

ICRC

The Astroparticle Physics Conference
34th International Cosmic Ray Conference
July 30 - August 6, 2015
The Hague, The Netherlands



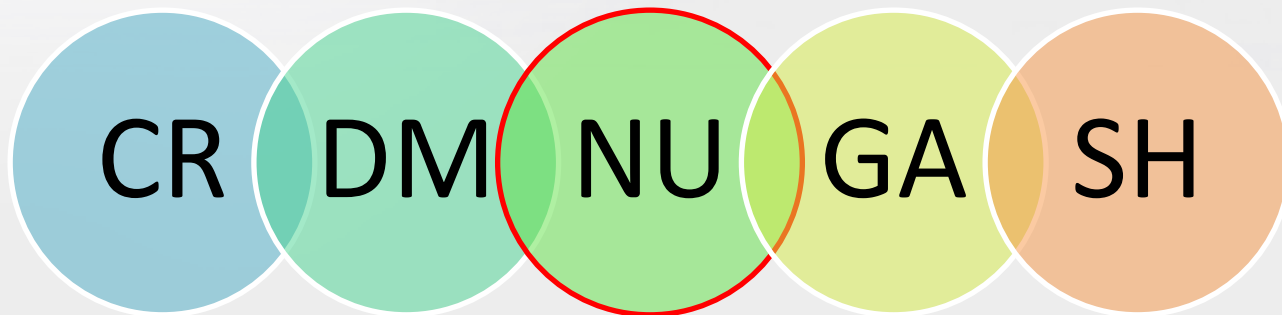
Rapporteur's report on **Neutrino Astronomy**

Aya Ishihara
Chiba University



The field of neutrino astronomy

- Exciting and rapidly glowing “young” field with a long history and design/construction



Rapidly glowing

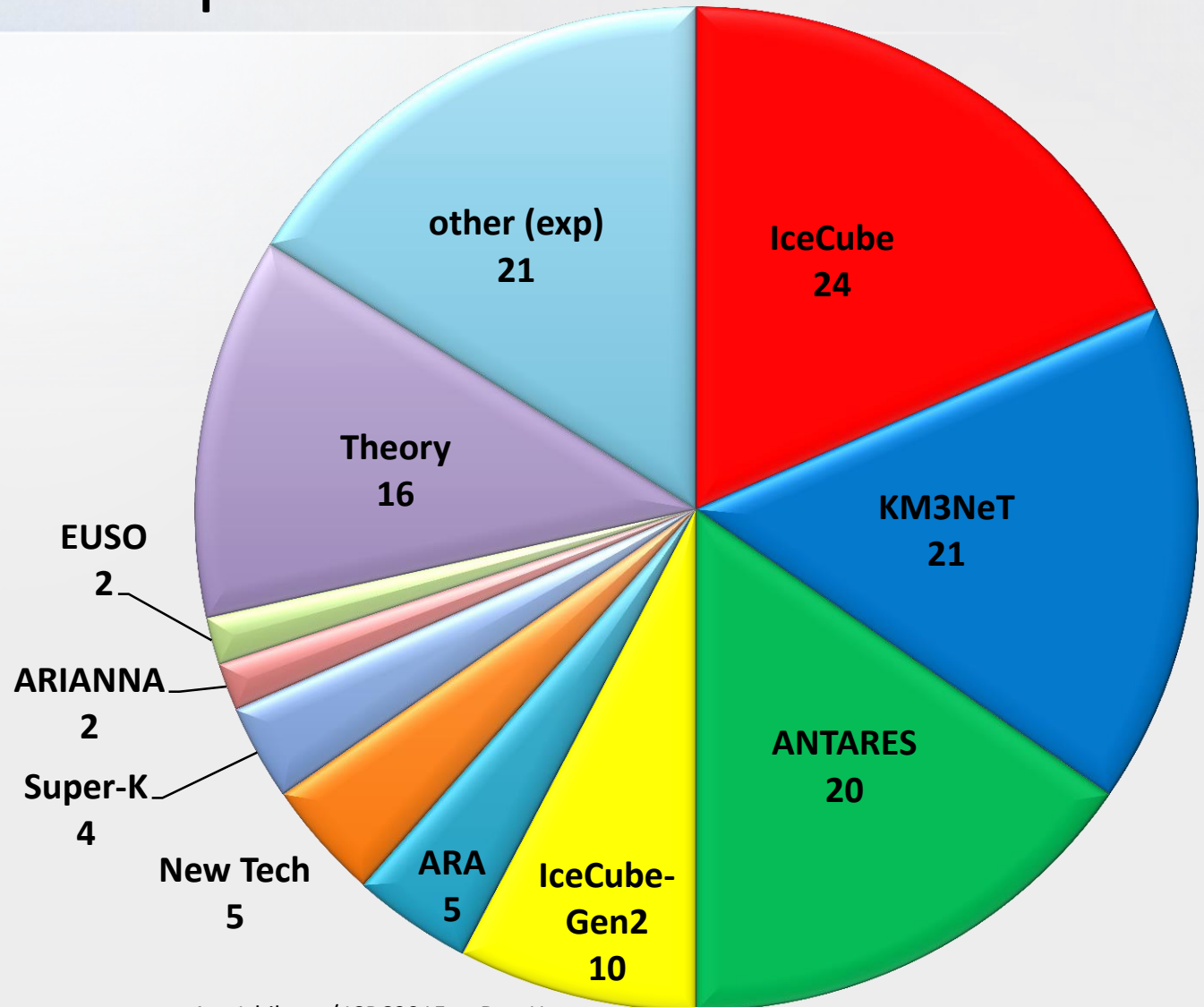
At ICRC2013, Category NU joined; 24 oral and 66 poster contributions

- Here at Den Haag, 40 talks and 90 posters

Plus directly related review/highlight talks on:

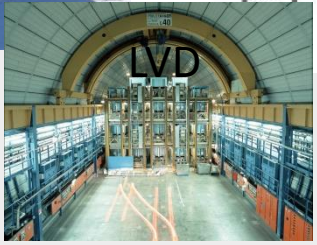
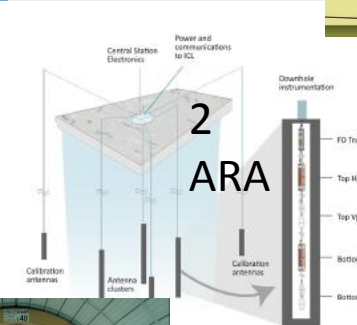
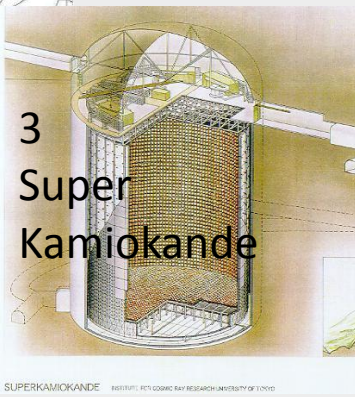
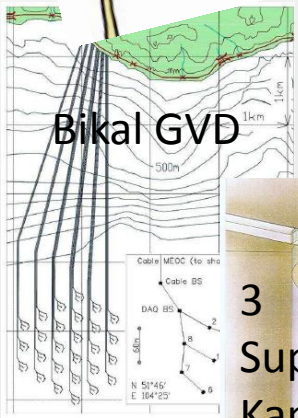
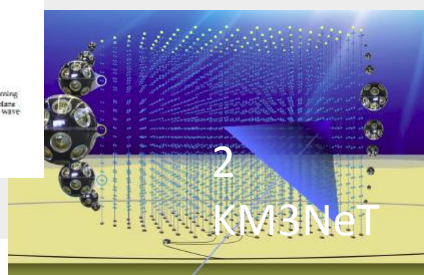
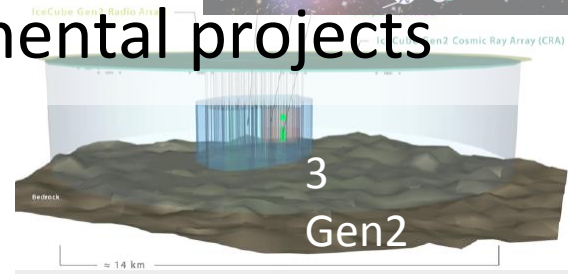
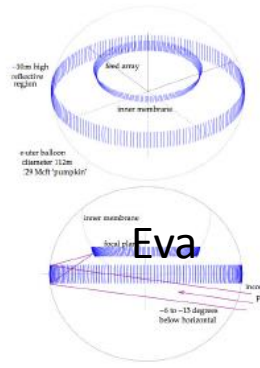
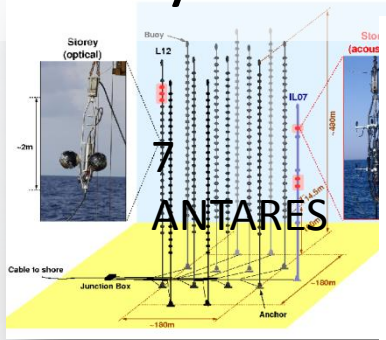
- ▶ **Neutrino Astronomy** by C. Kopper
- ▶ **Radio-Cherenkov Neutrino Detectors** by S. Barwick
- ▶ **Multi-Messenger Cosmic Neutrinos** by M. Ahlers
- ▶ **Antares and KM3NeT** by C. James
- ▶ **Neutrino properties** by A. Smirnov
- ▶ **Atmospheric neutrinos with IceCube** by P. Desiati

Statistics: orals+posters



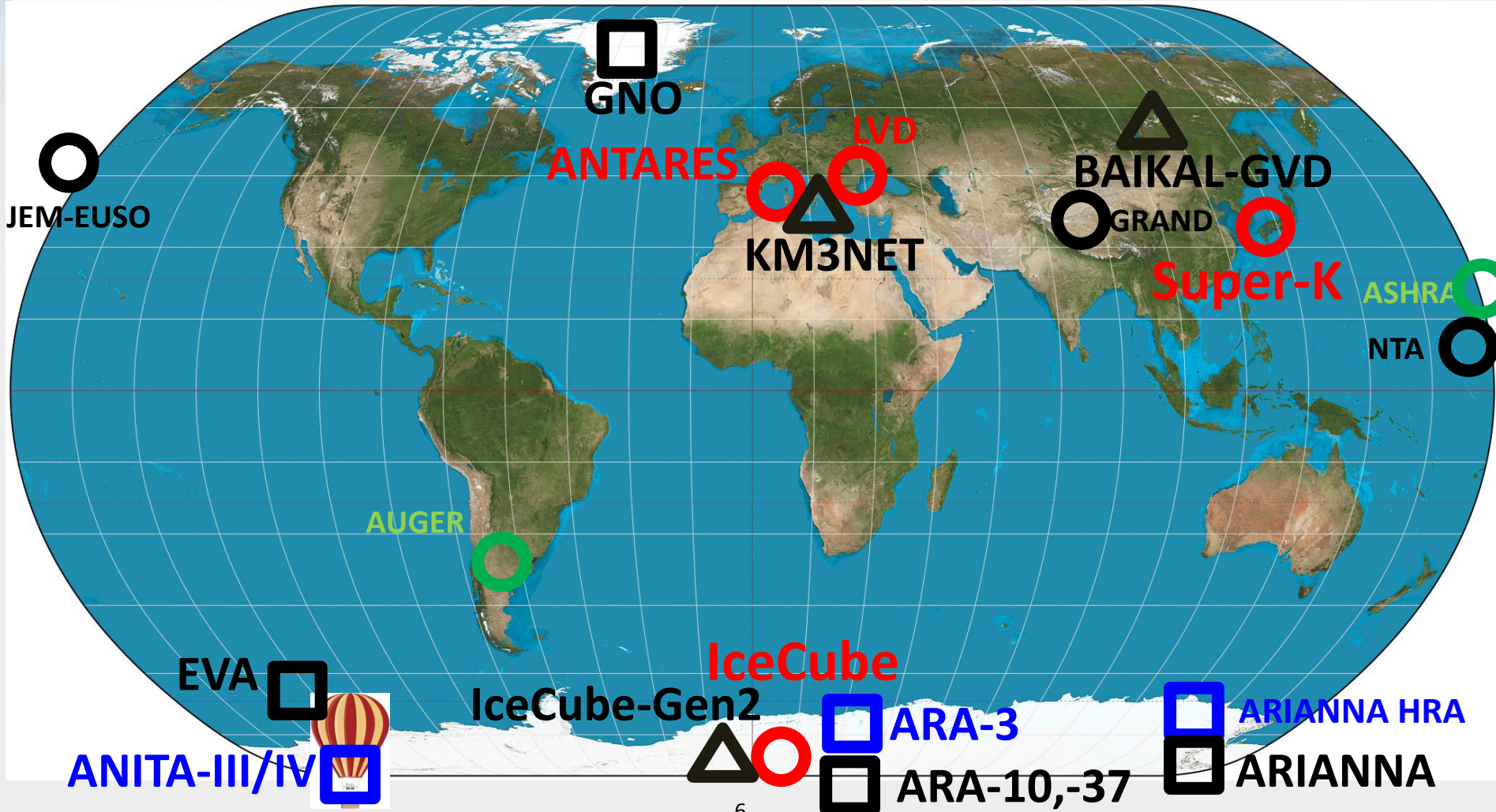
NU session 40 talks overview

- Talks are dominated by various experimental projects



Updated Neutrino Telescopes

- Cherenkov light detector
- Cherenkov radio detector
- Proposed Cherenkov light projects
- Proposed Cherenkov radio projects
- nu air shower proposed
- nu air shower



Two big themes throughout **this** ICRC

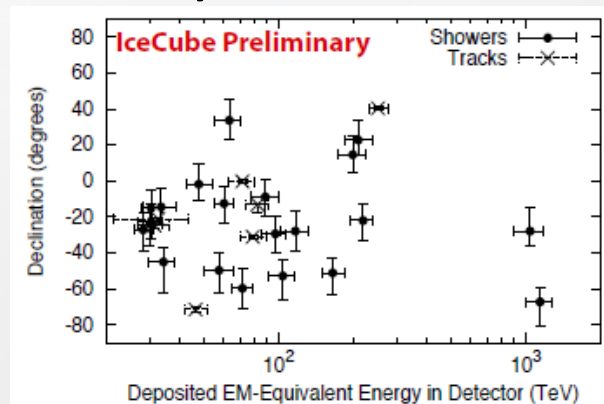
What is the origin
of the neutrino
flux being
measured by
IceCube?

Is there any other
neutrino flux
from different
origin?

Is there
measurable
cosmic
neutrino flux?
Yes!

