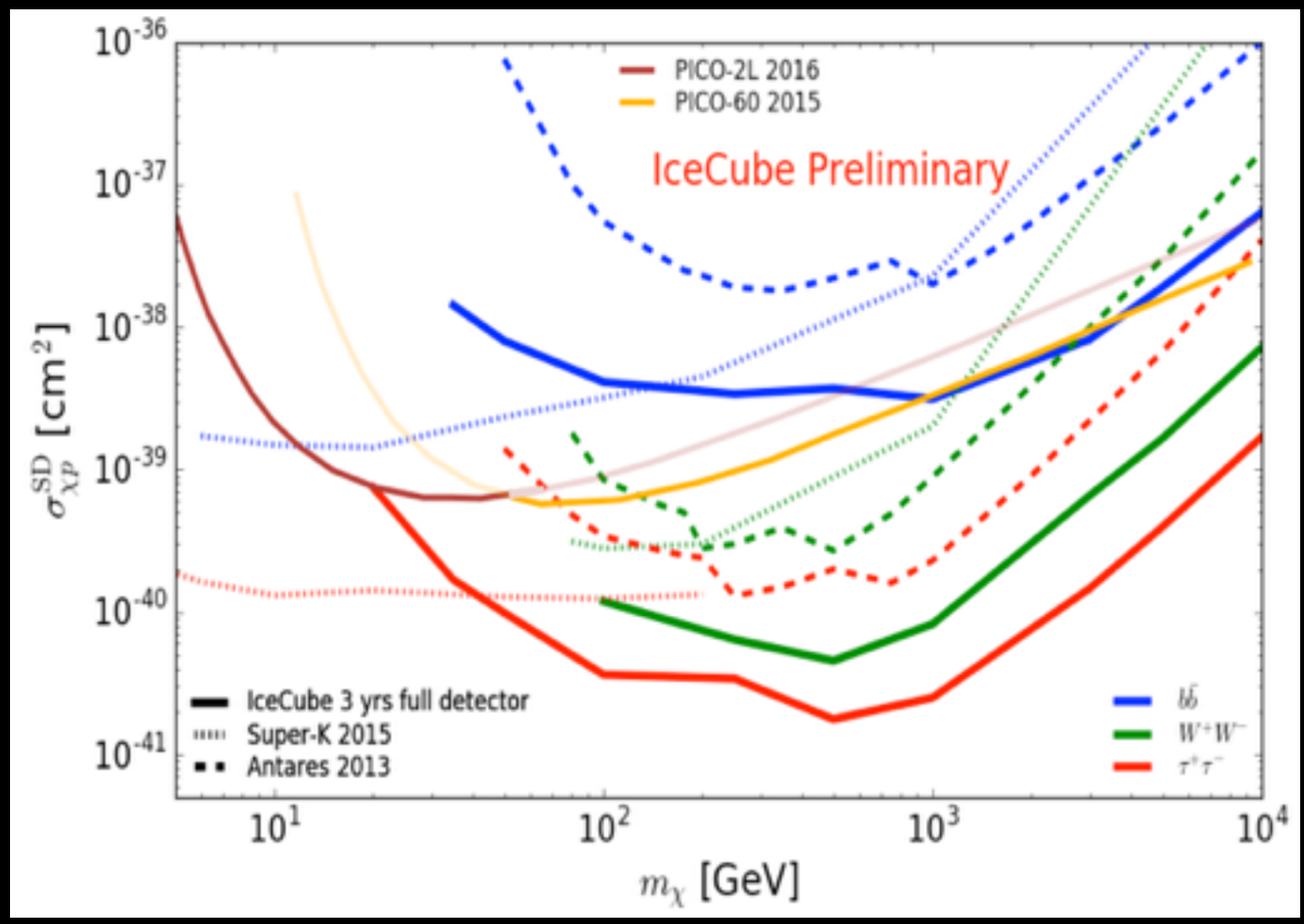
- Magnetic monopoles would produce bright tracks relative to muon tracks
- Separate analysis performed to search for monopoles above and below Cherenkov threshold
- No evidence found -> flux limits set as a function of $\beta = v/c$

