High Energy Cosmic Neutrino Fluxes

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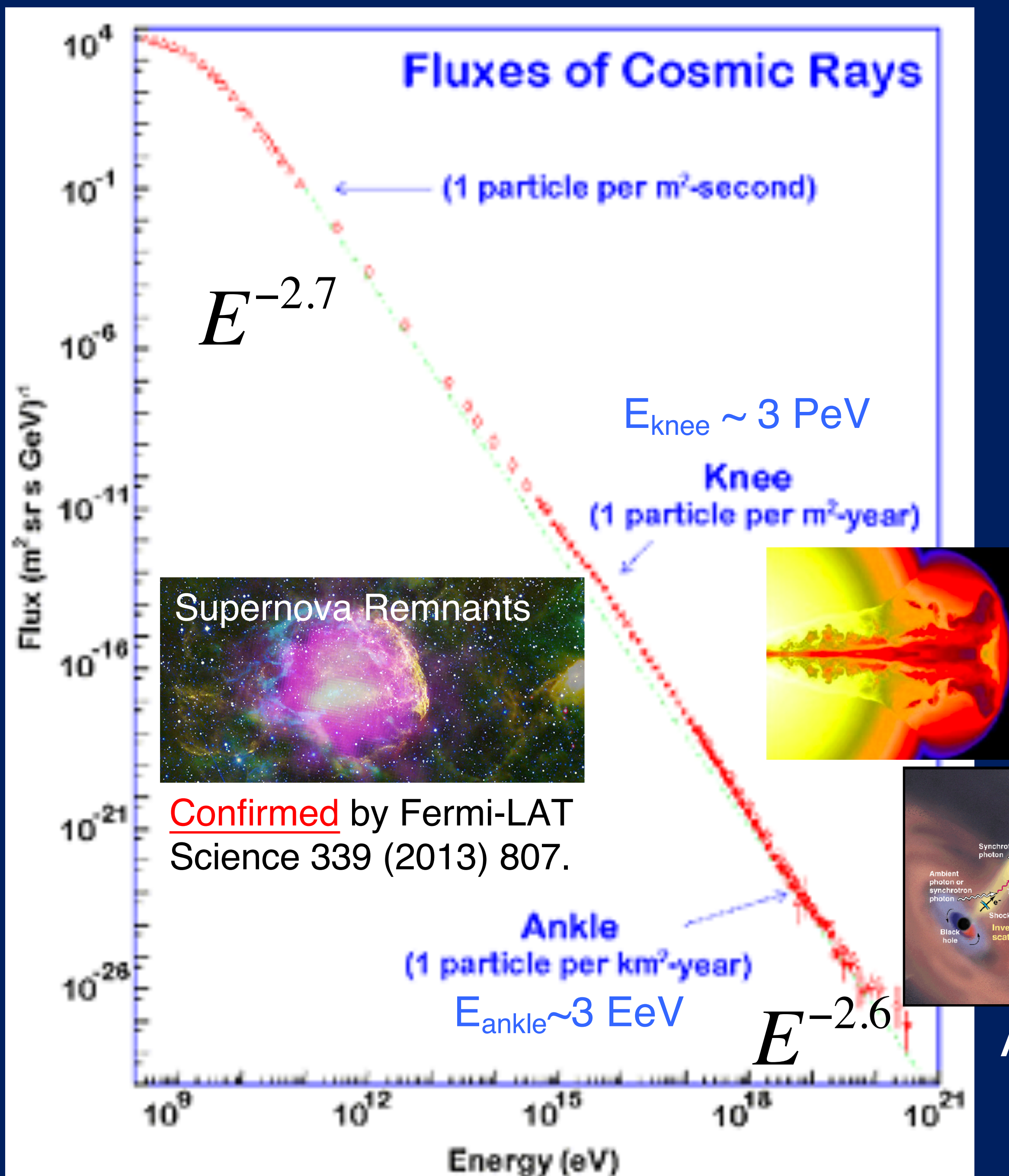
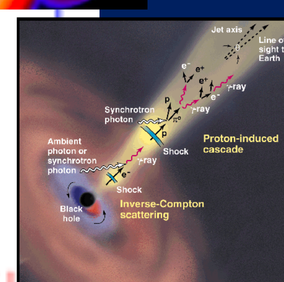
Moorea, French Polynesia

High Energy Neutrinos: Why?

Origin of Cosmic Rays with E up to 10^{20} eV ?

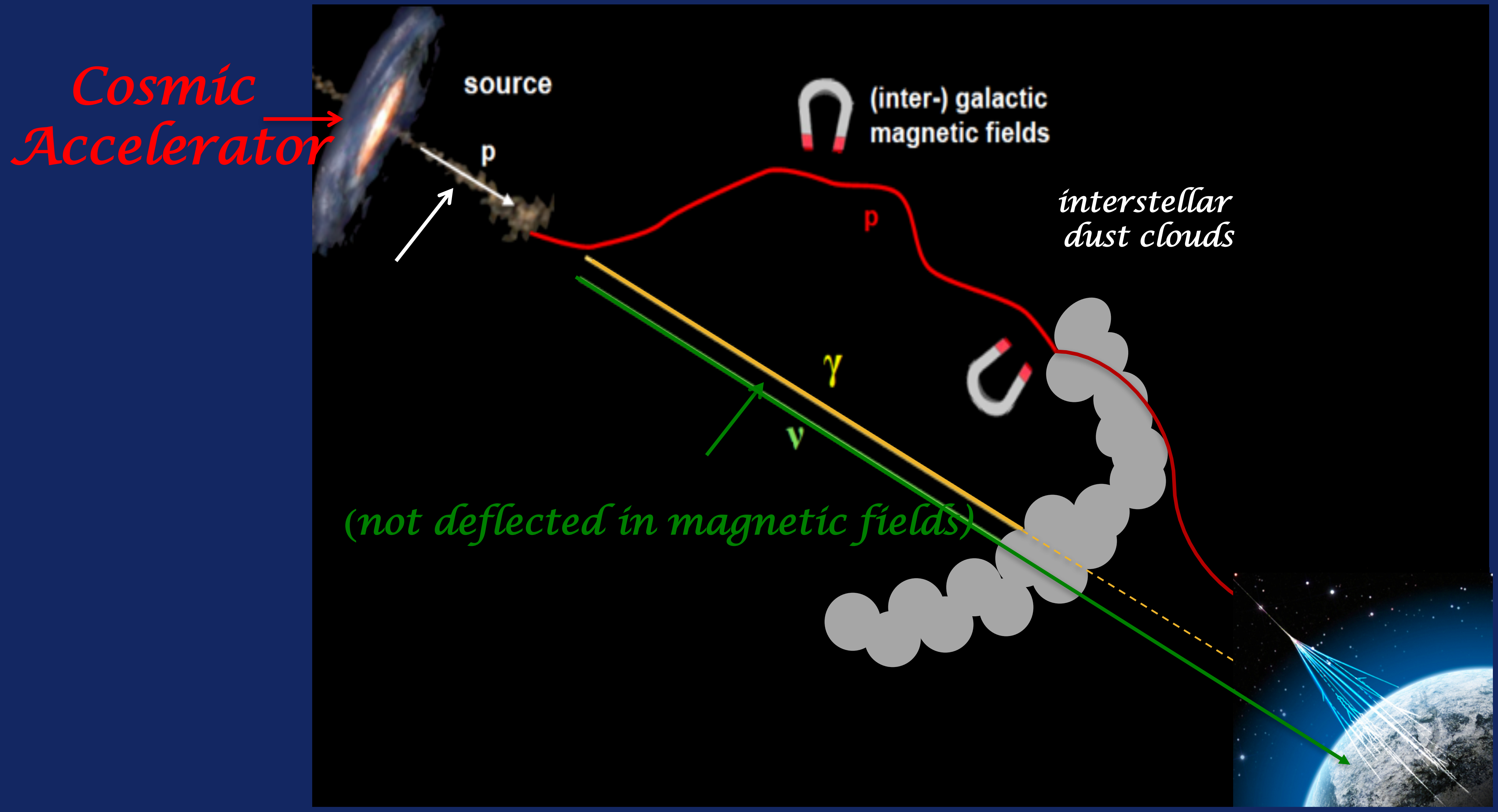


GRB?



AGN?

High Energy Neutrinos: Why?



Neutrinos as probes of the high-energy Universe complementary to γ-rays and cosmic rays

High Energy Neutrinos: Why?

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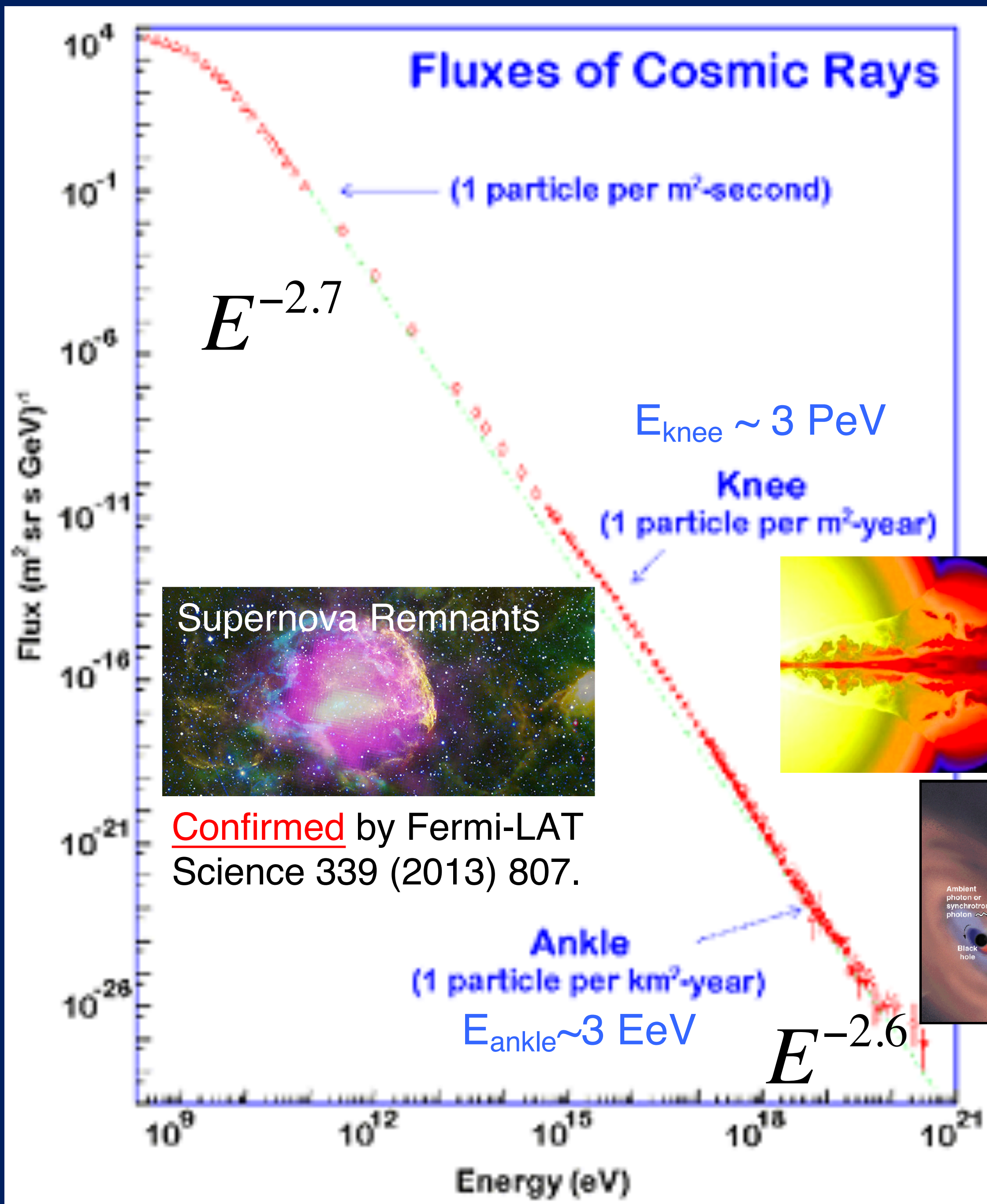

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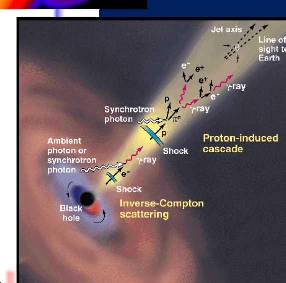


AGN?

- ν source searches
- ν flux measurements

TeV-PeV neutrino production

$p + p \rightarrow \pi + \ldots \rightarrow \nu + \ldots$

hadro production

$p + \gamma \rightarrow \Delta \rightarrow (p + \pi \rightarrow p + \gamma\gamma)$
$\rightarrow n + \pi \rightarrow n + \nu + \ldots$

photo production

$E_\nu \sim E_p/20 \sim E_\gamma/2$

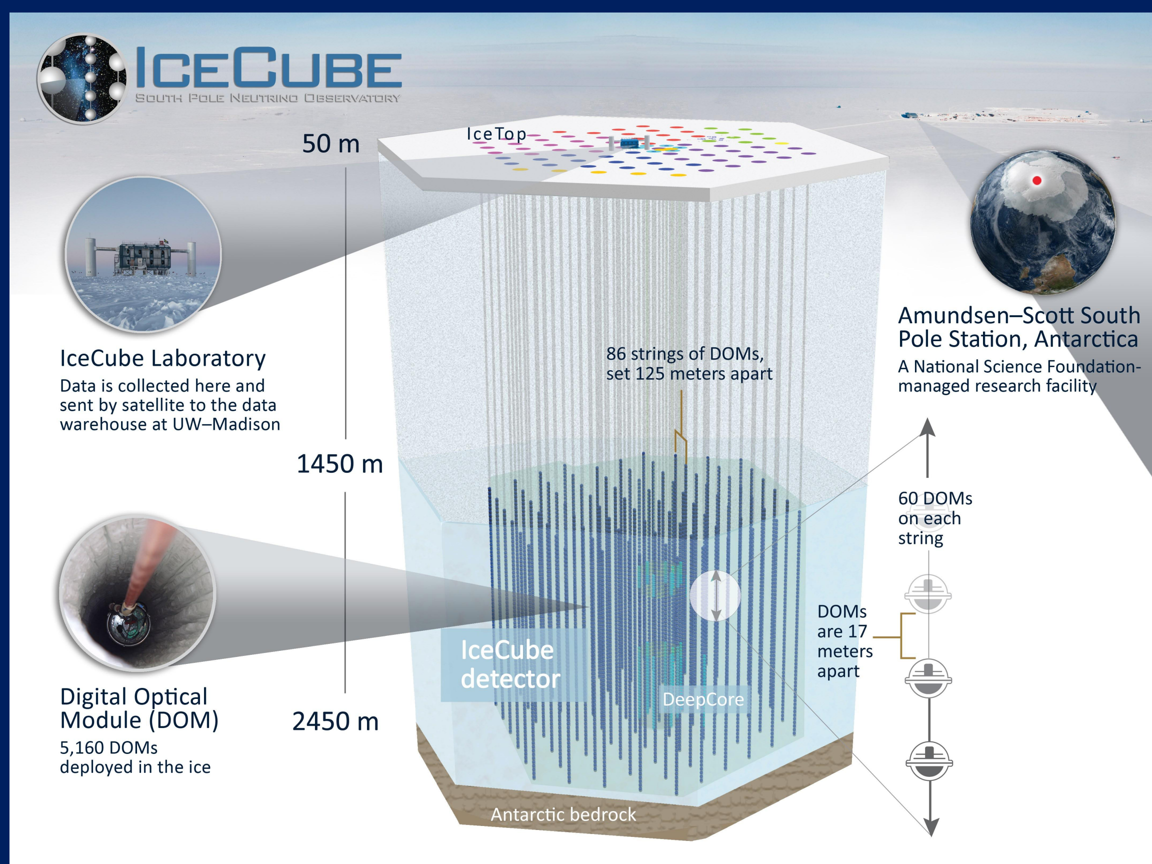
(simple multimessenger model)

- CR spectrum formation $\quad \Phi_{CR} \sim E_{CR}^{-\gamma_{CR}}$
- CR acceleration
  - Fermi mechanism: $\gamma_{CR} \sim 2$
- CR propagation

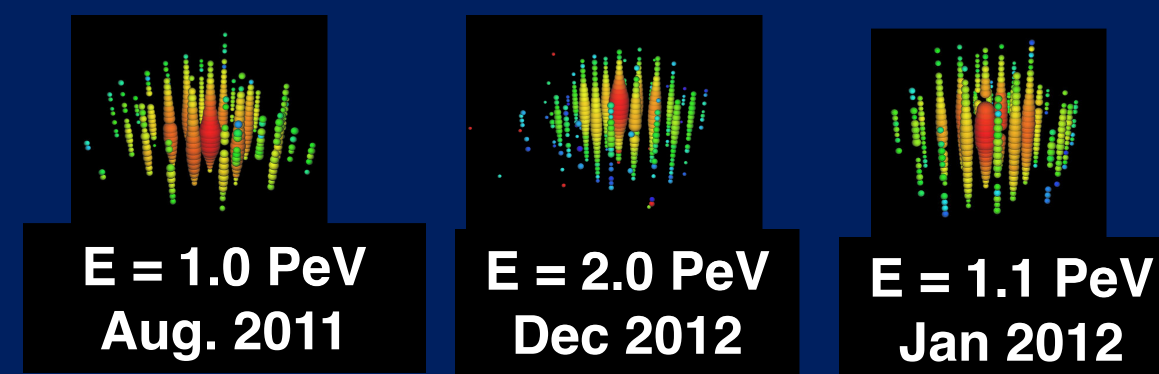
- ν benchmark model: $\gamma_\nu \sim 2$ $\quad \Phi_\nu \sim E_\nu^{-\gamma_\nu}$

Neutrino Telescopes Main Goals:

- ν source searches no sources have been found so far
- diffuse/unresolved ν flux measurements observed!



talk by J. Madsen



2012: discovery of astrophysical PeV neutrinos

Neutrino Telescopes Main Goals:

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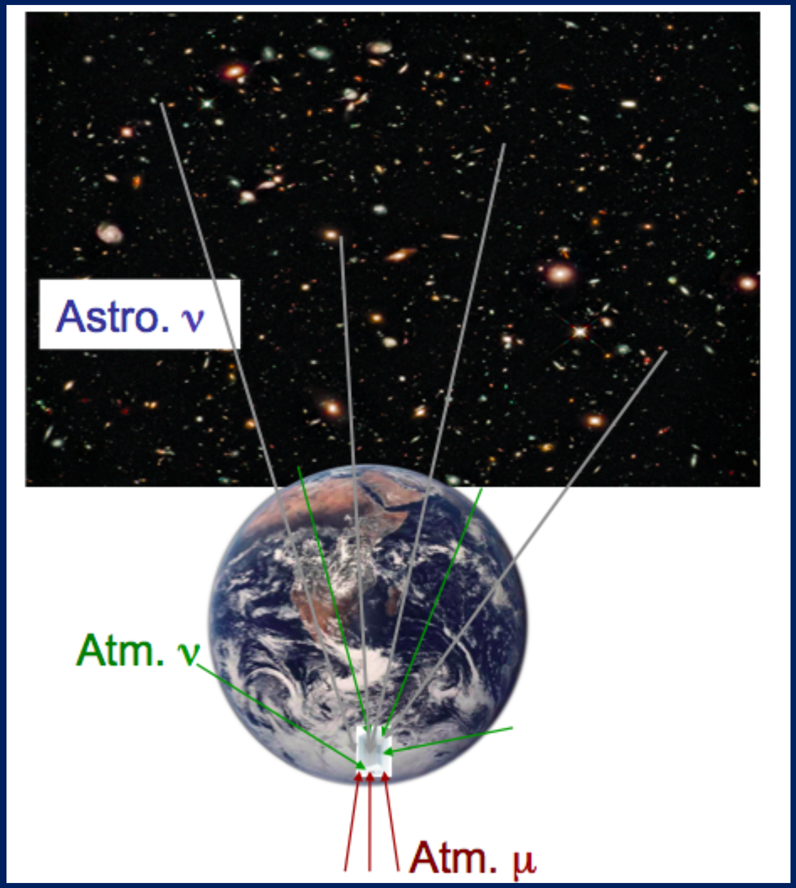
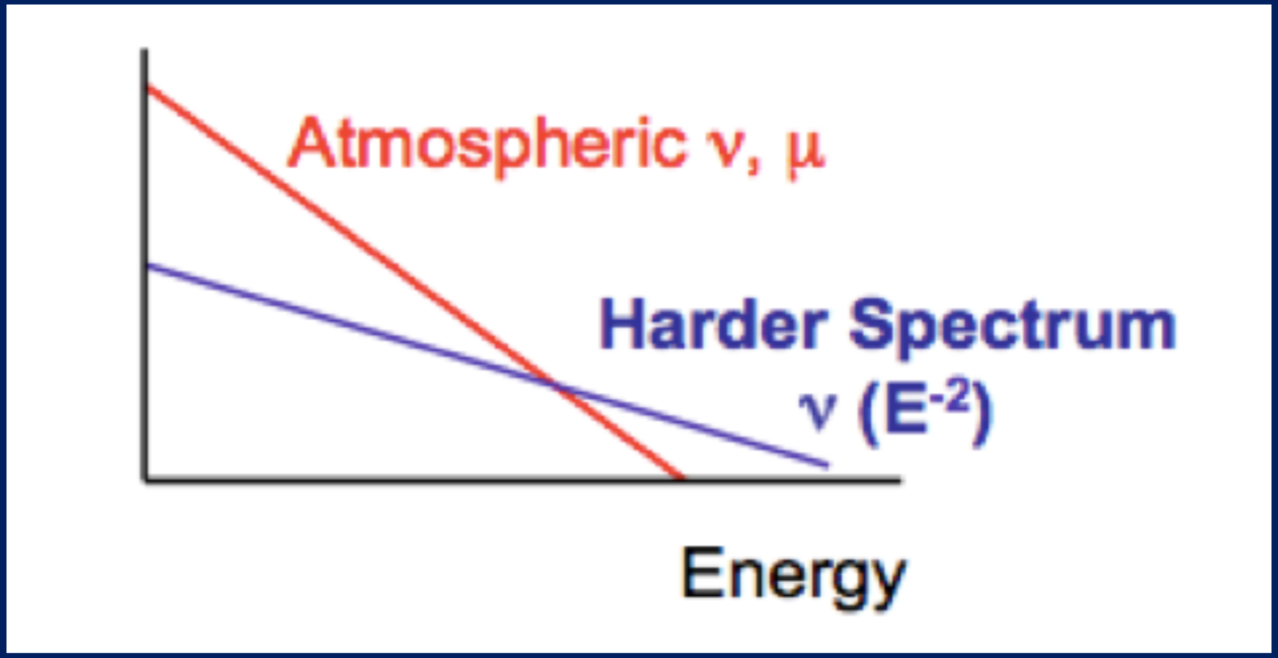


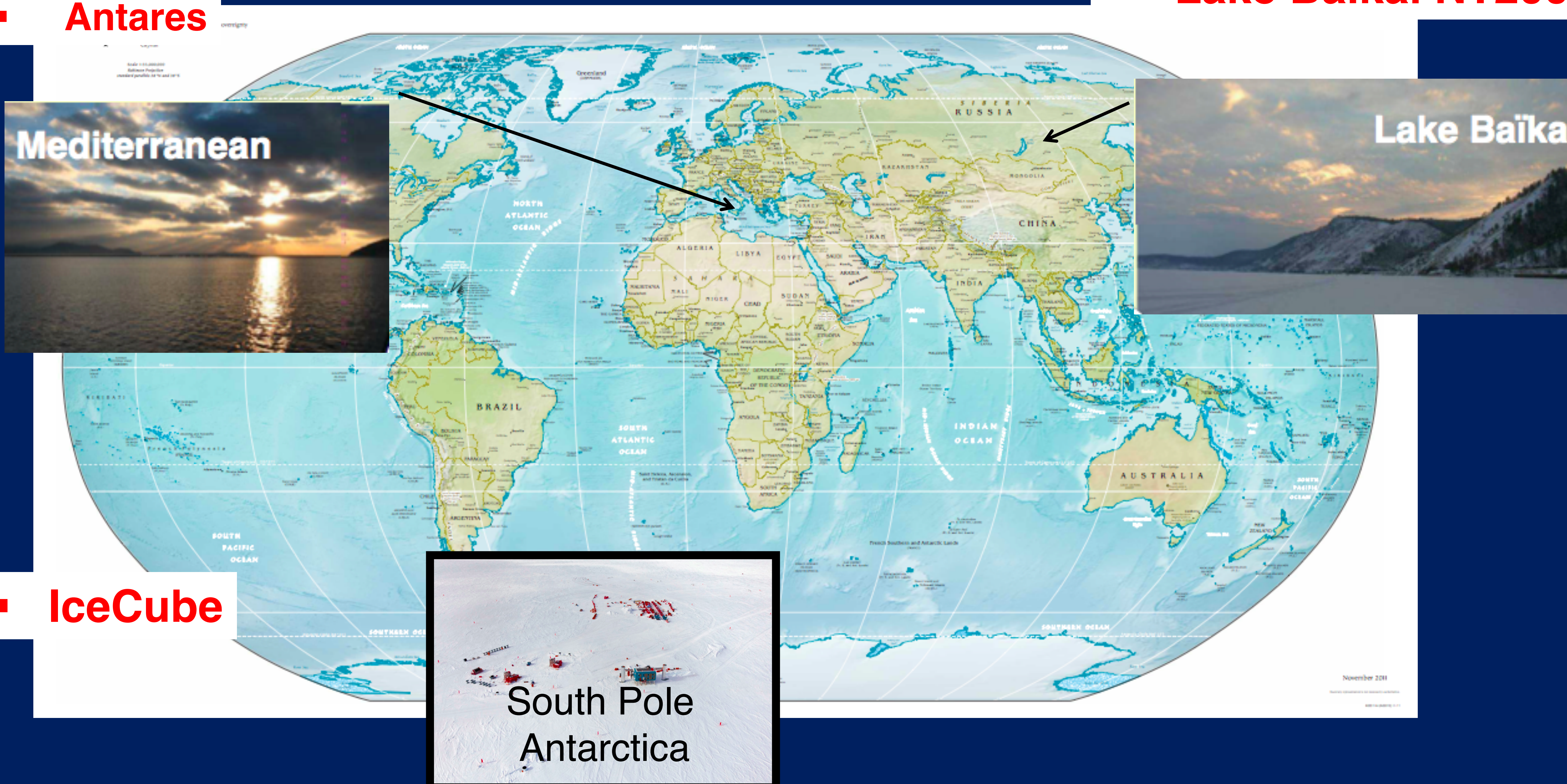


This talk focuses on diffuse flux results

High Energy Neutrinos: Where?

Techniques: optical detection (in operation)

- **Antares**
- **Lake Baikal NT200+**
- **IceCube**



High Energy Neutrinos: Where?

NT-200+

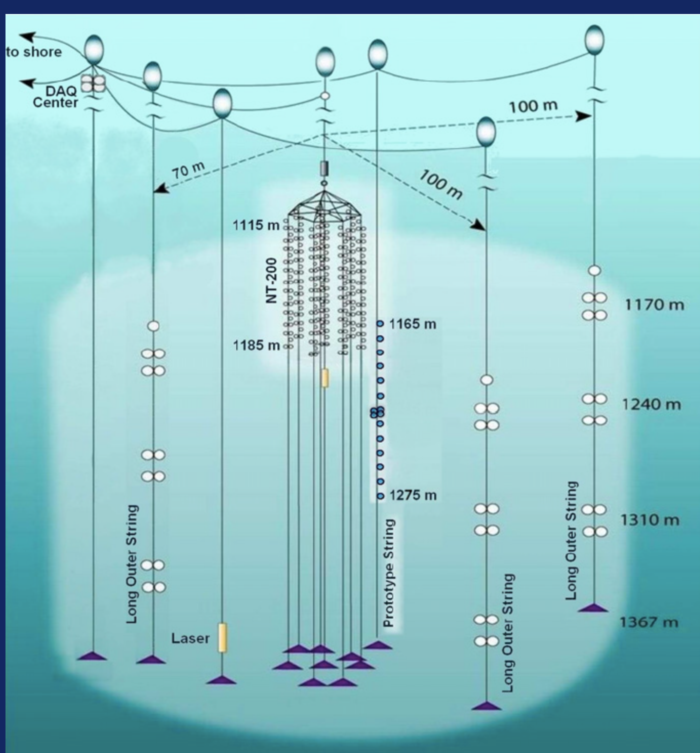
- 8+3=11 strings
- 192+36=228 PMTs
- 1/2000 km^3 of volume
- Medium: Lake Baikal
- Northern hemisphere

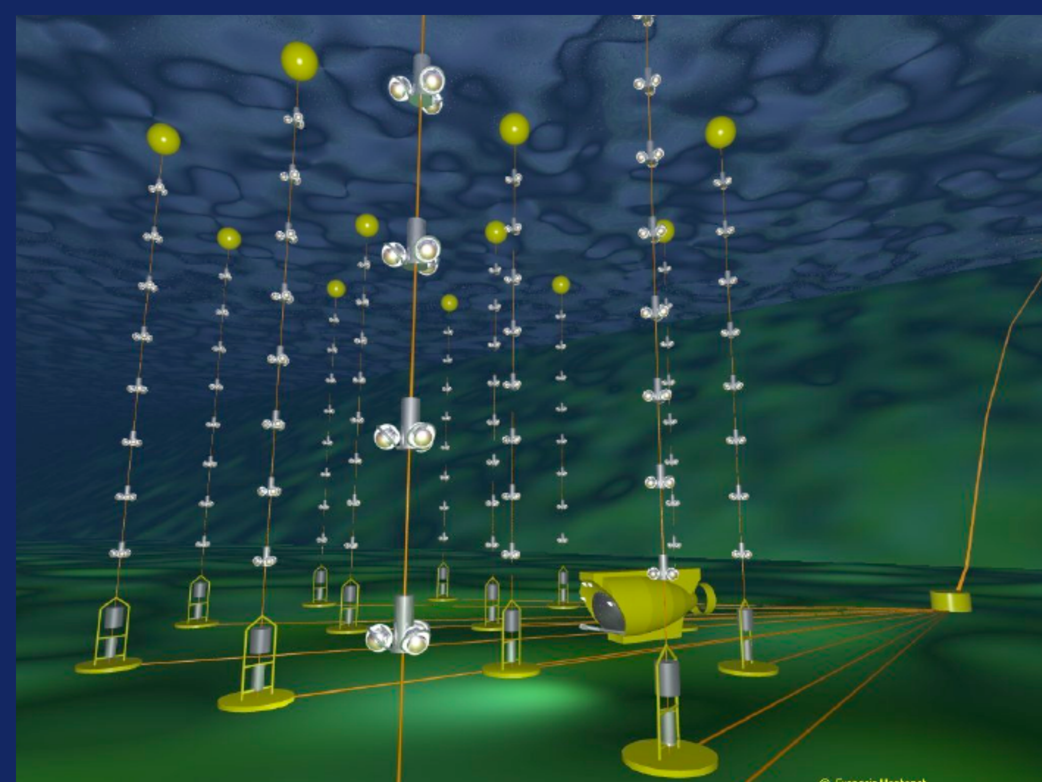
Antares

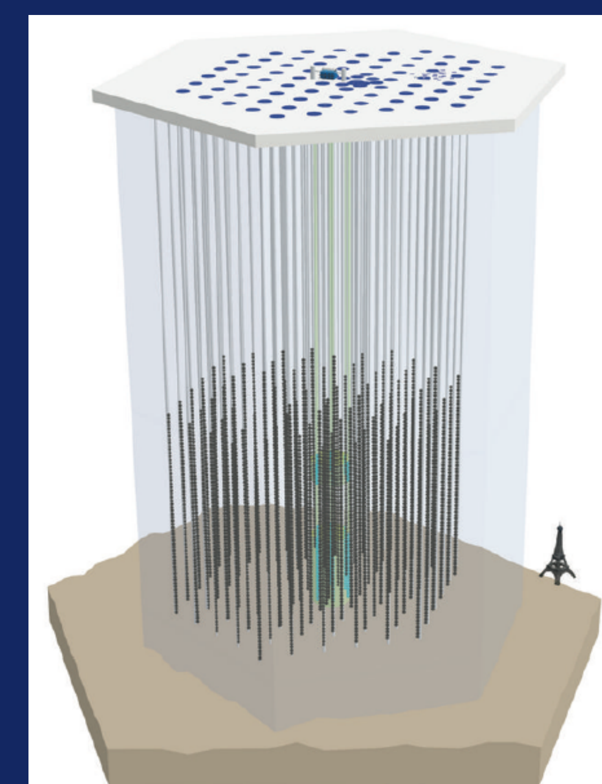
- 12 strings
- 885 PMTs
- 1/100 km^3 of volume
- Medium: Mediterranean Sea
- Northern hemisphere

IceCube

- 86 strings
- 5160 PMTs
- 1 km^3 of volume
- Medium: South Polar Ice
- Southern hemisphere

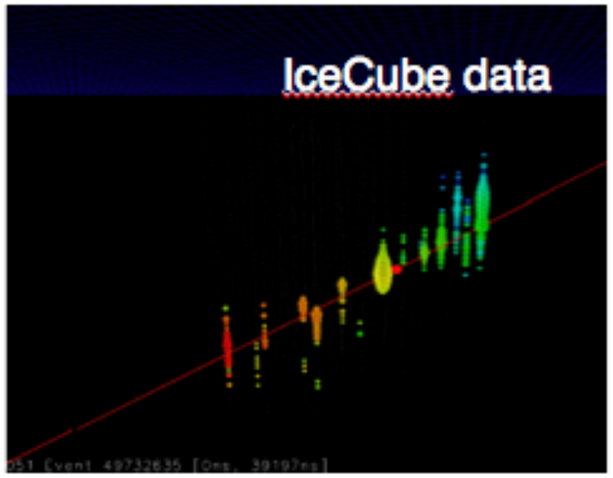


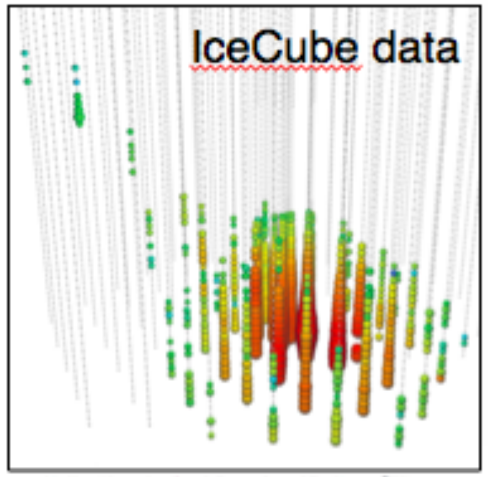


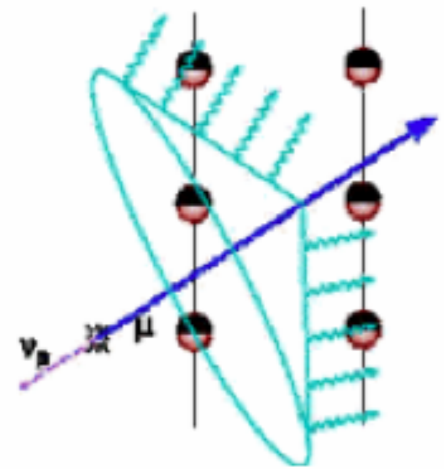


High Energy Neutrinos: How?

ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY

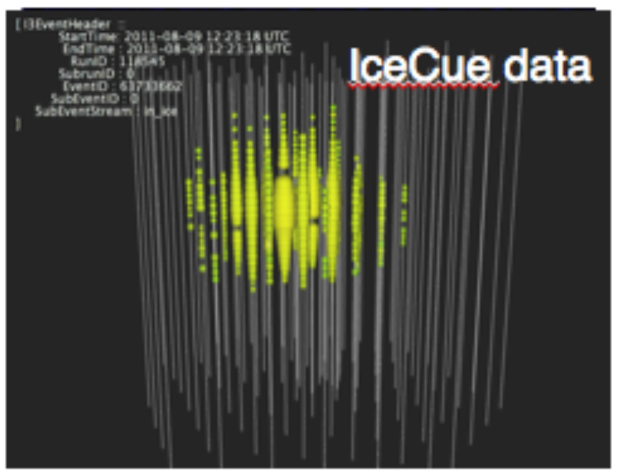


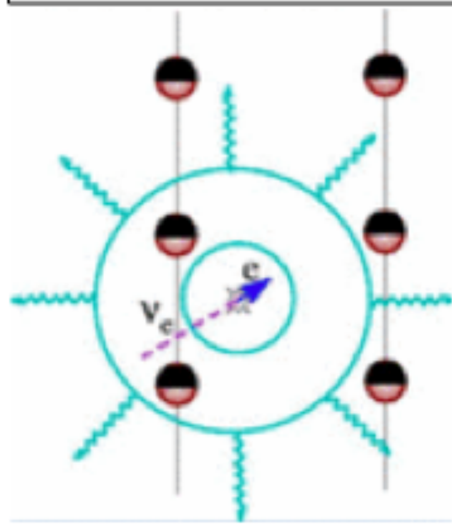




μ Tracks: (ν_μ)

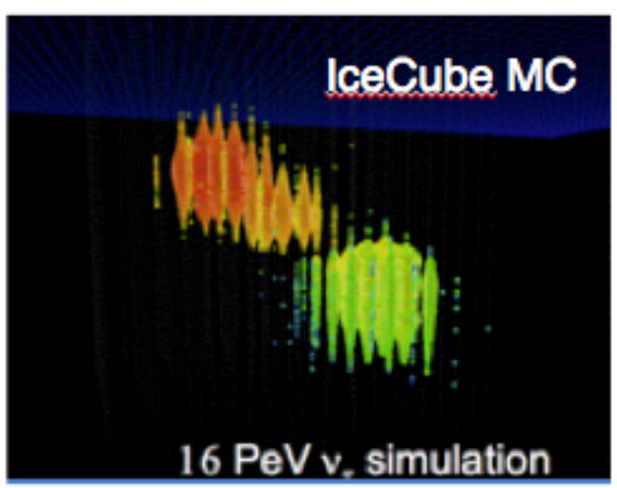
- $\boldsymbol{\nu_\mu + N \longrightarrow \mu + X}$
- through-going and starting μ
- energy resolution ~ factor of 2
- pointing resolution <1^o





Cascades:

- e-m and hadronic cascades
- $\nu_{e(\tau)} + N \rightarrow e(\tau) + X$
  $\nu_f + N \rightarrow \nu_f + X \quad f = e, \mu, \tau$
- Resolutions, cascades (contained in detector)
  - visible energy ~ 15%
  - angular ~ 10^o- 40^o



Composites

- starting events ("HESE","MESE","LESE")
- ν_τ ("double bangs" E_ν ~ 10's of PeV)

ν_τ not yet observed/identified

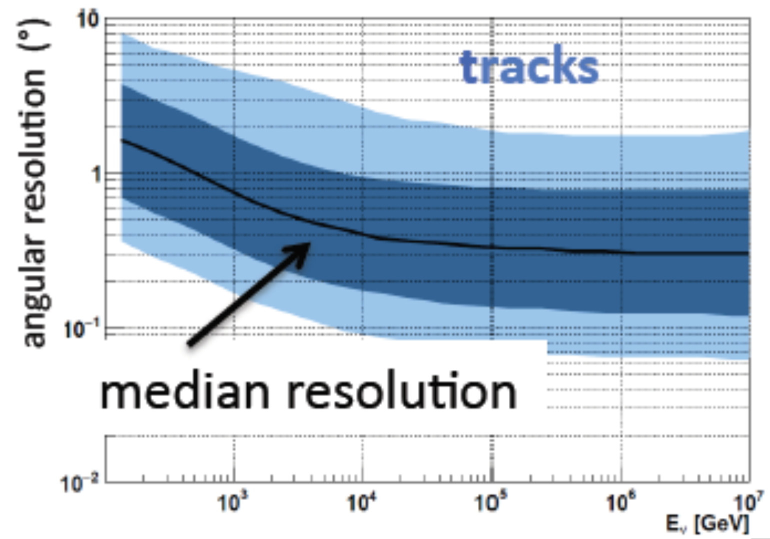
$\boldsymbol{\nu_\tau + N \longrightarrow \tau + X \longrightarrow X + X}$

High Energy Neutrinos: How?