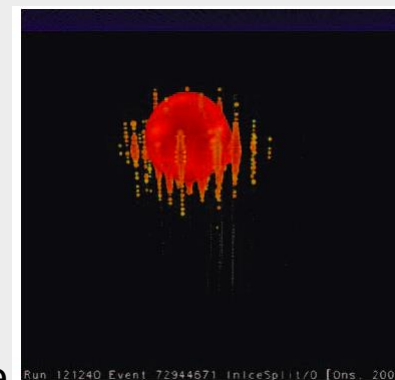
Reminder about the last ICRC at Rio

- IceCube reported 4sigma excess over background only hypothesis from the 2 year starting event analysis



arXiv:1309.7003 ICRC2013 paper# 0650

C. Kopper, N. Whitehorn, N. K. Neilson for IceCube



arxiv:1311.6519

IceCube highlights by S.R. Klein for IceCube

- Inferred that there is another interesting event.
Now known as 2PeV big-bird cascade-like nu event

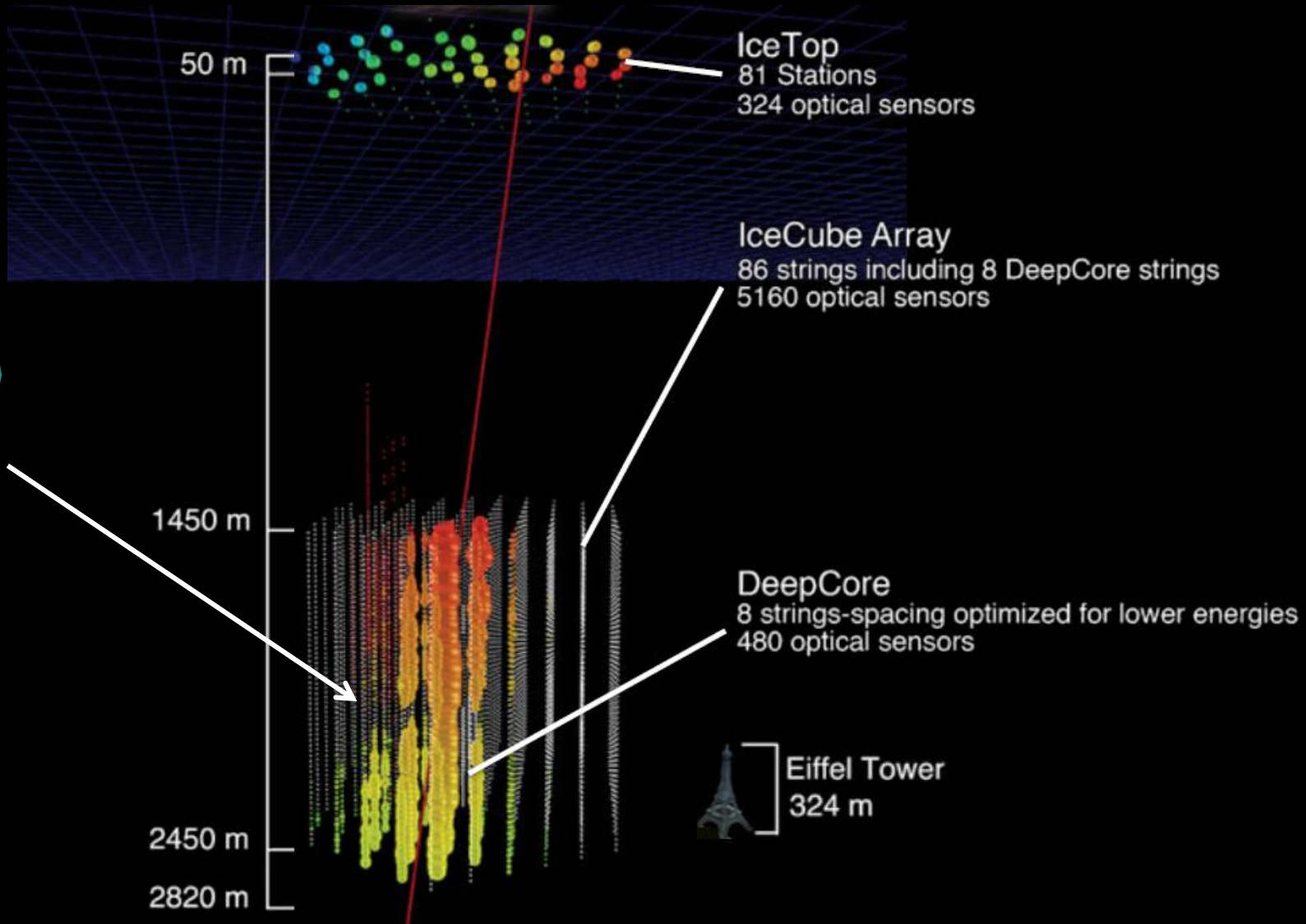


What is the current best estimation of flux?

Updates on cosmic ν measurements

- More statistics (extended data sample to date)
 - high energy starting event
- More channels (lowering threshold, different sky)
 - upward-going through-going muon events
 - particle shower (cascade) events
 - ν tau events
 - global fit to include samples from multiple channels

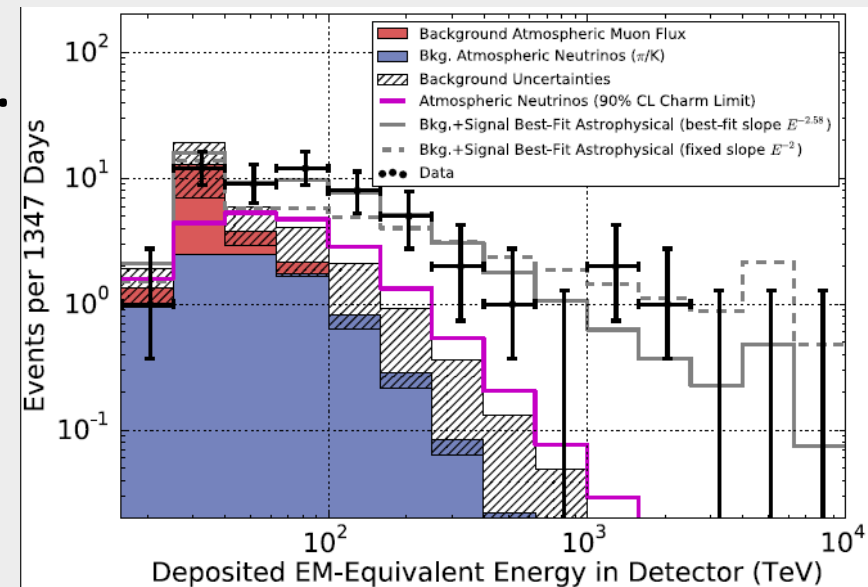
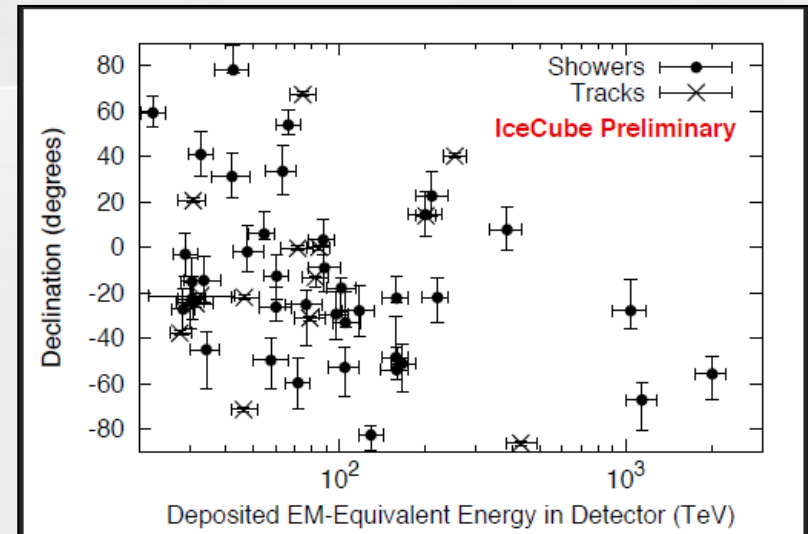
IceCube Detector



4 year data update of high energy starting event (HESE) analysis

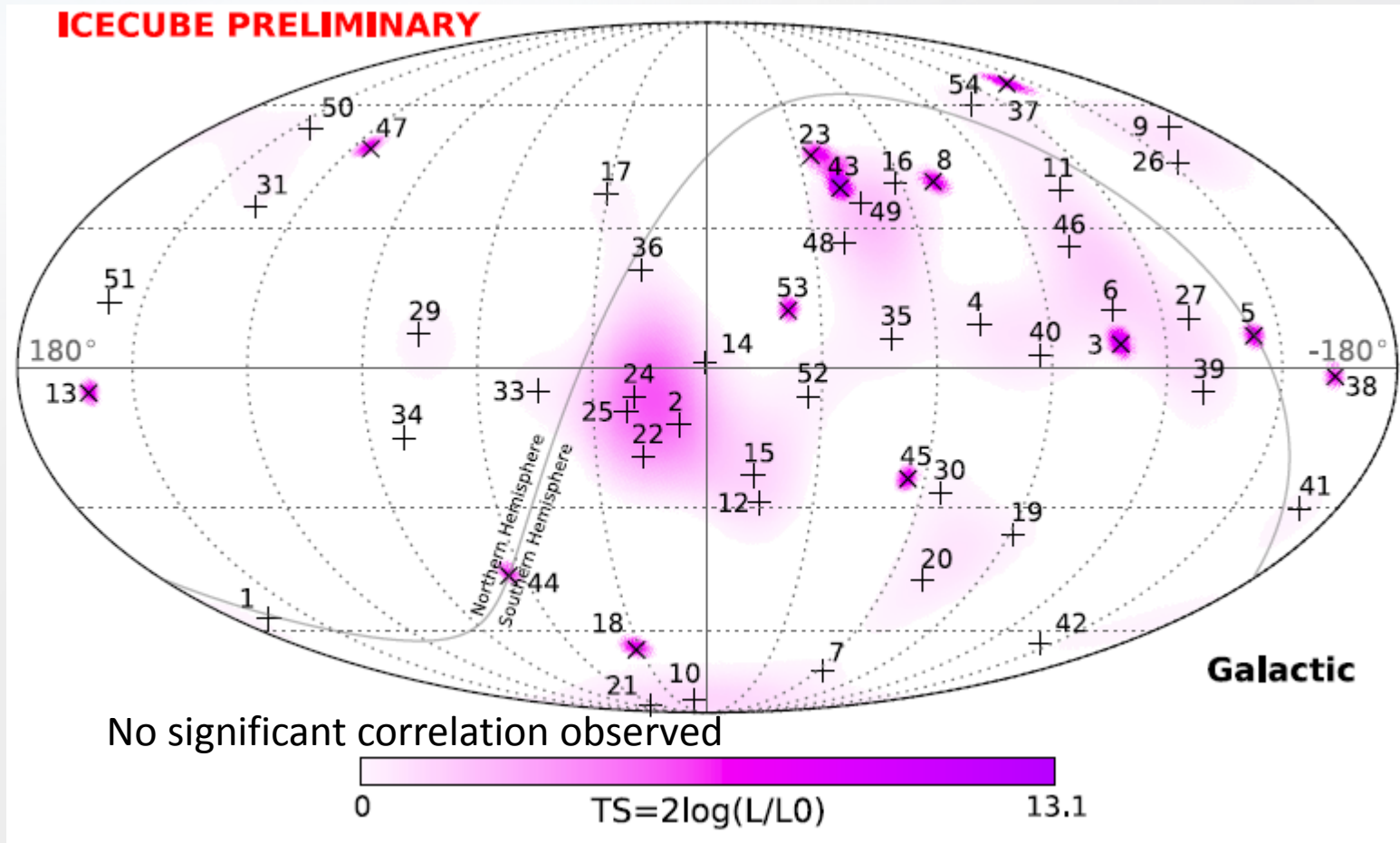
#278 C. Kopper

- Now 53(+1) events
- 6.5σ excess over atmospheric only hypothesis
- Compared to the previous publication (Phys. Rev. Lett. 113, 101101), a softer spectra preferred while consistent within error



4 year HESE data skymap

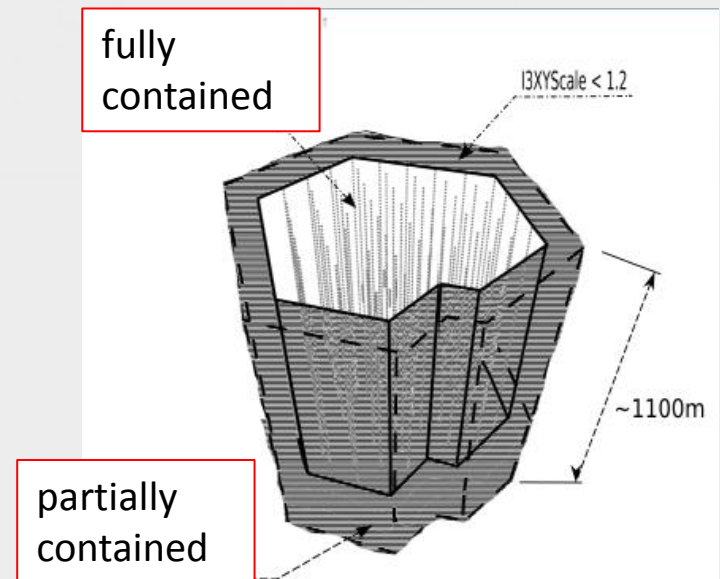
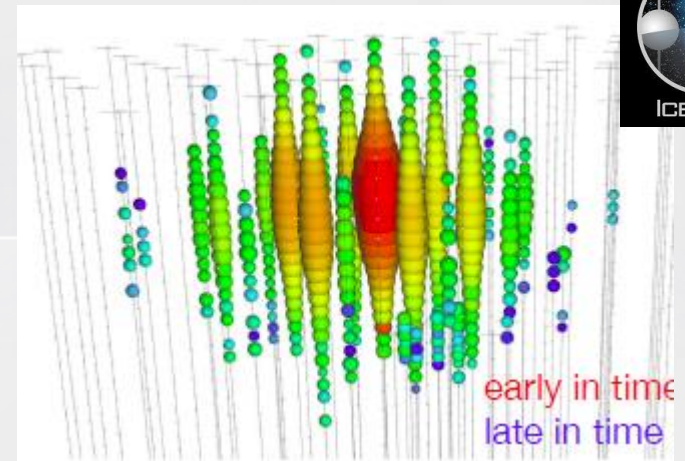
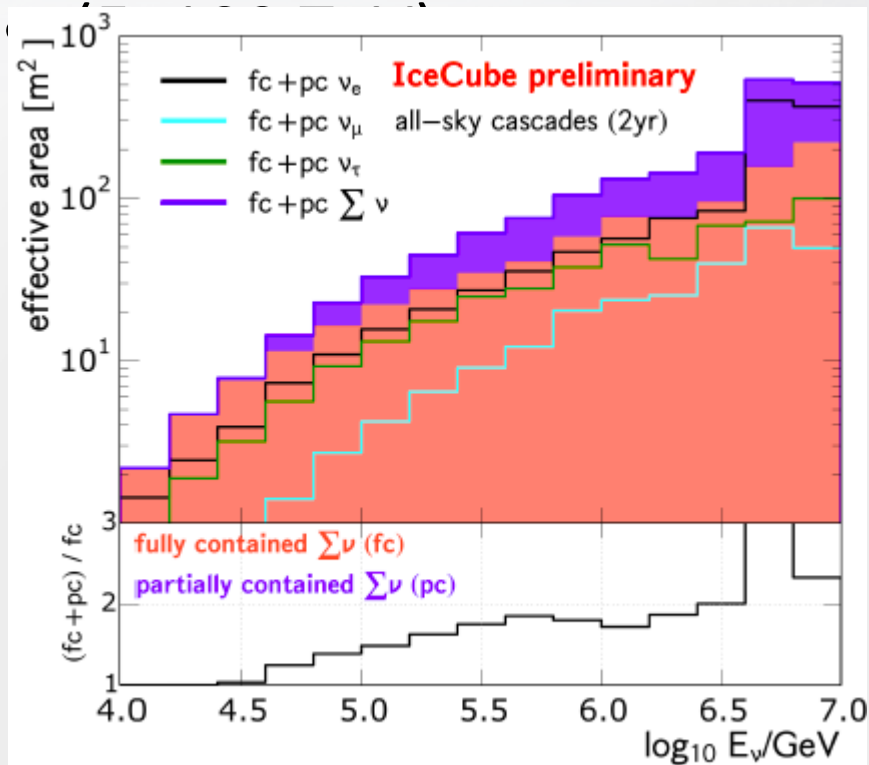
#278 C. Kopper



Cascade event analyses

#1208 H. Niederhausen

- 2 years sample
- partially contained cascades increase A_{eff} by up to x2



Cascade event analyses results

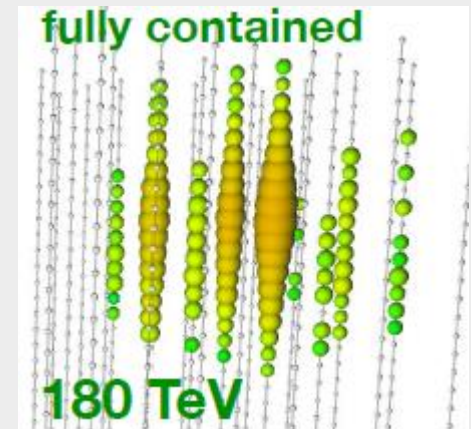
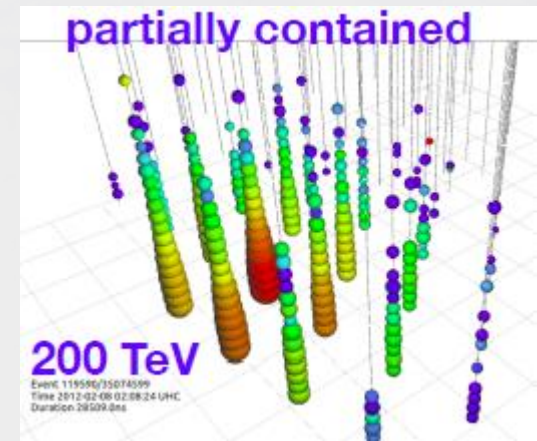
#1208 H. Niederhausen

- ✓ **172 Cascades found ($E > 10$ TeV)**
(including 20 partially contained $E > 35$ TeV)
- ✓ **60% (75% above 100 TeV) are NEW**
(i.e not found in other IceCube searches)
- ✓ **efficient atm. muon rejection**
(expect $< 10\%$ atm. μ to remain after at low E)