BEYOND STANDARD MODEL -DARK MATTER SEARCH

- Solar Dark Matter

PoS(ICRC2015) 1099





Neutrino bounds are competitive with Dark Matter direct detection

BEYOND STANDARD MODEL -DARK MATTER SEARCH

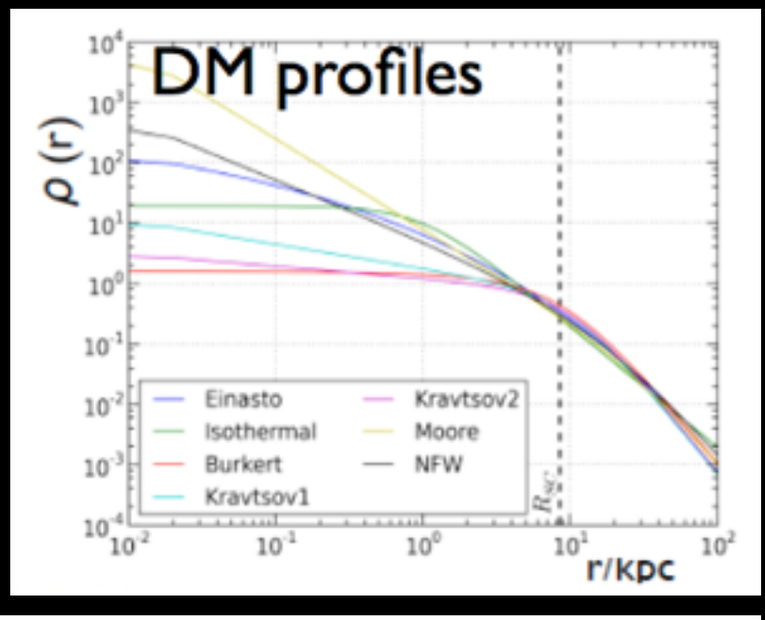
- Galactic Center / Halo

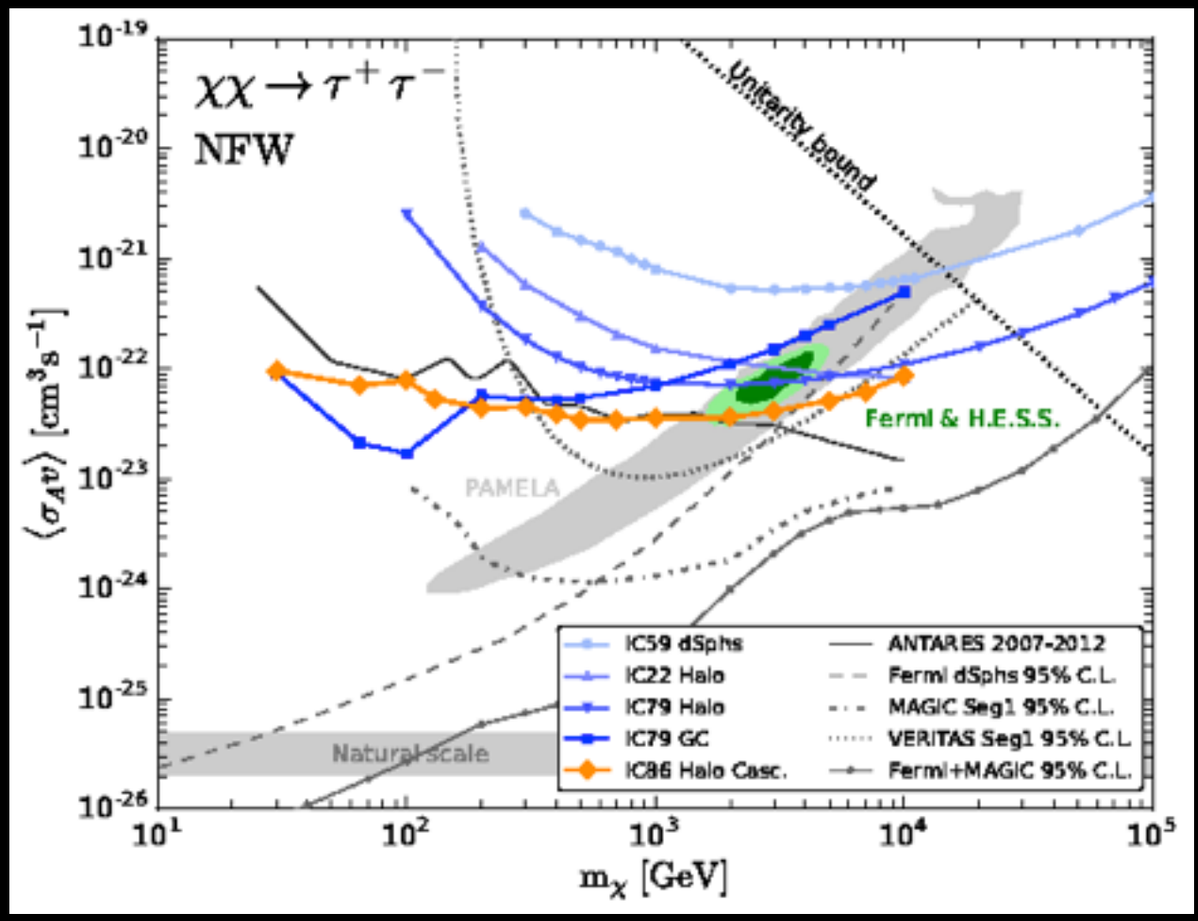
