



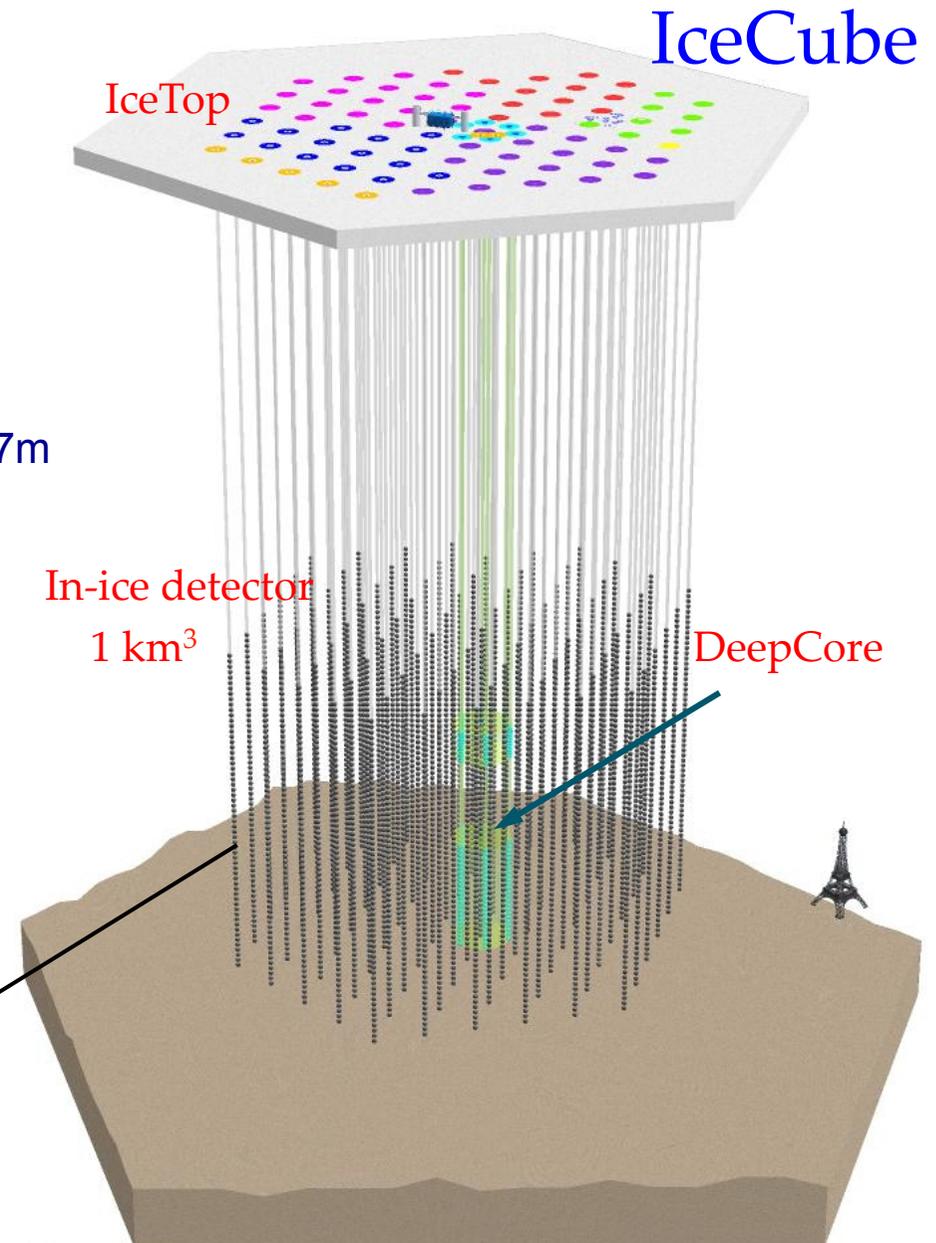
# The latest IceCube results

**K. Mase, Chiba Univ.**

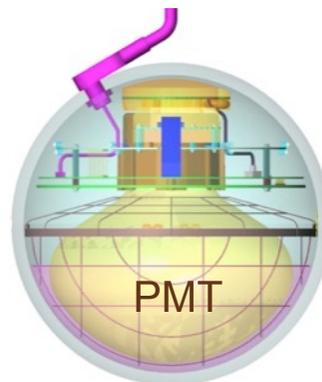


# The IceCube detector

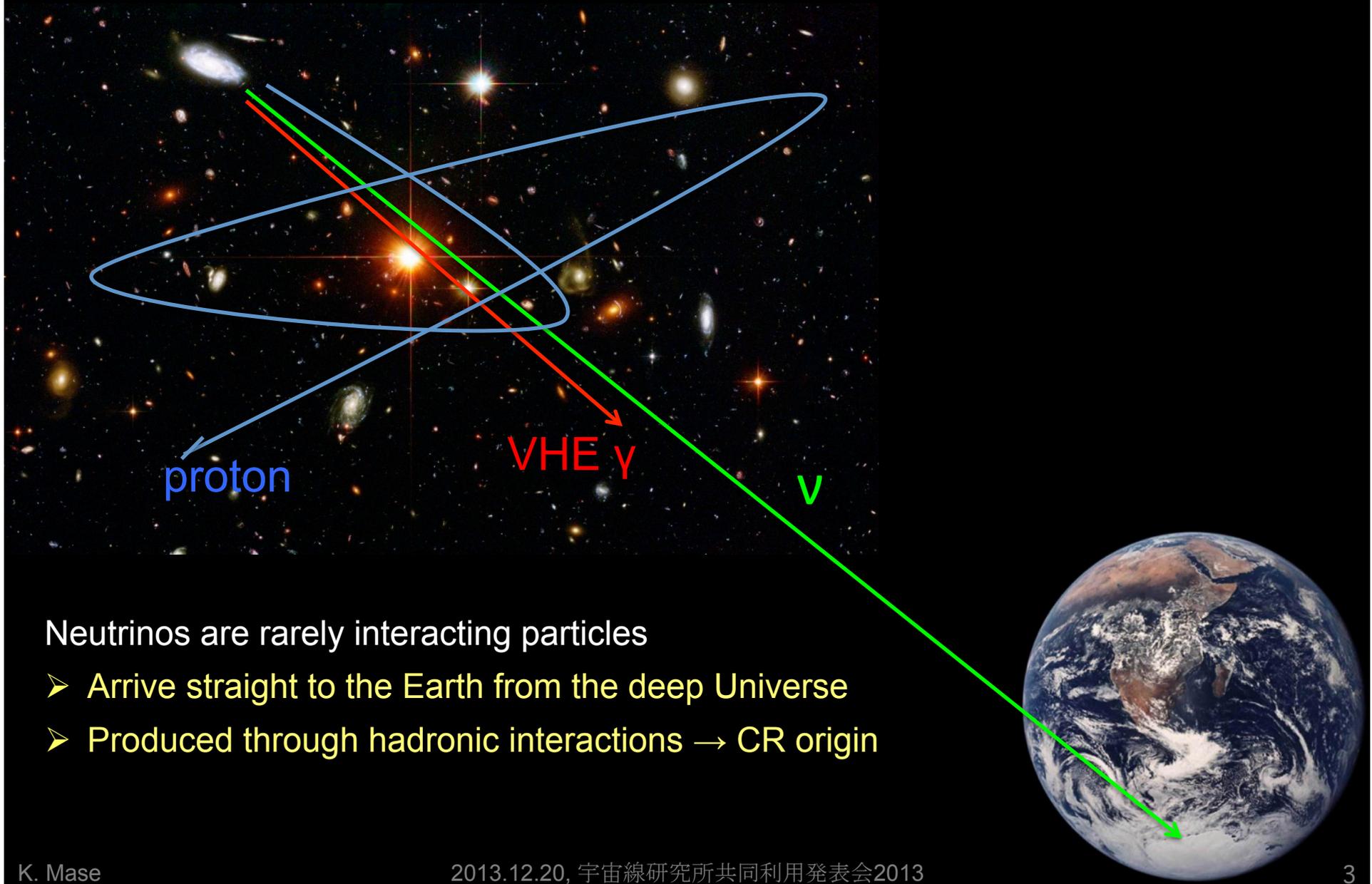
- ◇ Deployed in the Antarctica glacier
- ◇ In-ice + IceTop + DeepCore
- ◇ 86 strings (completed in 2010!)
- ◇ ~ 5,000 photo-multiplier tubes (PMTs)
- ◇ Detector volume: ~ 1 km<sup>3</sup>
- ◇ Detector spacing: horizontal 125m, vertical 17m
- ◇ ATWD 300MSPS
  - 3 different gains (x16, x2, x0.25)
- ◇ FADC for long duration pulse (6.4 μs)
- ◇ Targets for cosmic high energy neutrinos (mainly >~ 100 GeV)