ANTARES performances

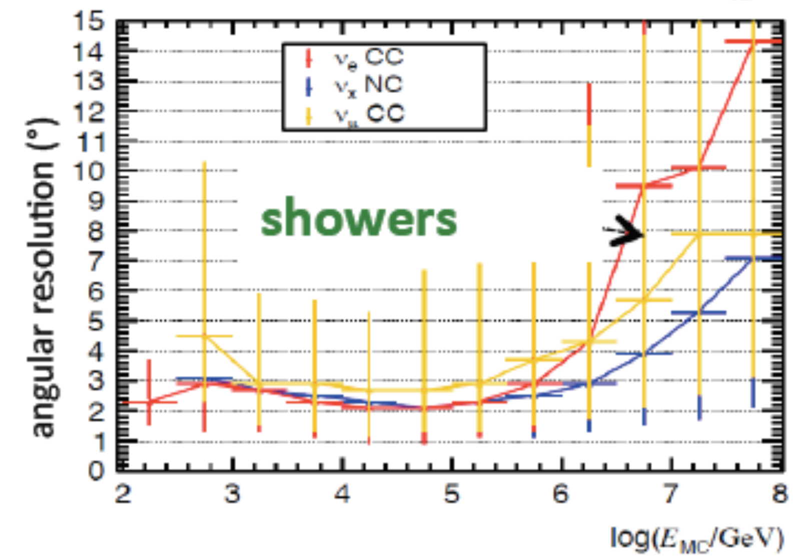
ANTARES angular resolution vs E_ν

Tracks (ν_μCC) **ideal tool for astronomy**
Median **<0.4°** above 10 TeV
90% purity



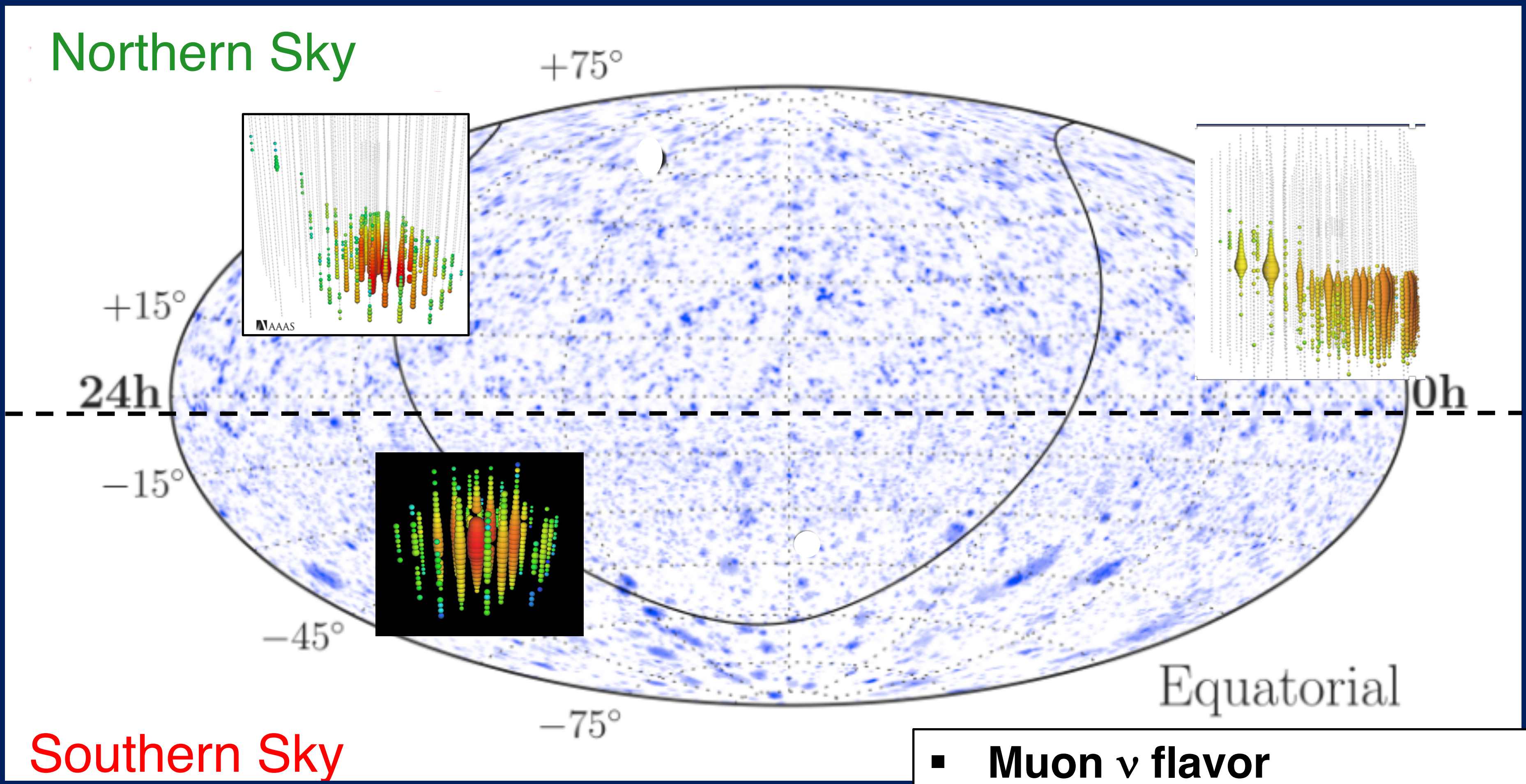
Upgoing **cascade events** (ν_eCC, NC)
Angular resolution **≈ 3°**
Shower confined within ≈ 10 m ➔ contained events

Good estimate of the ν energy, better than 10%



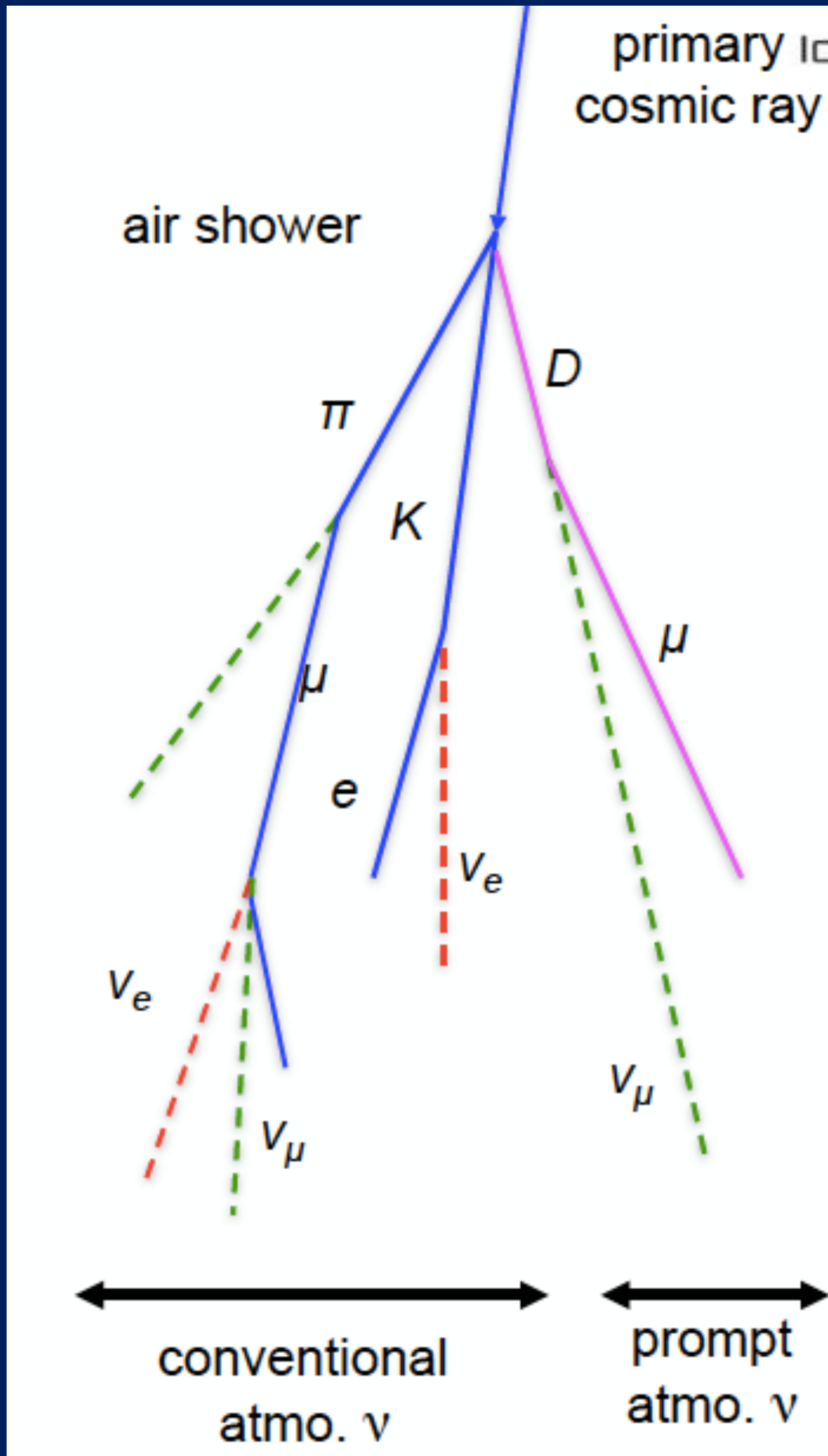
Antares: A. Margiotta (NOW2016)

High Energy Neutrinos: Flavors / Sky Sensitivities



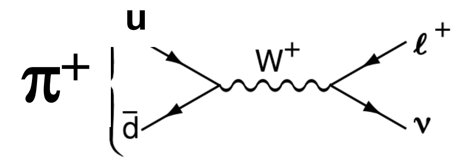
- **Muon ν flavor**
  - ✓ through-going muons   (Northern Sky only)
  - ✓ starting muons (**All-Sky**)
- **All flavor νs**
  - ✓ cascades (**All-Sky**)
    (ν_e+ν_τ dominated)
- Tau ν flavor (not observed)
  - ✓ double cascades   (**All-Sky**)

High Energy Neutrinos: Atmospheric “background”



Conventional neutrino flux
Decays of π,K mesons

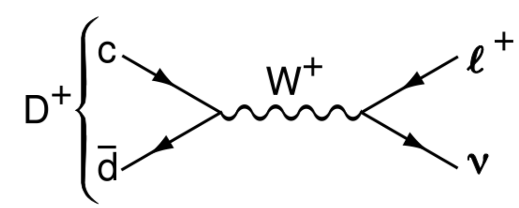
$$\pi, K \rightarrow \mu + \nu_\mu \rightarrow e + \nu_e + \nu_\mu$$



- steeply falling spectrum ($E^{-3.7}$)
- flux peaked at horizon
- ν_μ dominated

Prompt neutrino flux

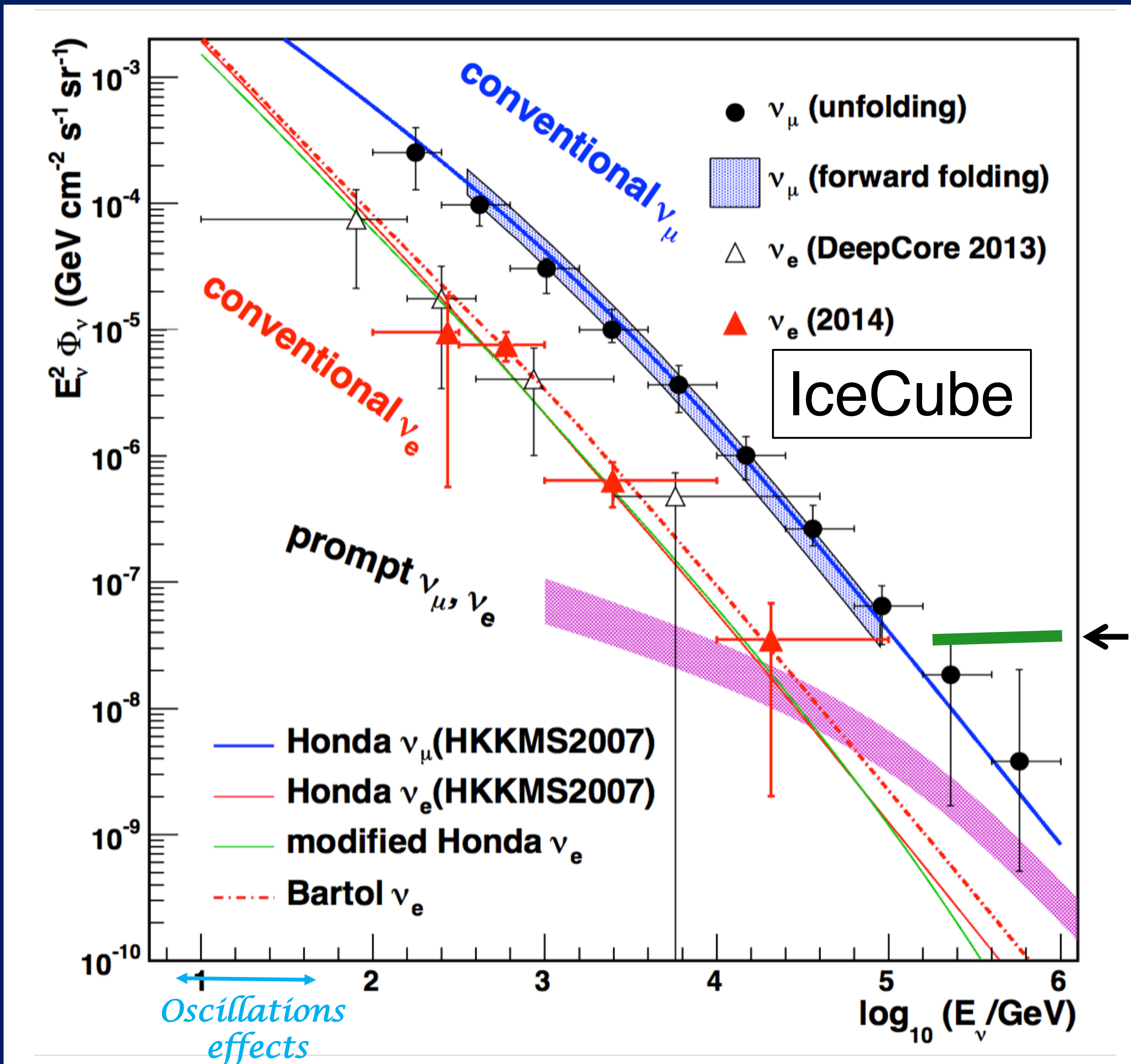
- not yet directly observed



- spectrum follows CR ($E^{-2.7}$)
- flux isotropic
- equal parts ν_μ and ν_e

ERS: R. Enberg et. Al.,Phys. Rev. D78, 043005 (2008)
A. Bhattacharya et.al. (2015), arXiv:1502.01076.