- $> 60\%$ of observed cascade events are estimated to be cosmic neutrino induced events

$$\Phi_V = \phi \times (E_V/100 \text{ TeV})^{-\gamma}$$

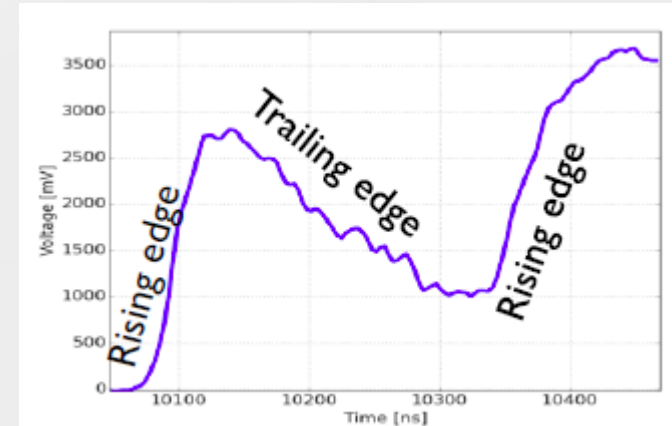
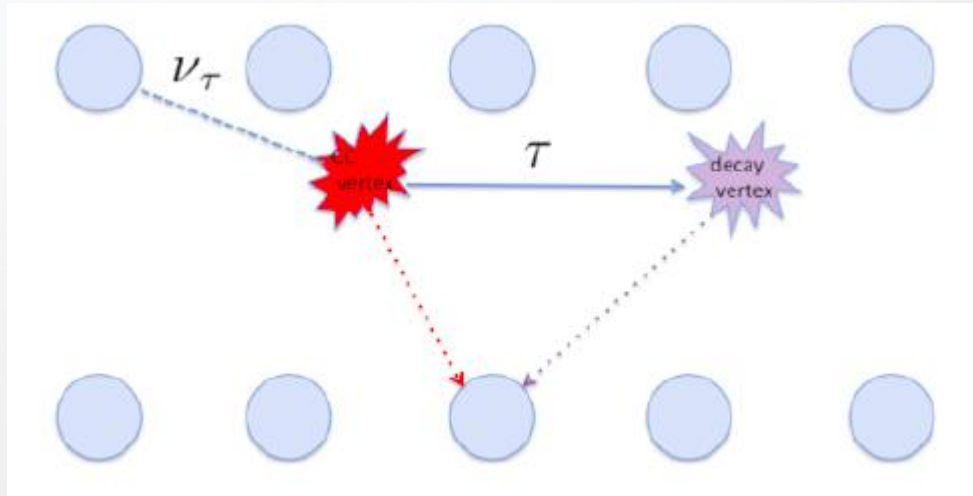
ϕ (per flavor) [$10^{-18} \text{ GeV}^{-1} \text{ s}^{-1} \text{ sr}^{-1} \text{ cm}^{-2}$]	$2.3^{+0.7}_{-0.6}$
γ	$2.67^{+0.12}_{-0.13}$



Searches for tau neutrinos with IceCube

#544 D. Williams

- 3 year search for neutrino induced tau events



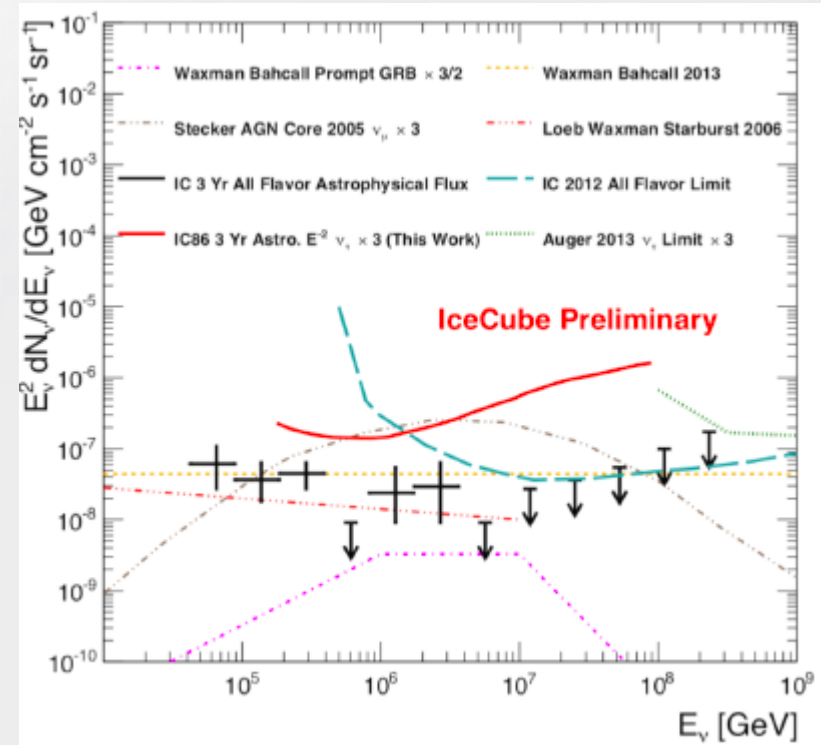
When a sequential cascades are too close to be well resolved, it may appear as a double pulse waveform = Rising and trailing edges identified using 1st time derivatives

Results from tau neutrino analyses with IceCube

#544 D. Williams

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

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

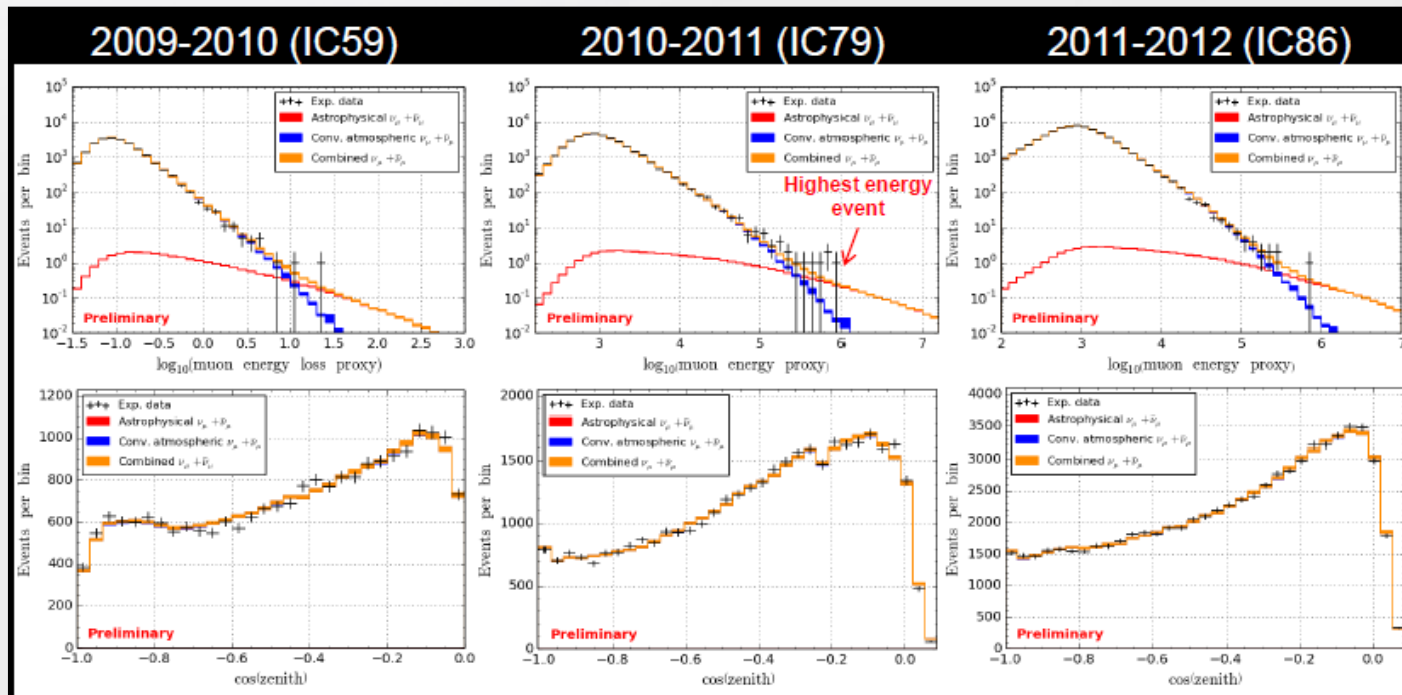


- Double pulse signature select high energy tau neutrinos efficiently
- Higher energy double bang search under development

Upward-moving through-going muon analyses

#642 L. Rädcl

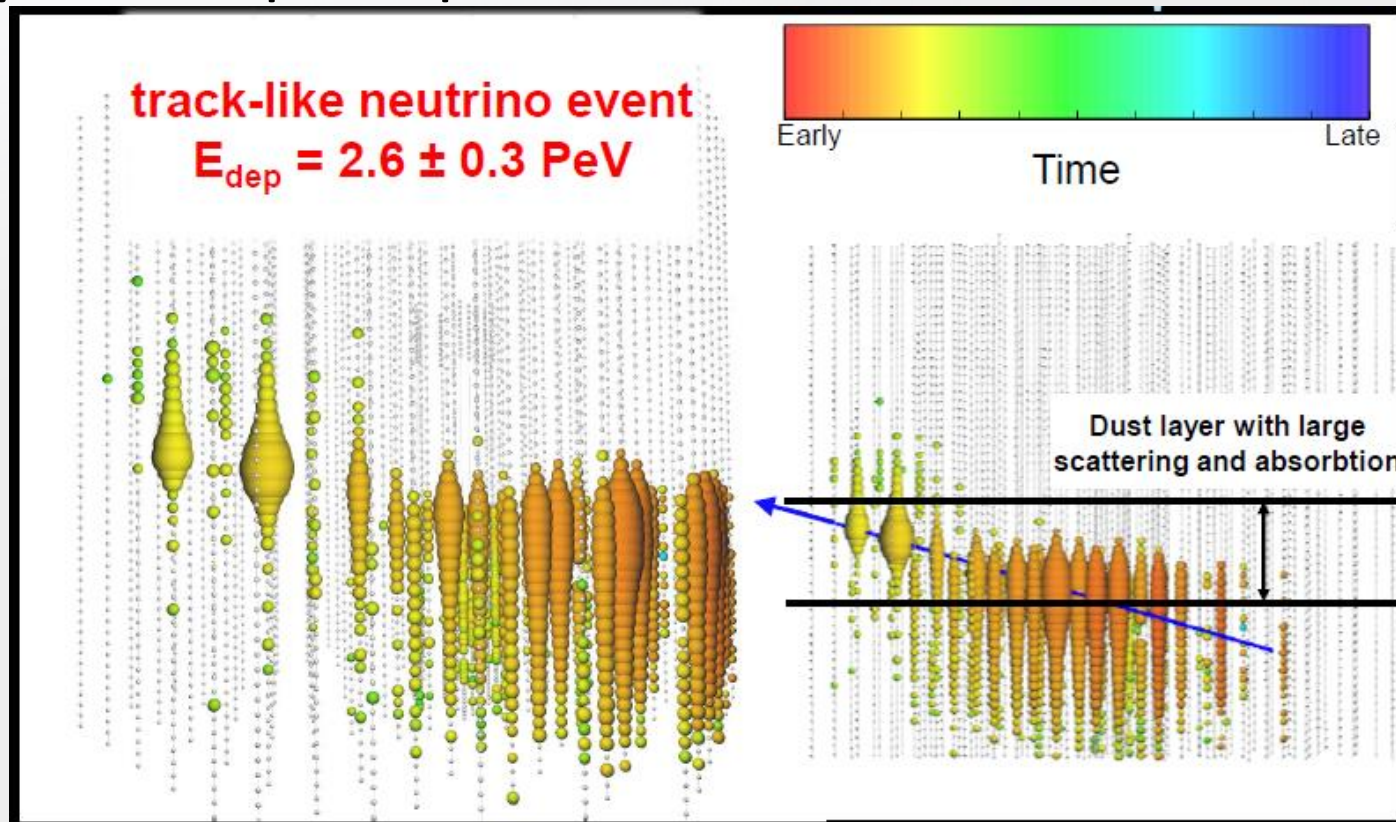
- Aiming at 6 year sample analysis
- In this ICRC, presented results of 3 year sample analysis
- Atmospheric-only hypothesis excluded by 4.3σ
- Stay tuned for the 6 year results



Upward-moving through-going muon analyses

#642 L. Rädcl

- The Highest energy neutrino induced event in the 6 year sample reported



ATEL #7856

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5 Aug 2015; 11:50 UT

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Detection of a multi-PeV neutrino-induced muon event from the Northern sky with IceCube

ATel #7856; *Sebastian Schoenen and Leif Raedel (III, Physikalisches Institut, RWTH Aachen University) on behalf of the IceCube Collaboration on 29 Jul 2015; 20:47 UT*

Credential Certification: Marcos Santander (santander@nevis.columbia.edu)

Subjects: Neutrinos, Request for Observations

Referred to by ATel #: 7868

 Tweet 31
 Recommend 130

We observed a muon event with an energy of multiple PeV originating from a neutrino interaction in the vicinity of the IceCube detector. IceCube is a cubic-kilometer neutrino detector installed in the ice at the geographic South Pole mostly sensitive to neutrinos in the TeV-PeV energy range. The event is the highest-energy event in a search for a diffuse flux of astrophysical muon neutrinos using IceCube data recorded between May 2009 and May 2015. It was detected on June 11th 2014 (56819.20444852863 MJD) and deposited a total energy of 2.6 +/- 0.3 PeV within the instrumented volume of IceCube, which is also a lower bound on the muon and neutrino energy. The reconstructed direction of the event (l2000.0) is R.A. = 110.34 deg and Decl.: 11.48 deg. For simulated events with the same cn.gsfc.nasa.gov/gcn/gcn3_archive.html ctected better than 1 deg and 50% better than 0.27 deg.

Related

7868 HAWC TeV gamma-ray follow-up observation of the sky region of IceCube's multi-PeV neutrino-induced event

7856 Detection of a multi-PeV neutrino-induced muon event from the Northern sky with IceCube

← Follow up by HAWC

Global fit analysis of multiple-channels

#490 L. Mohrmann

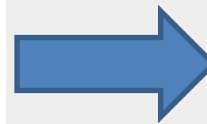
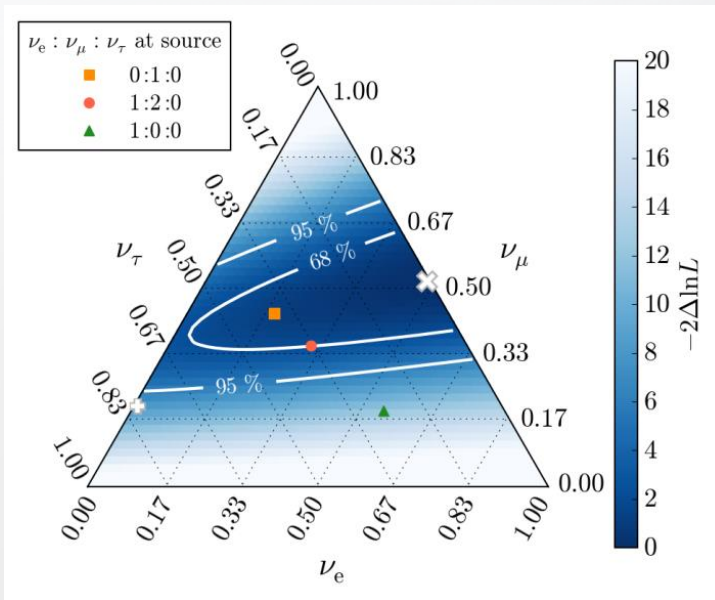
- Prospects including more channels following recently submitted/accepted paper (arxiv:1507.03991)
 - Inclusion of Tau channel indicates to help neutrino flavor ratios

ID	Signatures	Observables	Period
T1	throughgoing tracks	energy, zenith	2009–2010
T2	throughgoing tracks	energy, zenith	2010–2012
S1	cont. showers	energy	2008–2009
S2	cont. showers	energy	2009–2010
H1*	cont. showers, starting tracks	energy, zenith	2010–2014
H2	cont. showers, starting tracks	energy, zenith, signature	2010–2012
DP*	double pulse waveform	signature	2011–2014
PS*	part. cont. showers	energy	2010–2012

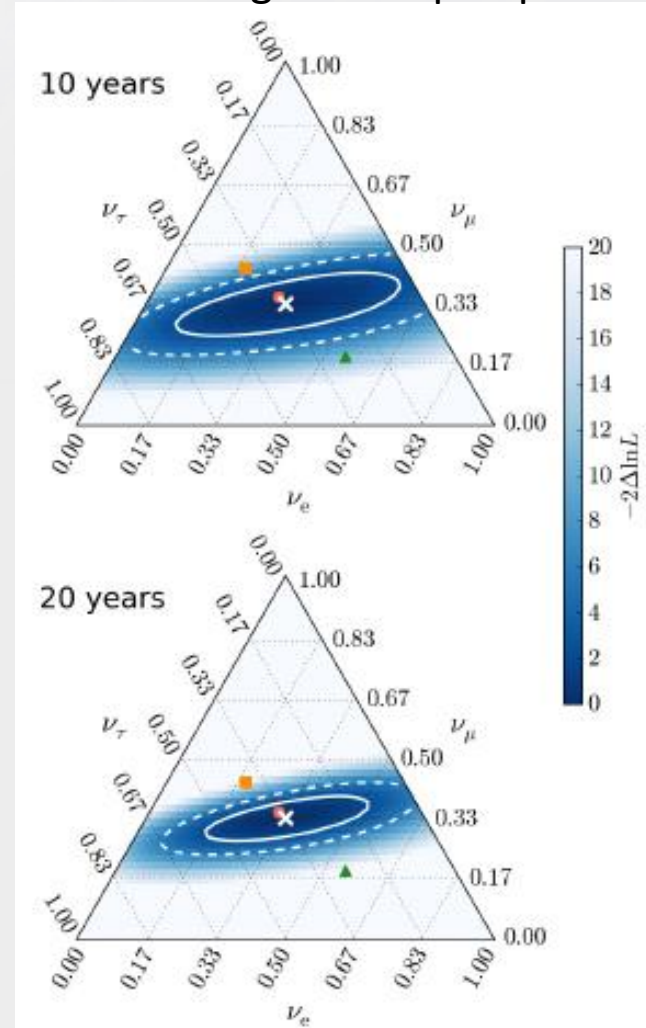
Global fit analysis results/prospects

#490 L. Mohrmann

Flavor ratio global fit with more channels



Flavor ratio global fit prospects



What is the origin
of the neutrino
flux being
measured by
IceCube?

