IceCube
SOUTH POLE NEUTRINO OBSERVATORY

EUROPEAN PHYSICAL SOCIETY
HEP2015

Methods for Detection of Astrophysical Tau Neutrinos in IceCube

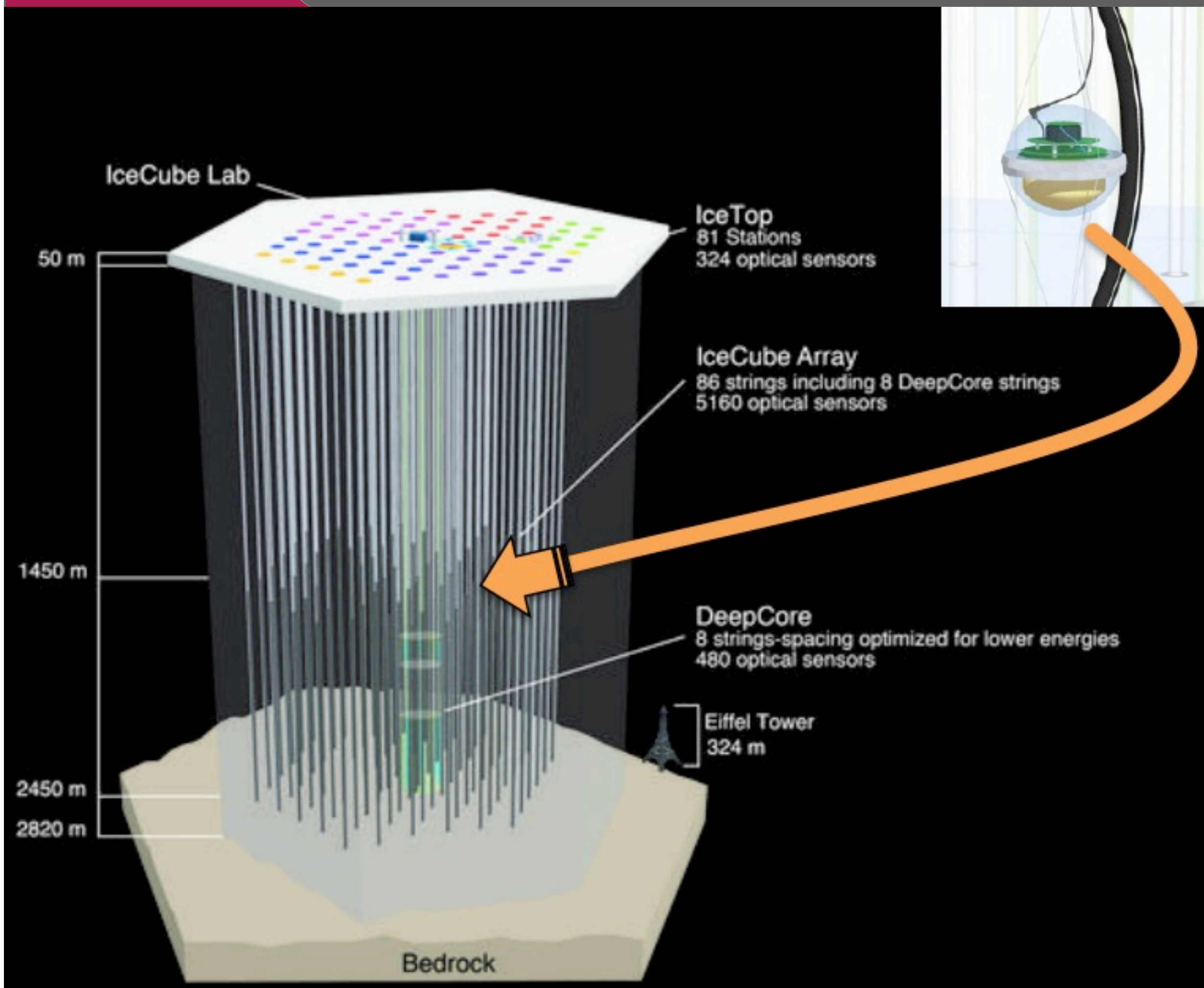
Tomasz Palczewski
for the IceCube Collaboration
University of Alabama

Methods to identify high-energy tau neutrino interactions in IceCube, a cubic-kilometer neutrino detector deployed in the glacial ice at the geographical South Pole will be described. An algorithm will be presented for detecting double pulse signature, which can be an indication of the tau neutrino interaction and subsequent decay of the tau lepton inside the detector. The recent results for astrophysical tau neutrinos with three years of IceCube data will be shown. Future prospects for tau neutrino detection in IceCube will be discussed.

Outline

- IceCube detector
- Detection principle
- ν_τ signatures in IceCube
- Lollipop analysis (22 string configuration)
- Double bang analysis
- Double pulse signature analysis (in 3y of IceCube data)
- Conclusions

IceCube detector



86 strings with 60 Digital Optical Modules (DOMs) (IceCube + DeepCore)