Digital Optical Module (DOM)

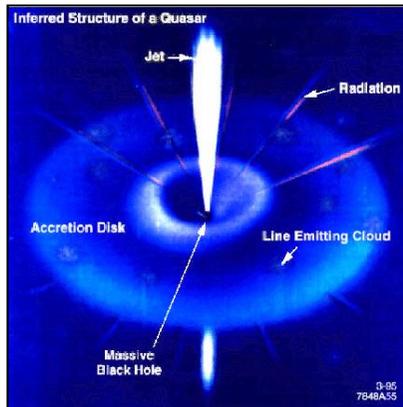


# ■ Why neutrinos to observe objects



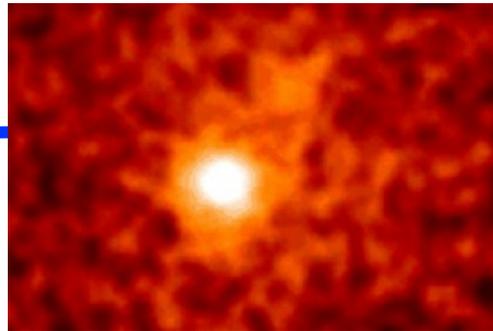
# Targets

Explore the universe with neutrinos



■ AGNs

■ Cosmic ray origin

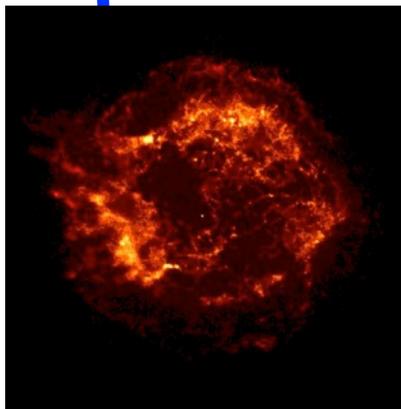


■ GRBs

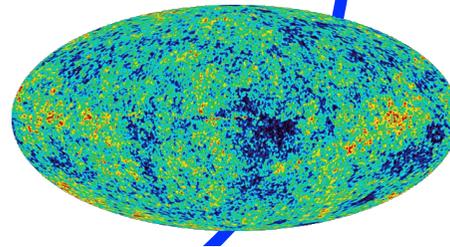


■ Dark Matter

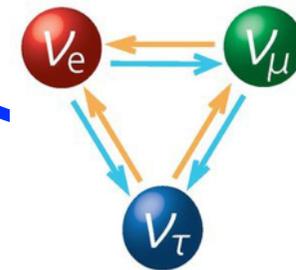
■ Particle physics



■ Supernova



■ Cosmogenic neutrinos

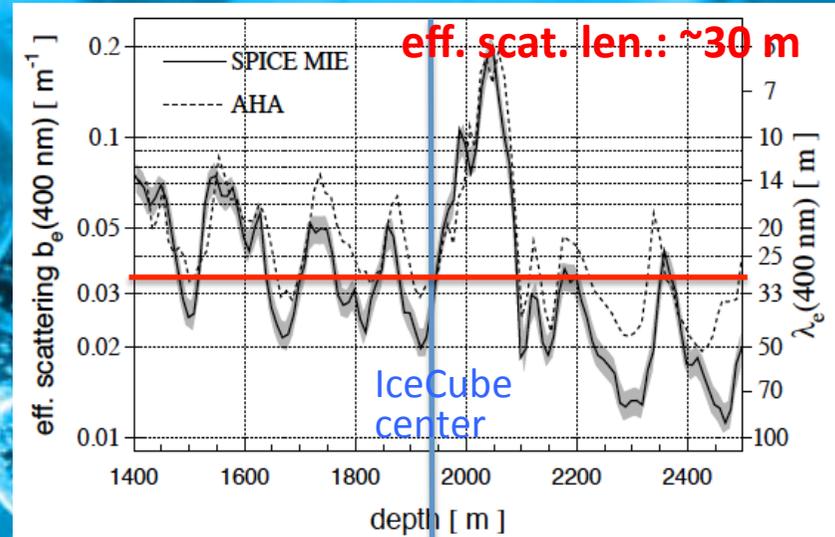
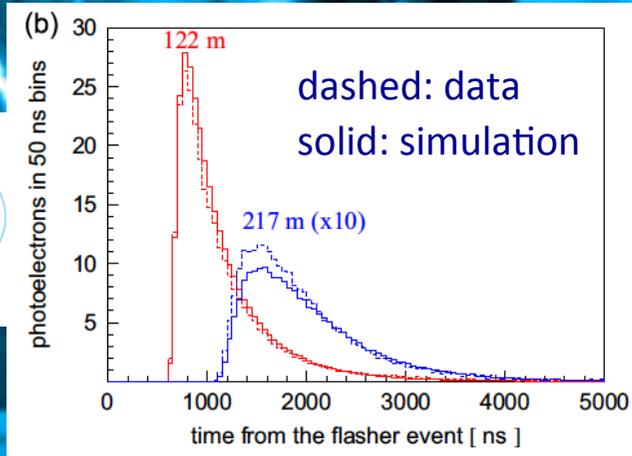
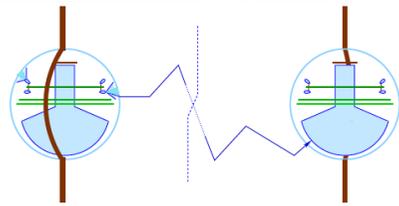


■ Neutrino oscillation

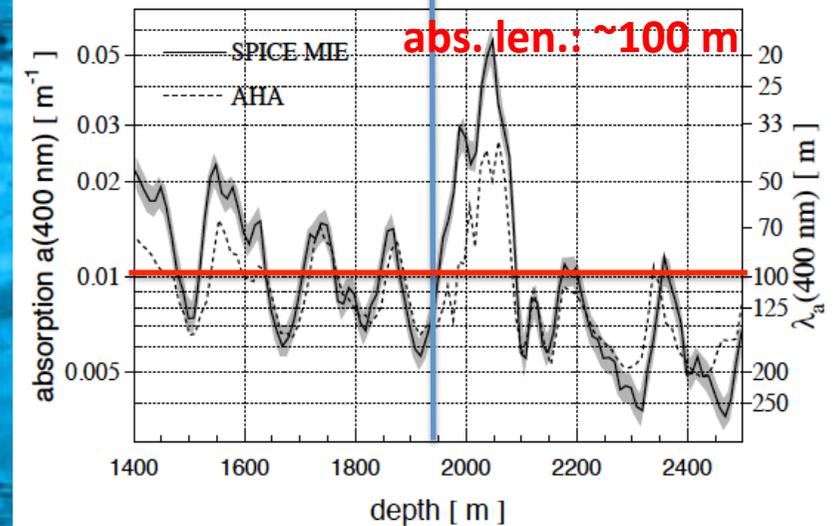
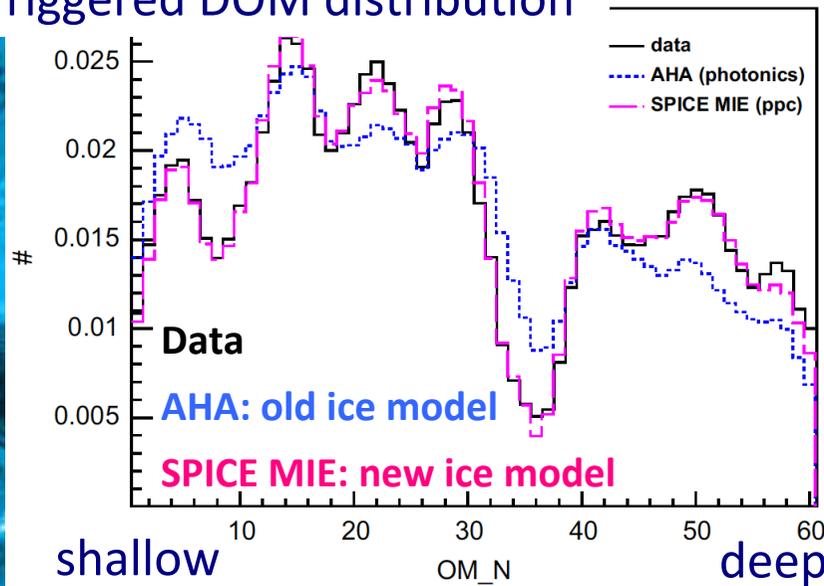
# Calibration of our detector: ice