High Energy Neutrinos: Atmospheric “background”



Astrophysical neutrinos

Waxman-Bahcall Bound (all flavor)

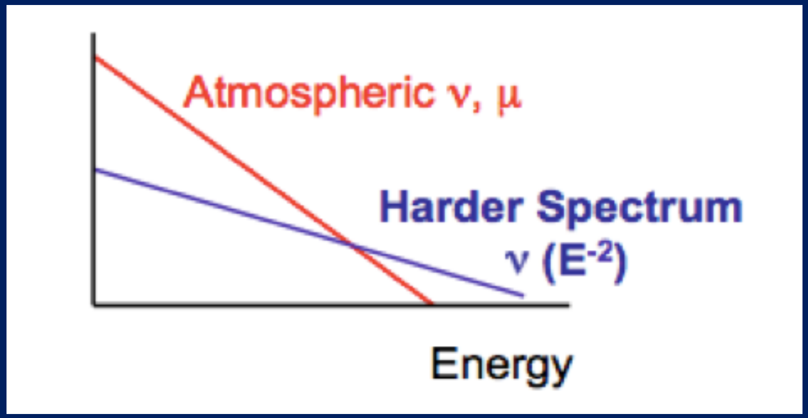
$$E_\nu^2 \Phi_{\rm WB} \approx 3.4 \times 10^{-8}\ \mathrm{GeV/cm^2\,sr\,s}$$

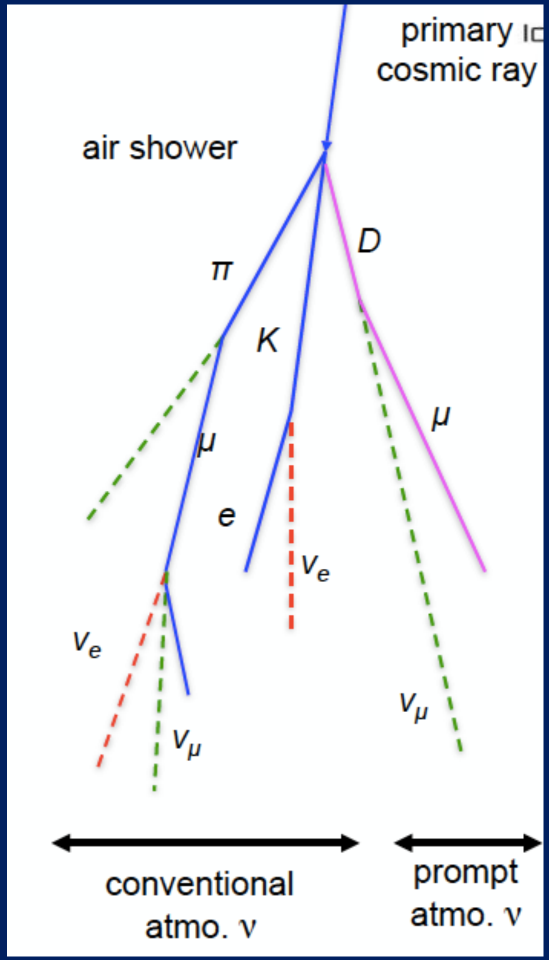
Benchmark model:
Fermi acceleration at shock fronts

High Energy Neutrinos: Atmospheric “background”

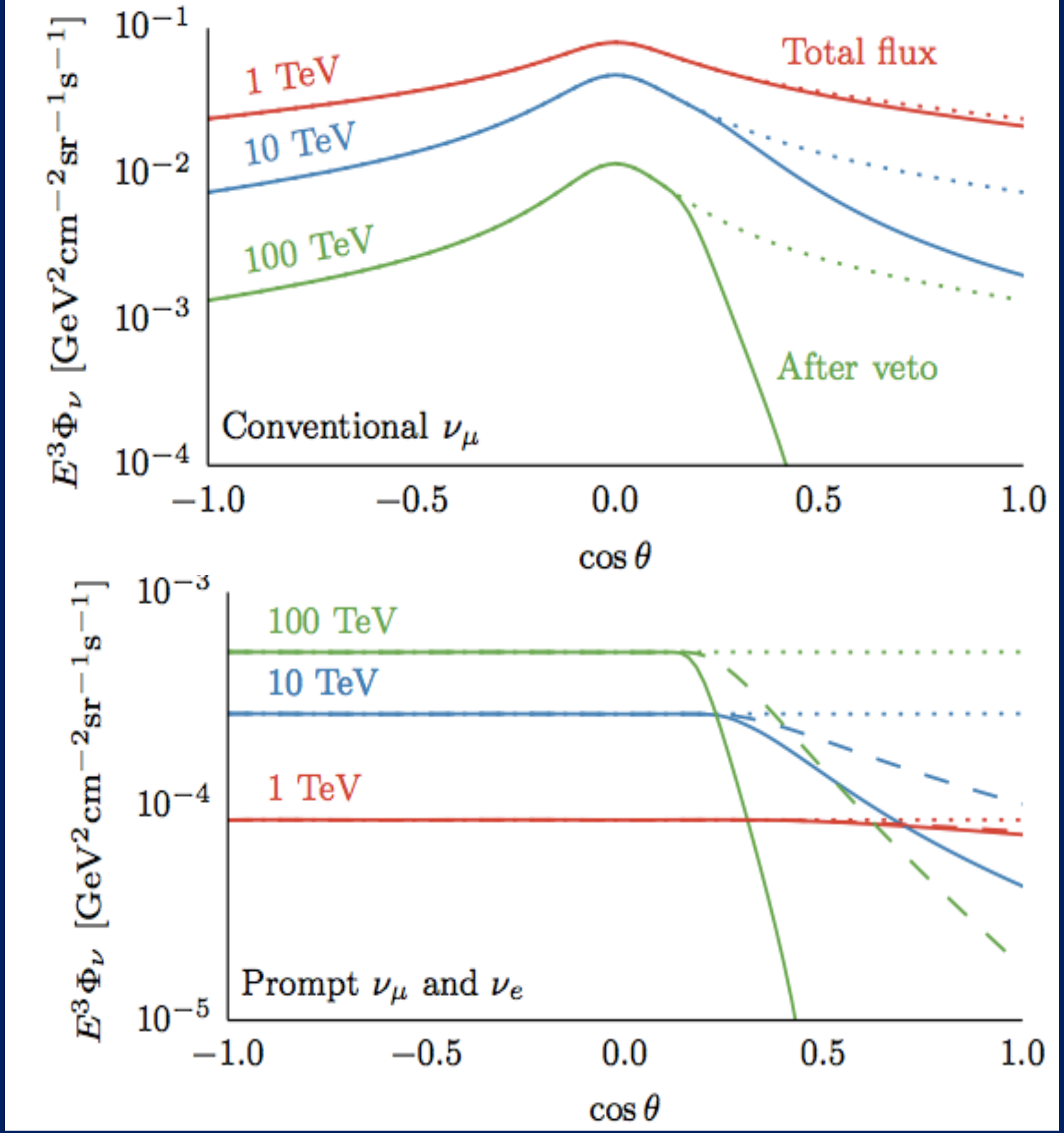
How to distinguish atmospheric from cosmic neutrinos?

Use information about both energy <u>and</u> direction





T. Gaisser et al, Phys. Rev. D 90, 023009 (2014)

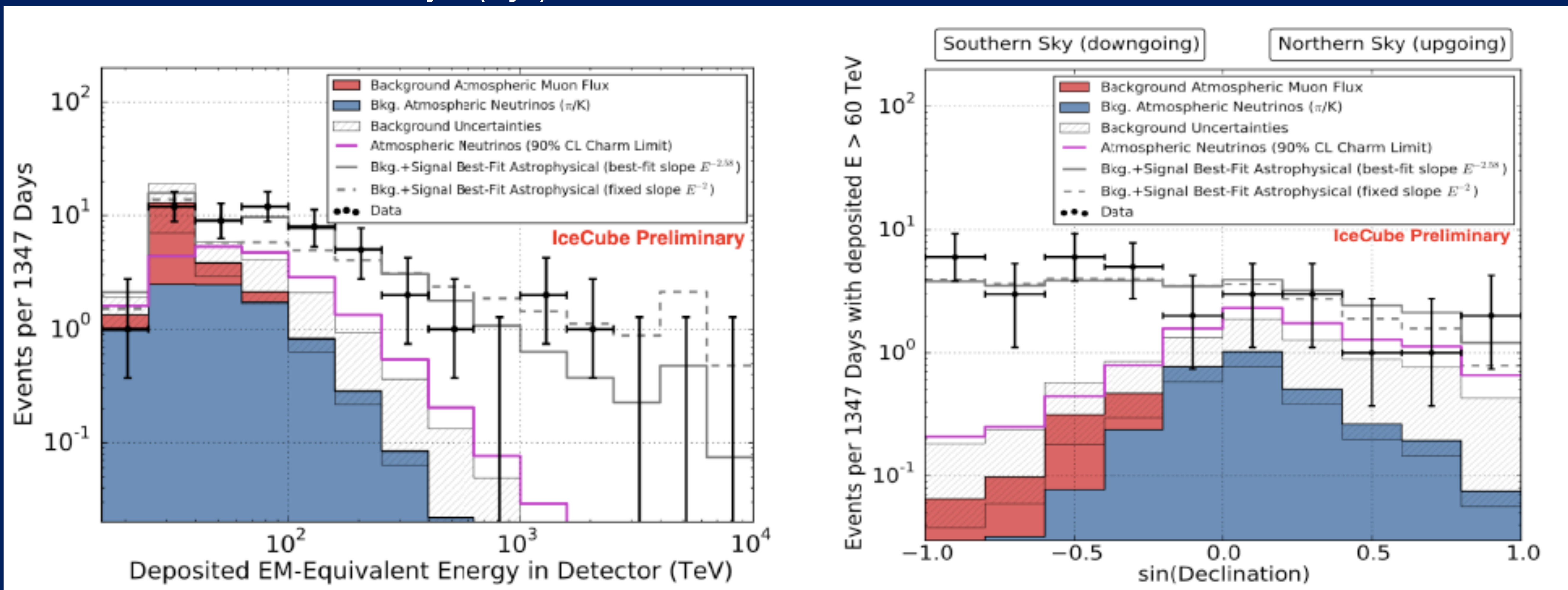


High Energy Neutrinos: The IceCube HESE Flux

2010-2014 data (4yr), High Energy Starting Events(HESE): starting tracks+ cascades

PoS(ICRC2015) 1081

- 54 events in 1347 days (4yr)



- Likelihood fit analysis method
- Soft spectral index (best fit astrophysical flux result, large uncertainties)
- Significance: 6.5σ
- Flux isotropic (extragalactic)

$$\Phi_{\nu+\bar{\nu}} = \Phi_{\text{astro}} \cdot \left(\frac{E}{100\,\text{TeV}}\right)^{-\gamma_{\text{astro}}}$$

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PoS(ICRC2015) 1081

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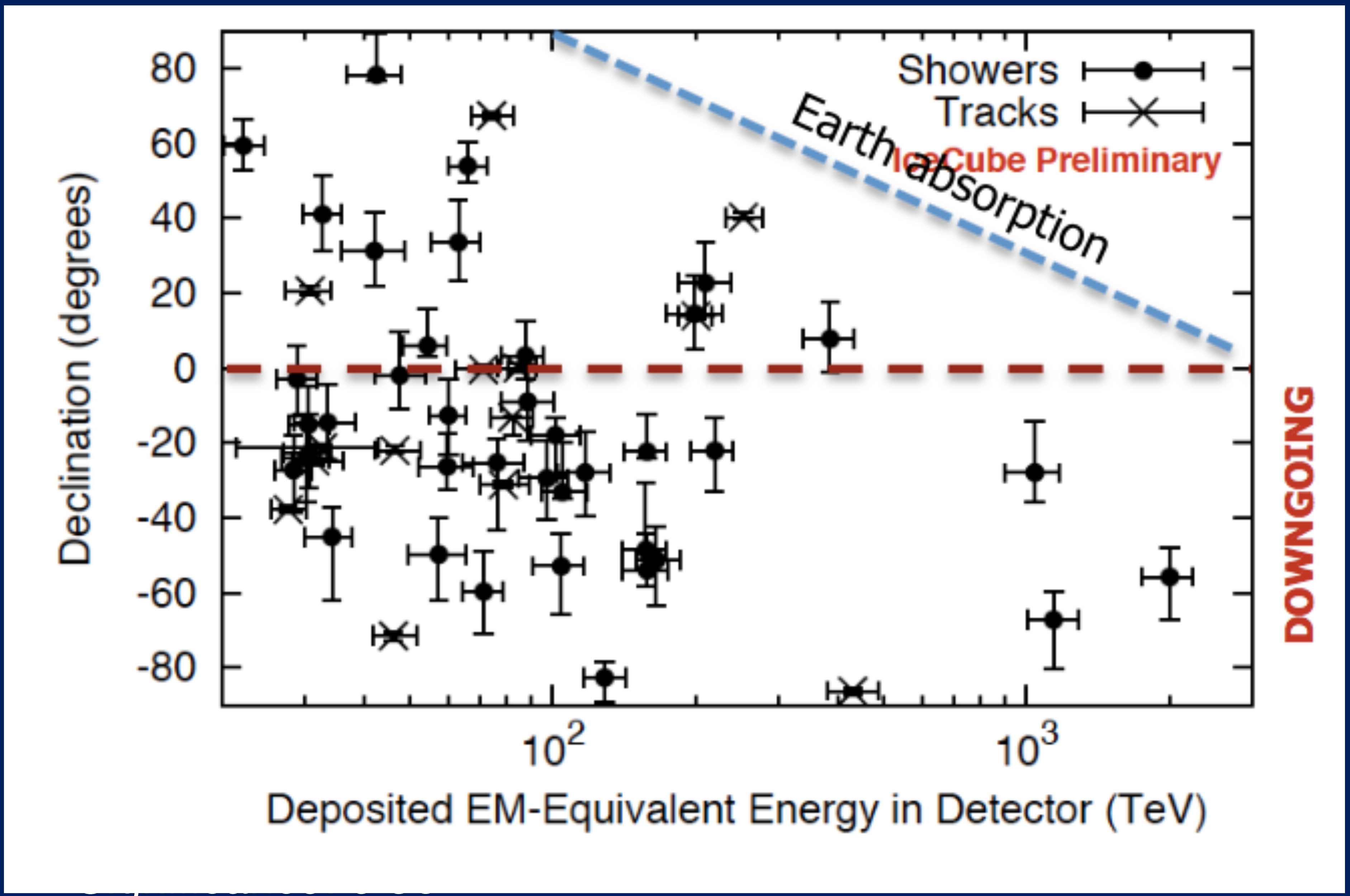
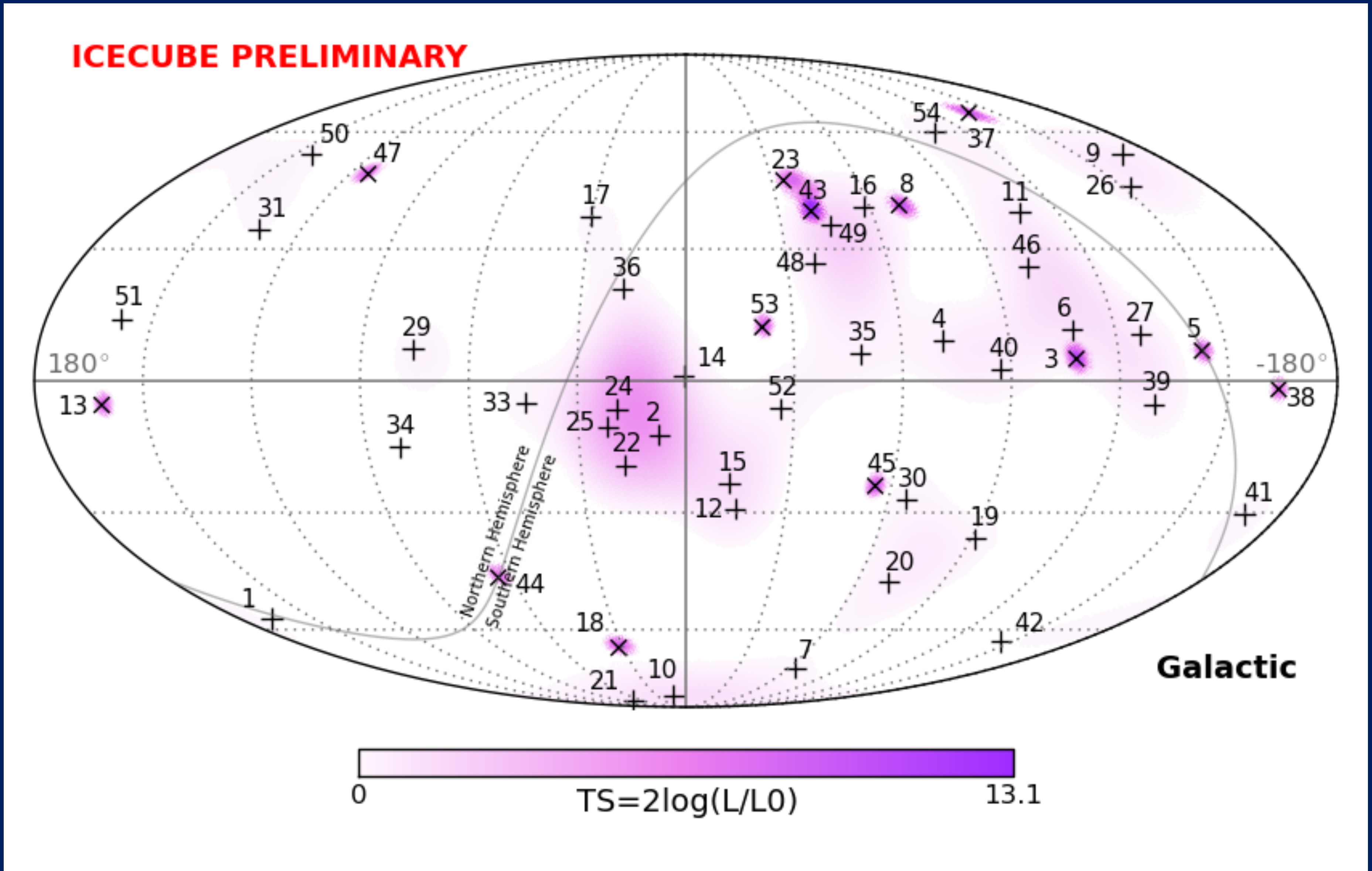


- Flux isotropic (extragalactic)

High Energy Neutrinos: The IceCube HESE Flux

2010-2014 data (4yr), High Energy Starting Events(HESE): starting tracks+ cascades
PoS(ICRC2015) 1081



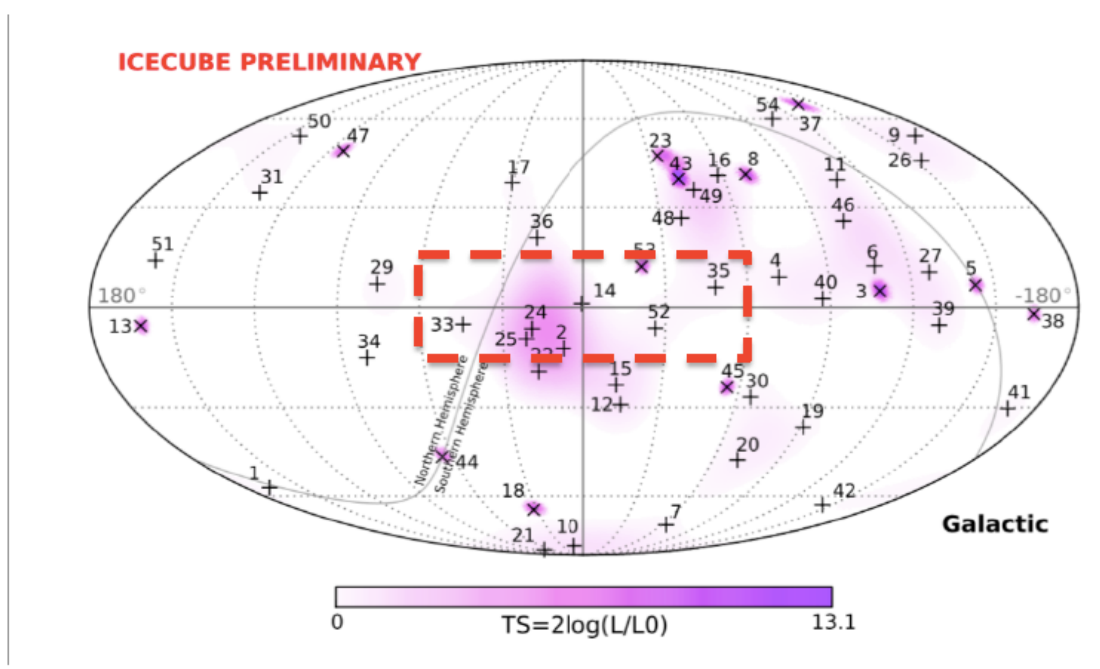
- Significance of the warm spot p-value 44% (58%) for cascades (all events)
- No evidence of (significant) correlation (neither spacial nor temporial e.g. GRB's)

The HE Galactic diffuse neutrino flux

- The interaction of HE CRs with the gas contained in the galactic disk is a guaranteed source of HE neutrinos.
- <u>One example model (HE galactic neutrinos)</u> Villante, Pagliaroli, Evoli, arXiv:1606.04489

Detectability in IceCube

From: Villante (NOW2016)



According to **Case C**, **about 2.5 showers in the red box** may be of **galactic origin** (less than 1 in **Case A** and **Case B** ...)