The origin of the cosmic ν

- Theoretical works (NU01)
 - Models to describe the PeV events and their implication
 - Multi-Messenger Cosmic Neutrinos highlight talk by M. Ahlers
 - their photon counterparts [583, Reimer]
 - galaxy clusters [55, Zandanel]
 - BL Lacs [733, Petropoulou], GRB [100, Lili] Peaks at ~ 100 PeV
 - Constraints on galactic components [34, Winter]
 - Galactic Ridge, or a spatial dependent model [1010, Marinelli], [179Neronov]
- Searches for neutrino objects in the sky
 - Conventional point source searches with more data
 - inclusion of different channels
 - Multi-messenger studies
 - Transient
 - Follow-up
 - Correlations

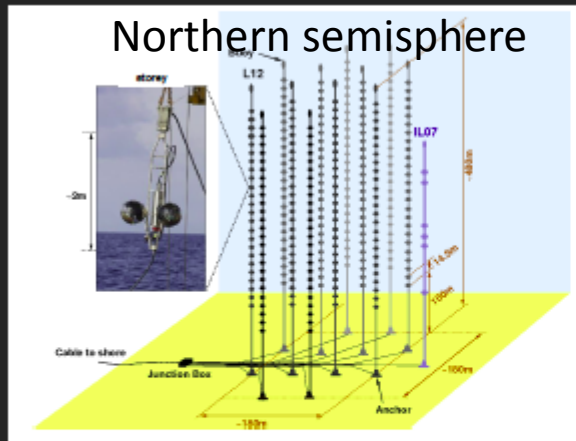
Combined point source search in Southern sky by ANTARES/IceCube

#634 J. Barrios Marti



While Antares is smaller device, IceCube has higher energy threshold for Southern sky \Rightarrow complementally

Antares

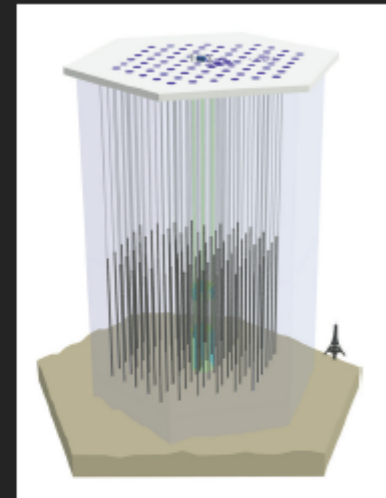


Mediterranean Sea

$1/100 \text{ km}^3$

885 PMTs

IceCube



South Pole glacier

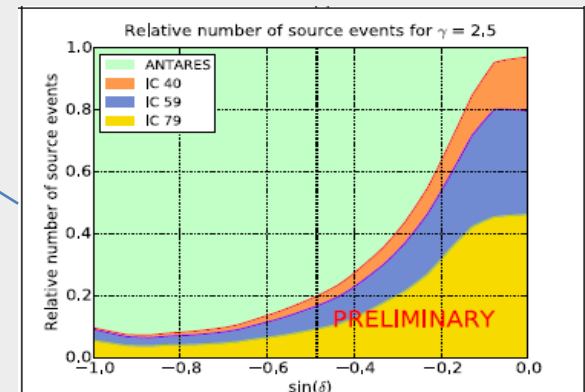
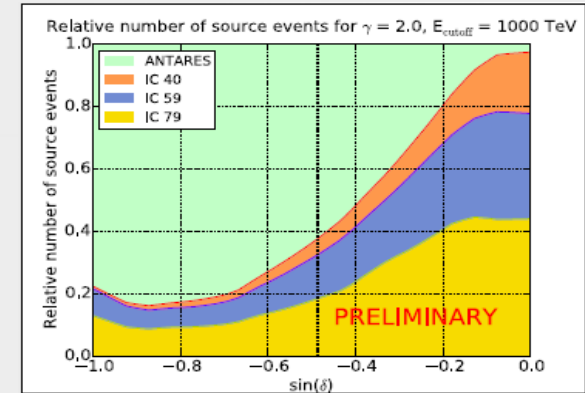
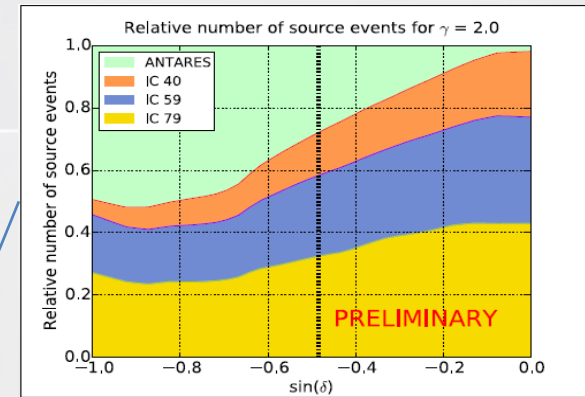
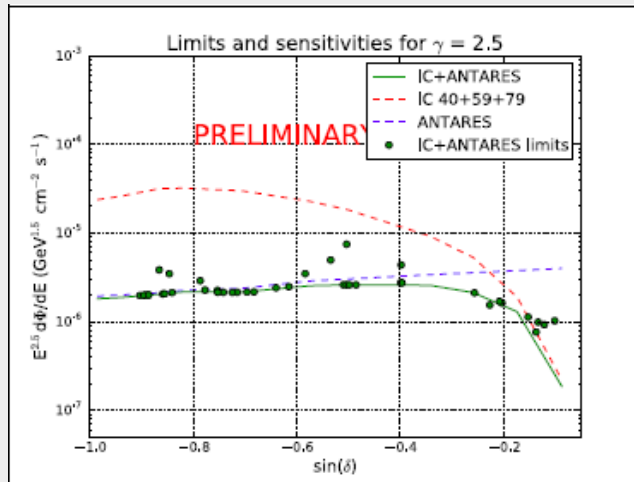
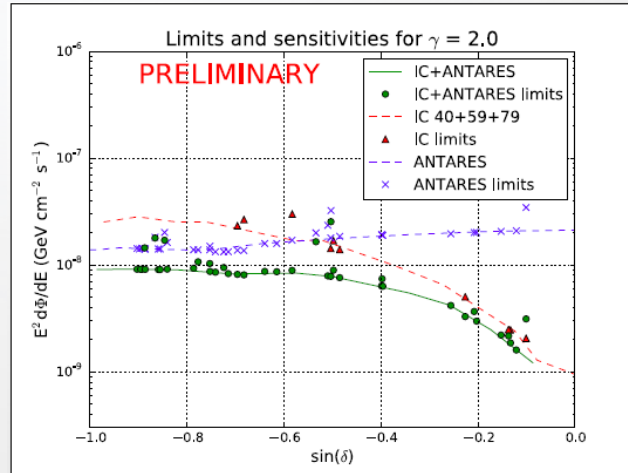
1 km^3

5160 PMTs

C. Kopper

Combined Point source search in Southern sky by ANTARES/IceCube

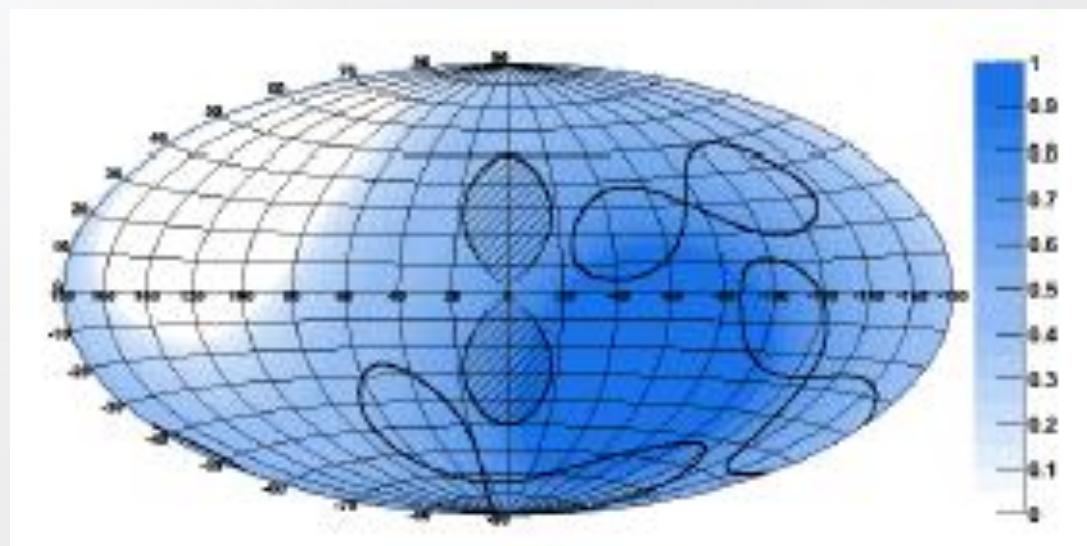
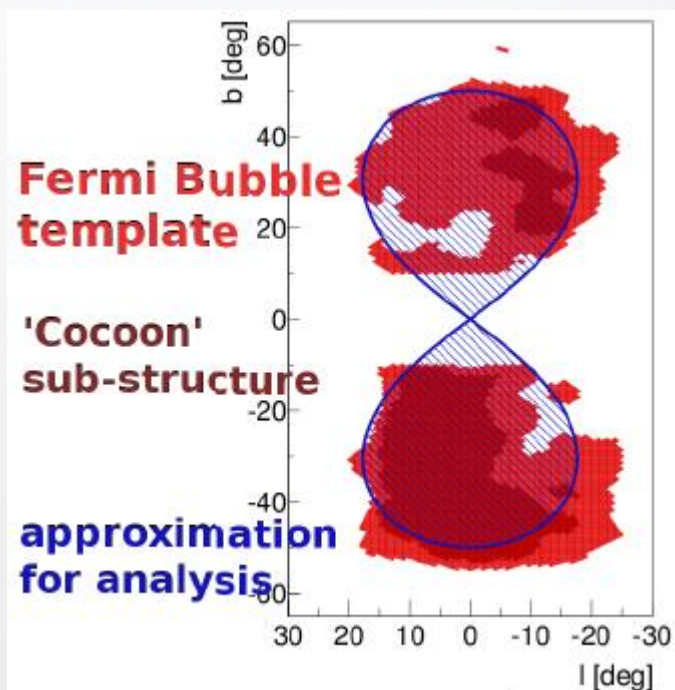
#634 J. Barrios Marti



Relative fraction of signal events for different energy source spectra

Neutrino fluxes from the Fermi Bubble

#349 S. Hallmann



$$\Phi_\nu \propto E^{-\alpha} \times \exp(-E/E_{\text{cutoff}})$$

index α	2.0	2.18*
norm γ	3 – 6	5 – 10
norm ν	1.2 – 2.4	1.8 – 3.6
	(in $10^{-7} \text{ GeV}^{(\alpha-1)} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$)	

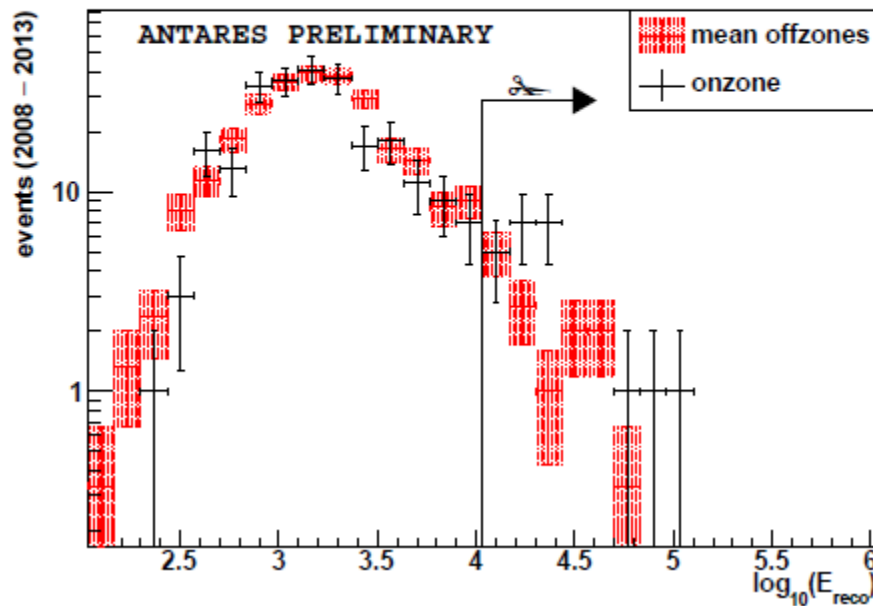
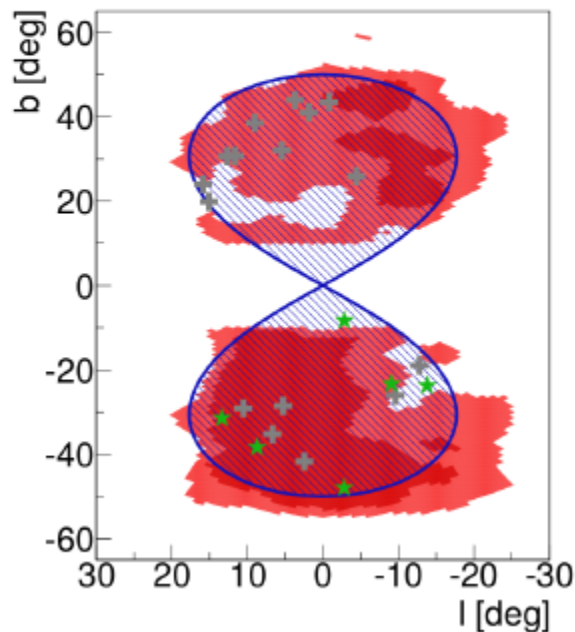