Ice properties calibrated by LEDs installed in DOMs

NIM A, 711, 73 (2013)



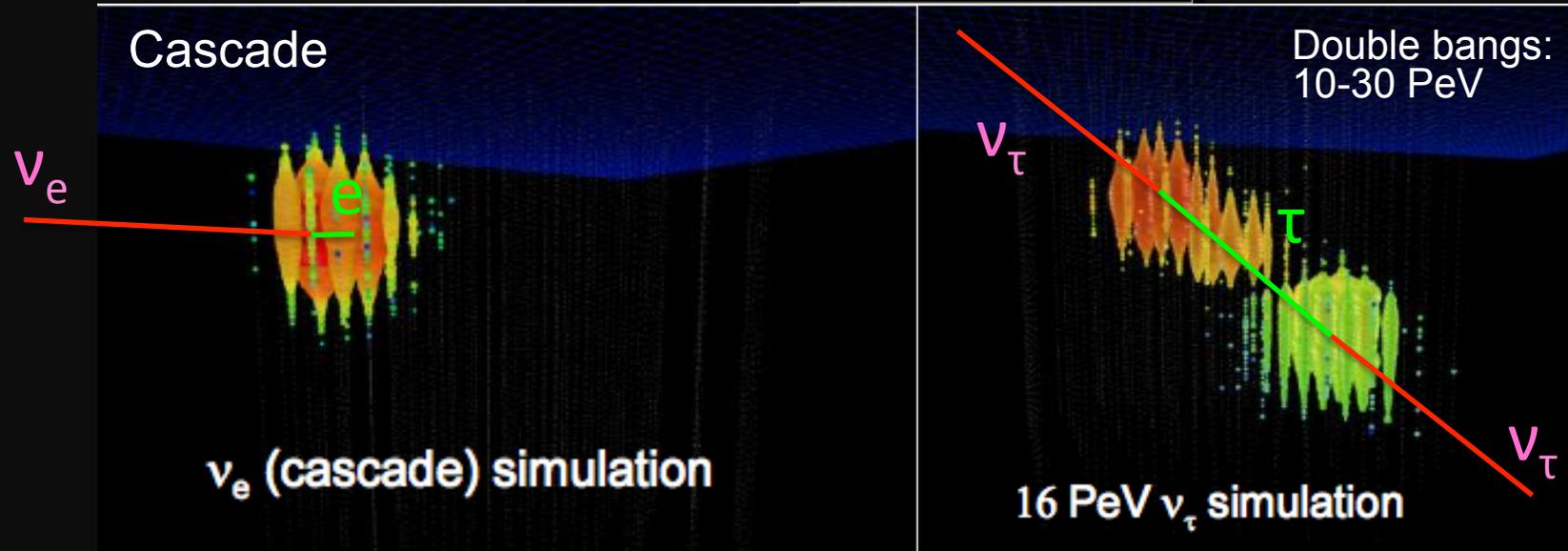
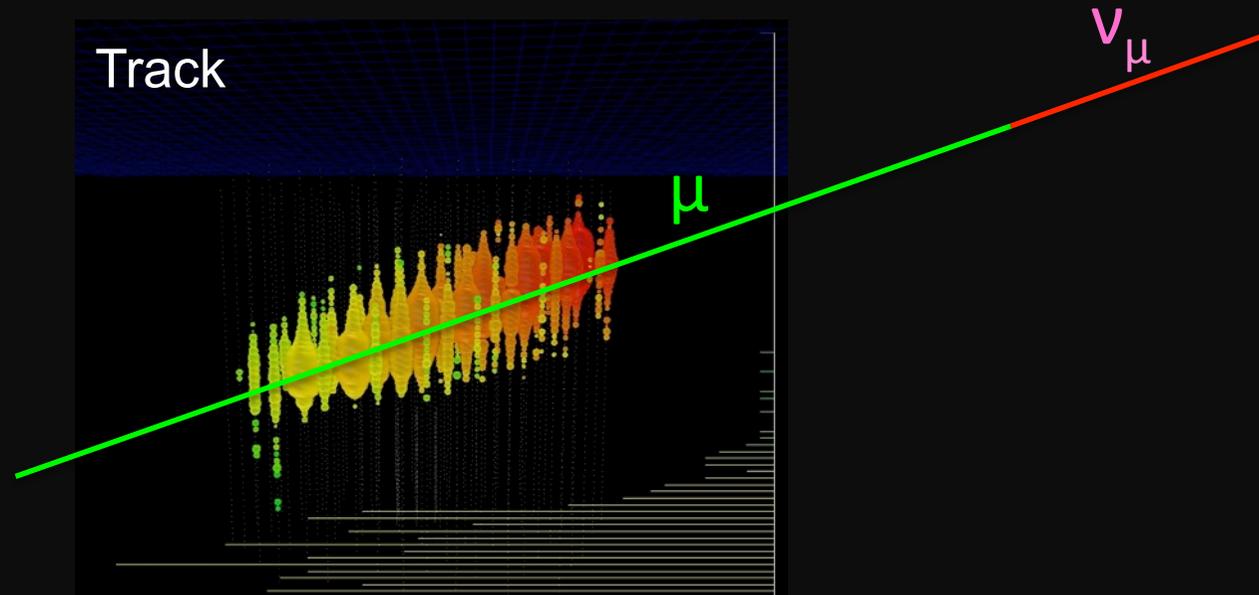
## Triggered DOM distribution