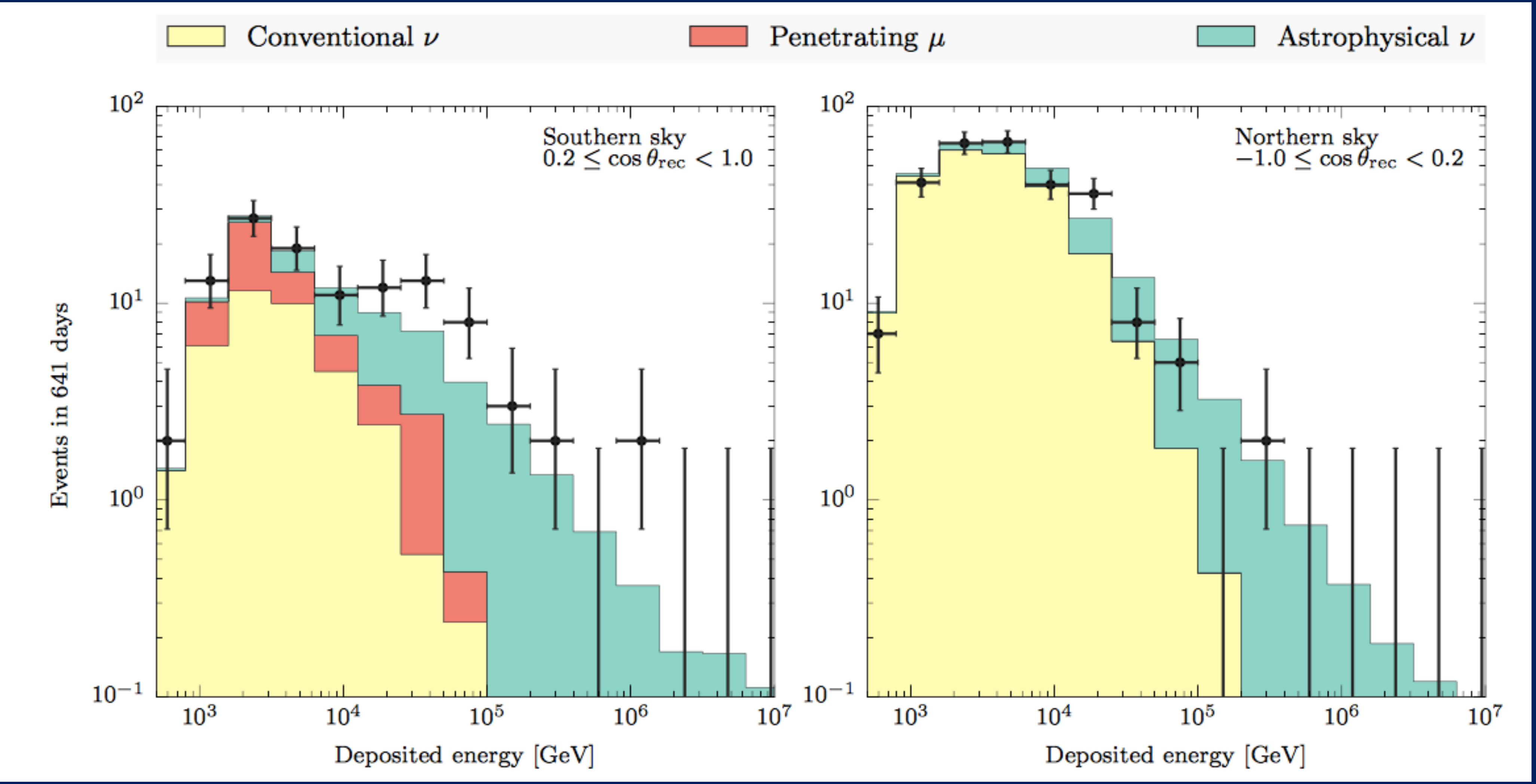
Models:
A: CR flux homogenous in the Galaxy
B: CR flux follows the distribution of galactic sources (SNRs, Pwne)
C: CR flux has an index that depends on the galactocentric distance
(from propagation model with radially dependent transport properties)

<u>Models A,B,C:</u> The integrated galactic diffuse ν flux is always subdominant with respect to the isotropic signal (5-15%)

Current IceCube HESE data cannot exclude a sub-dominant flux of Galactic origin. More data needed (or e.g. use MESE lower energy data)

All-flavor All-Sky Astrophysical Neutrinos

2010-2012 data (2 years), Medium Energy Starting Events (MESE)
Phys.Rev.D91:022001 (2015)



Parameter	Best-fit value	No. of events
Penetrating μ flux	$1.73 \pm 0.40\, \Phi_{\mathrm{SIBYLL+DPMJET}}$	30 ± 7
Conventional ν flux	$0.97^{+0.10}_{-0.03}\, \Phi_{\mathrm{HKKMS}}$	280^{+28}_{-8}
Prompt ν flux	$< 1.52\, \Phi_{\mathrm{ERS}}$ (90% CL)	< 23
Astrophysical Φ_0	$2.06^{+0.35}_{-0.26} \times 10^{-18}$ $\mathrm{GeV^{-1}\, cm^{-2}\, sr^{-1}\, s^{-1}}$	87^{+14}_{-10}
Astrophysical γ	2.46 ± 0.12	

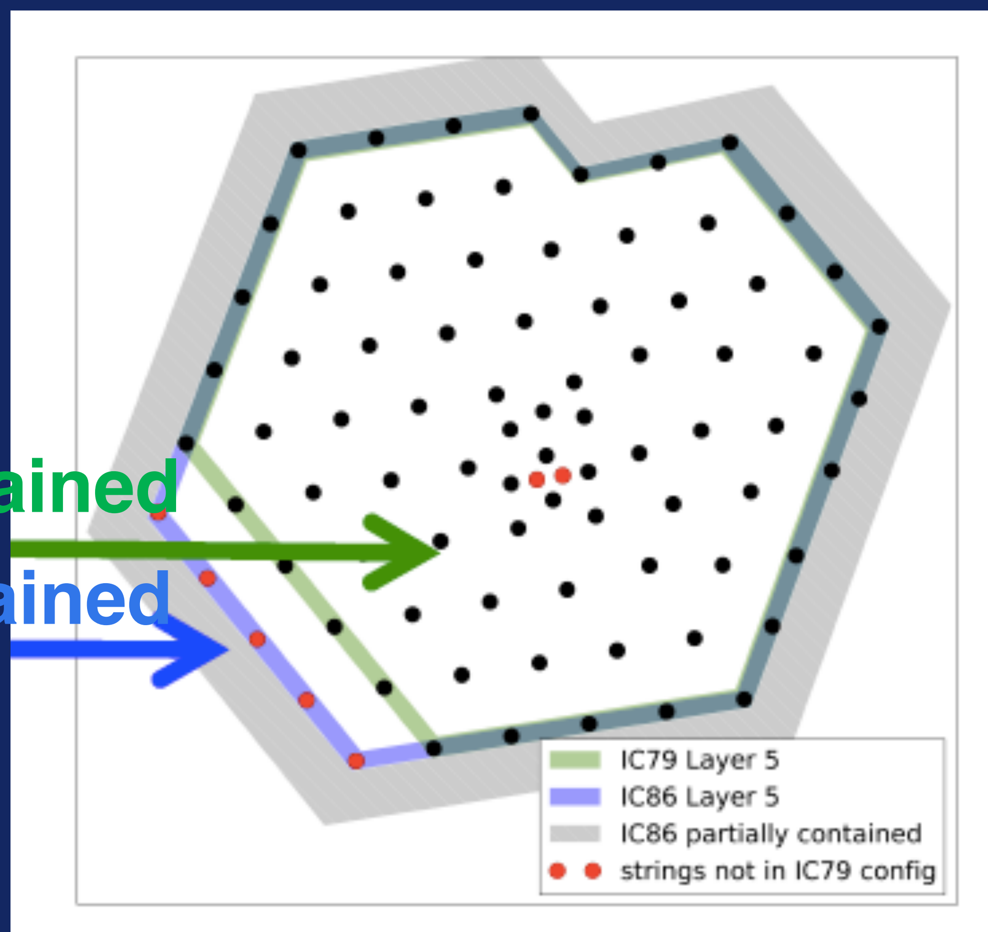
Astrophysical neutrinos remain the dominant component in the Southern sky down to a deposited energy of 10 TeV

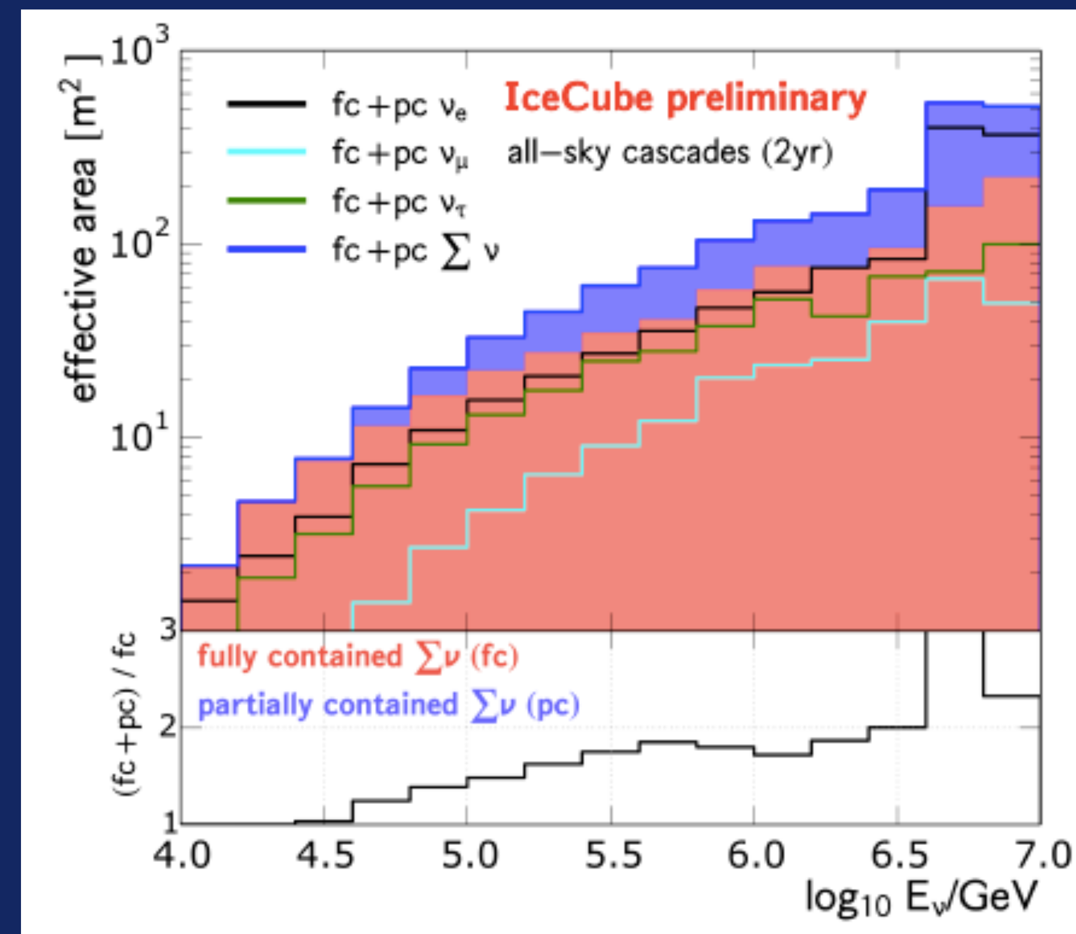
All-Sky Astrophysical Cascades ($\nu_e+\nu_\tau$)

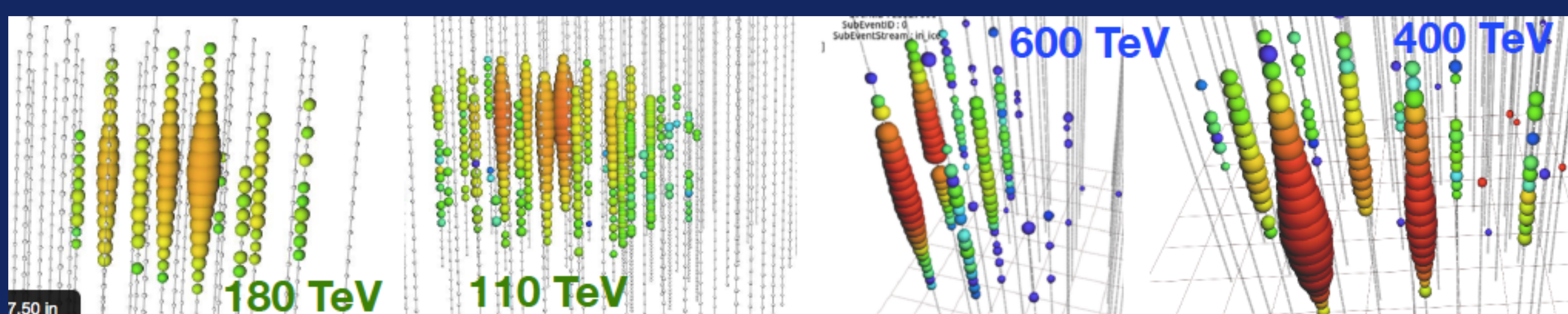
2010-2012 data (2 years), channel = “cascades” (fully contained and partially contained)
PoS (ICRC2015) 1109

Fully Contained

Part. Contained







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All-Sky Astrophysical Cascades ($\nu_e+\nu_\tau$)

2010-2012 data (2 years), channel = “cascades” (fully contained and partially contained)
PoS (ICRC2015) 1109

Analysis Method

maximum likelihood based **template method**:

match observed deposited energy distribution (data) to prediction (simulation)

astrophysics, nuisance, data

$$L(\boldsymbol{\theta_r}|\underline{n}) = \underset{\boldsymbol{\theta_s}}{\operatorname{argmax}} L(\boxed{\boldsymbol{\theta_r}}, \boxed{\boldsymbol{\theta_s}}|\boxed{\underline{n}}) = \underset{\boldsymbol{\theta_s}}{\operatorname{argmax}} \prod_{i=1}^{3}\prod_{j=1}^{N} \frac{\mu_{ij}(\boldsymbol{\theta_r},\boldsymbol{\theta_s})^{n_{ij}}}{n_{ij}!} e^{-\mu_{ij}(\boldsymbol{\theta_r},\boldsymbol{\theta_s})}$$

+ quadratic penalty terms for nuisance parameters

$$\mu_{ij}(\boldsymbol{\theta_r},\boldsymbol{\theta_s}) = \mu_{ij}^{atm.\mu} + \boxed{\mu_{ij}^{atm.\nu}} + \boxed{\mu_{ij}^{astro.\nu}}$$

model assumptions

conventional ν: HKKMS06 (*)
[PRD75, 043006, 2007]

prompt ν: ERS08 (*)
[PRD78, 043005, 2008]

astro ν: **single, unbroken powerlaw**

$$\boxed{\Phi_\nu = \phi \times (E_\nu/100\,\mathrm{TeV})^{-\gamma}}$$

per flavor normalization (ϕ), **spectral index** (γ)

(*) modified according to PRD89 062007 (2014) and PRD90 023009 (2014)

parameter	penalty
γ	-
ϕ	-
ϕ_{conv}	1.0 ± 0.3
ϕ_{prompt}	1^{+3}_{-1}
ε	1.00 ± 0.15

ε: include energy scale related systematics (DOM efficiency + Ice properties)

All-Sky Astrophysical Cascades ($\nu_e+\nu_\tau$)

2010-2012 data (2 years), channel = “cascades” (fully contained and partially contained)
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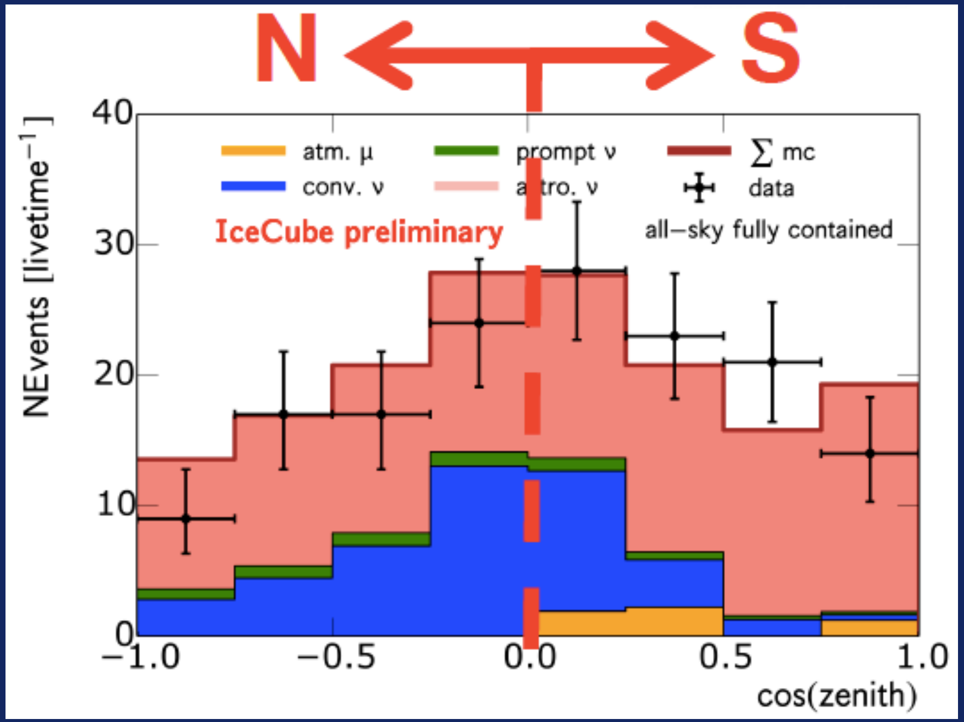

- Observed 152 f.c. events (energies 10 TeV – 1 PeV) (largely uncorrelated with starting events)

All-Sky Astrophysical Cascades (ν_e+ν_τ)