Neutrino fluxes from the Fermi Bubble

#349 S. Hallmann

analysis update: 6/3 (1, 2, 3) off-zone events, 6 on-zone events

4-year analysis: 33/3 (9, 12, 12) off-zone events, 16 on-zone events



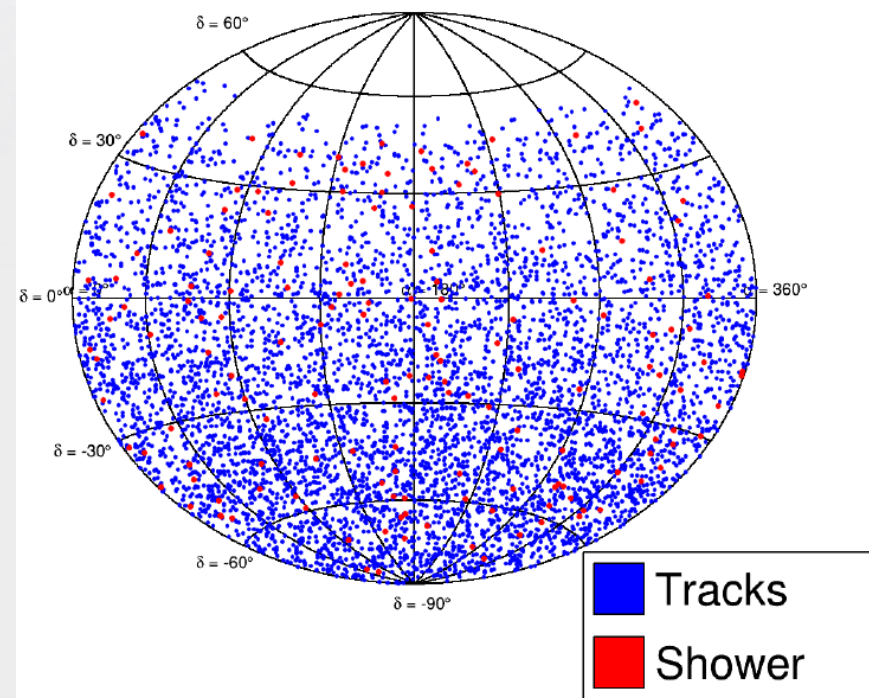
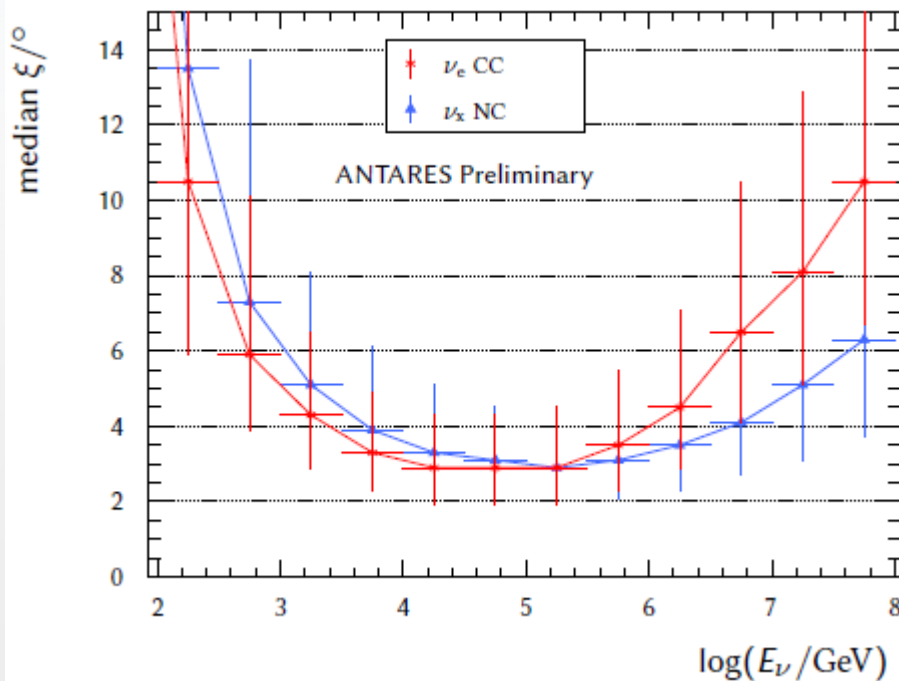
13 events average background, 22 events seen $\rightarrow 1.9\sigma \rightarrow$ limit

- In the previous 4 year analysis, average 11 bg and 16 found (1.4 sigma)
- Additional year sample combined, average 13 bg and 22 found (1.9sigma)



Track+Cascade event point source search #637 T. Michael

- Good cascade median angular error

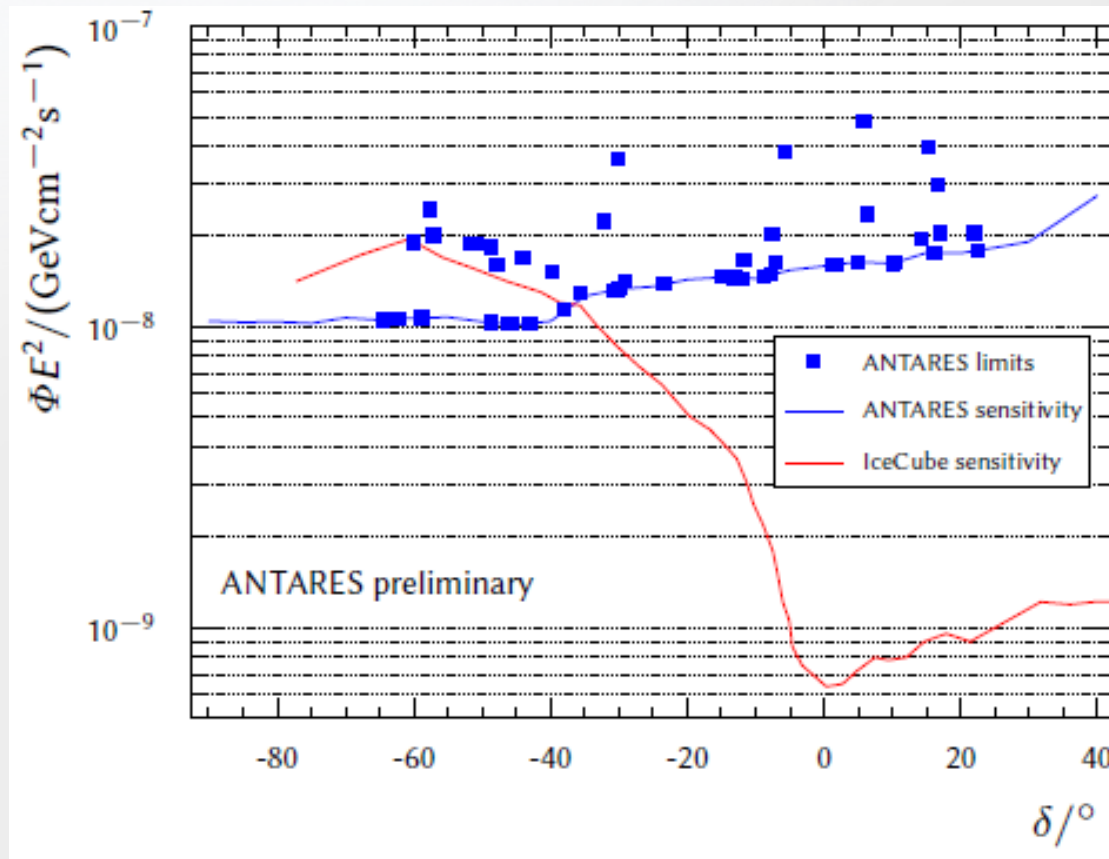


- 1622 days from 2007 to the end of 2013
(185 days of 5-line data not included in shower channel)
- contains 6261 muon track candidates and 156 cascade events (90 % purity)



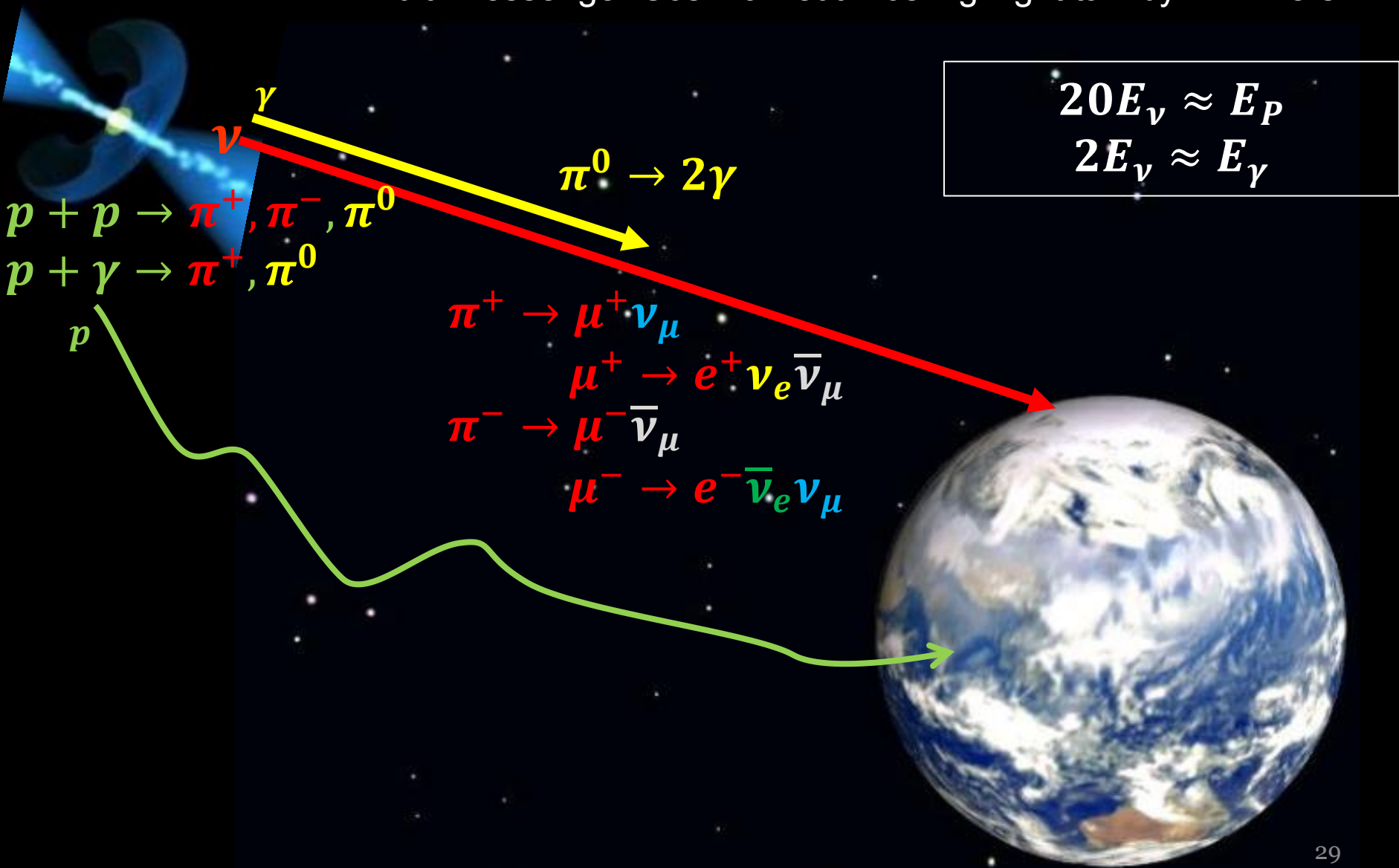
Track+Cascade event point source search #637 T. Michael

- showers improve sensitivities by about 30 %



Multi-Messenger Astrophysics

Multi-Messenger Cosmic Neutrinos highlight talk by M. Ahlers



Multi-messenger approach

- #675 M. Santander
 - IceCube high energy neutrinos followup by VERITAS
- # 680 A. Keivani
 - AMON IceCube+Fermi-LAT correlation search
- # 734 G. Golup
 - Searches for Correlations in Auger, TA and IceCube events
- #1219 V. Van Elewyck
 - Virgo-ligo and ANTARES correlations
- #969 A. Mathieu
 - Optical and X-ray follow up on ANTARES events
-

No positive detection yet, good potential for future detection
Faster alert system under development in neutrino telescopes

Is there any
other neutrino
flux from
different
origin?

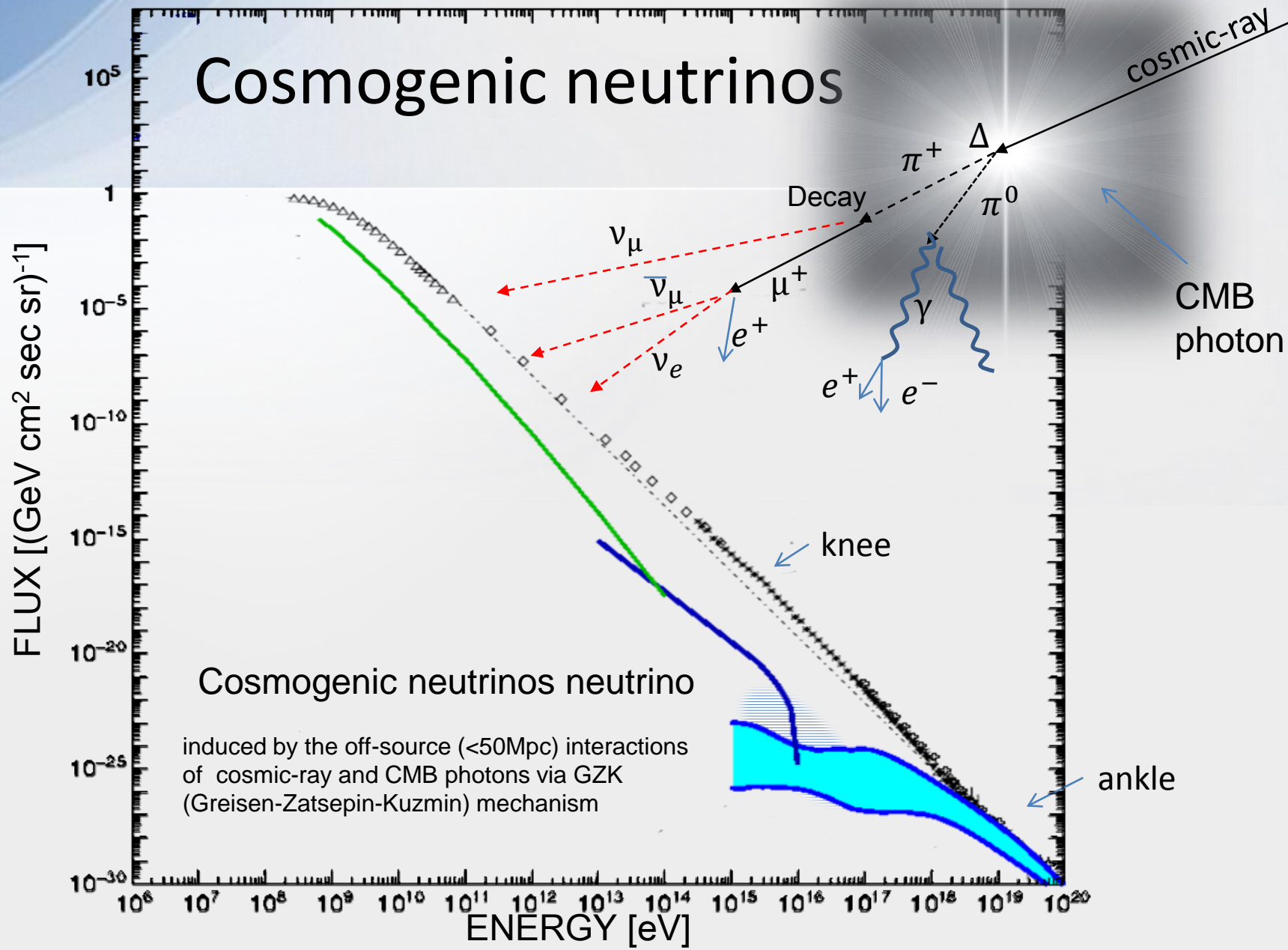
Searches for the other neutrino components