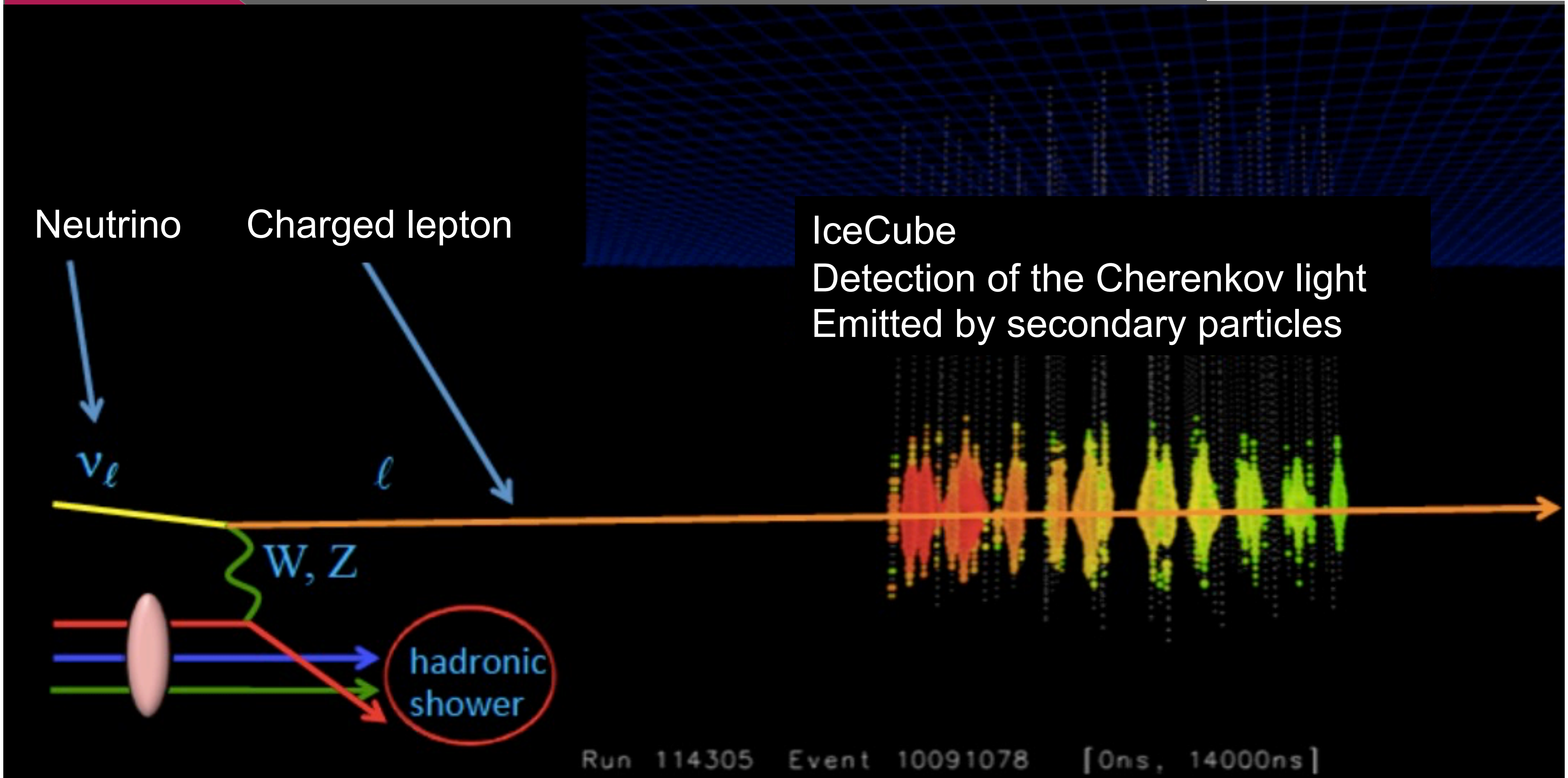
Optical sensor
10” photomultiplier (PMT)
+ in situ signal digitization
in pressure glass sphere

Deployed between
1450 and 2450 m depth

81 IceTop surface stations

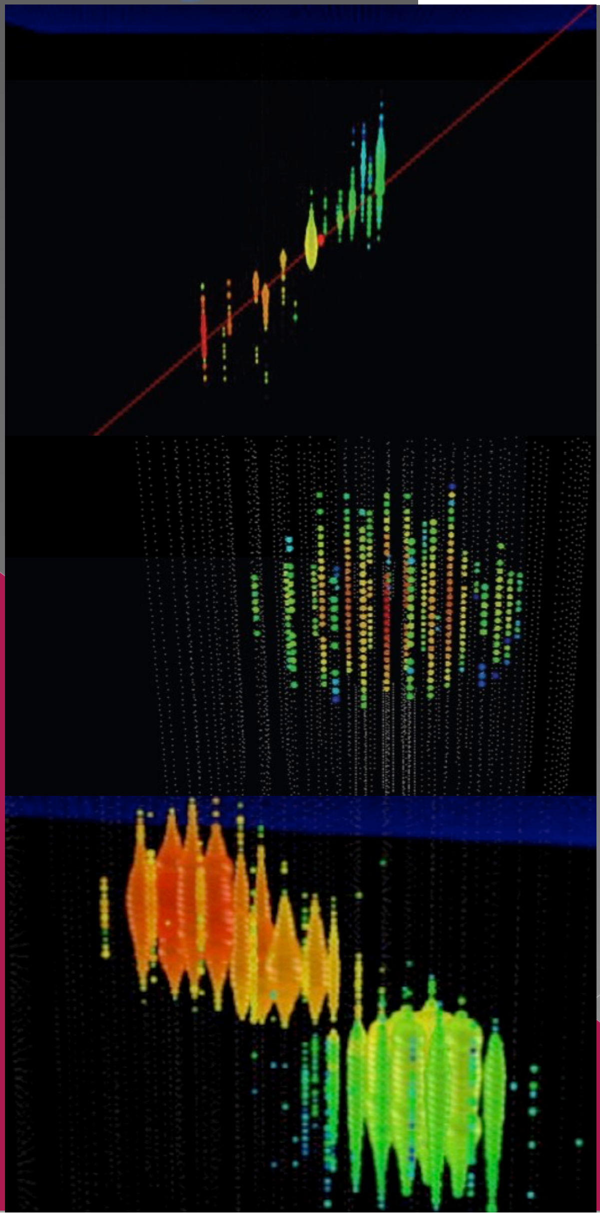
Construction complete December 2010 (data taking since 2005)

Detection Principle



Detection Principle

The characteristic pattern (topology) of the Cherenkov light provides information about the energy, direction, and flavor of the parent neutrino



Track-like events

- good angular resolution, limited energy resolution when not fully contained in the detector volume
- source - ν_μ CC interactions