2010-2012 data (2 years), channel = "cascades" (fully contained and partially contained)
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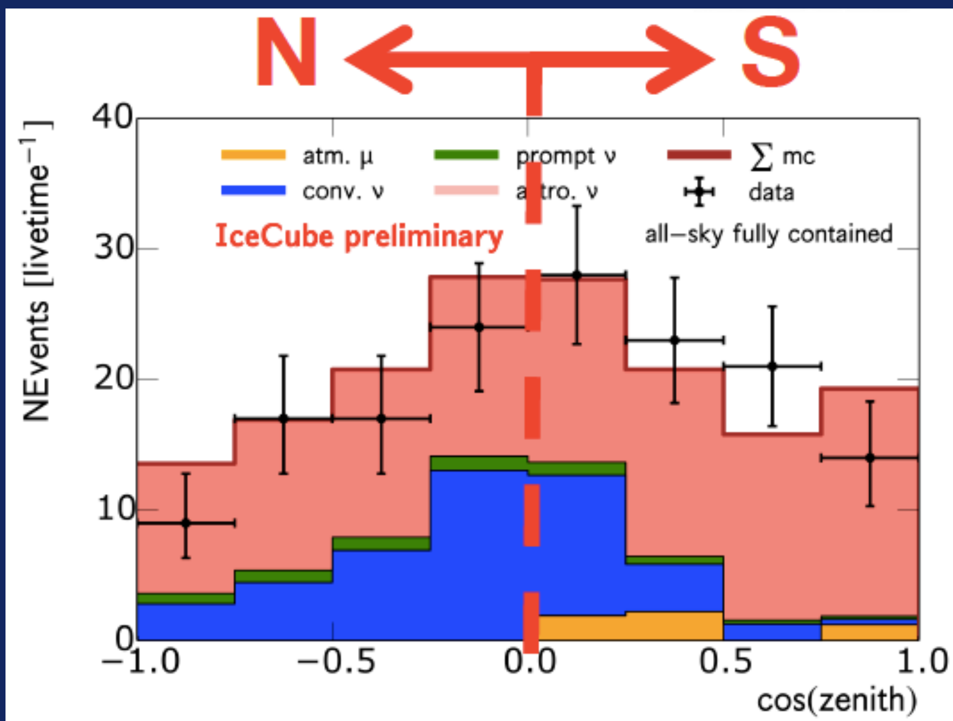
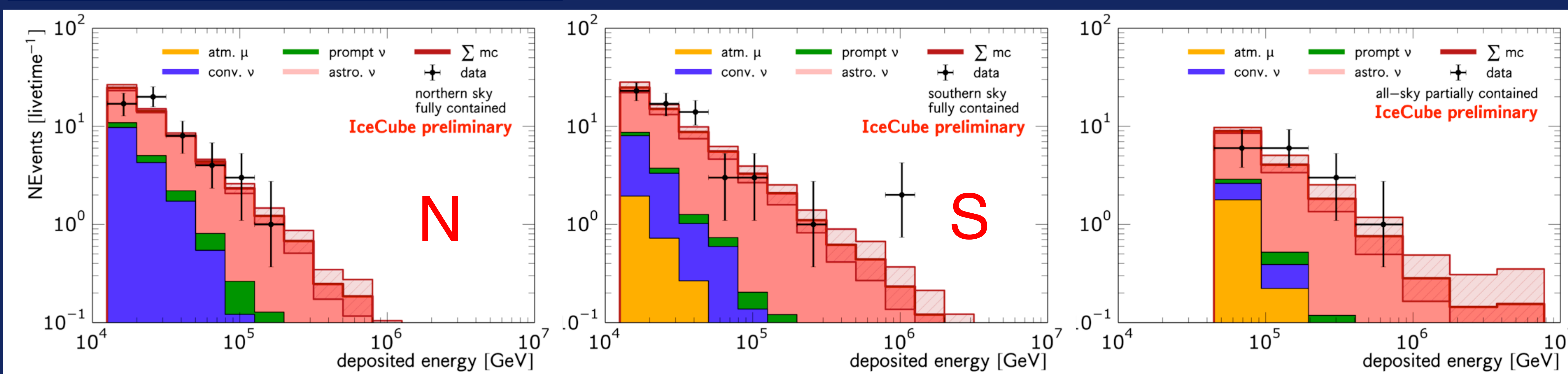


- Observed 152 f.c. events (energies 10 TeV – 1 PeV) (largely uncorrelated with starting events)
- Observed 20 p.c. events (energies 30 TeV – 1 PeV)
- Bg only hypothesis rejected at 4.7σ
- Soft spectral index $\gamma = 2.67^{+0.12}_{-0.13}$ for astrophysical ν's
- Reject γ = 2.0 at 3.5σ (" E^{-2} without cutoff ")
- Astrophysical ν's: No evidence for deviation from single, <u>unbroken</u> power-law in the cascade channel (ν_e+ν_τ)



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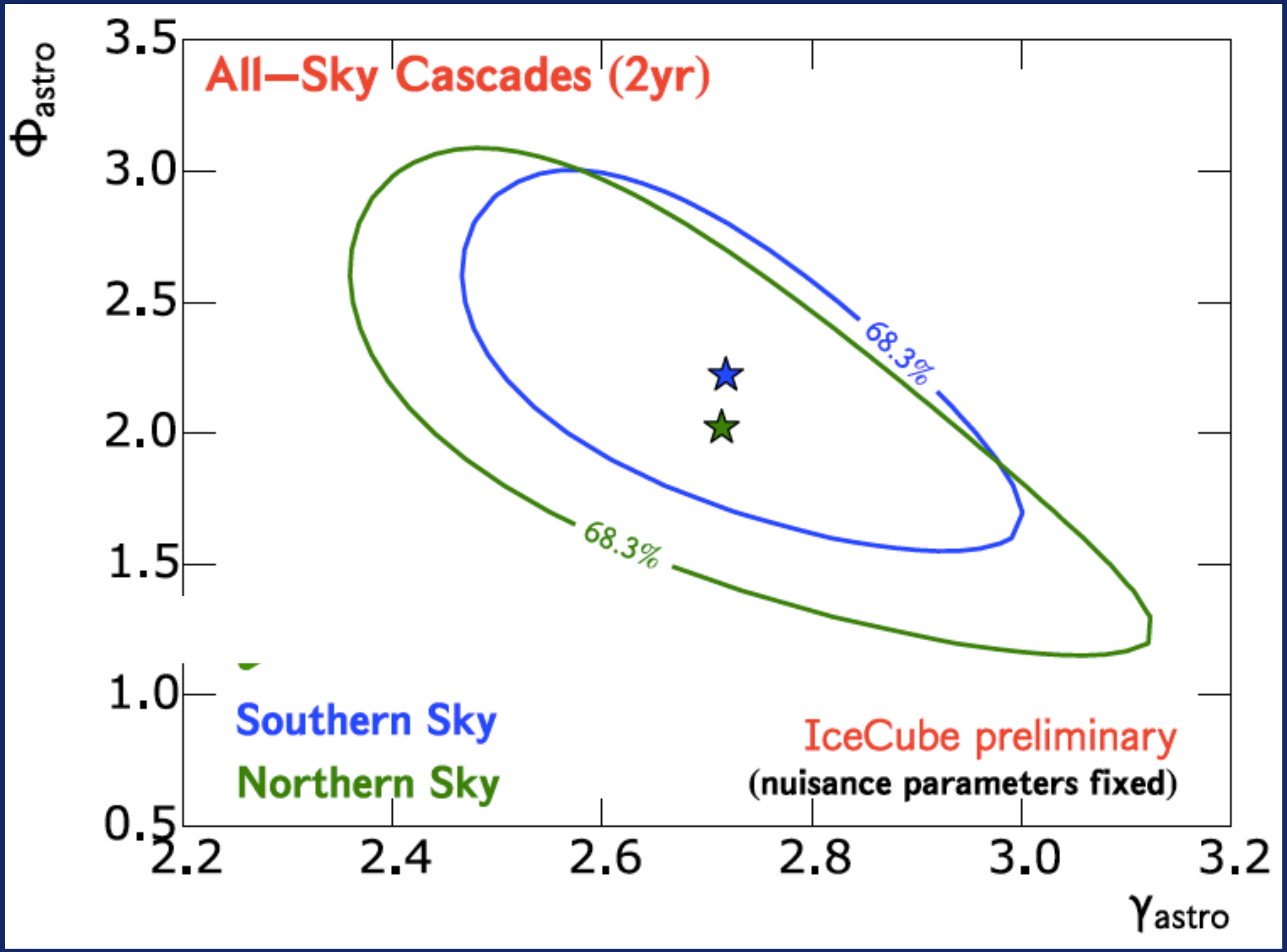
All-Sky Astrophysical Cascades ($\nu_e+\nu_\tau$)

2010-2012 data (2 years), channel = “cascades” (fully contained and partially contained)
PoS (ICRC2015) 1109

$$\Phi_{\nu+\bar{\nu}} = \Phi_{\text{astro}} \cdot \left(\frac{E}{100\,\text{TeV}}\right)^{-\gamma_{\text{astro}}}$$

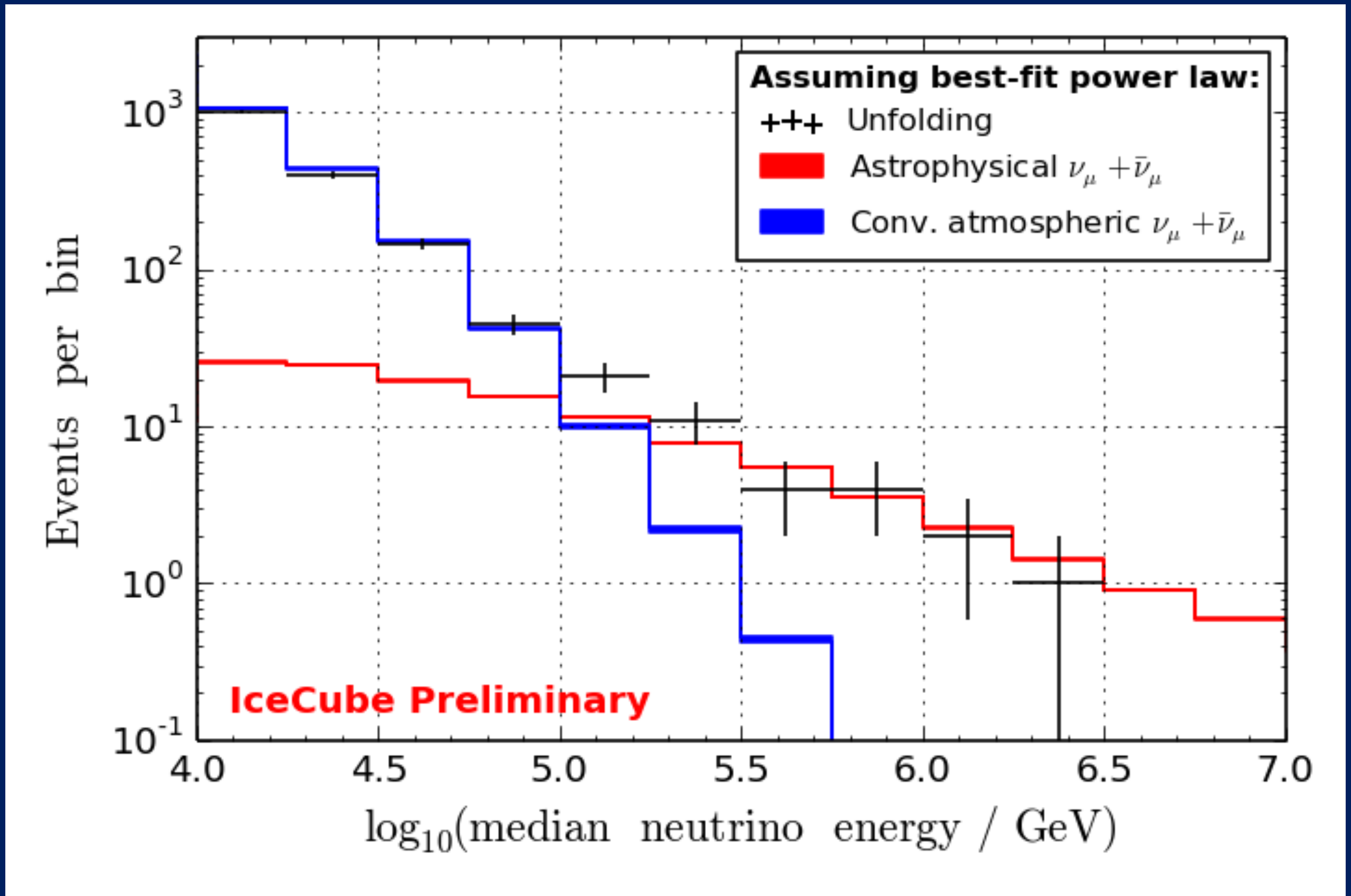


Isotropic?
Yes (within large uncertainties):

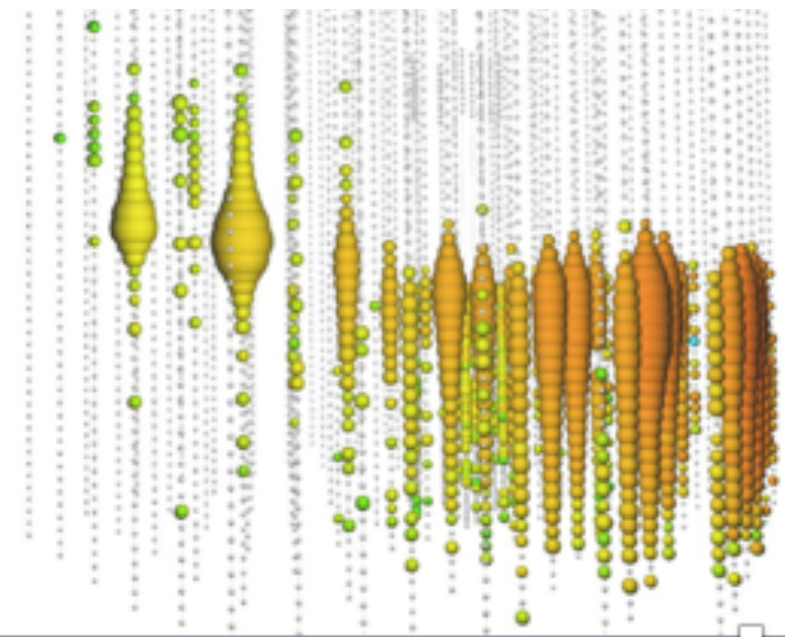
ν fluxes (Northern and Southern Skies) consistent within large uncertainties

ν_μ Northern-Sky Astrophysical Neutrinos

2009-2015 data (6 years) channel="tracks"
PoS(ICRC2015) 1079



June 2014
deposited energy:
2.6 ± 0.3 PeV
DEC=11.42° RA=110.63°



5.6σ detection of astrophysical flux

$\Phi = \Phi_0 \times E^{-\gamma}$ best fit γ=2.08 +/- 0.13

ν_μ Northern-Sky Astrophysical Neutrinos

2009-2015 data (6 years) channel="tracks"
PoS(ICRC2015) 1079; e-print: arXiv:1607.08006, submitted to The Astrophysical Journal

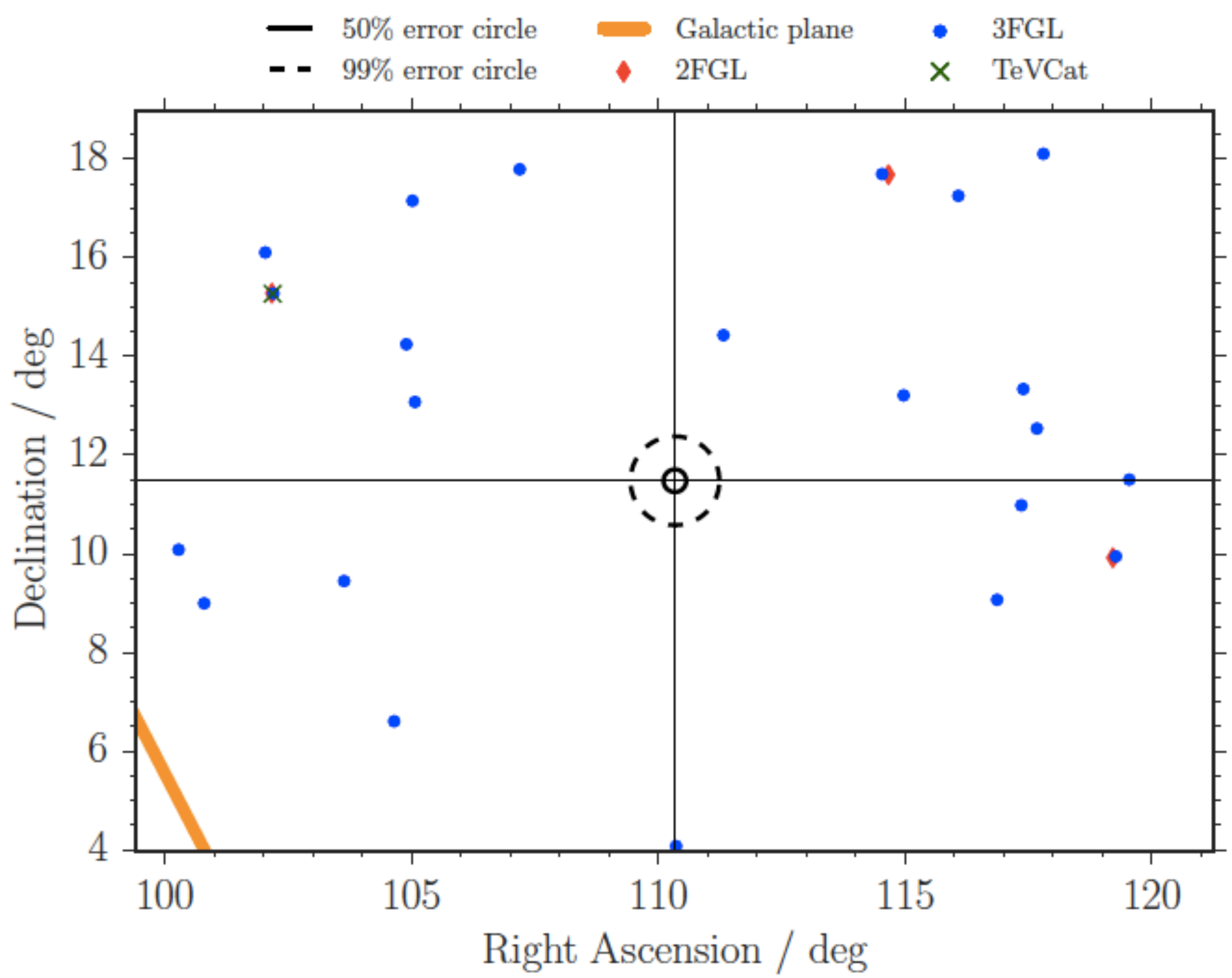


Figure 15. Window centered around the arrival direction of the multi-PeV track-like event. The solid (dashed) black line shows the 50% (99%) error circle for the angular reconstruction. The orange line indicates the galactic plane. Additionally, the gamma-ray sources of the catalogs Wakely & Horan (2007); Acero et al. (2015); Nolan et al. (2012) within the window are shown.