**New ice model describes our data better!**

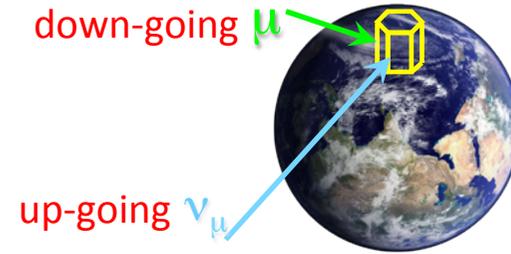
# Particle identification

Angular resolution  
Tracks:  $\sim 1^\circ$   
Cascades:  $\sim 10^\circ$

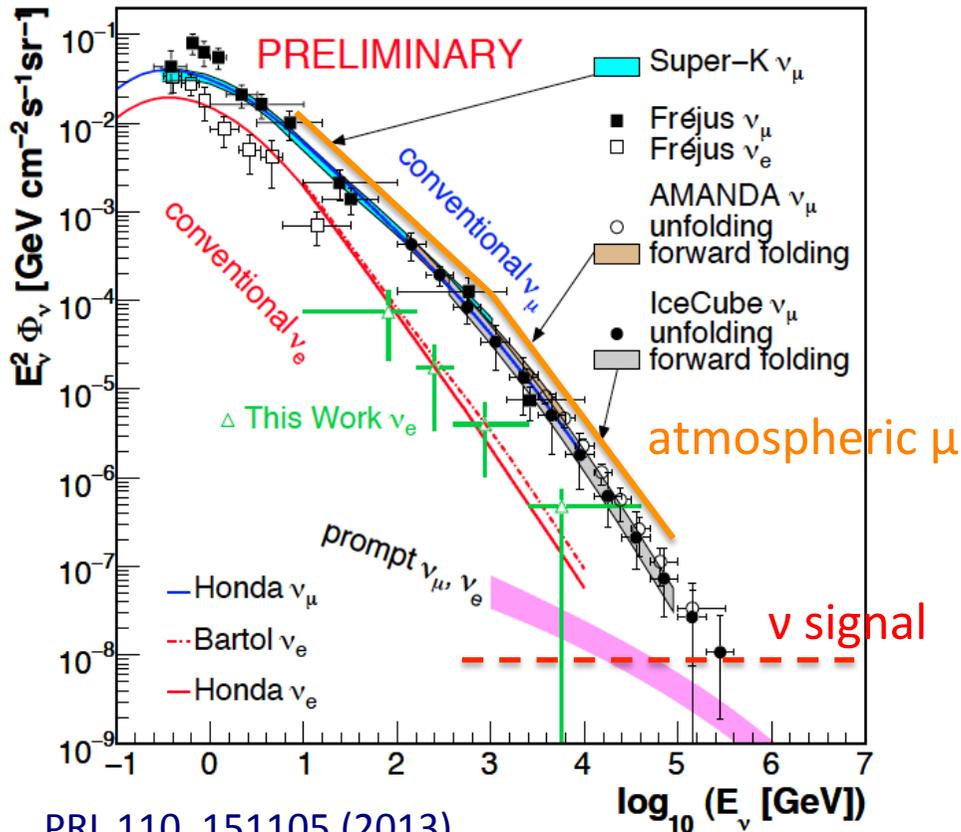


Note: neutral current events also generate cascades

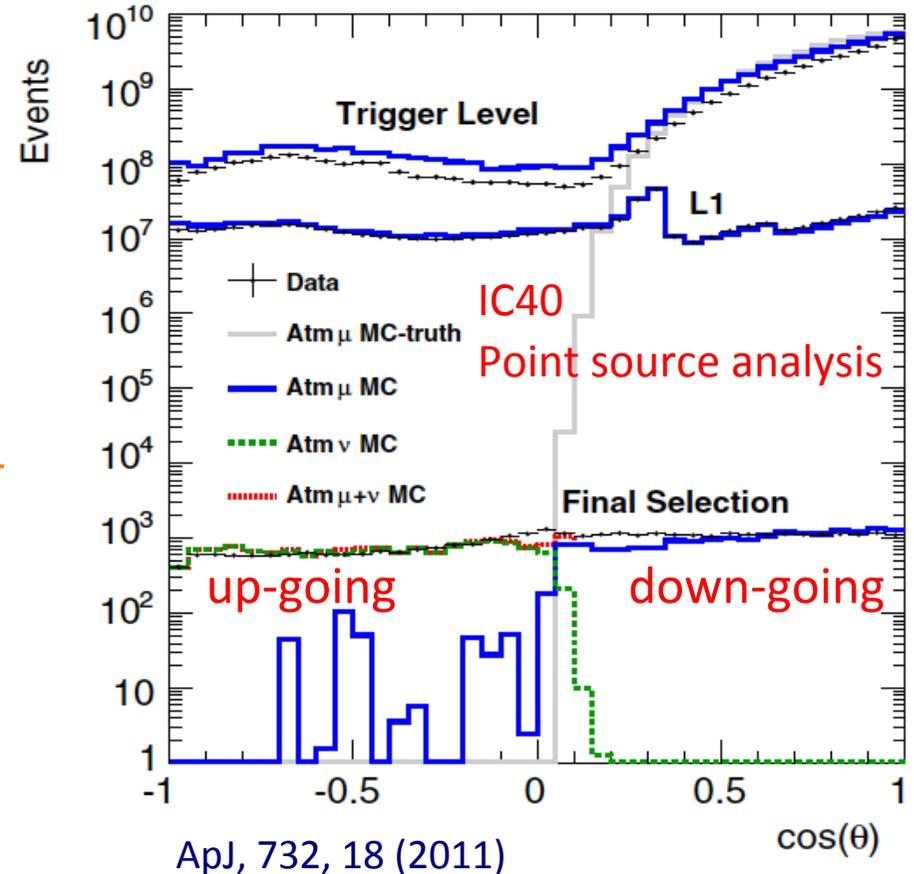
# Backgrounds



Energy spectra @ surface



Zenith angle distribution @ detector



- Three main backgrounds: **Atm μ**, **Atm ν**, **prompt ν** (all CR originated)
- Essentially **energy** and **zenith angle** information used for signal searches

# Two cascade like events found in 2011-2012 data

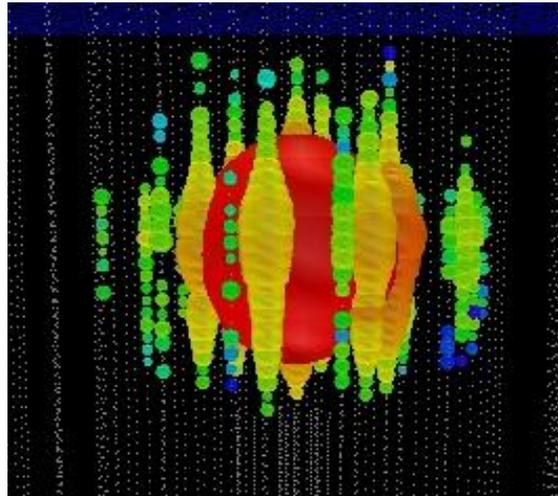
May, 2011 - May, 2012 (350.9 days), IC86 configuration

PRL 111, 021103 (2013)

Either CC interaction of  $\nu_e$  or NC interaction of any flavor  $\nu$

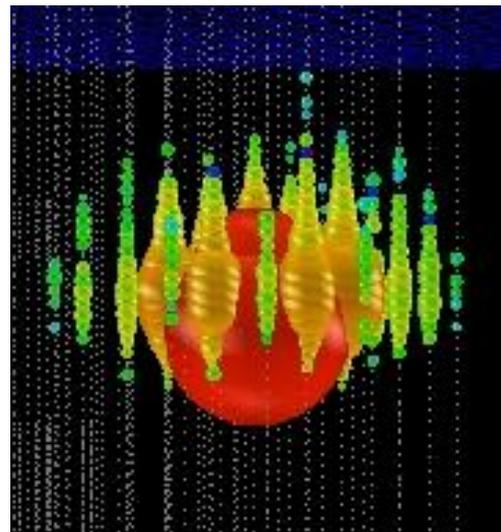
## “Bert”

Aug., 9<sup>th</sup>, 2011  
Run 118545  
-Event 63733662  
NPE:  $7.0 \times 10^4$   
NDOM: 354  
 $1.04 \pm 0.16$  PeV



## “Ernie”

Jan, 3<sup>rd</sup>, 2012  
Run 119316  
-Event 36556705  
NPE:  $9.6 \times 10^4$   
NDOM: 312  
 $1.14 \pm 0.17$  PeV



	event rate in 615.9 days
Atmospheric muons	$0.038 \pm 0.004$
conventional atmospheric neutrinos	$0.012 \pm 0.001$
prompt neutrinos*	$0.033 \pm 0.001$
<b>total background</b>	<b><math>0.082 \pm 0.004</math></b>

\* R. Enberg et al., PRD78, 043005 (2008)

Significance:  $2.8\sigma$

Highest energy neutrinos ever seen!