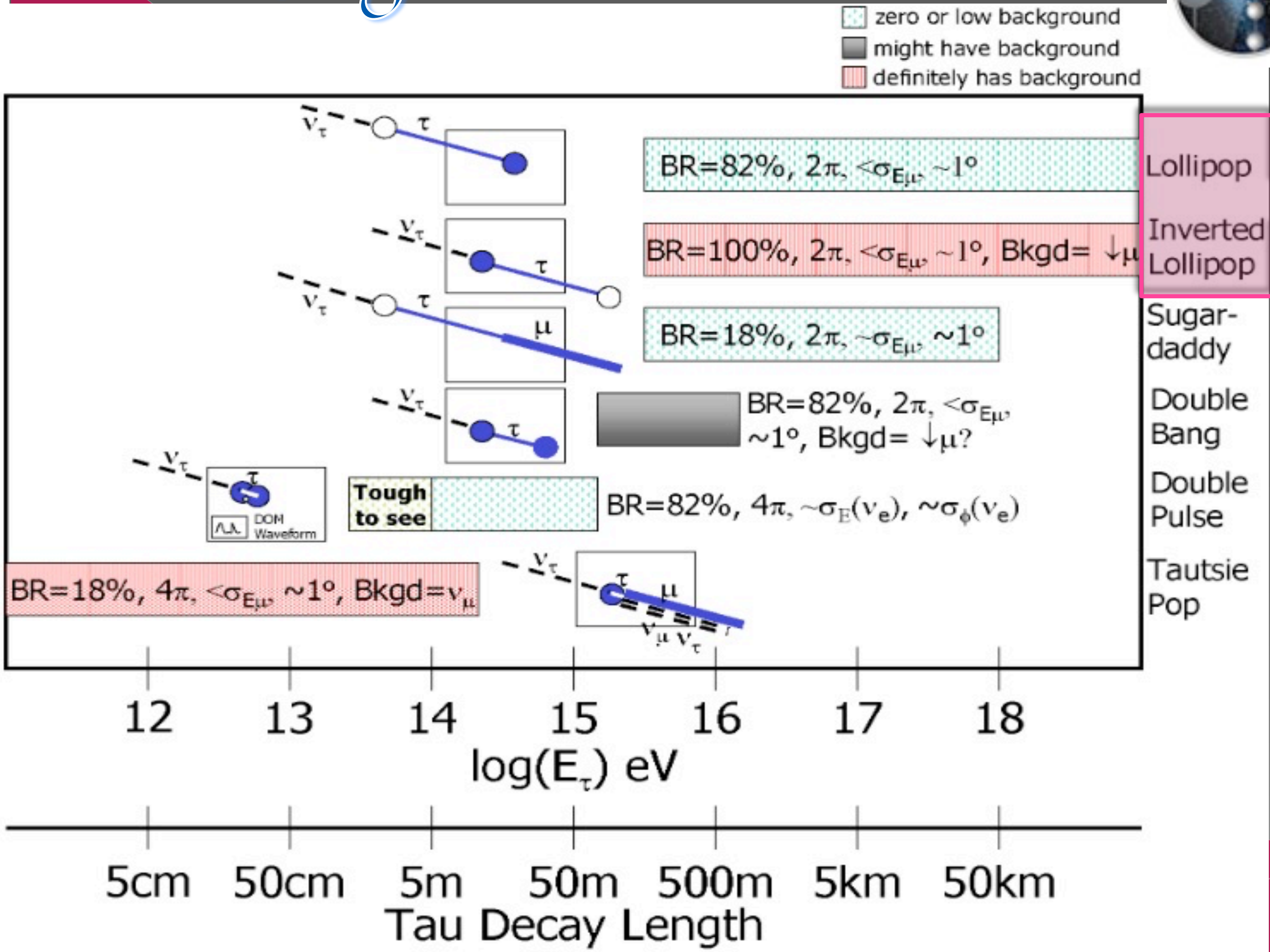
Cascade-like events

- good energy resolution, limited angular resolution
- source - ν_e, ν_μ, ν_τ NC + ν_e, ν_τ CC interactions

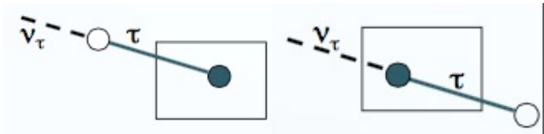
Composite events

- mixture of track-like and cascade-like events or multiple cascade events
- high-energy ν_τ CC as a possible source

ν_τ signatures in IceCube



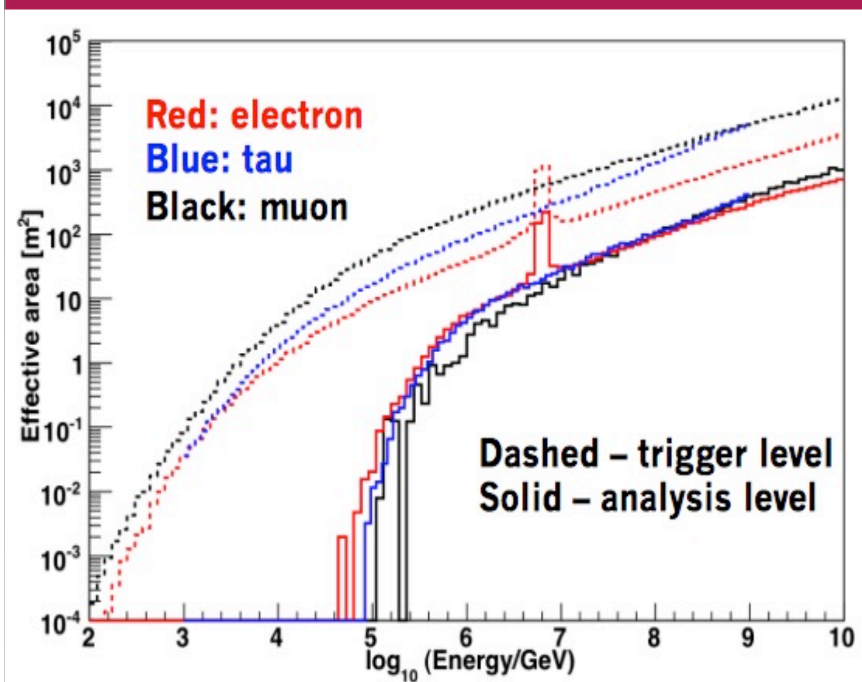
Partially contained double bangs



Lollipop analysis

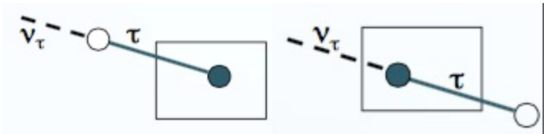
Published in Phys. Rev. D86, 022005 (2012)

- The first dedicated search for PeV-scale tau neutrinos of astrophysical origin
- 22-string configuration with an instrumented volume of roughly 0.25 km^3



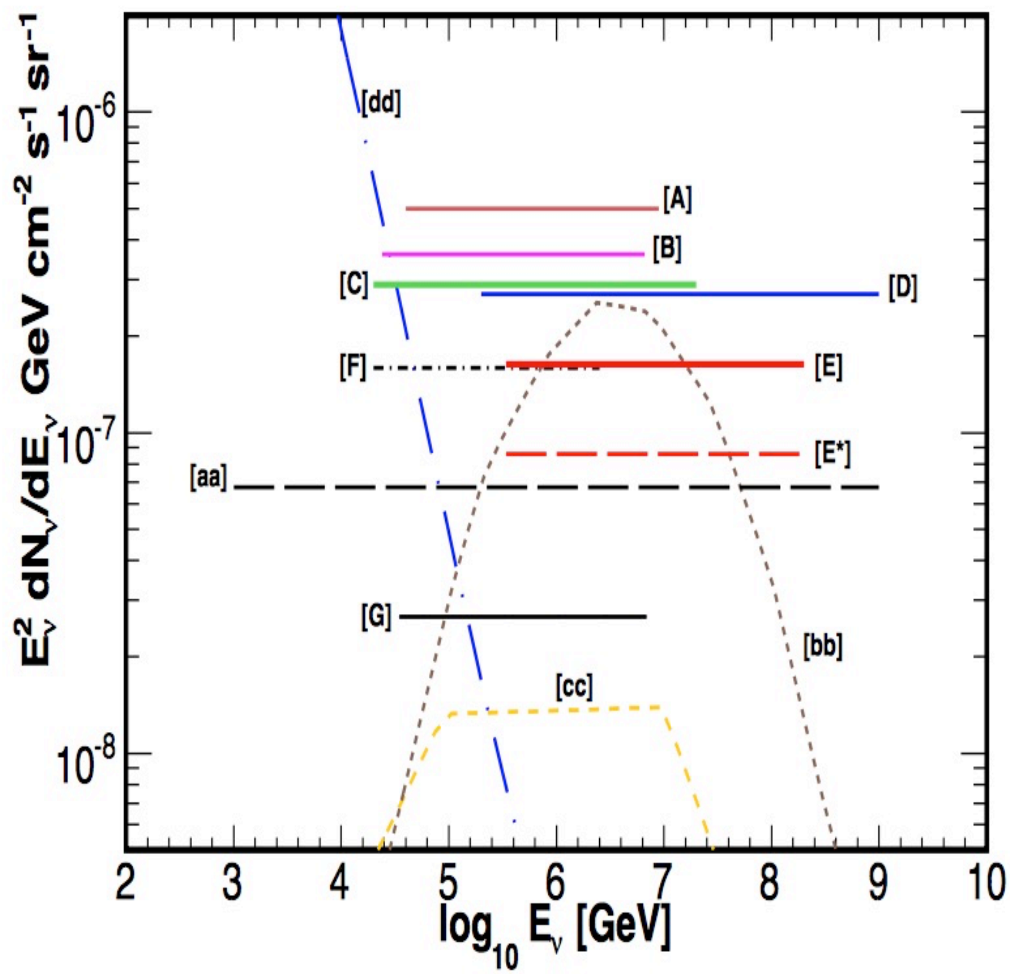
- Predicted background
  0.6 ± 0.19 (stat.) +0.56 (syst) – 0.58 (syst) events
- 3 events observed