June 2014
deposited energy:
2.6 ± 0.3 PeV
DEC=11.42° RA=110.63°

Median muon energy: 4.5 ± 1.2 PeV
Median ν energy: 8.7 PeV

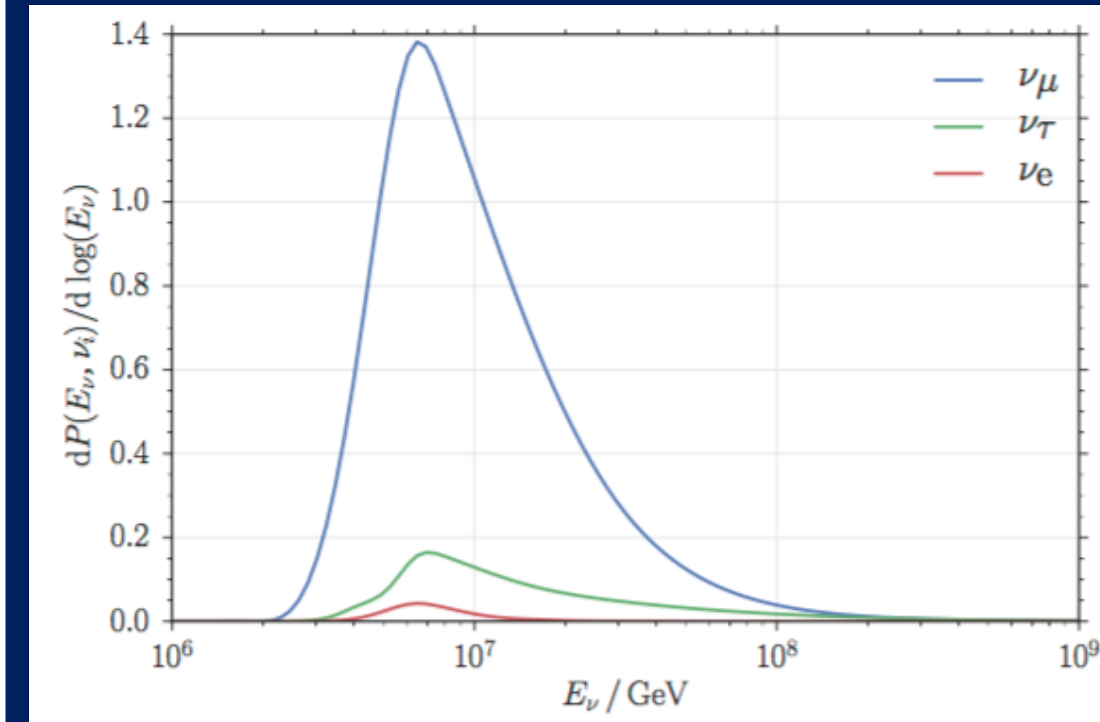


Figure 8. Probability distribution of primary neutrino energies that could result in the observed multi-PeV track-like event. The total probabilities for the different flavors are 87.7%, 10.9% and 1.4% for ν_μ, ν_τ and $\bar{\nu}_e$, respectively.

ν_μ Northern-Sky Astrophysical Neutrinos

2009-2015 data (6 years) channel="tracks"
PoS(ICRC2015) 1079; e-print: arXiv:1607.08006, submitted to The Astrophysical Journal

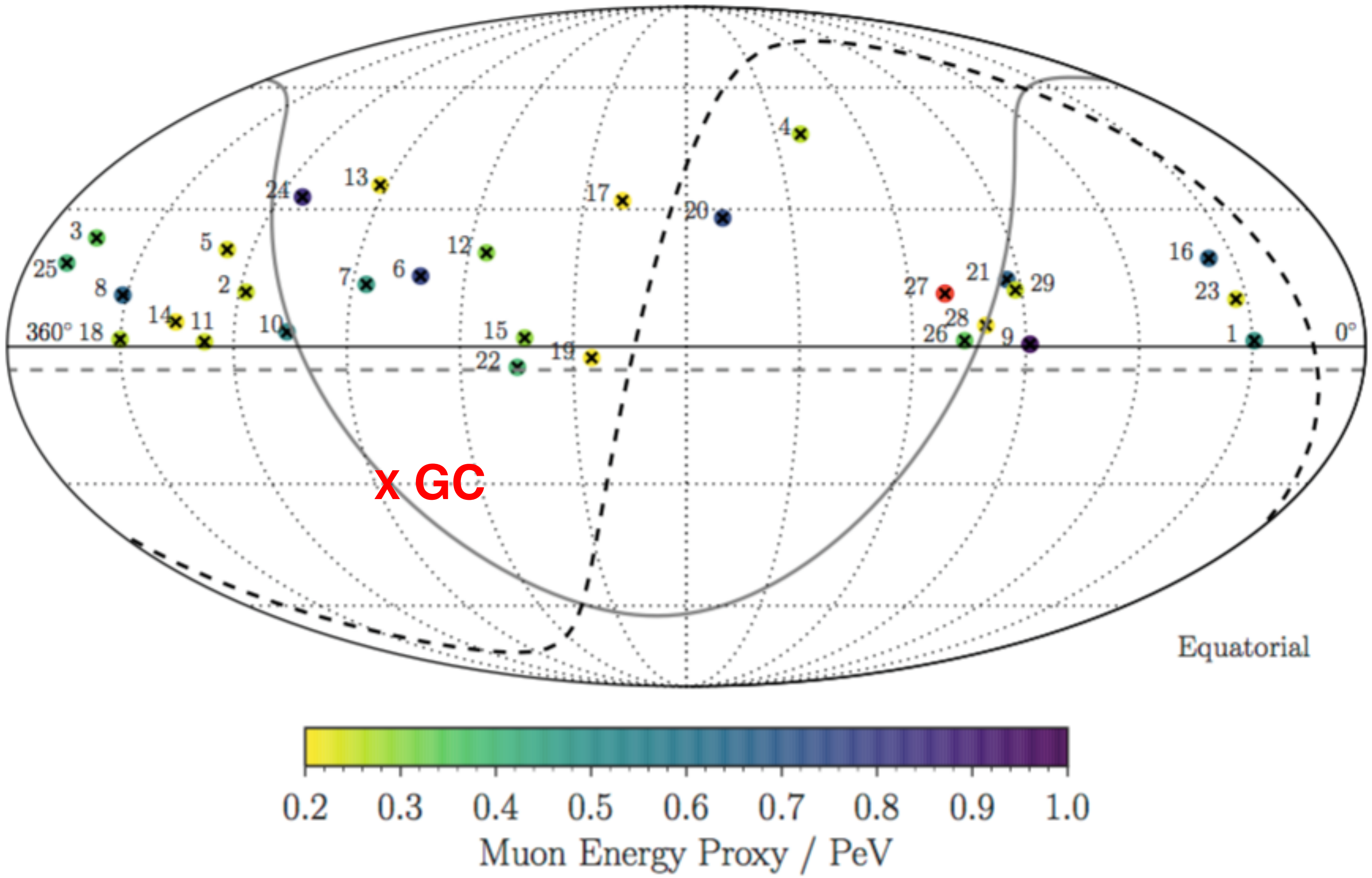


Figure 16. Arrival directions of events with a muon energy proxy above 200TeV. Given the best-fit spectrum the ratio of astrophysical to atmospheric events is about two to one. The horizontal dashed gray line shows the applied zenith angle cut of 85°. The curved gray line indicates the galactic plane and the dashed black line the supergalactic plane (Lahav et al. 2000). The multi-PeV track event is shown as a red dot and the energy proxy value listed in Tab. 4.

ν_μ Northern-Sky Astrophysical Neutrinos

2009-2015 data (6 years) channel="tracks"
PoS(ICRC2015) 1079; e-print: arXiv:1607.08006, submitted to The Astrophysical Journal

$$\Phi_{\nu+\bar{\nu}} = \Phi_{\mathrm{astro}} \cdot \left(\frac{E}{100\,\mathrm{TeV}}\right)^{-\gamma_{\mathrm{astro}}}$$

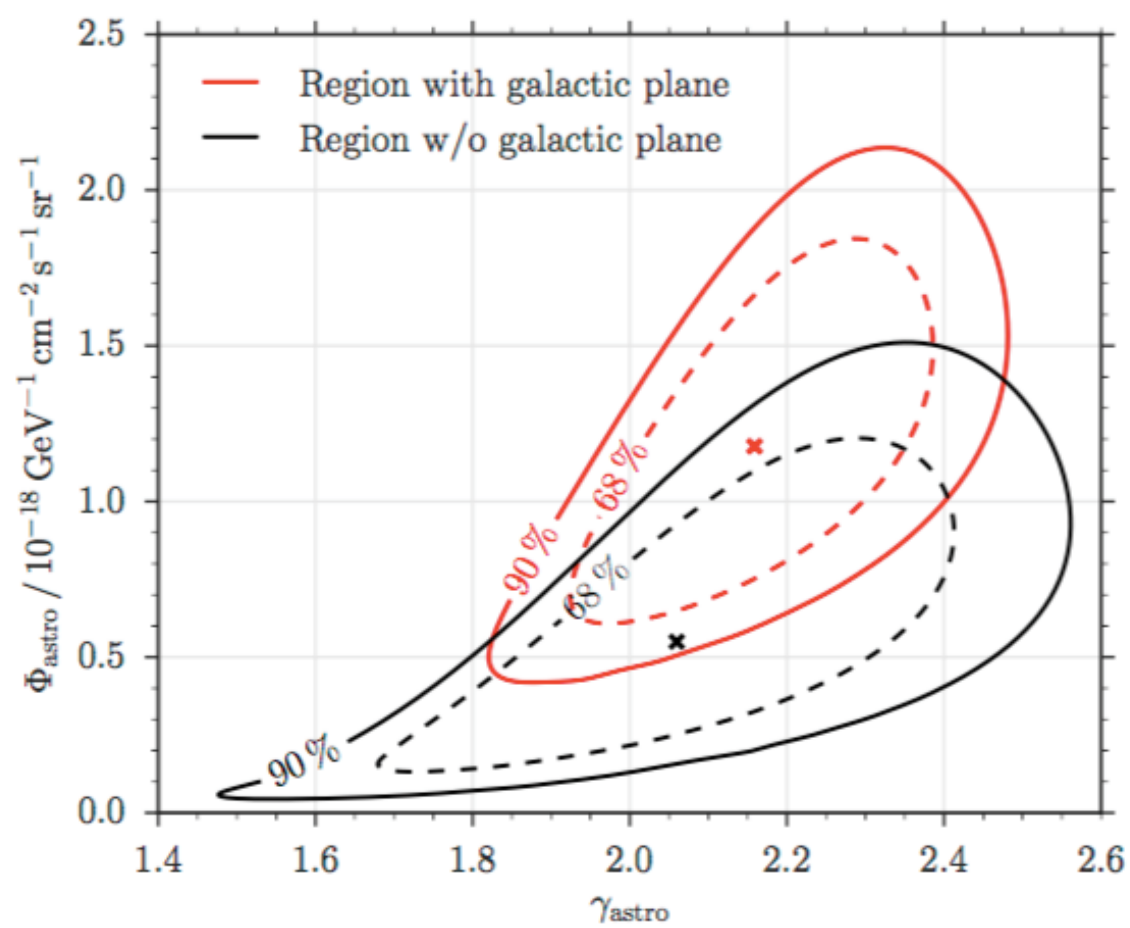


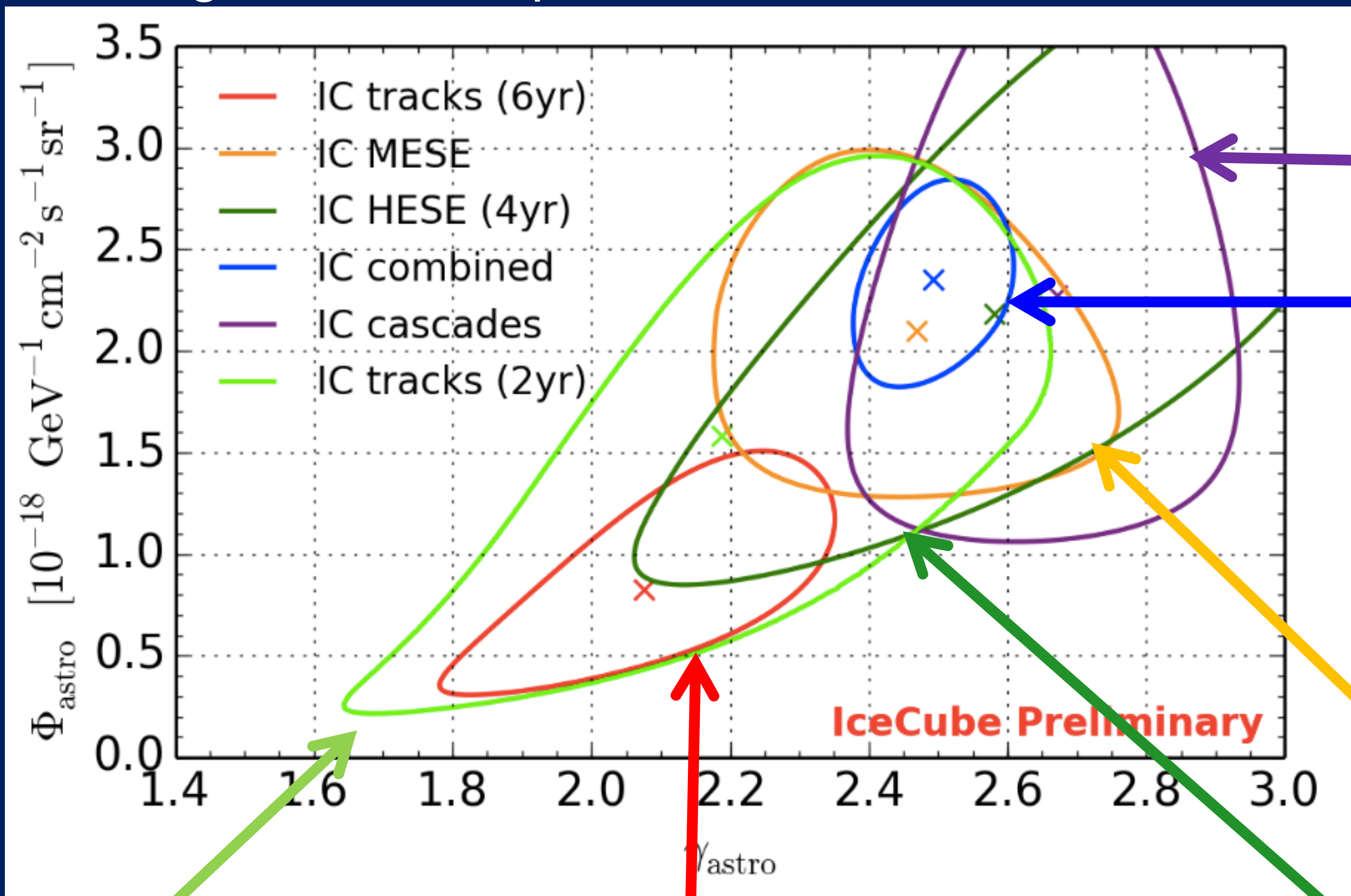
Figure 17. Two-dimensional profile likelihood scans of the astrophysical parameters Φ_{astro} and γ_{astro} for the two disjoint right ascension regions, one containing the Northern Hemisphere part of the galactic plane (red) and the other not (black). The contour lines at 68% and 90% CL assume Wilks theorem.

Northern Sky Isotropic? Yes (within large uncertainties):

ν fluxes (Northern Sky) with and without Galactic plane) consistent within large uncertainties

IceCube: Astrophysical Neutrinos, Flux Results Comparison

Assumed equal ν flavor ratios $(f_e:f_\mu:f_\tau)_\oplus$ = 1:1:1 at Earth
and single unbroken power-law fit



All Sky Cascades (ν_e+ν_τ) 2yr
E>10 TeV
PoS (ICRC2015) 1109

Combined fit $\nu_e + \nu_\mu + \nu_\tau$
PoS(ICRC2015) 1066

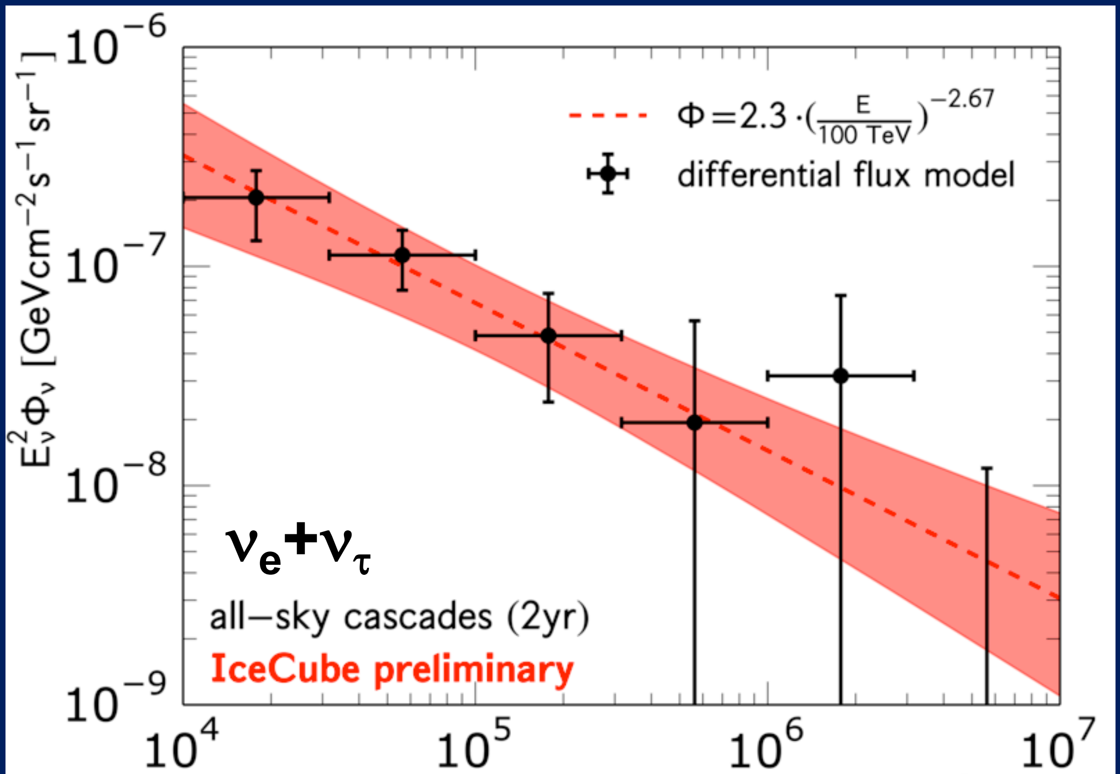
All Sky MESE $\nu_e + \nu_\mu + \nu_\tau$ 2yr
E>1 TeV
PRD 91, 022001 (2015)