# ■ Bert visits Tokyo

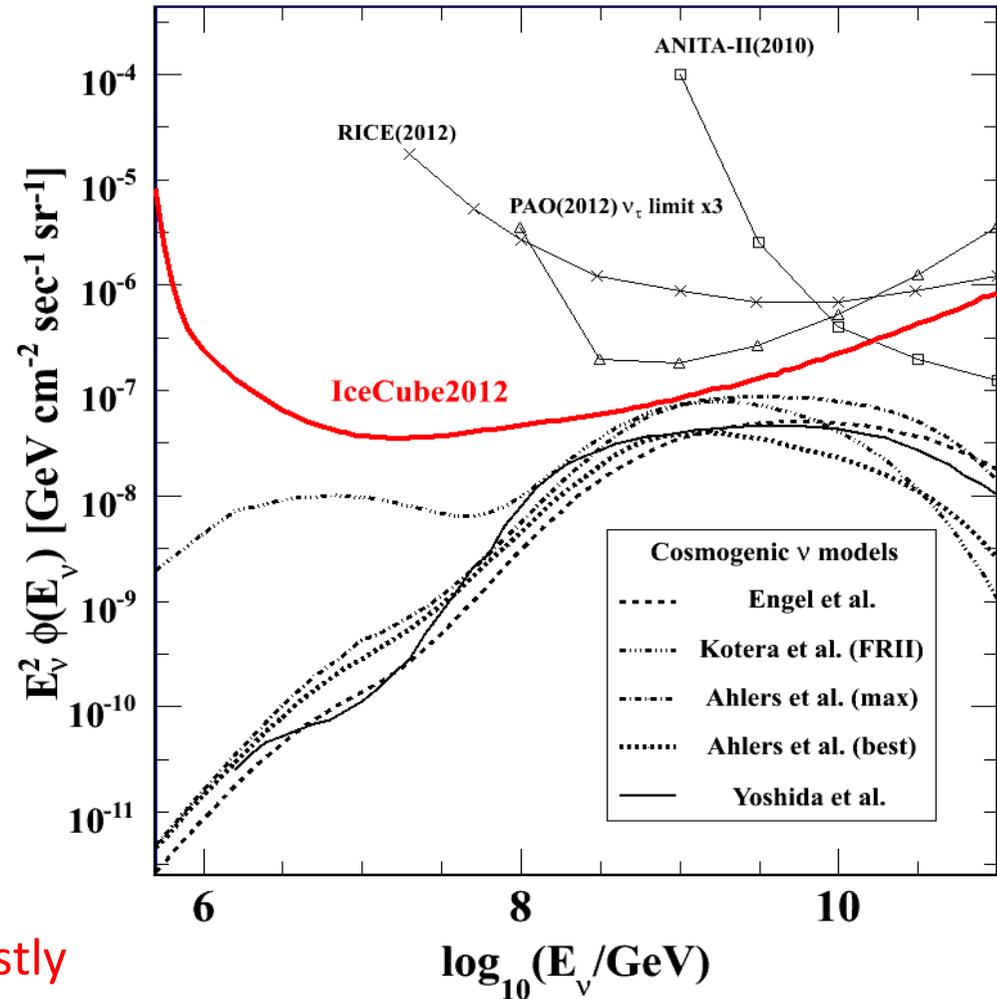
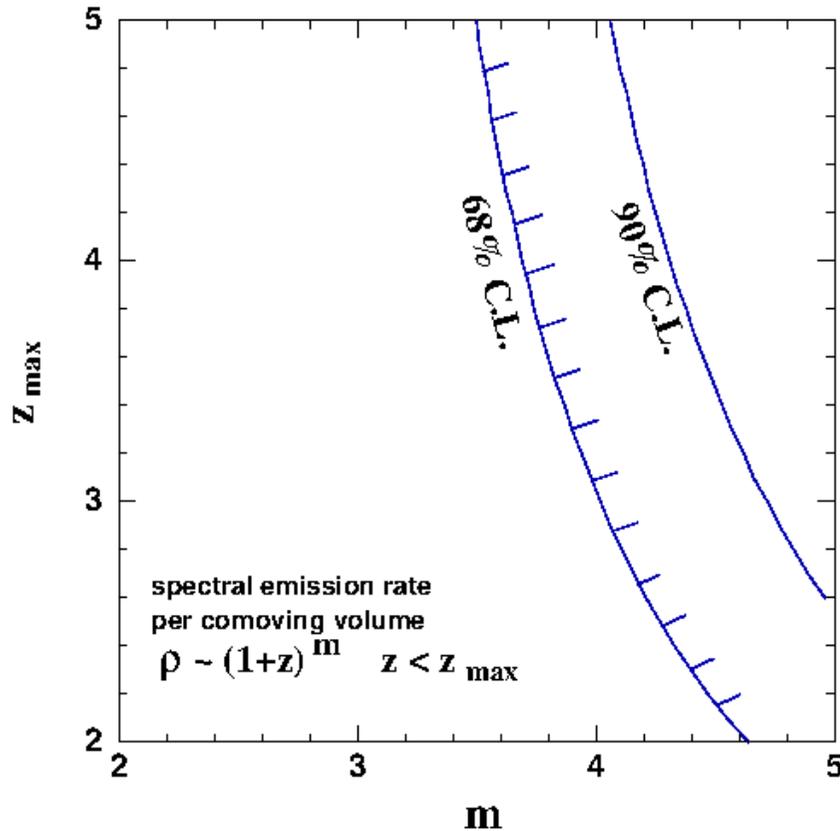


# Limits on EHECR origin

Energies of two PeV events are too low to be explained by cosmogenic neutrinos

No events observed above 100 PeV

PRD, 88, 112008 (2013)



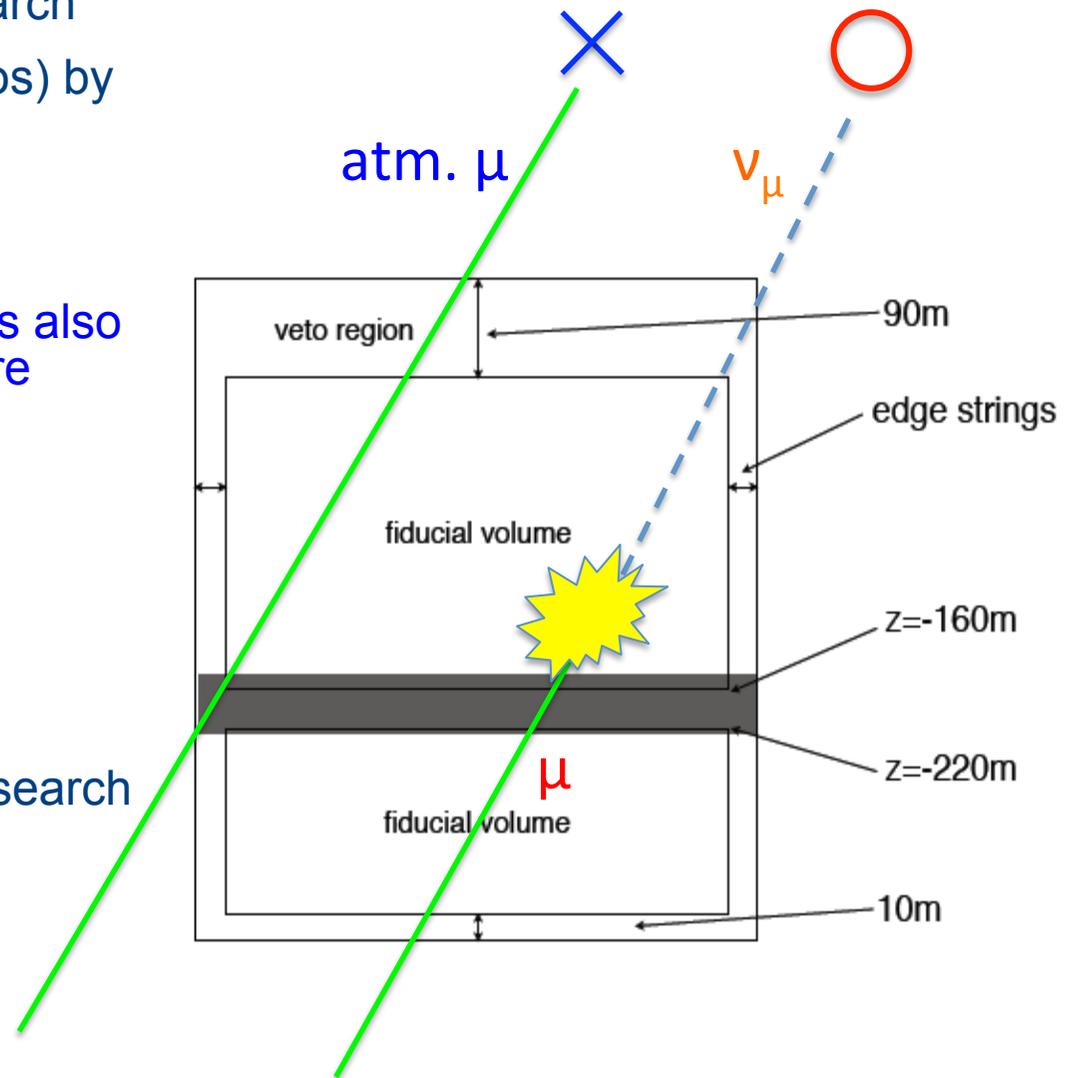
High evolution models ( $m > 4$ ) are mostly ruled out such as FR-II class of AGN