Cross-section to be constrained

Particle Physics

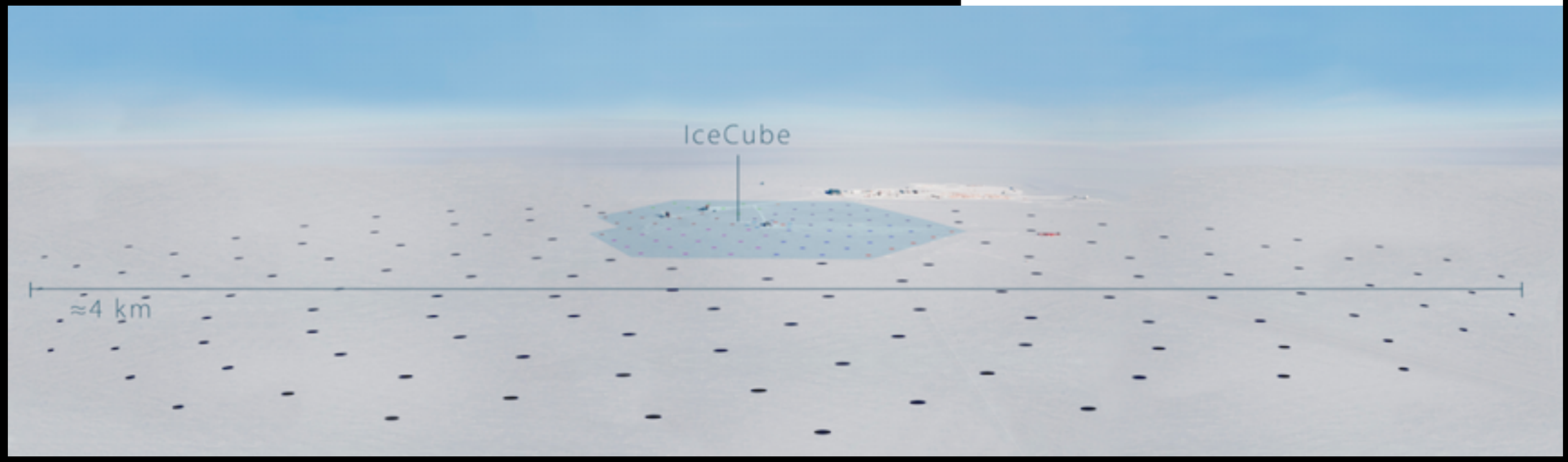
$$\frac{d\Phi}{dE} = \frac{1}{4\pi} \frac{\langle \sigma_A v \rangle}{2m_\chi^2} \Sigma_f \frac{dN_\nu}{dE} B_f \times \int_\Omega d\Omega' \int \rho^2(r(l,\phi'))dl(r,\phi')$$