(after inspection emerge as being compatible with background)



Lollipop analysis

Published in Phys. Rev. D86, 022005 (2012)

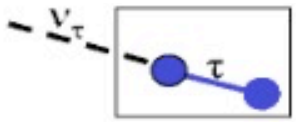


[A]: AMANDA-II cascade all-flavor limit (1001 live-days)
[B]: IC22 cascade all-flavor limit (257 live-days)
[C]: Baikal all-flavor limit (1038 live-days)
[D]: AMANDA-II UHE all-flavor limit (457 live-days)

E: all flavor limit from this analysis
E*: all flavor sensitivity from this analysis

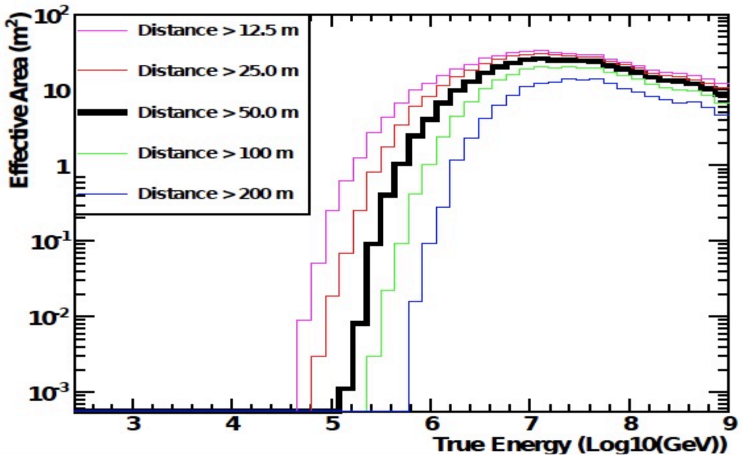
[F]: ANTARES '07-'09 νμ x 3 334 d
[G]: IC40 muon neutrino sensitivity x3

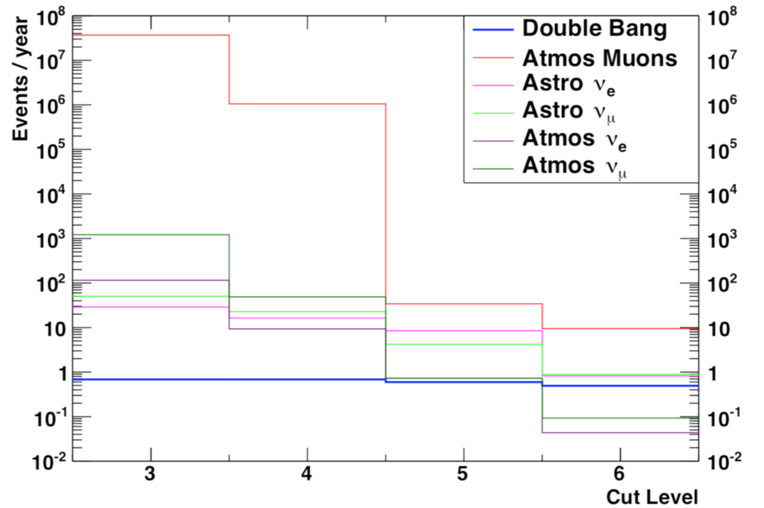
[aa]: Waxman-Bahcall (νμ and νμ) model 1998 × 3/2
[bb]: Stecker AGN (Seyfert) 2005
[cc]: Waxman-Bahcall Prompt GRB model
[dd]: At- mospheric neutrino flux (Bartol + Sarcevic standard model)



Double bang analysis Predicted event rates

A search for well separated double bangs





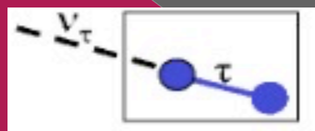
Data Sample	Events in 1 y
Astrophysical ν_τ CC	$(4.93 \pm 0.01) * 10^{-1}$
Atmospheric muons	(9.5 ± 1.8)
Astrophysical ν_e	$(8.2 \pm 1.3) * 10^{-1}$
Astrophysical ν_μ	$(8.9 \pm 0.2) * 10^{-1}$
Atmospheric ν_e	$(4.4 \pm 0.2) * 10^{-2}$
Atmospheric ν_μ	$(9.3 \pm 0.2) * 10^{-2}$

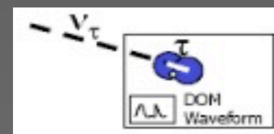
Still background dominated by atmospheric muons. Further studies underway to reduce background.