Cosmogenic neutrino search results from

- Auger
- ARA

Head up from

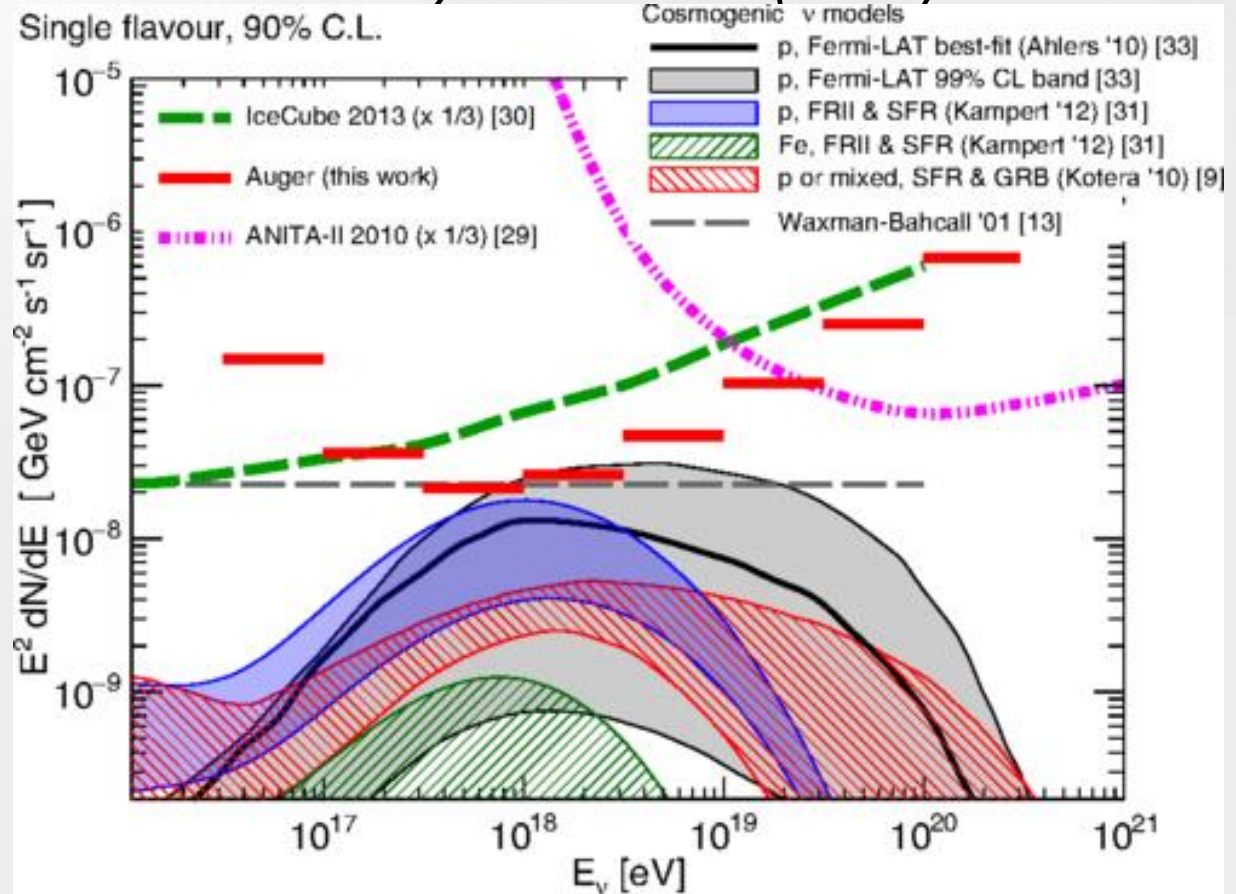
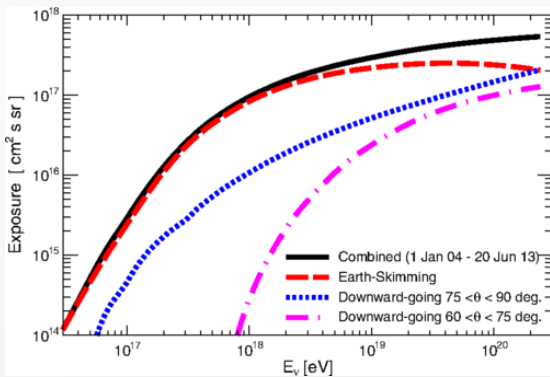
- IceCube
- ANITA
- ARIANNA



Limits from Auger collaboration

#1121, C. Bleve

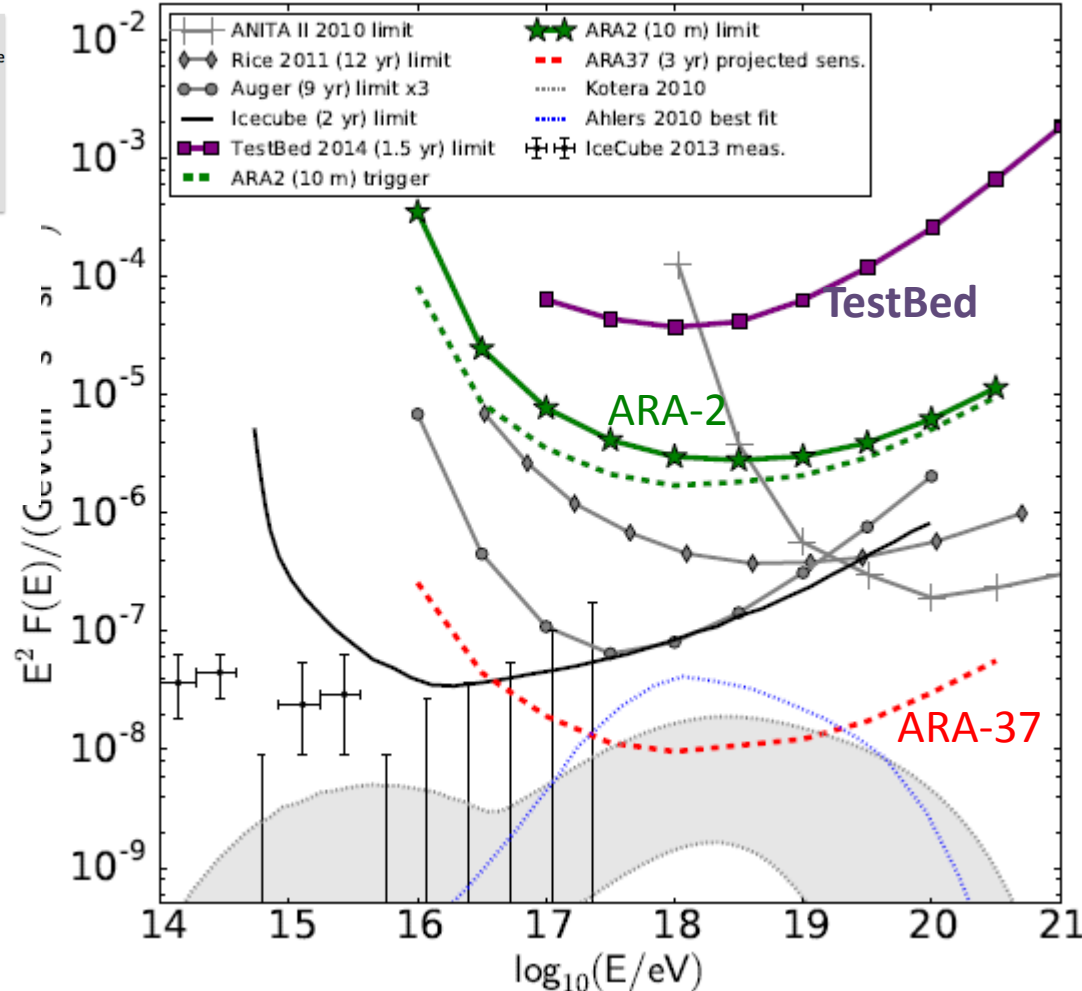
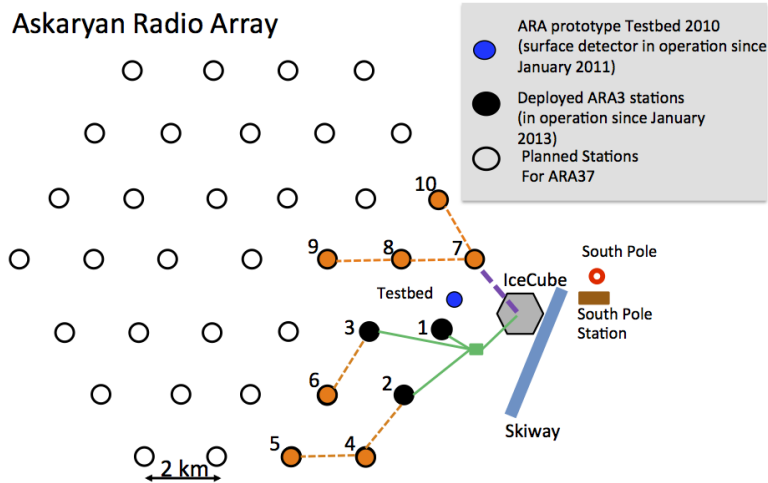
Phys. Rev. D 91 (2015) 092008



Limits from ARA collaboration

#1293, A. O'Murchadha

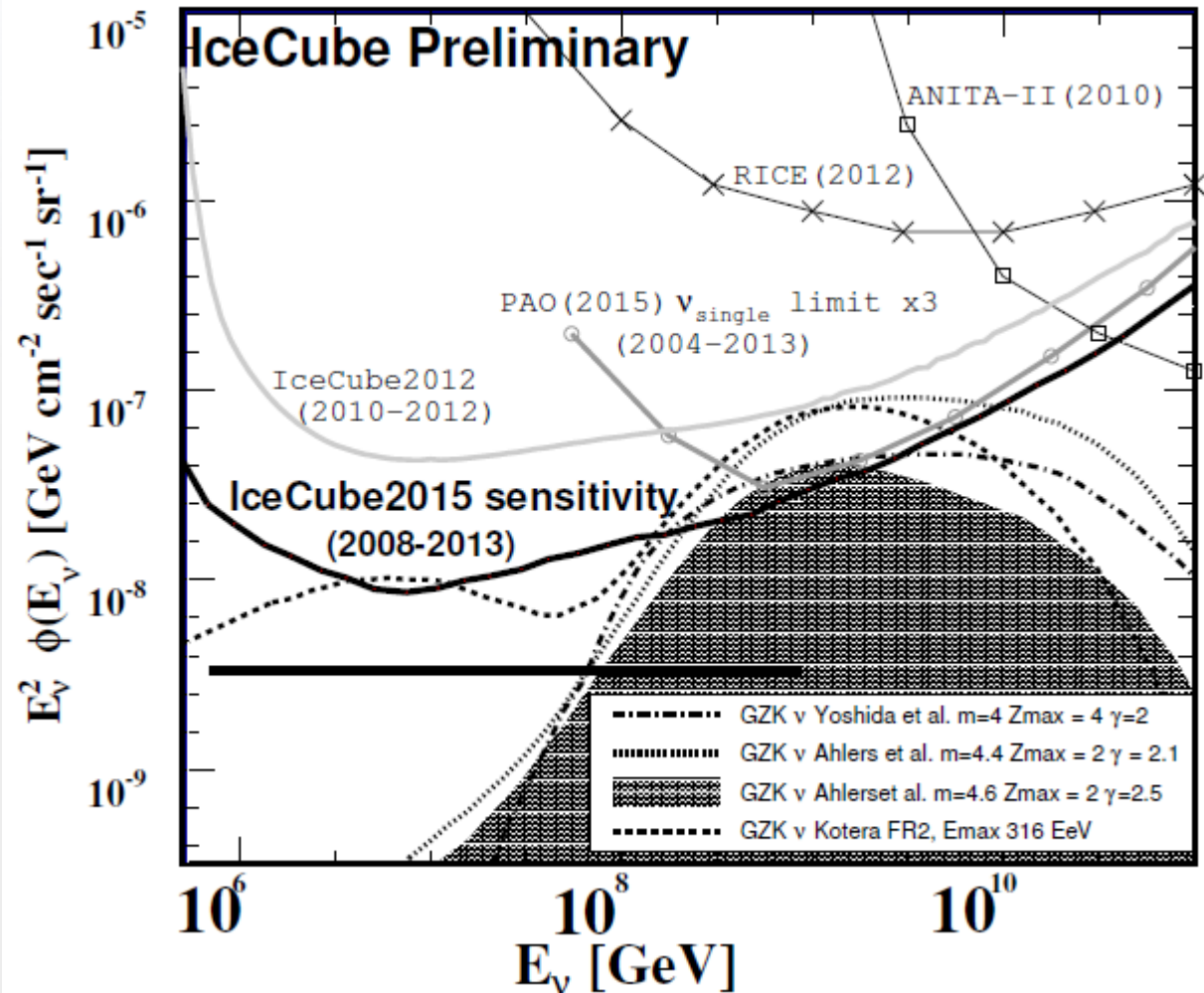
arXiv:1507.08991



IceCube's sensitivity above 10PeV

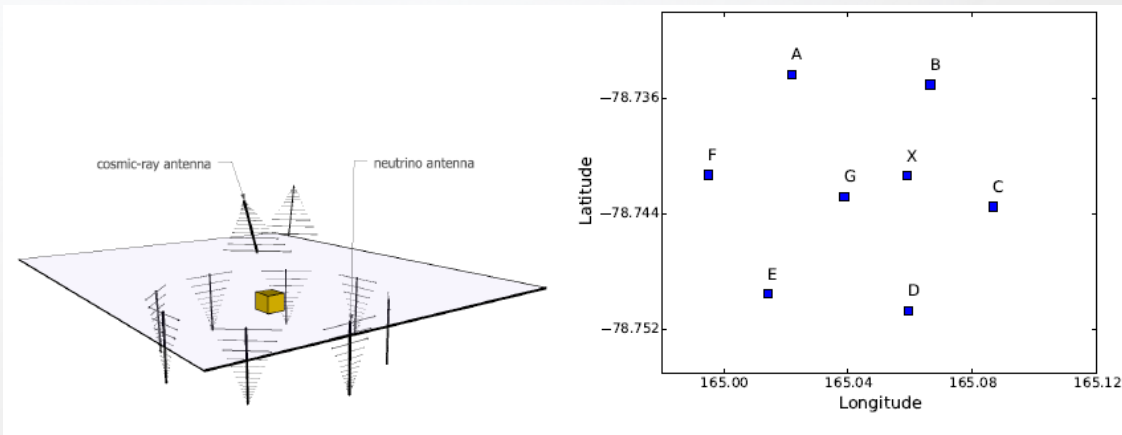
#463, A. Ishihara

- 6 year sample sensitivity
- As well as GZK, will constrain the models to explain PeV flux but peaks at higher energies



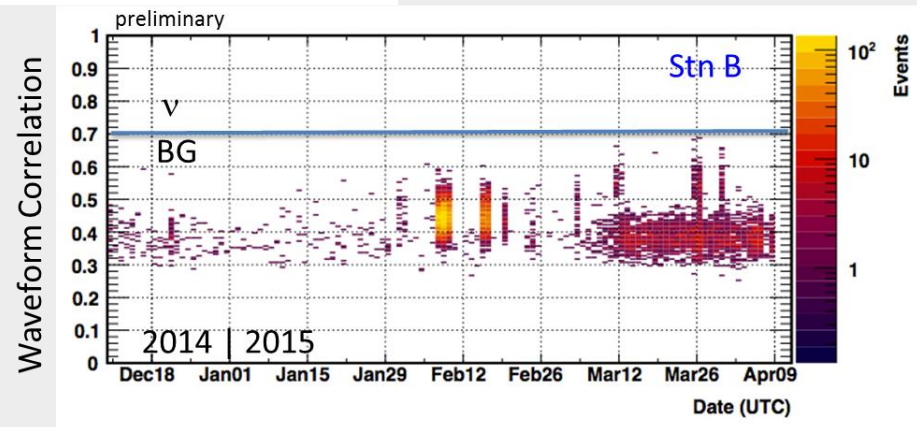
Heads up from ARIANNA collaboration

ARIANNA-HRA successfully completed in 2014/2015



Poster 820, S. Barwick
Poster 822, A. Nelles

- No ν events from any of the HRA stations from 4 months of operation



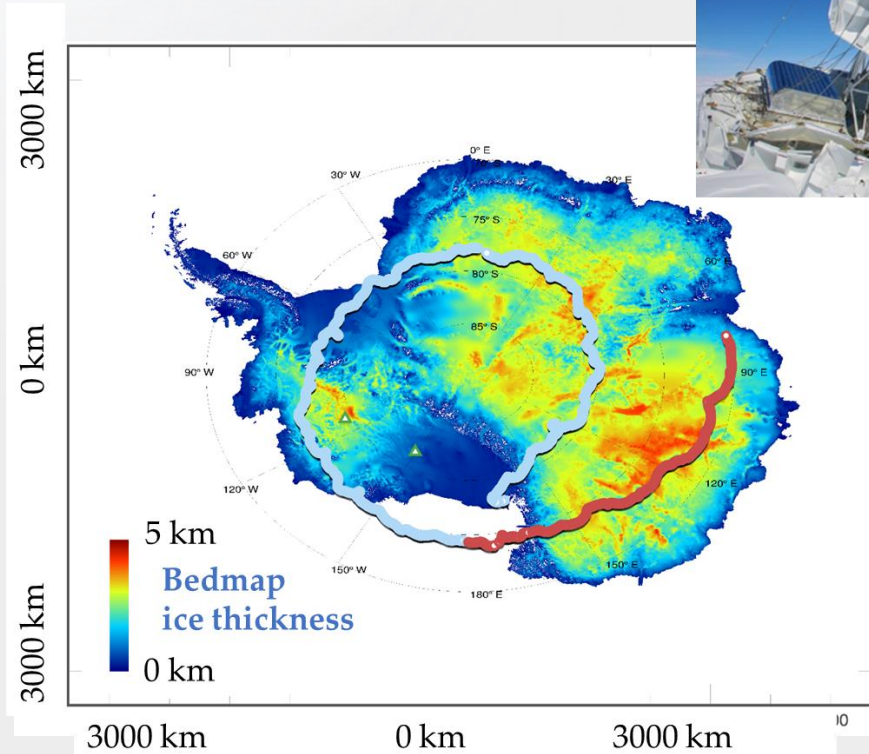
Reports from ANITA collaboration

#1217 S. Wissel

ANITA-III Flight



- 22 day flight
- ~60% aperture
- 84 M events recorded



Termination
2015-01-08
~23:50 UT

ANITA-IV Planned in 2016/2017 season!