Dark Matter distribution





IceCube collaboration, arXiv: 1606.00209



ICECUBE EXTENSION

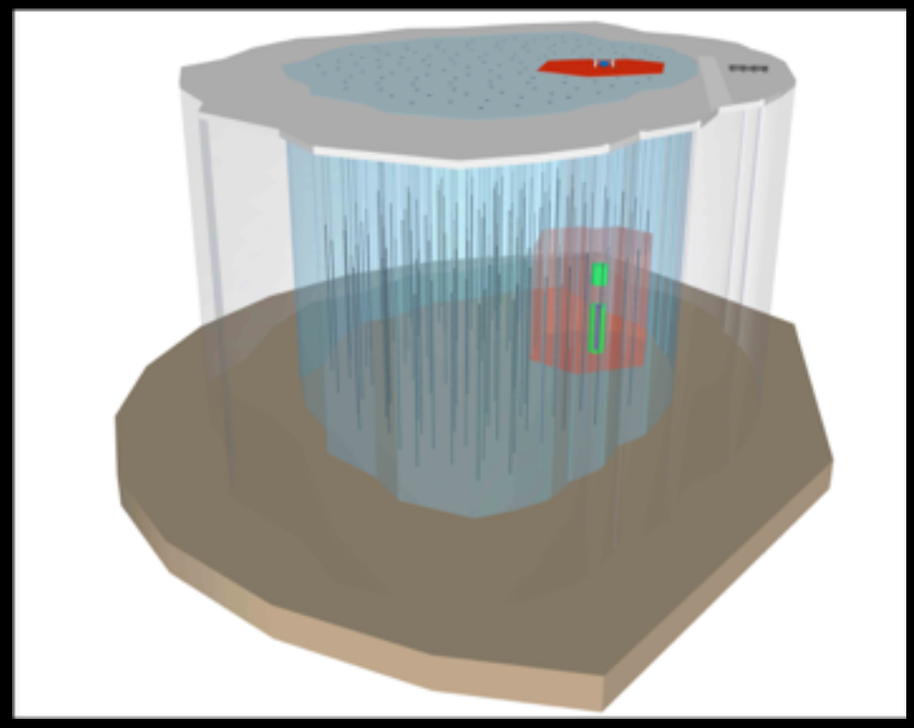
IceCube - Gen2

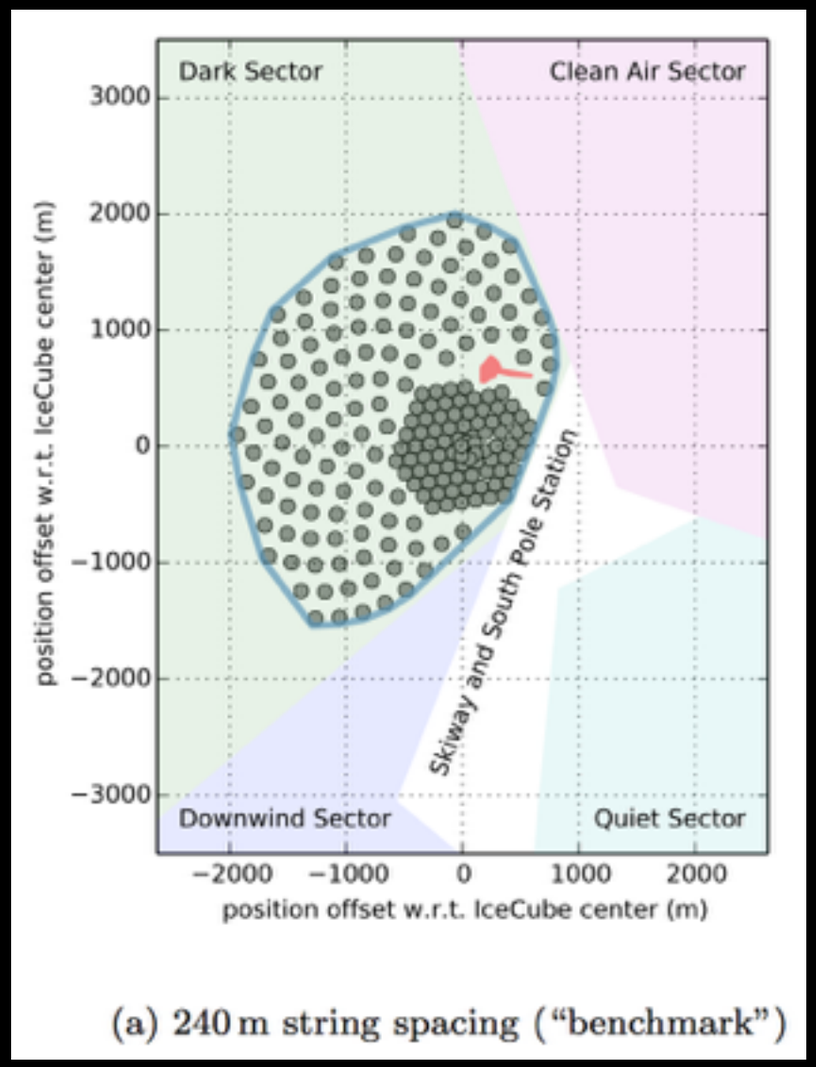