Astrophysical per flavor flux is $E^2\Phi_\nu = 1.0 * 10^{-8}$ GeV s^{-1} cm^{-2} sr^{-1}

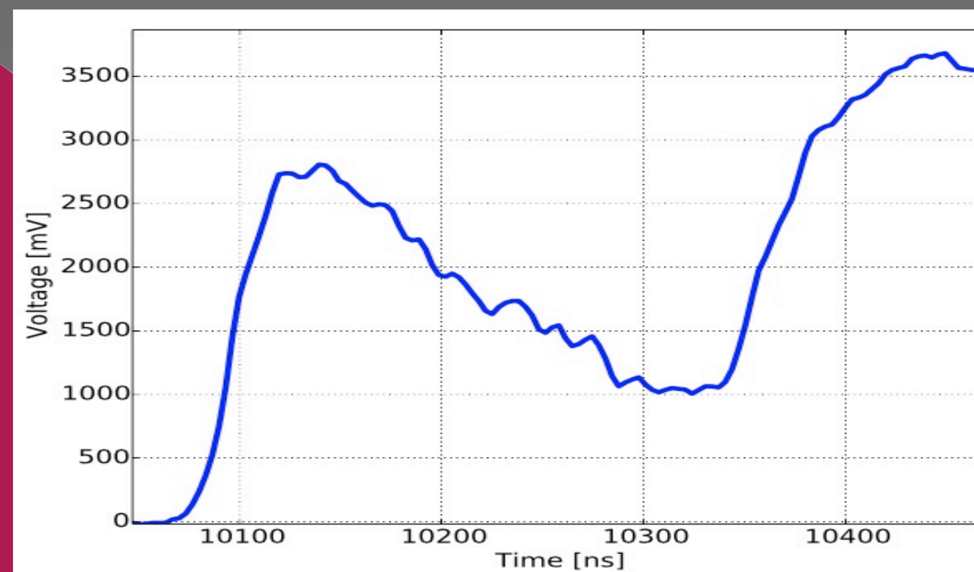
Double Pulse analysis

Double bang → Double pulse





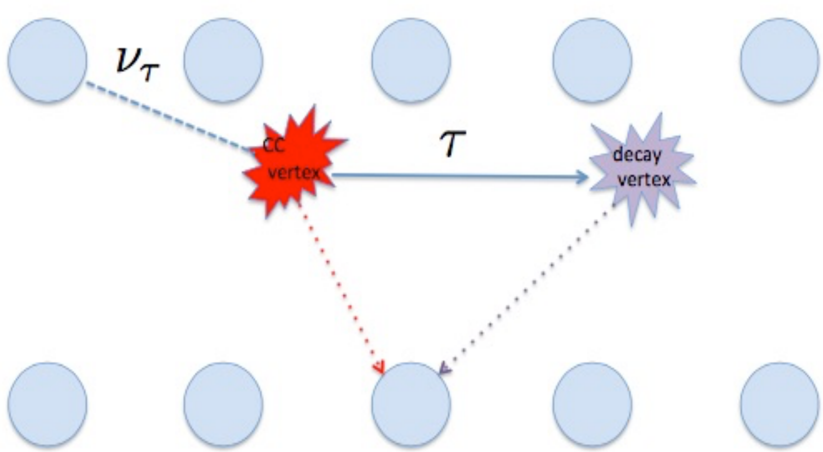
For close cascades,
a double pulse signature
can appear in the digitized waveform



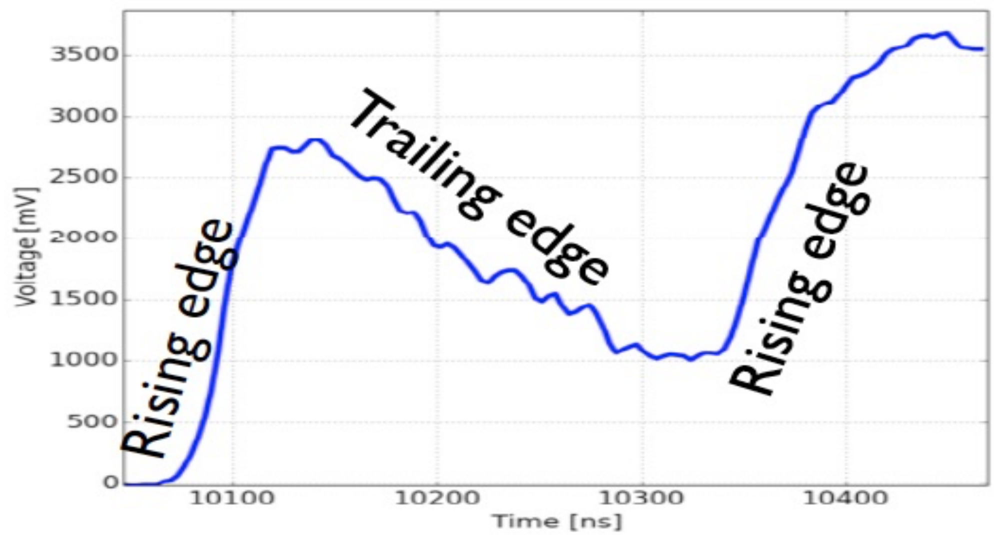
Simulated double pulse waveform
from a ν_τ CC interaction

Double Pulse analysis Signature

Resolved double pulses **will only be produced in high energy ν_τ interactions**
→Event selection: IceCube Extremely High Energy (EHE) filter + at least 2000 PE + more cascade-like event cut + containment cut.
Individual DOM waveforms are then examined for double pulse characteristics