Future

So far, a lot of interesting results/updates but these are only a half story

... Because there are many studies for future

- KM3NeT
 - ARCA #1014 P. Piattelli
 - ORCA #532 J. Brunner
- IceCube-Gen2
 - PINGU #1379 K. Clark
 - HE extension #741 E. Blaufuss
- Other
 - EVA #843 A. Romero-wolf
 - Phased Array #1297 K. Bechtol
 - GNO #828 S. Wissel,
 - Baikal-GVD #1142 and #1093 B. Shaybonov
 - NTA #1170 G. Hou

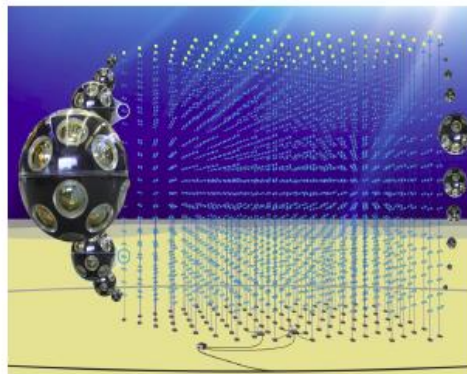
KM3NeT-ORCA

#532 J. Brunner

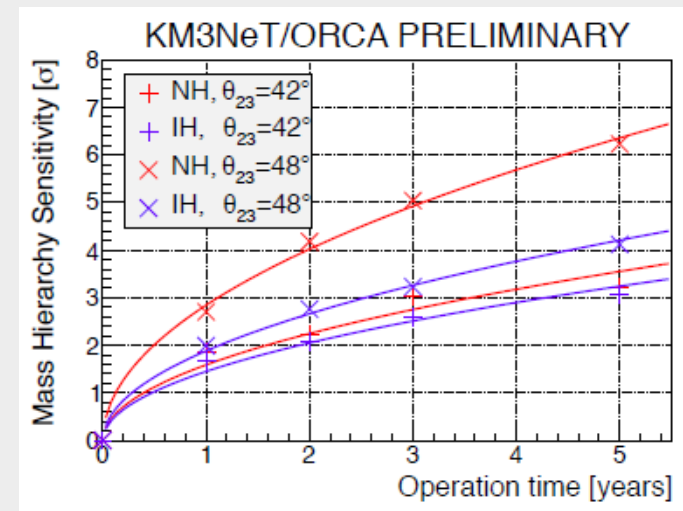
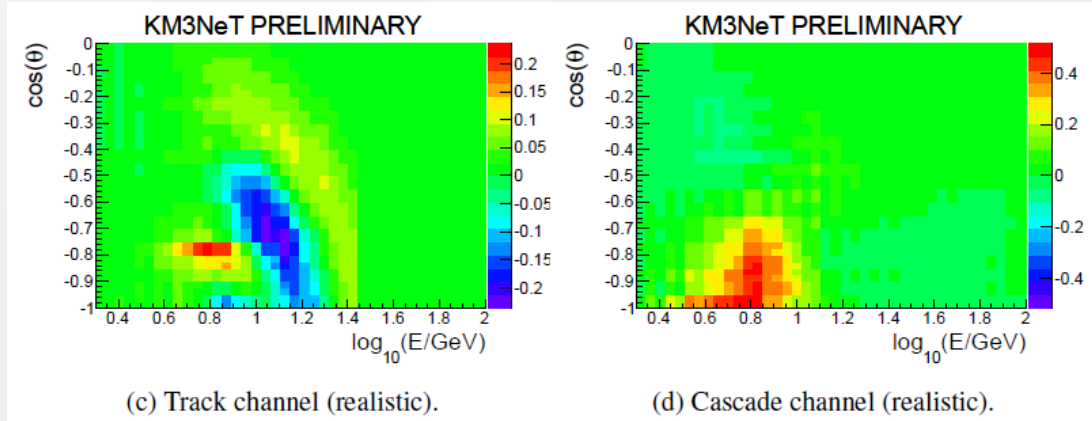
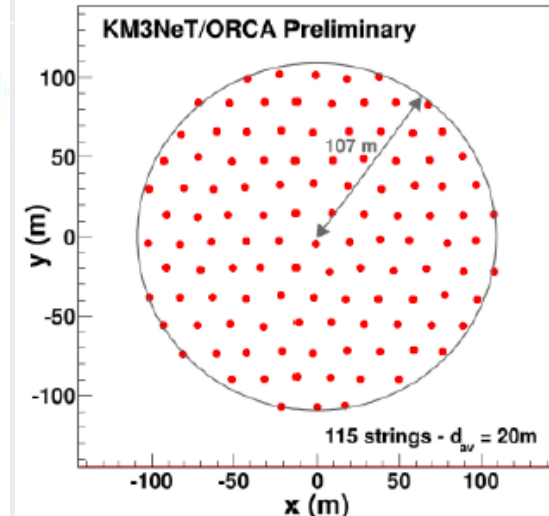
Also

- #578
- #748
- #1120
- #935

115 lines, 20m spaced,
18 DOMs/line 6m spaced
 Instrumented volume ~ 3.8 Mt, 2070 OM

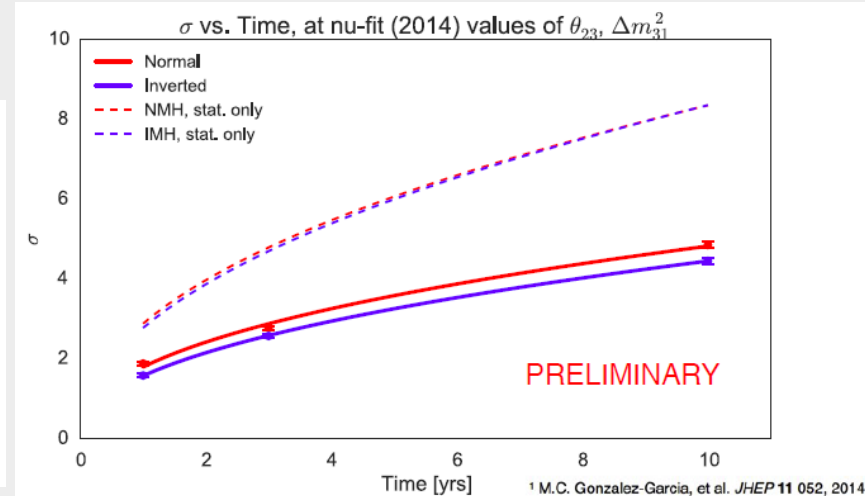
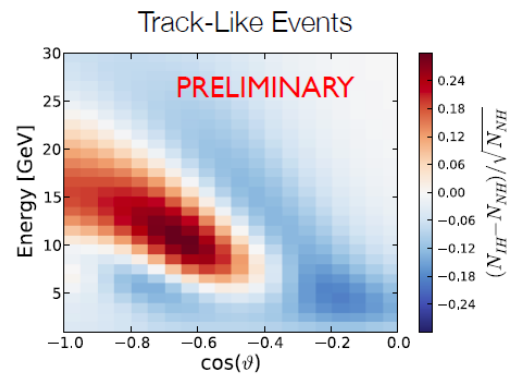
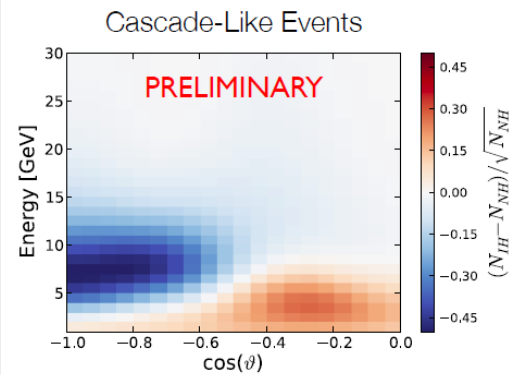
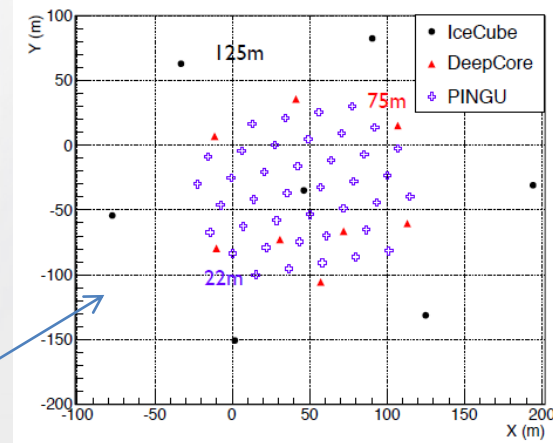
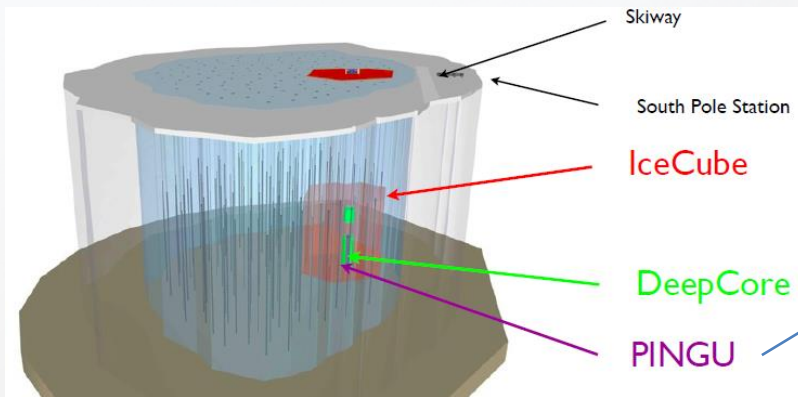


PHASE-I 6-7 STRINGS



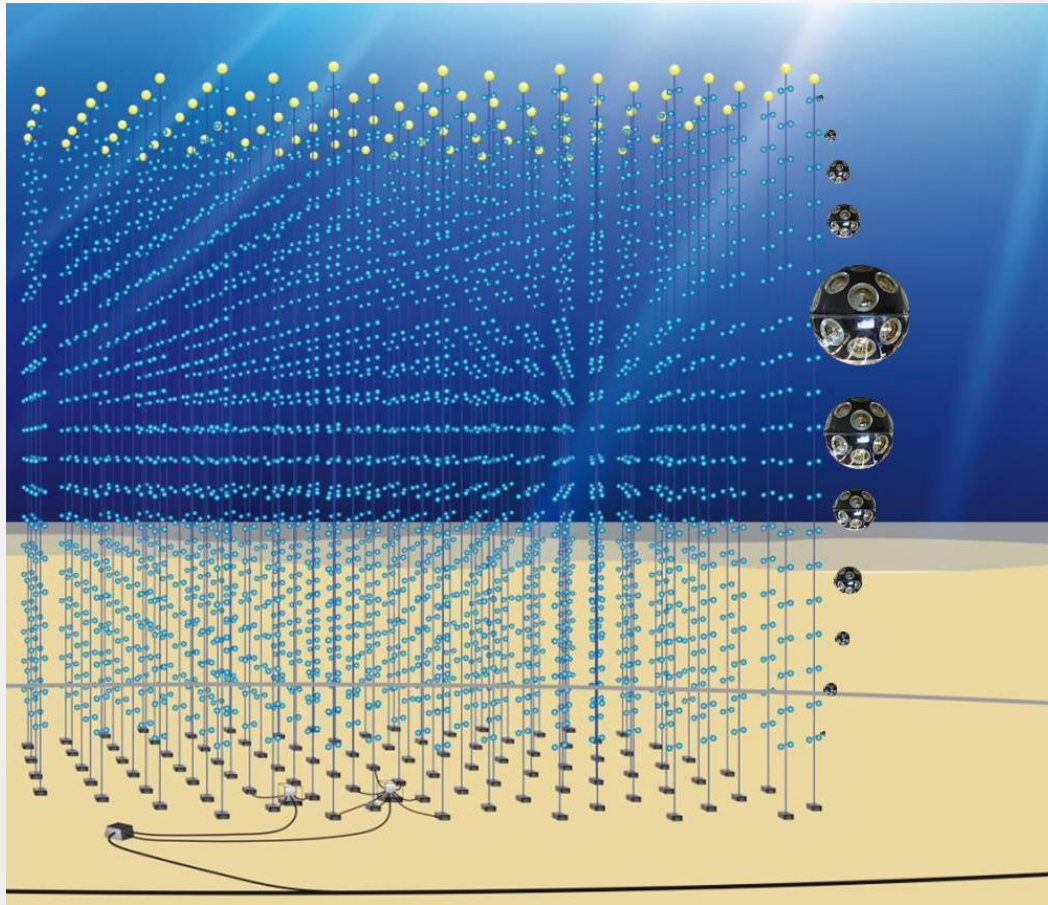
PINGU

#1379 K. Clark

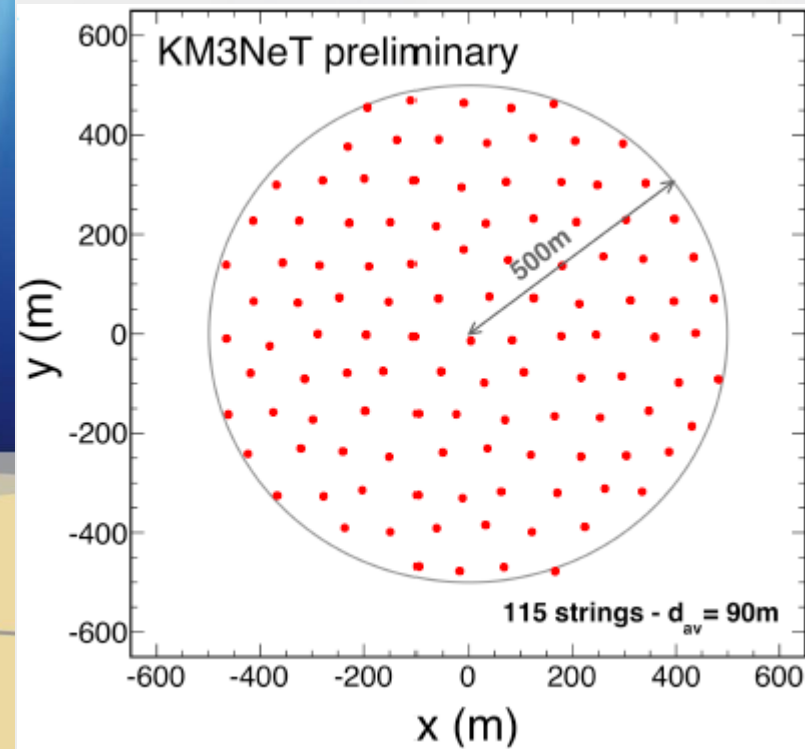


KM3NeT-ARCA

#1014 P. Piattelli



115 detection units per building block
18 DOM per DU
Vertical DOM spacing 36 m
Inter-DU spacing 90 m



2 of the block ~ 1km³ volume

KM3NeT-ARCA

#1014 P. Piattelli

KM3NET optical module

- 17-inch glass sphere
- Segmented cathode area with 31x3inch PMTs
- 19 down, 12 up

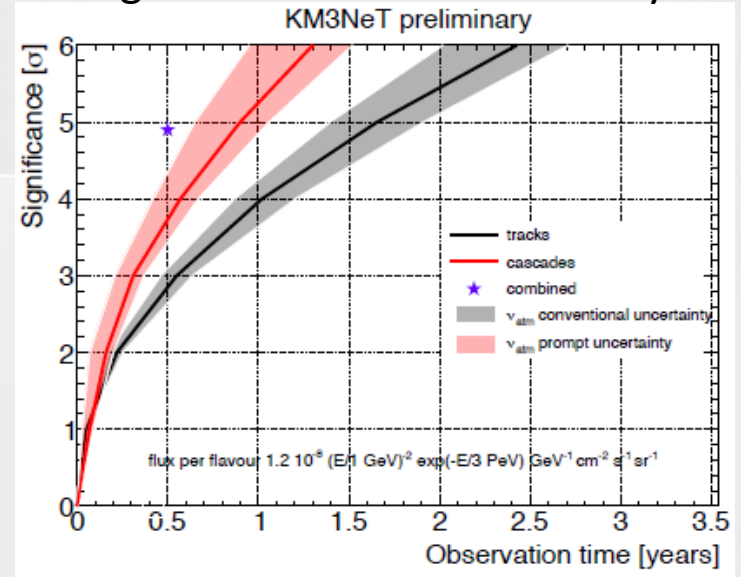


Also

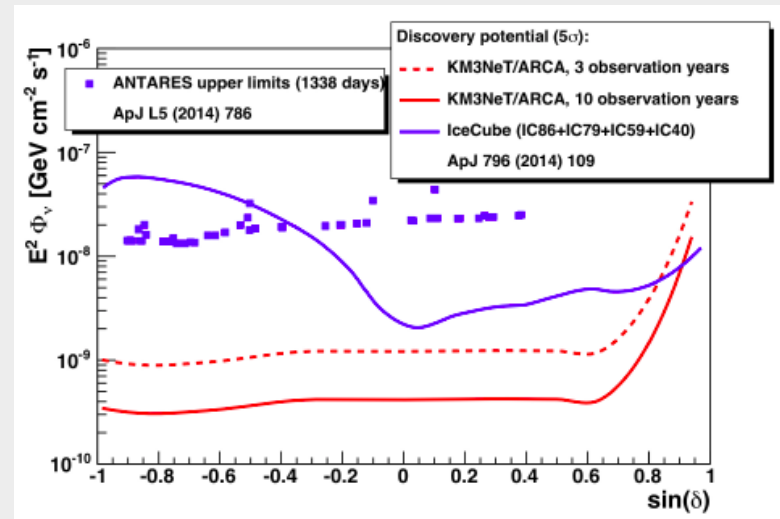
- #986
- #1310
- #1298
- #937
- #1282
- #1186
- #1175
- #838
- #1279