High Energy Array

- More events
- Higher energy

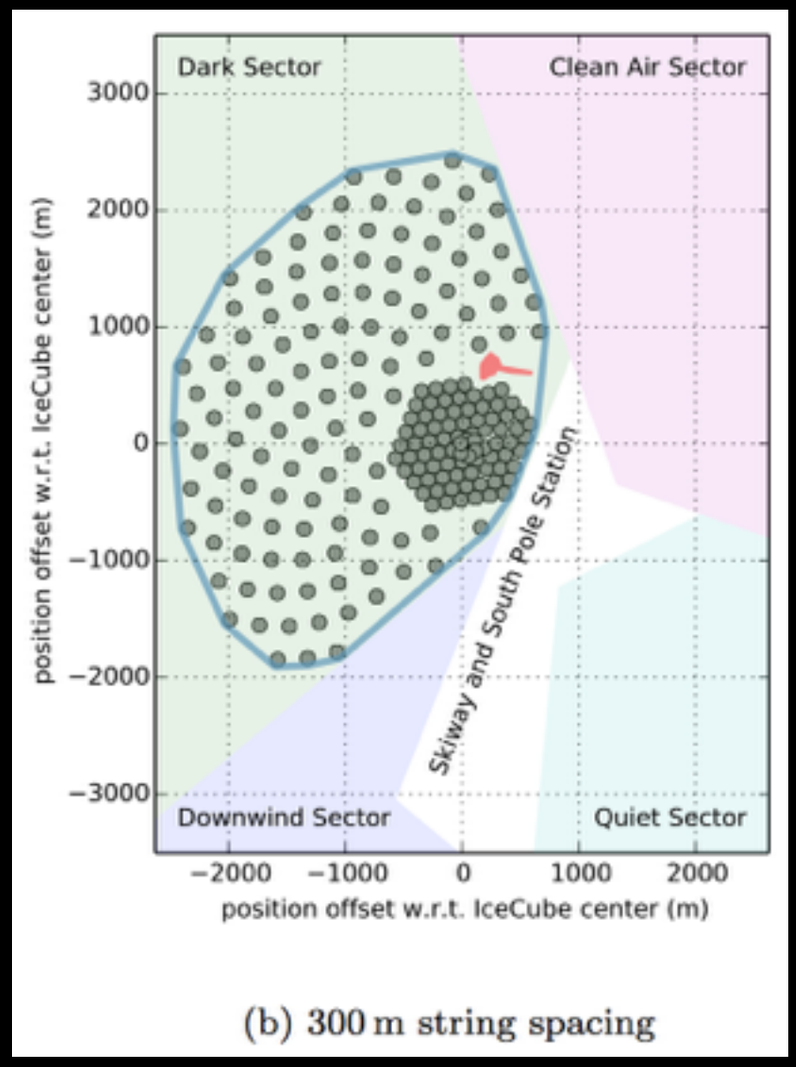
Physics Goal

- Point source
- GZK neutrino
- flavor composition





(a) 240 m string spacing ("benchmark")