ν_τ double bang event topology

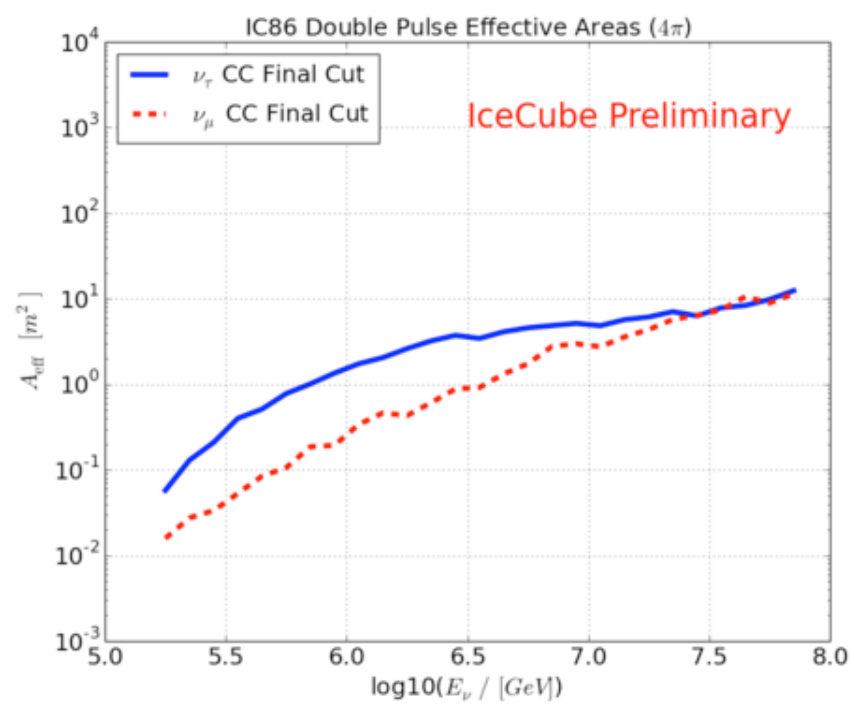


Simulated double pulse waveform from a ν_τ CC interaction

Double Pulse analysis Predicted event rates

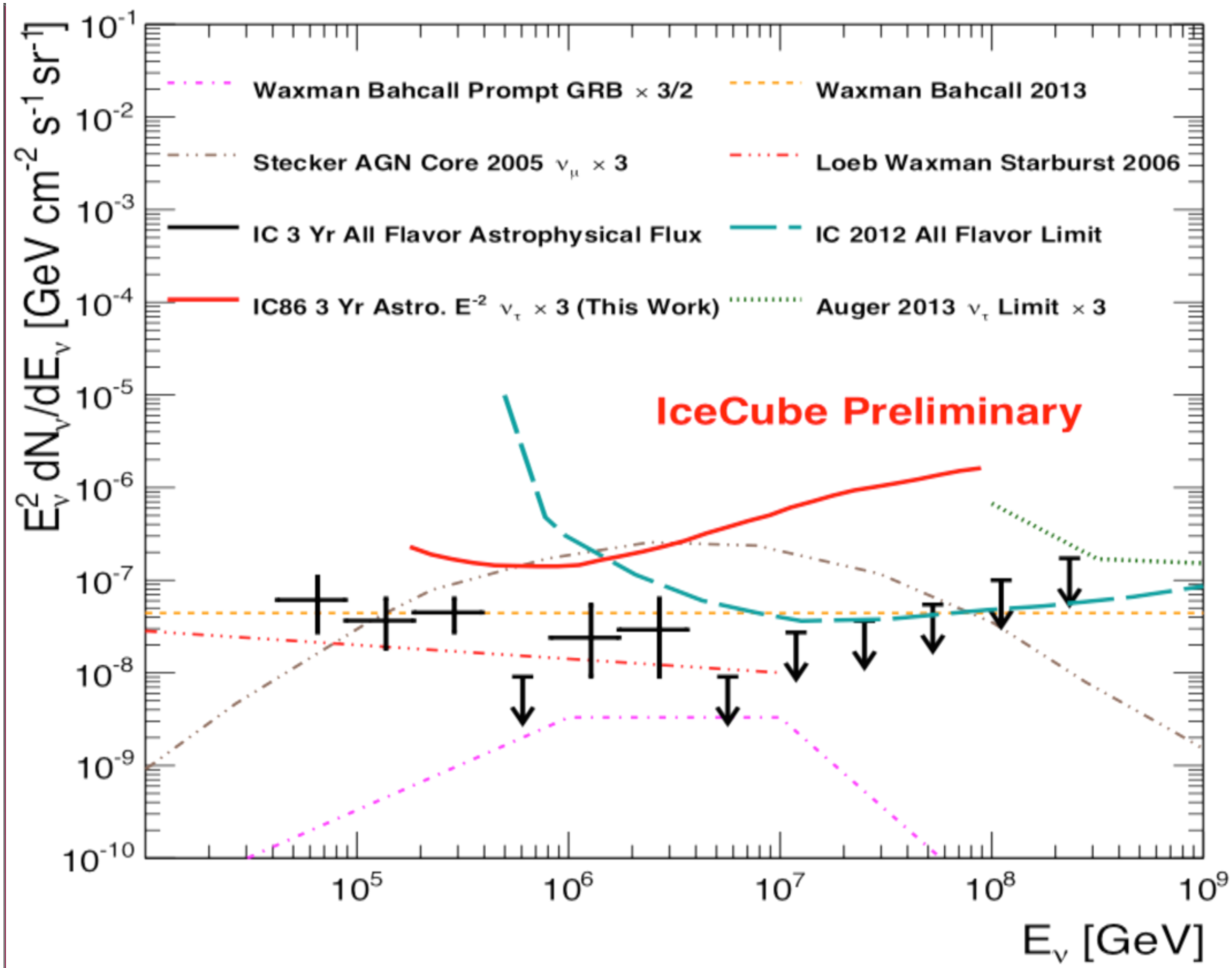
First IceCube search to be more sensitive to tau neutrinos than to any other flavor

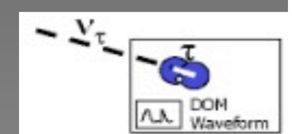
Data Sample	Events in 914 days
Astrophysical ν_τ CC	$(5.4 \pm 0.1) * 10^{-1}$
Astrophysical ν_μ CC	$(1.8 \pm 0.1) * 10^{-1}$
Astrophysical ν_e	$(6.0 \pm 1.7) * 10^{-2}$
Atmospheric ν	$(3.2 \pm 1.4) * 10^{-2}$
Atmospheric muons	$(7.2 \pm 5.8) * 10^{-2}$



Astrophysical per flavor flux is
$E^2\Phi_\nu = 1.0 * 10^{-8}$ GeV s^{-1} cm^{-2} sr^{-1}

Double pulse analysis results





No candidate events found in 914 days of data
ν_τ flux limit is 5.1 * 10-8 GeV s-1 cm-2 sr-1 between 0.21 and 72 PeV

Conclusions

- **No astrophysical ν_τ candidate events observed yet**
- Different types of IceCube analyses are undergoing
  - **Double bang** (ongoing studies to reduce background)
  - **Double pulse search**, which is more sensitive to PeV tau neutrinos than to any other flavor, can be enriched with more data (4^{th} year)
  - … new ideas are under investigation
- Proposed high-energy array will have significantly higher (5 – 10 times) sensitivity to astrophysical tau neutrinos