differential limit per one energy decade

# High energy starting event search

Science, 342, 1242856 (2013)

- Follow-up of the EHE neutrino search
- Search contained events (neutrinos) by using outer layers as veto
- Atmospheric muon backgrounds reduced
- Atmospheric neutrino backgrounds also reduced as atmospheric muons are normally accompanied
- Also sensitive to the southern sky
- 420 Mton fiducial mass
- All flavor
- > 50 TeV
- 3 times better than EHE neutrino search @ 1 PeV



# Deposited energy and zenith angle distributions

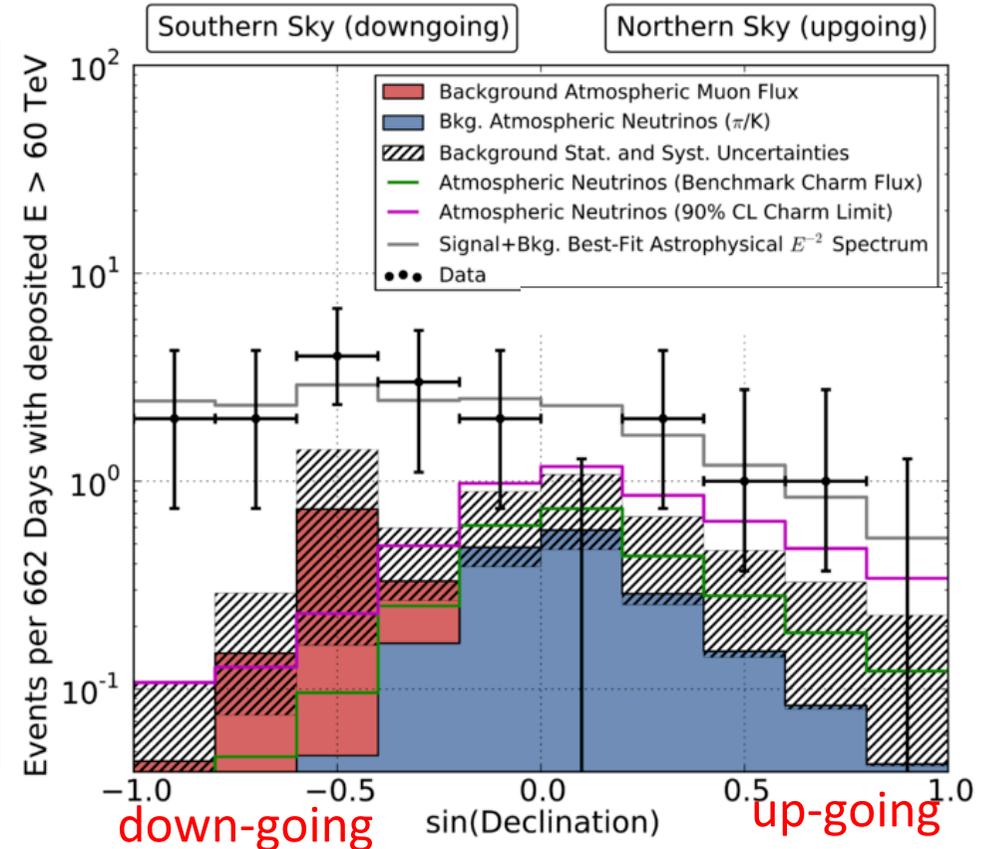
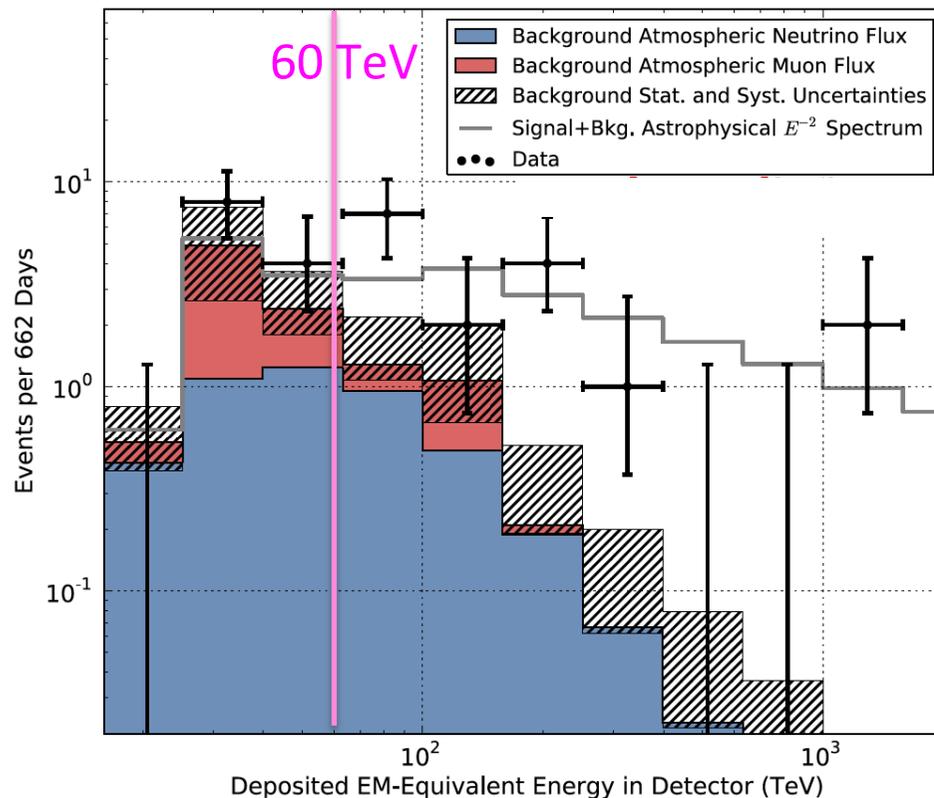
Other 26 events found! (19 cascades, 7 tracks)

Significance:  $4.1\sigma$  (26+2 events combined)

Science, 342, 1242856 (2013)

Expected BG:  $10.6^{+5.0}_{-3.6}$

$E > 60 \text{ TeV}$



- Energy spectrum harder than that of backgrounds
- Best fit:  $E^{-2.2 \pm 0.4}$
- $E^2\phi = 3.6 \pm 1.2 \times 10^{-8} \text{ GeV/cm}^2/\text{s}/\text{sr}$  (3 flavors)