Diffuse flux

5 σ significance in less than one year

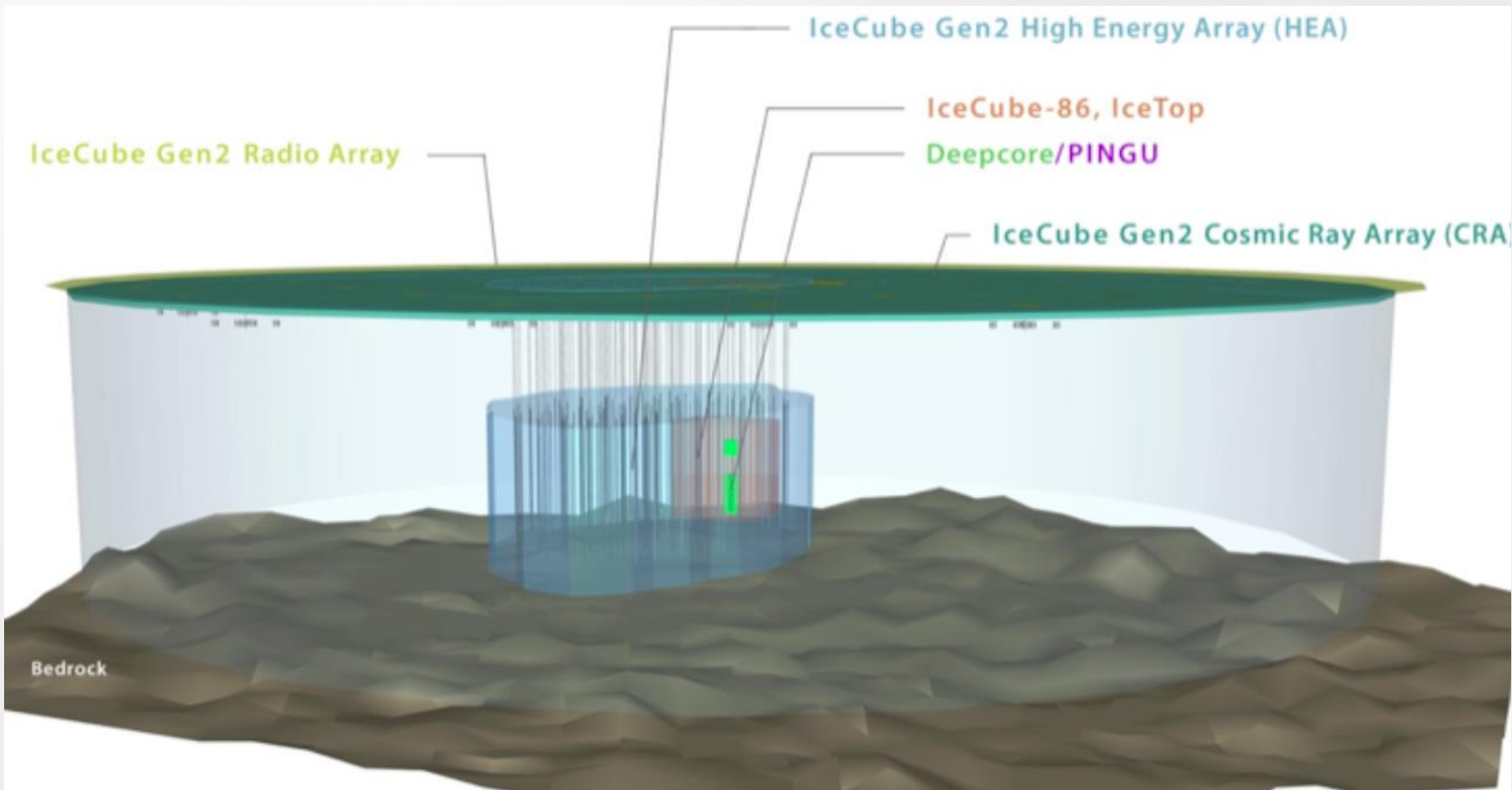


Point source



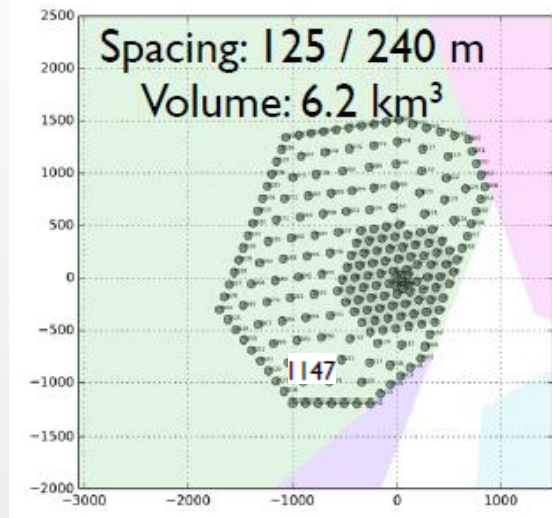
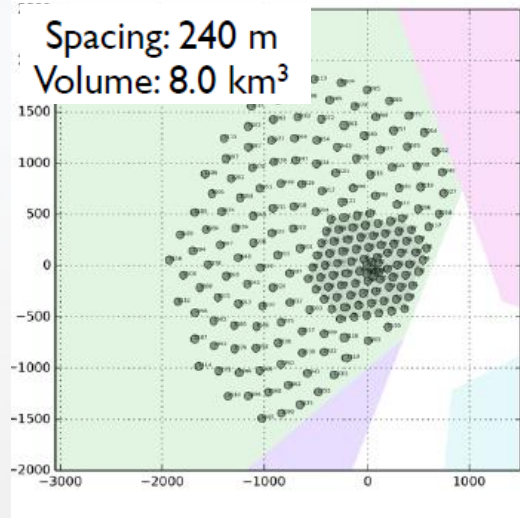
Gen2 High energy extension

#741 E. Blaufuss



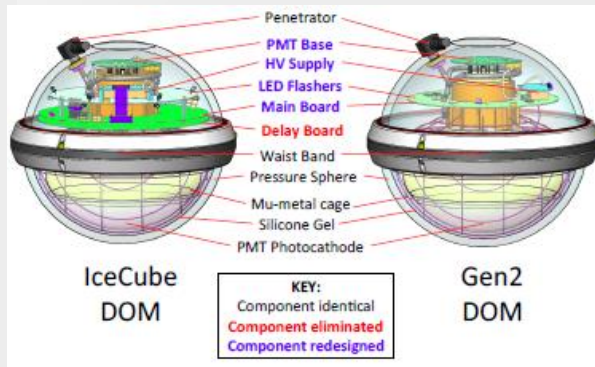
Gen2 High energy extension

#741 E. Blaufuss

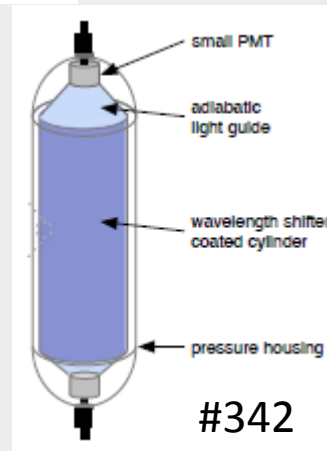
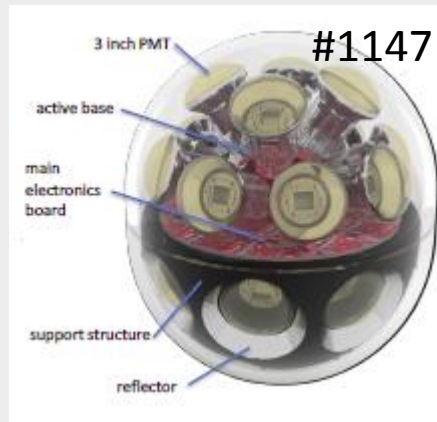


Point source sensitivity study indicates 10 years of observation with Gen2 HEA is equivalent to >200 yrs of IC86

#1137



#1148

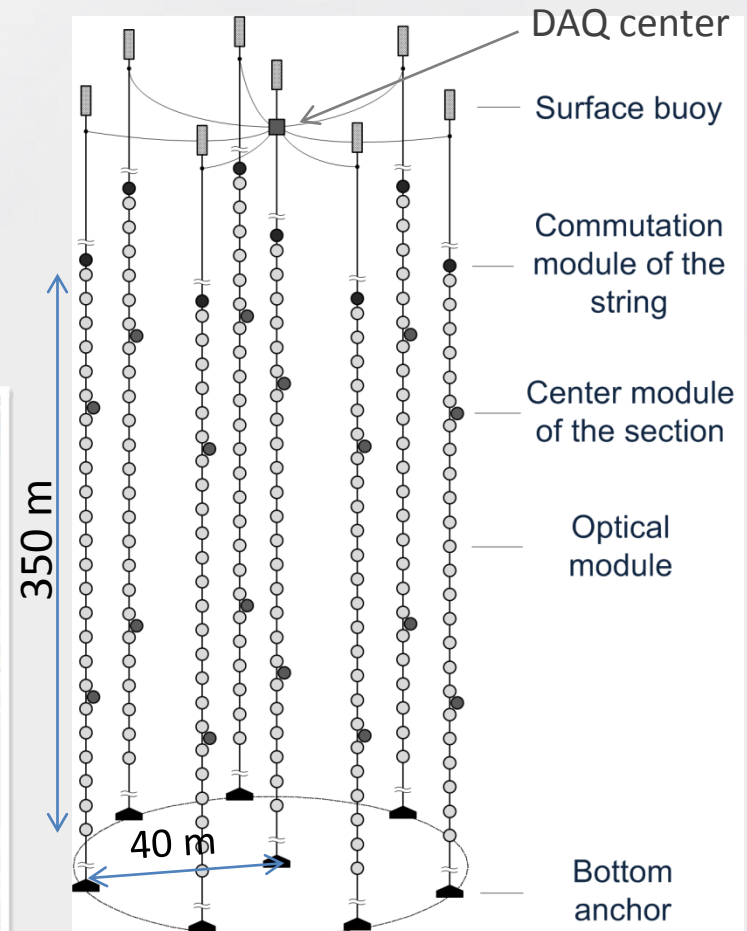
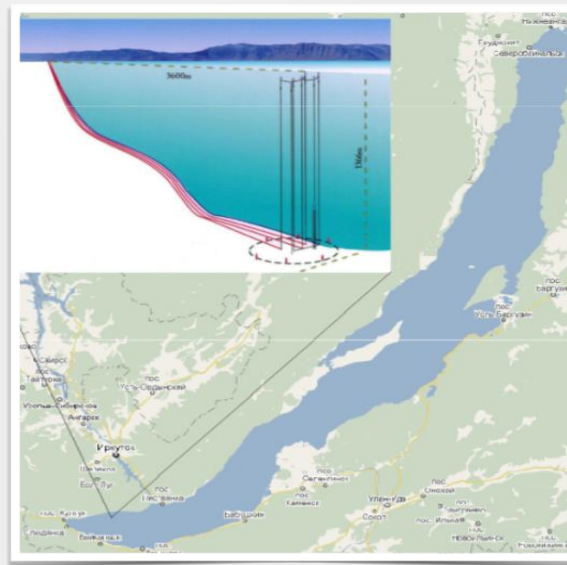


Bikal-GVD

#1142 B. Shaybonov

8-12 clusters of 1920 to 2304 optical modules to work as a half km³ detector

- First cluster installed in April 2015
- Full configuration planned in 2020



Conclusions

- The observations of steady beam of neutrinos from (somewhere in) the Universe activated many studies in this field to answer questions:
 - What are the flux shape and flavor?
 - What is the origin of the neutrino flux being measured by IceCube?
 - Is there any other neutrino flux from different origin?
- Many theoretical works and follow up/correlation multi-messenger studies
- Still, larger next generation detectors are needed:
 - KM3NeT
 - IceCube-Gen2
 - BIKAL-GVD
 - The higher energy/cosmogenic neutrino projects
 - ARA, ARIANNA, ANITA, GNO, EVA....

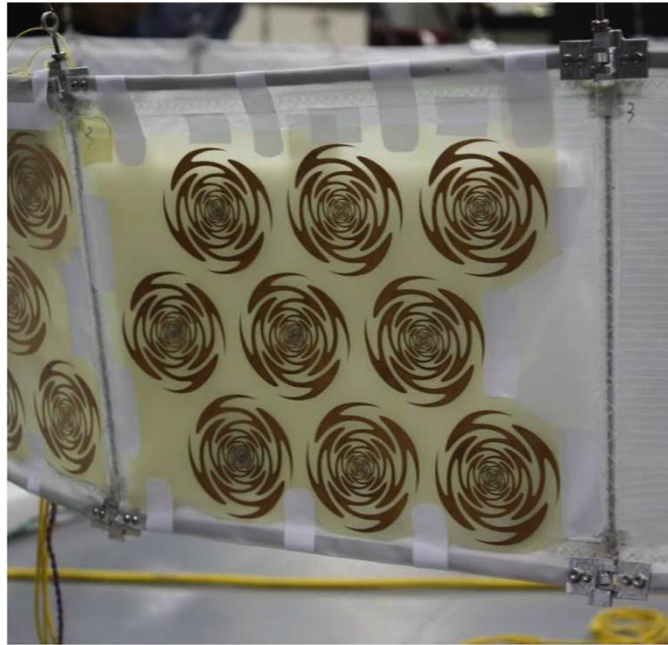
Backup

EVA

#843 C. Pfendner



1/20th scale model balloon.
This balloon has 28 gores
compared to the 280 gores of
the full scale balloon.



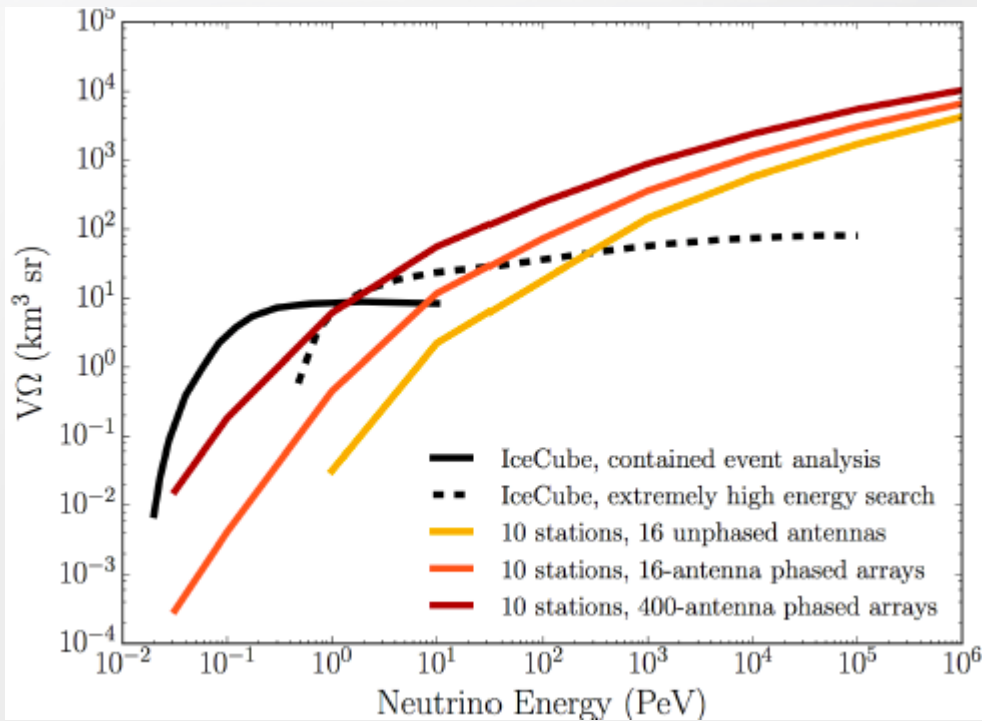
Dual-polarized sinuous
antenna feeds.



Balloon and feed
system.

Phased Array

#1297 K. Bechtol



Phased Array Concept

16 antenna phased array example
Co-located but distinct "pointing" and "trigger" arrays