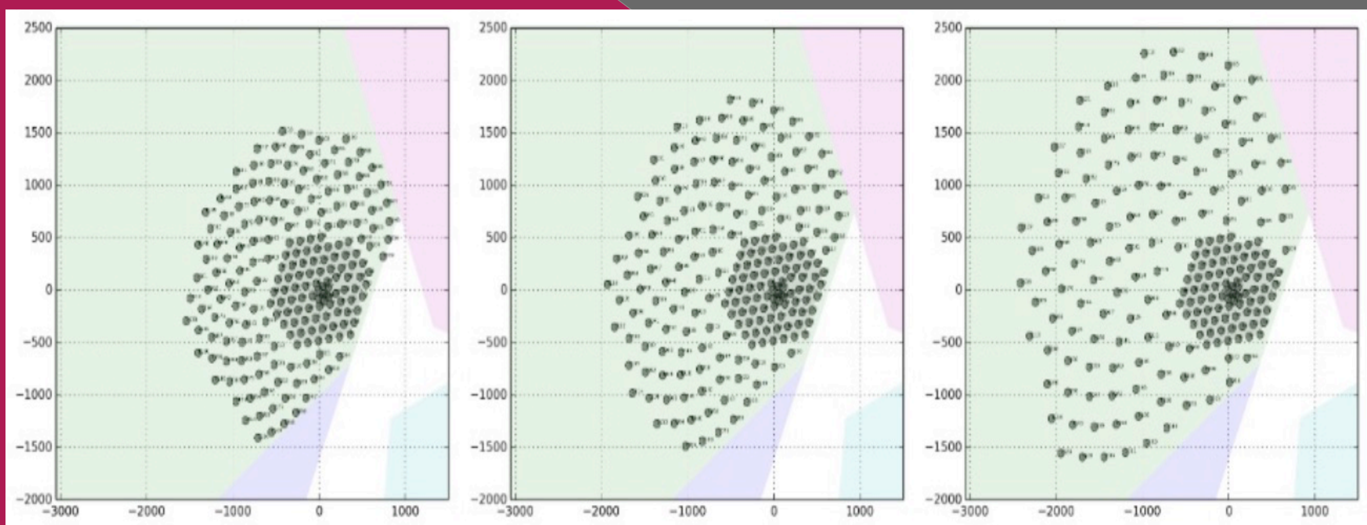
BACKUP SLIDES

High Energy Array and PINGU

arXiv 1412.5106, (2014).

High Energy Array:

• The sensitivity studies are underway using full detector simulations of several benchmark geometries.



String spacing: ~240m
~ 200 PeV
cascade events/10 years
~ 500 – 1000 ν_μ above
100 TeV (μ energy)

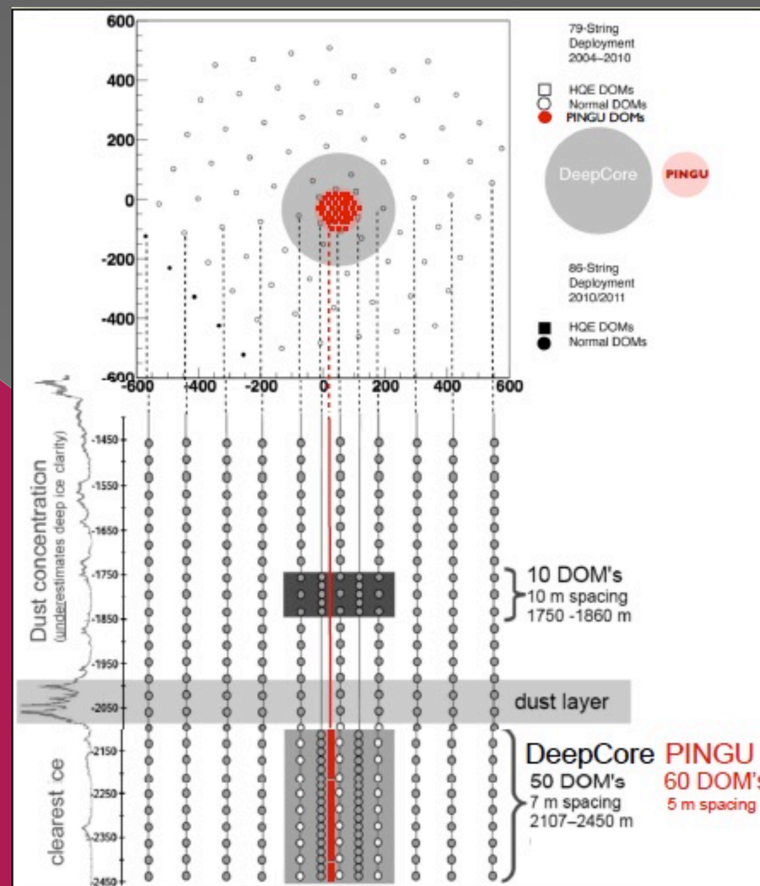
comparable number of strings -> neutrino energies above 50 TeV with high efficiency

High Energy Array and PINGU

arXiv 1401.2046, (2014).

Precision IceCube Next Generation Upgrade (PINGU):
- low-energy in-fill array

- **<u>Neutrino mass ordering</u>**
- Atmospheric muon neutrino disappearance
- Tau neutrino appearance
- θ_{23} mixing angle
- probe the lower WIMP dark matter mass range
- open the possibility of future neutrino-based tomography of the Earth



New PINGU baseline geometry:
40 strings with 20m horizontal separation;
96 DOMs per string with 3m vertical separation

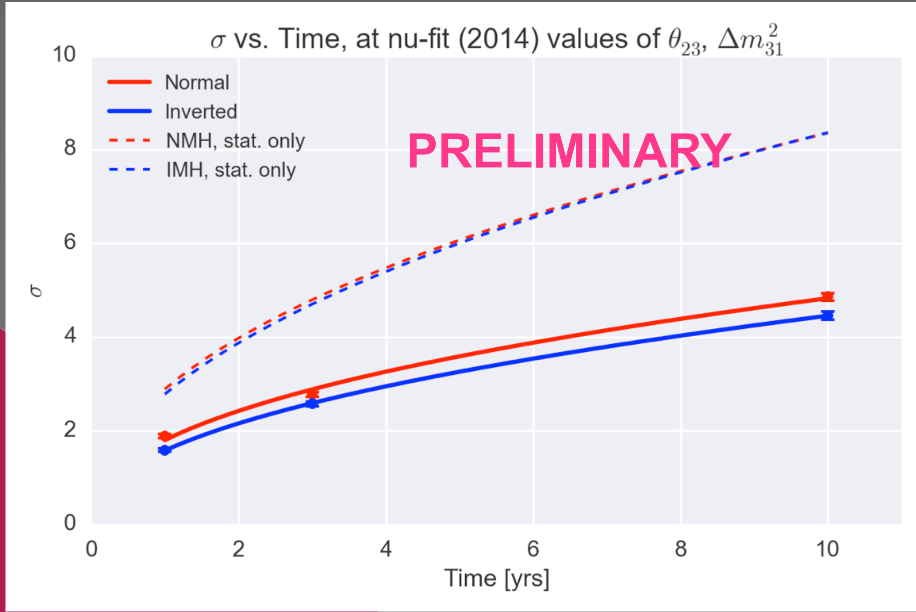
High Energy Array and PINGU

arXiv 1401.2046, (2014).