# Sky map and the significance

Test null hypothesis against the most likely

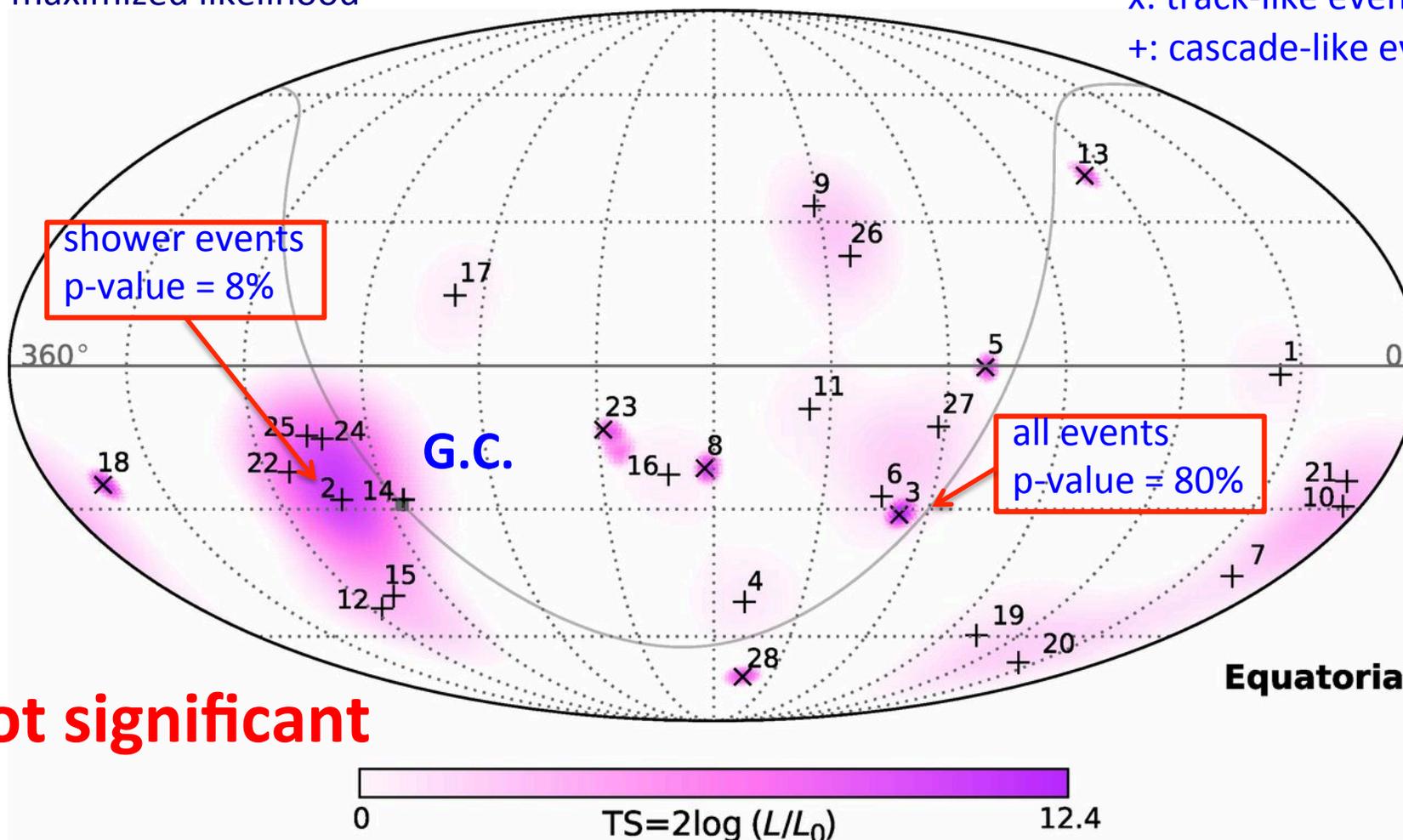
Science, 342, 1242856 (2013)