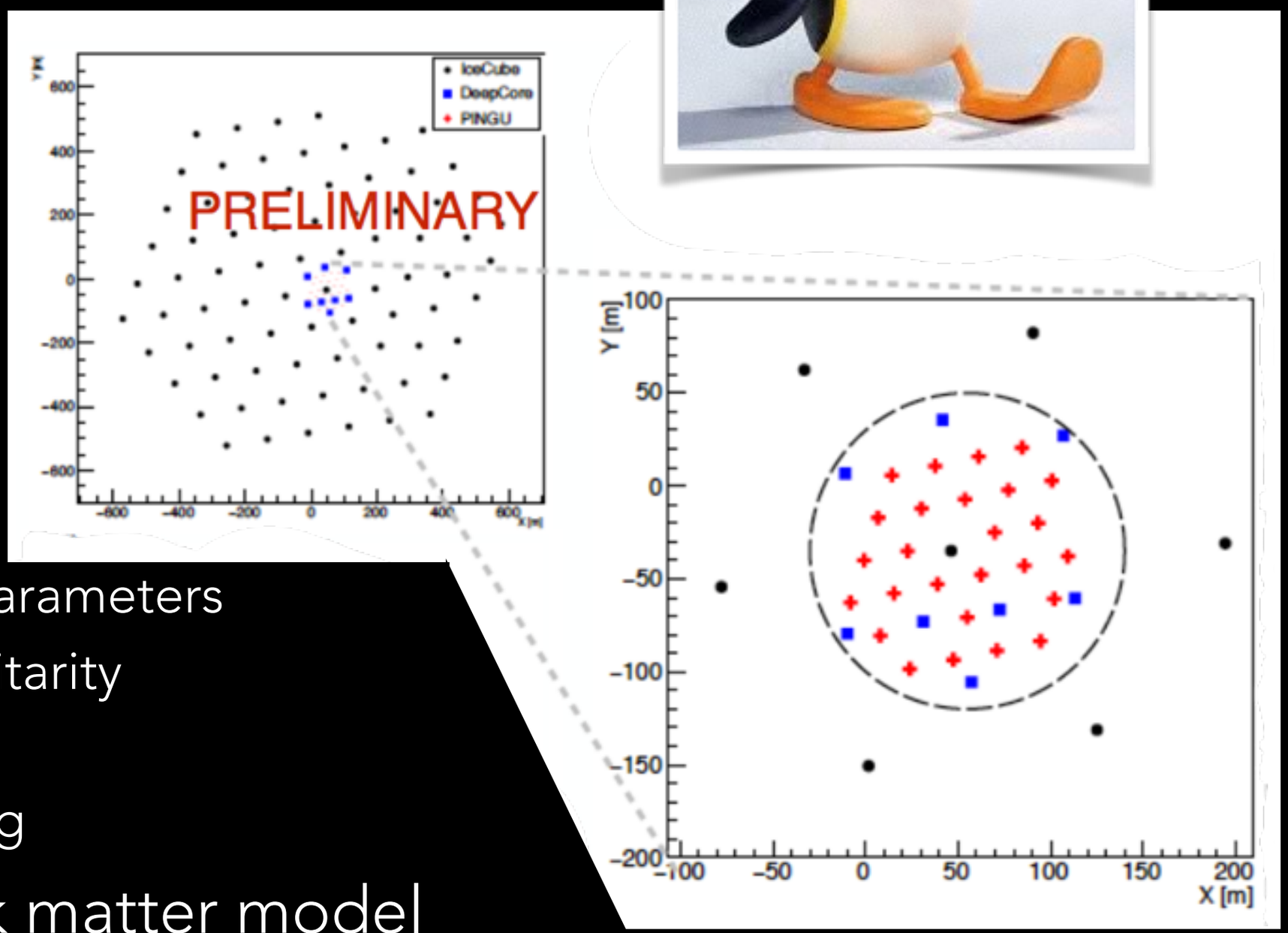


(b) 300 m string spacing

PINGU

-PRECISION ICECUBE NEXT GENERATION UPGRADE

volume ~ 5MT
with 20-26 strings



- Low energy neutrino (~ GeV)
- Neutrino oscillation physics
  - atmospheric mixing parameters
  - ν_τ appearance and unitarity
  - maximal mixing
  - neutrino mass ordering
- Test low mass dark matter model

Photo by WinterOvers

SUMMARY

- IceCube has opened a new window on the Universe / discovery of astrophysical neutrinos marks a new era in astroparticle physics
  - Where are the astrophysical neutrinos coming from?
- The IceCube Observatory is a multi-purpose experiment with a very broad science spectrum
- Great prospects for future search at IceCube and beyond
  - PINGU: low energy side, Gen2-HEA: high energy side