Precision IceCube Next Generation Upgrade (PINGU):

• low-energy in-fill array

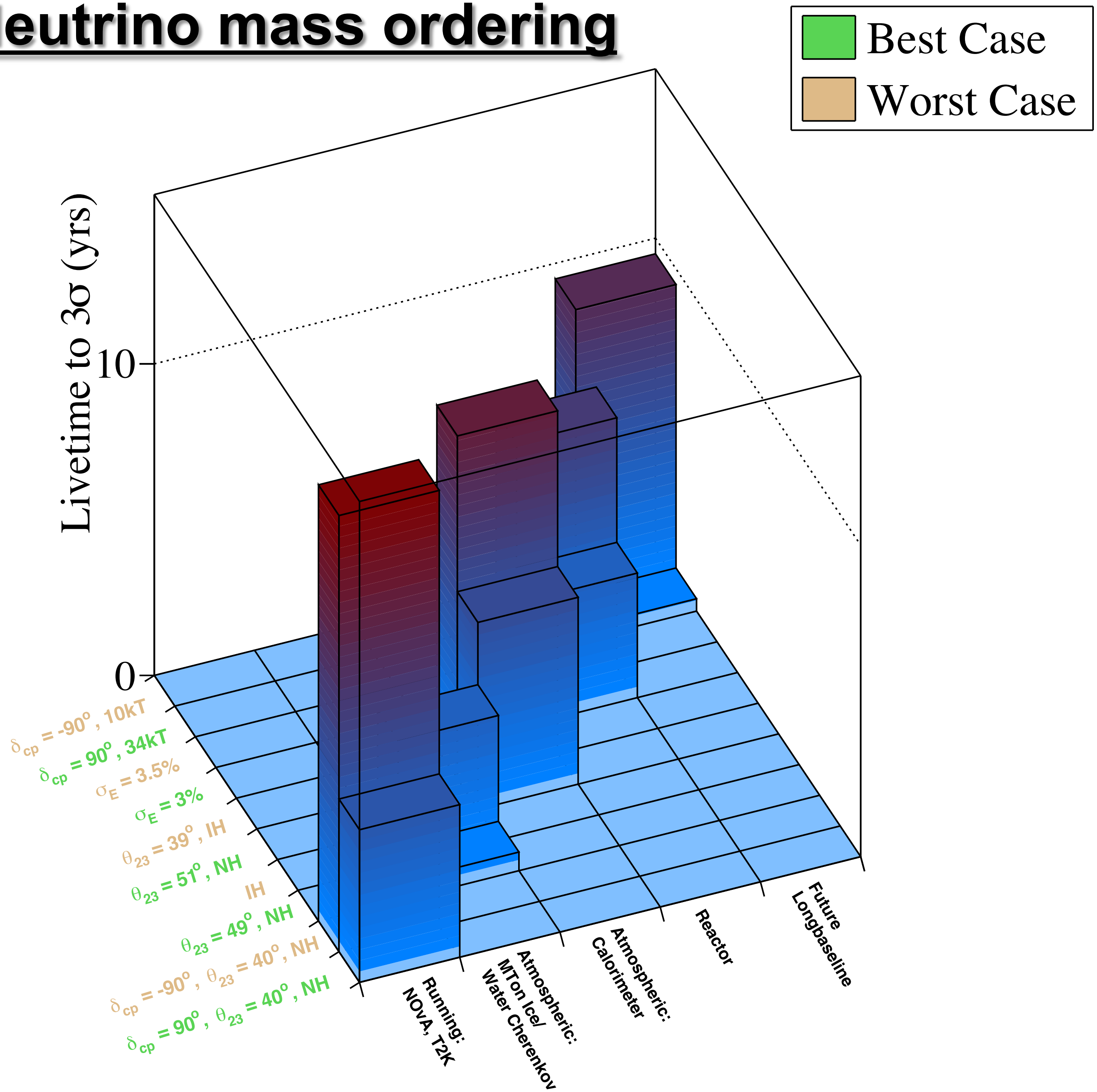
• **Neutrino mass ordering**
• Atmospheric muon neutrino disappearance
• Tau neutrino appearance
• θ_{23} mixing angle
• probe the lower WIMP dark matter mass range
• open the possibility of future neutrino-based tomography of the Earth



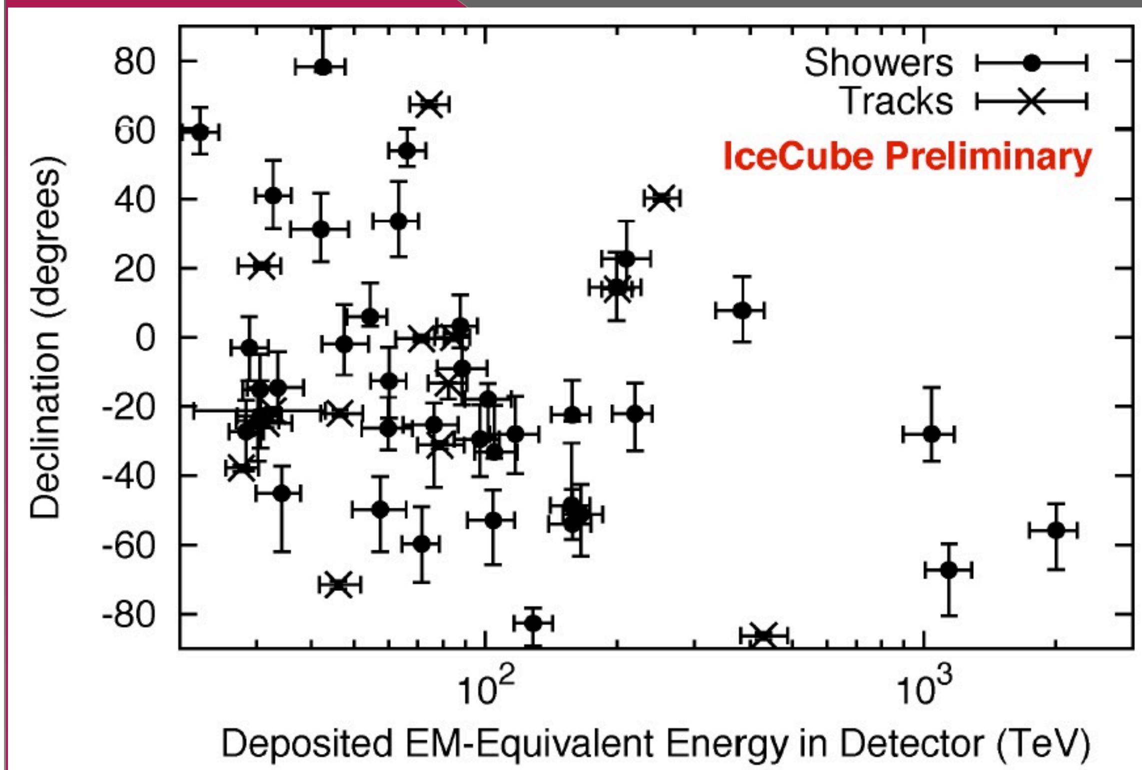
Still reach 3σ in ~3.5 – 4 yrs

New PINGU baseline geometry:
40 strings with 20m horizontal separation;
96 DOMs per string with 3m vertical separation

- **Neutrino mass ordering**



High-Energy Astrophysical Neutrinos



54 neutrino candidate events

39 cascade-like,
15 track-like events

dominant component:
cascade-like events
from the southern sky
(down-going)

The analysis was recently enriched with the fourth year of data (1347 days of total effective detector live-time).

Evidence for Extraterrestrial Neutrinos in four years of data