L0: null hypothesis

L: maximized likelihood

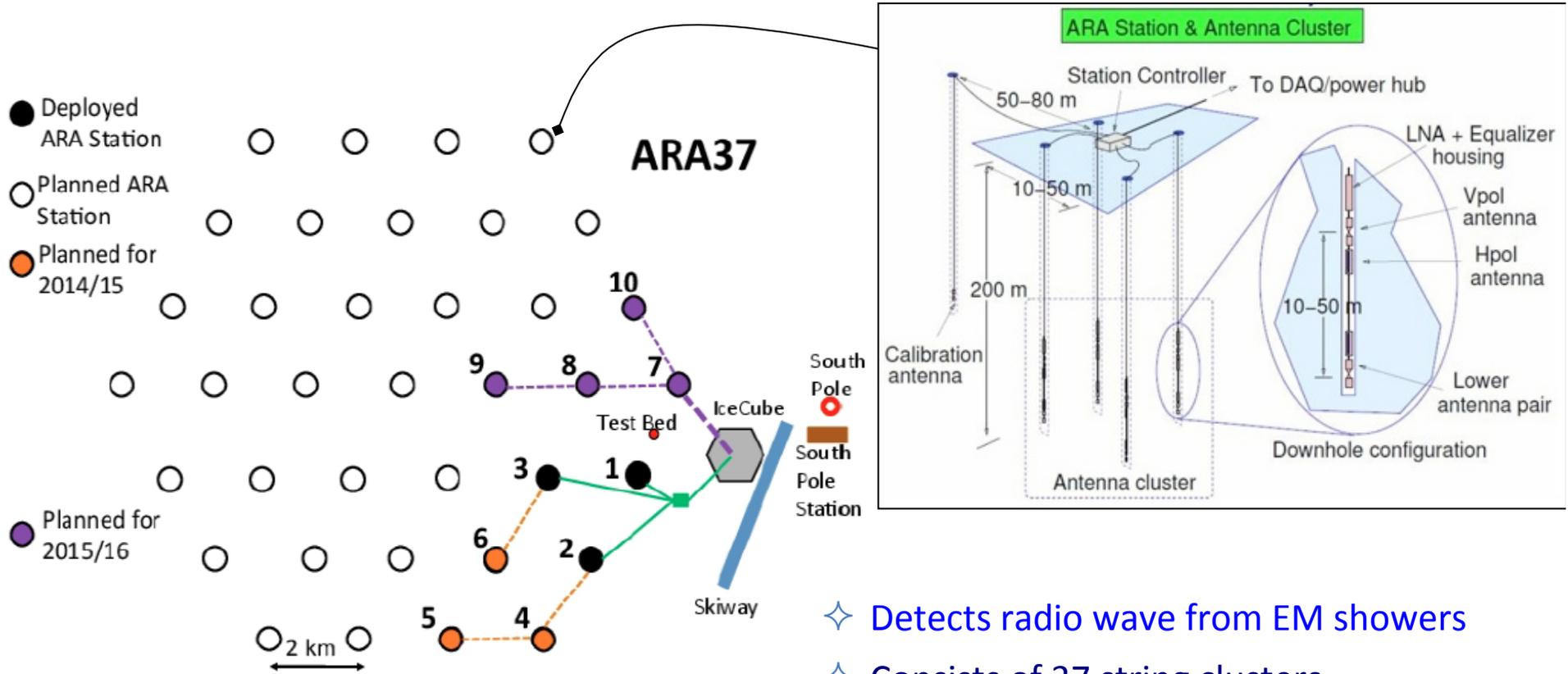
x: track-like events

+ : cascade-like events



**Not significant**

# Askaryan Radio Array (ARA)



**V-pol**

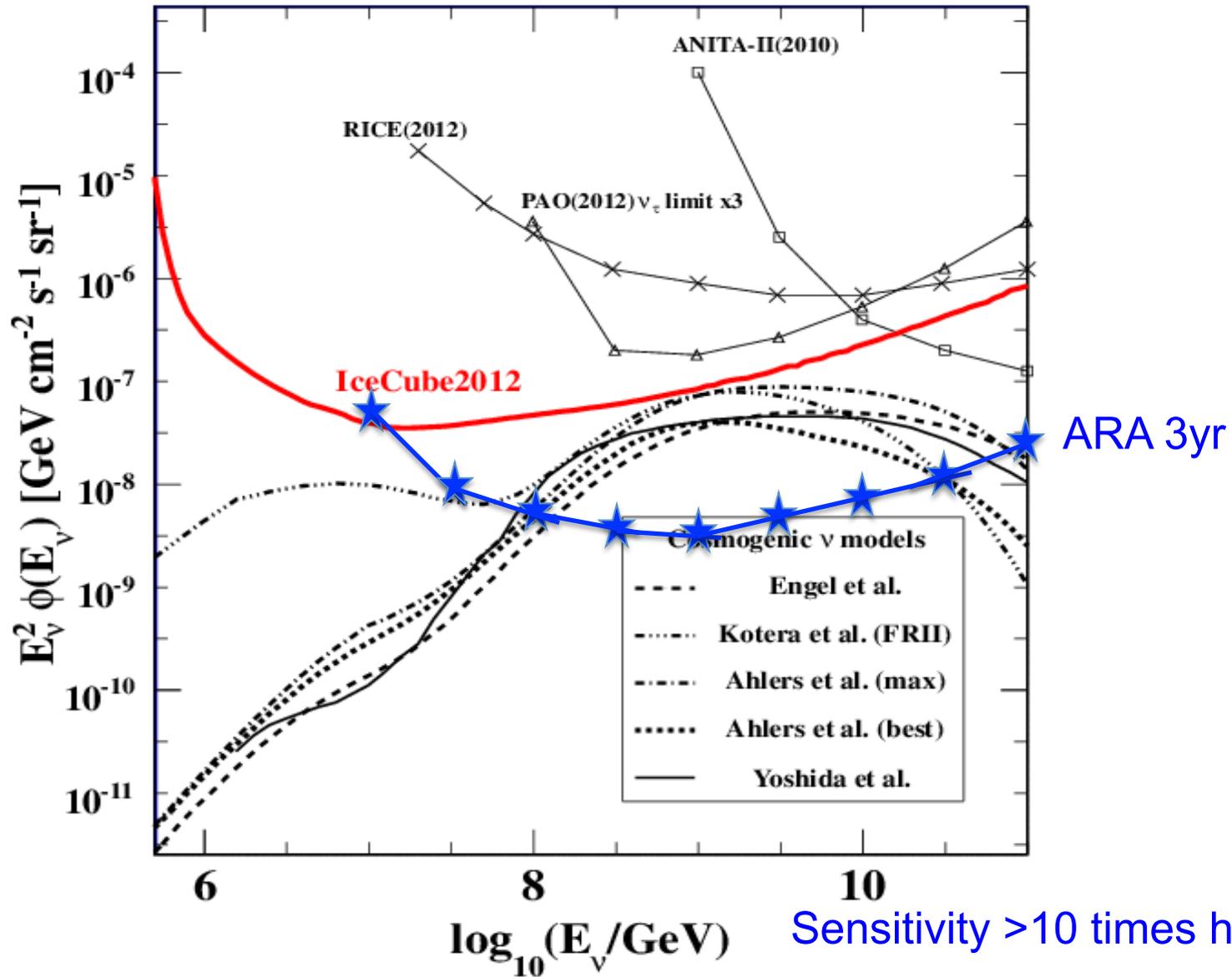


**H-pol**



- ✧ Detects radio wave from EM showers
- ✧ Consists of 37 string clusters
- ✧ Each cluster has 4 strings of 200m depth
- ✧ Each string has 2 Vpol + 2Hpol broadband antennas (150 – 800 MHz)
- ✧ **Total surface area: ~100 km<sup>2</sup>**
- ✧ **3 ARA stations ~ 1 IceCube**

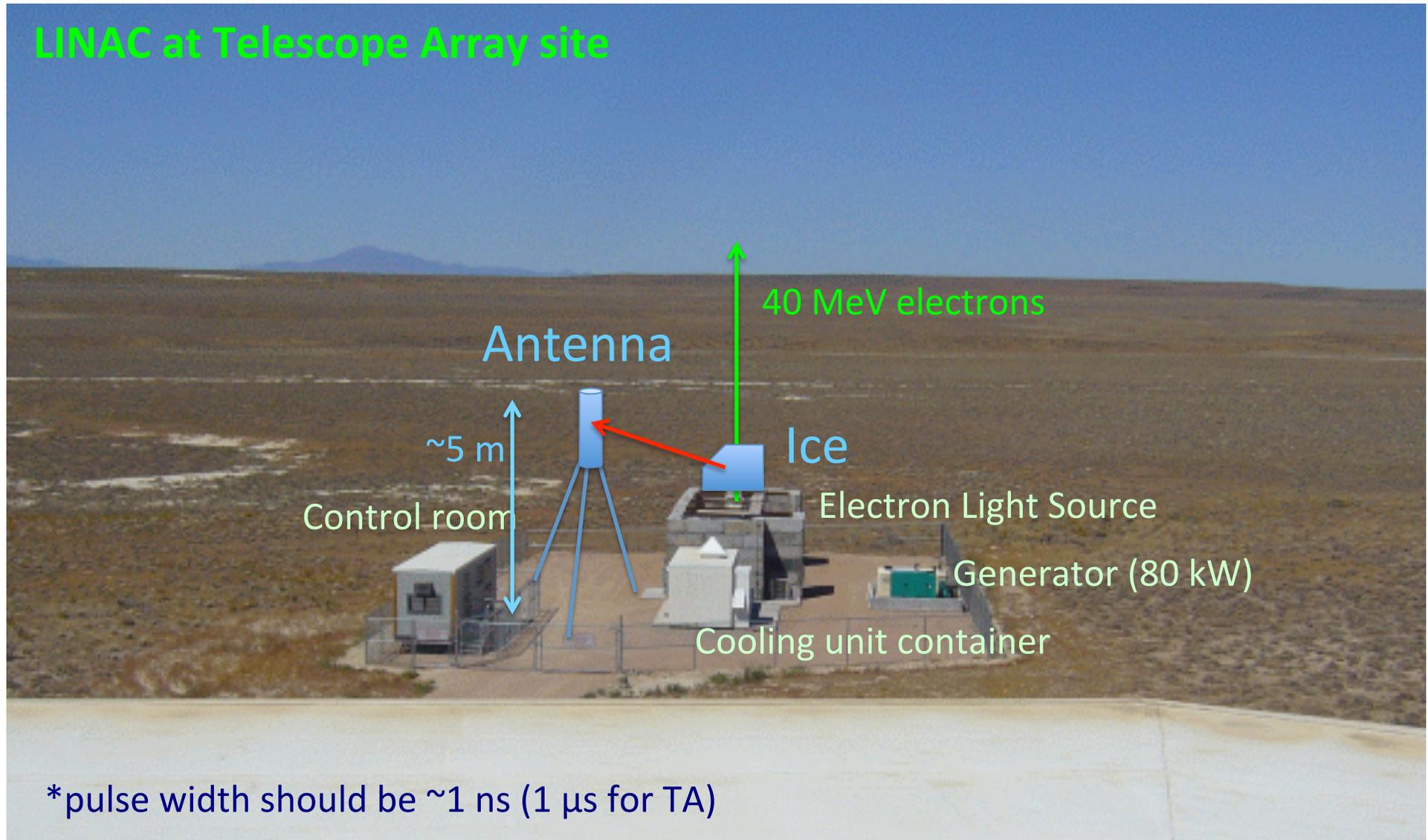
# The ARA sensitivity



Sensitivity >10 times higher  
>~10 events/yr

# Plan for end to end calibration with a LINAC

## LINAC at Telescope Array site



\*pulse width should be  $\sim 1$  ns ( $1 \mu\text{s}$  for TA)

# □ Summary

- **IceCube completed end of 2010 and performing as expected**
- **Two PeV neutrinos were observed (significance  $2.8\sigma$ )**
- **26 neutrino candidates observed by a follow-up search for high energy starting events (significance  $4.1\sigma$ )**
- **We have started to see other than backgrounds!**
- **We do not know yet what they are**
- **More data are coming**
- **Larger detector (ARA) is being constructed**