All Sky HESE $\nu_e + \nu_\mu + \nu_\tau$ 4yr
E>60 TeV
PoS(ICRC2015) 1081

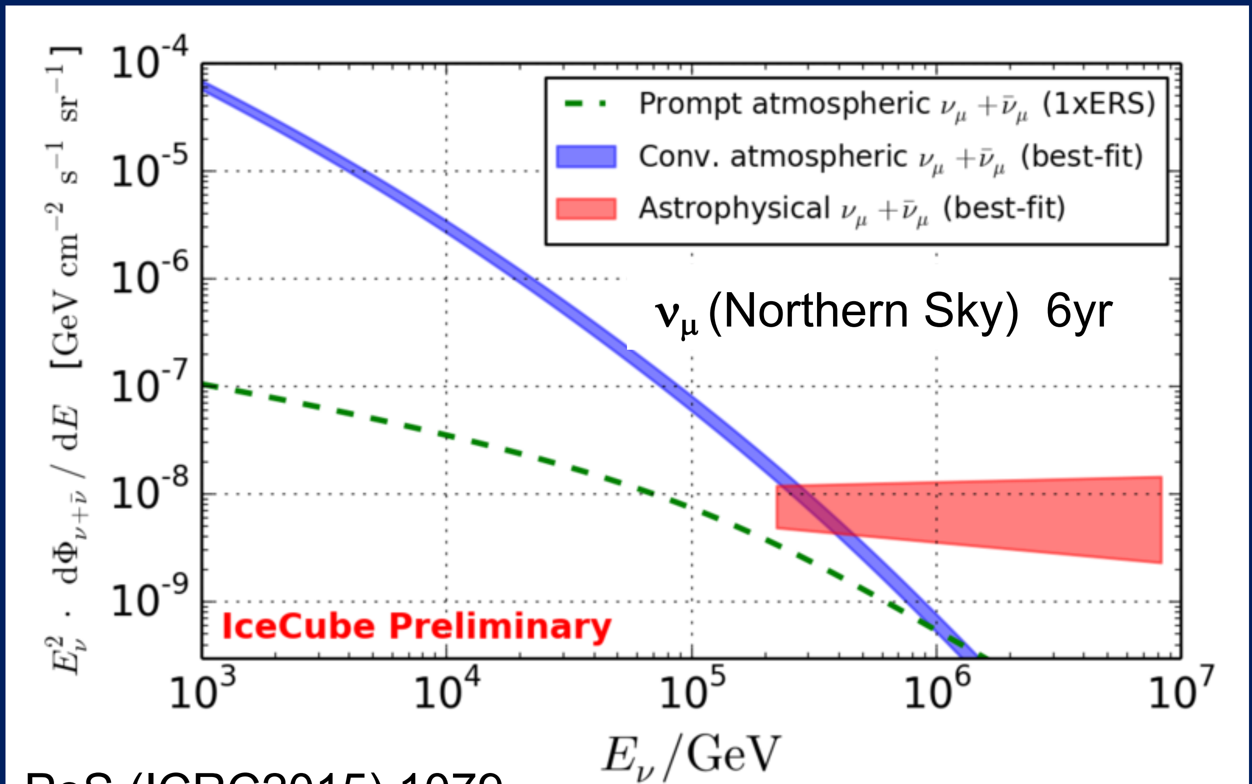
ν_μ (Northern Sky only) 2yr
PRL 115 (2015) 8, 081102

ν_μ (Northern Sky only) 6yr
PoS(ICRC2015) 1079

IceCube: Astrophysical Neutrinos, Flux Results Comparison

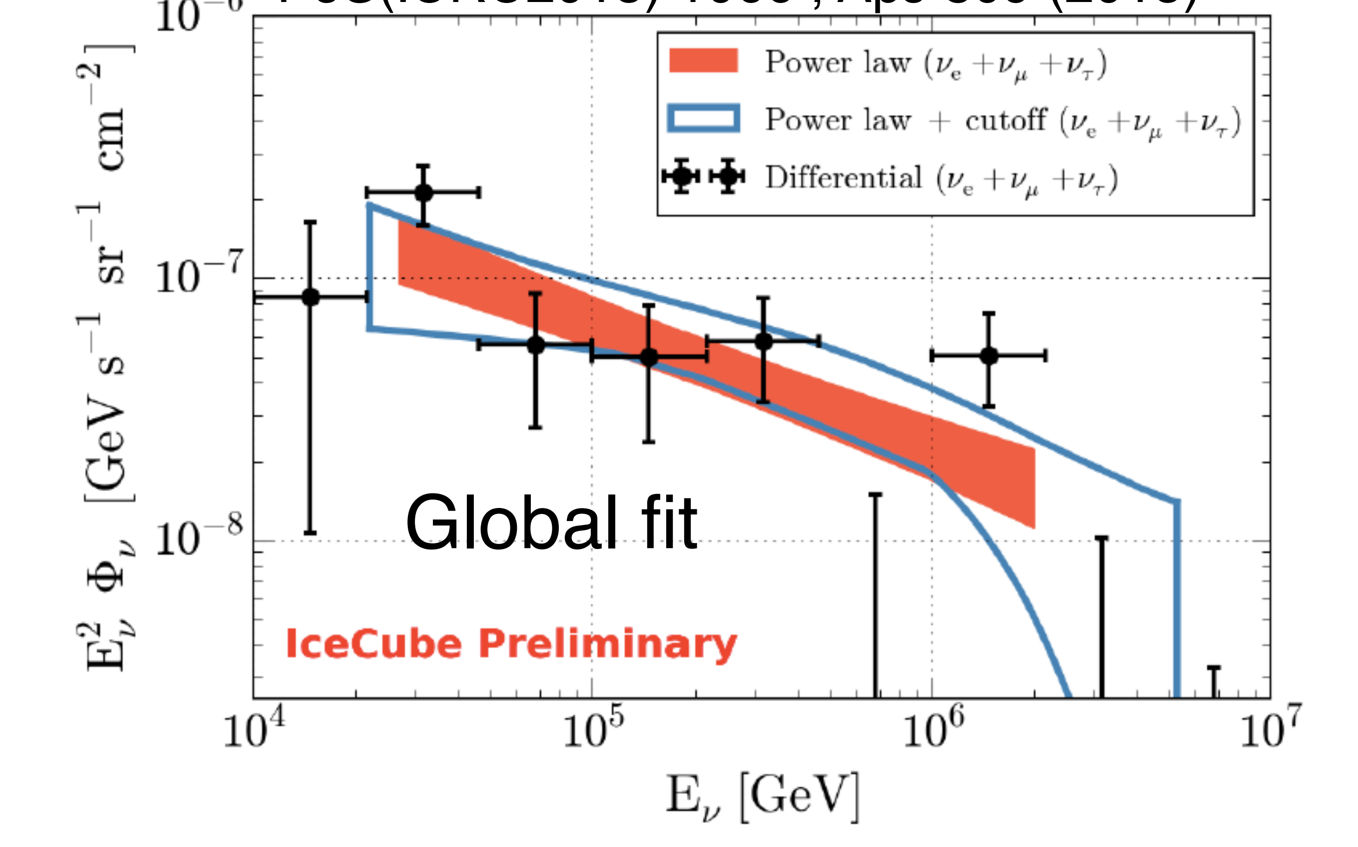


PoS (ICRC2015) 1109



PoS (ICRC2015) 1079

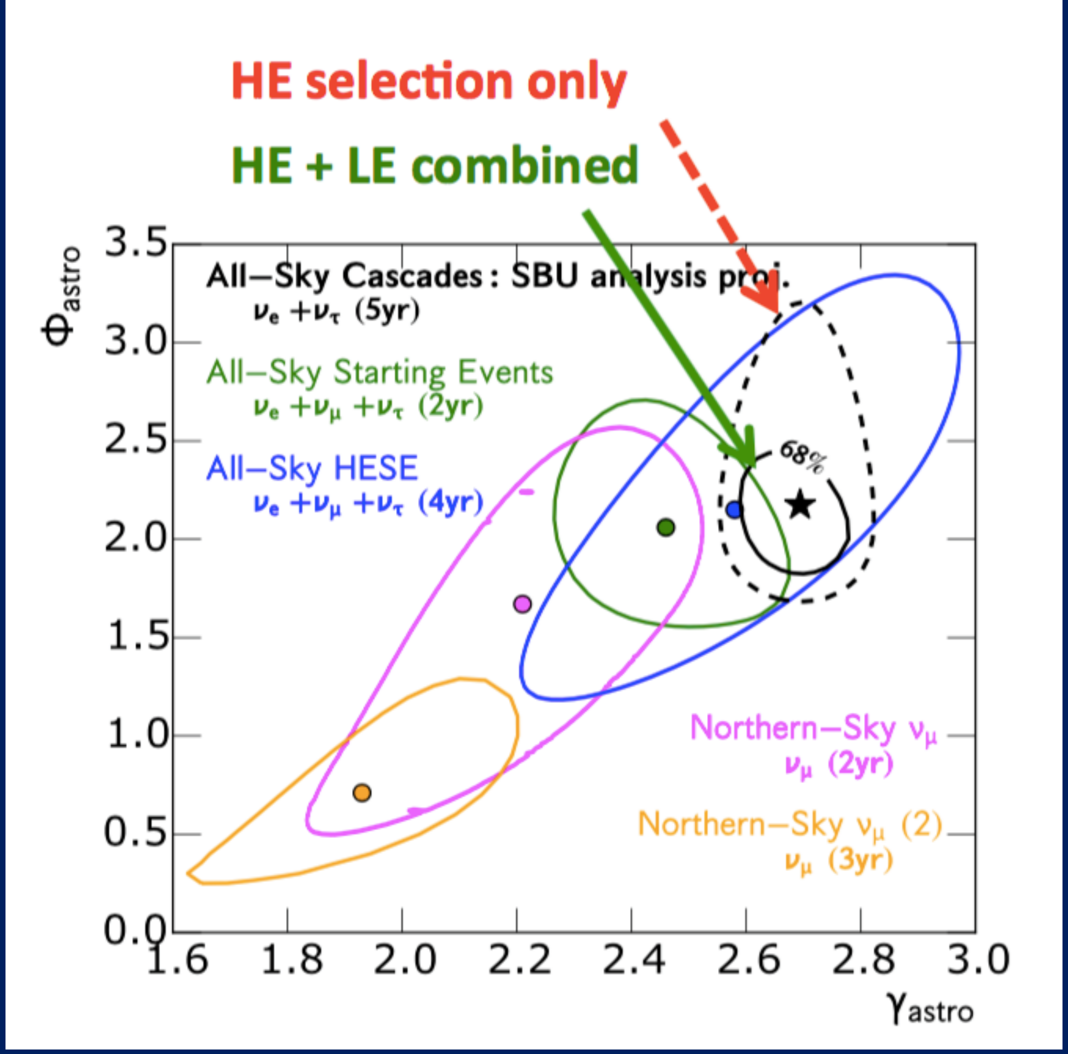
PoS(ICRC2015) 1066 , ApJ 809 (2015)



- Non-observation of Glashow Resonance events
- Break in the spectrum?
- Multiple components (galactic/extragalactic)?
- **Need more data!**
- **Syst. Uncertainty reduction**

IceCube: Astrophysical Neutrinos, $\nu_e+\nu_\tau$ (Cascades) Flux Measurement Outlook

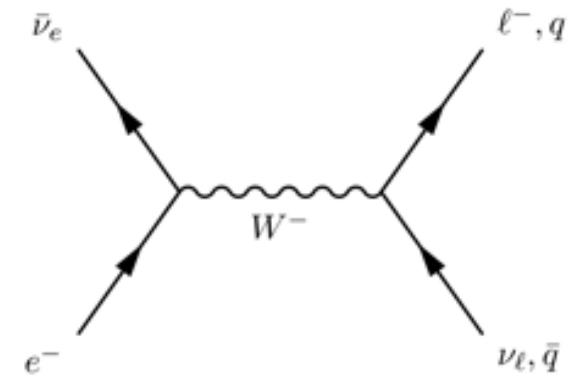
- Need more data! Multi-year data.
- Higher event selection efficiencies (~ 20%) with BDTs
- Syst. Uncertainty reduction (energy scale) by adding LE (1-10 TeV) contained cascades



- Multiple components fits possible (expected 6yr results ICRC2017)

CR sources pp vs pγ collisions: Glashow Resonance

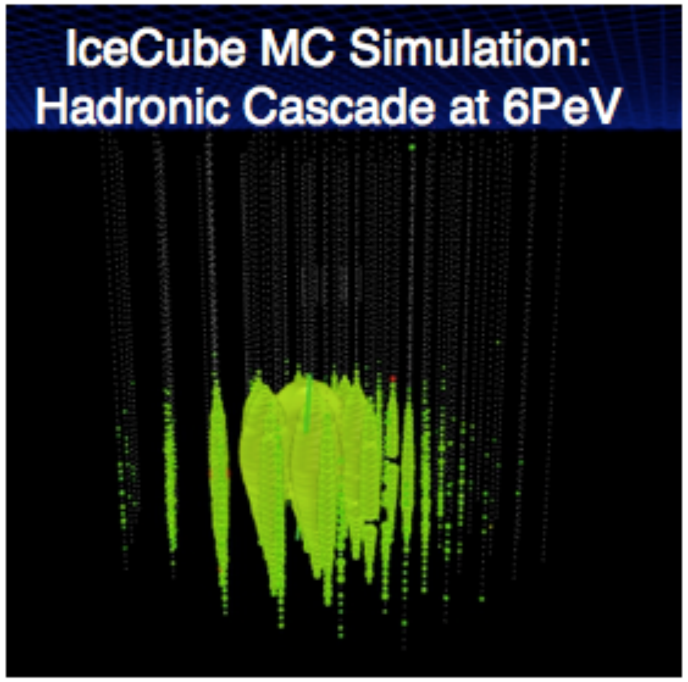
- Resonant W production $\overline{\nu_e} + e^- \rightarrow W^-$ at $E_\nu = 6.3$ PeV

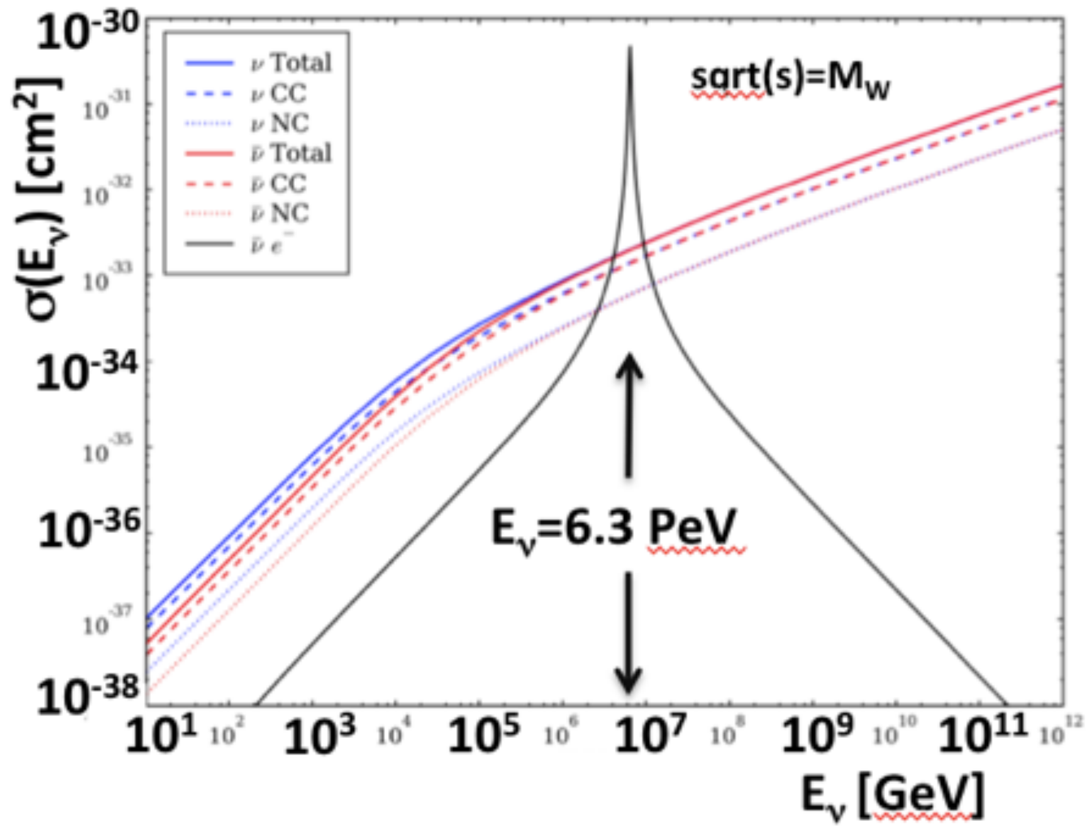


- Unique channel: sensitive to electron anti-ν flux

  IceCube does not distinguish ν and anti-ν induced DIS events

- Hadronic particle showers $W^- \rightarrow q\bar{q}$ are dominant: $\Gamma_{qq}/\Gamma_{tot} \sim 70\%$





CR sources pp vs pγ collisions: Glashow Resonance (IceCube)

Assumption: $(f_e : f_\mu : f_\tau)_S = (1 : 2 : 0)_S$
No spectrum energy cut-off

- proton collisions - pp

$$p + p \rightarrow N\left(\pi^0 + \pi^+ + \pi^-\right) + \ldots$$

anti-ν_e and ν_e produced equally
at Earth: anti-ν_e : ν_e = 1 : 1*

- proton photon scattering – pγ

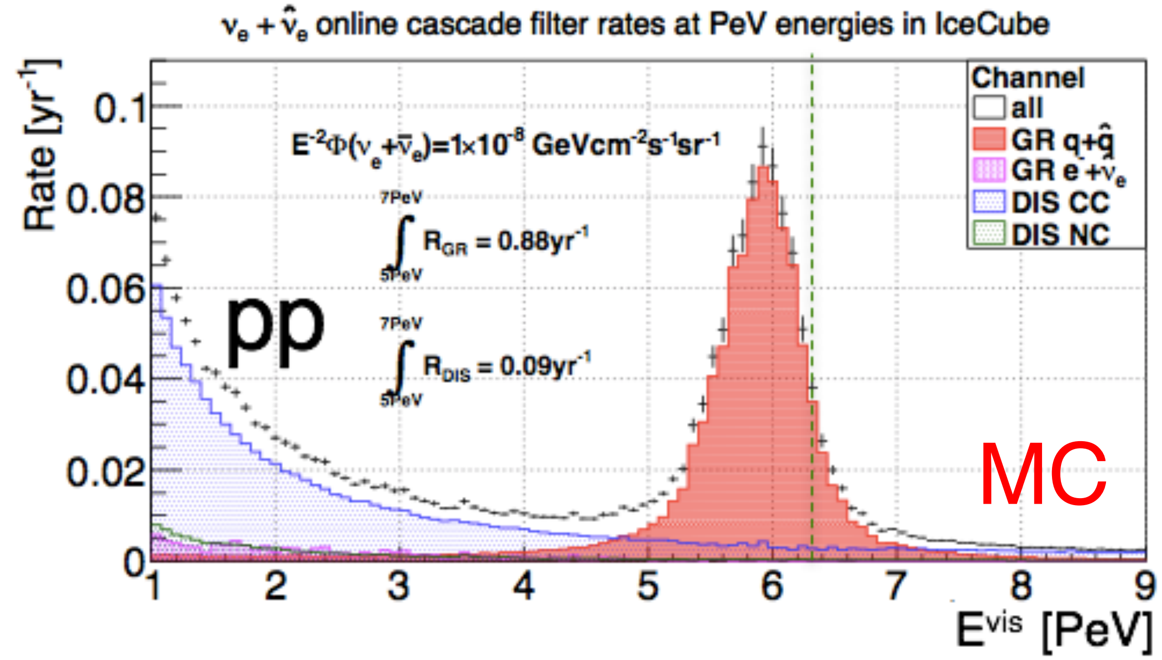
$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{cases} \pi^+ + n \\ \pi^0 + p \end{cases}$$

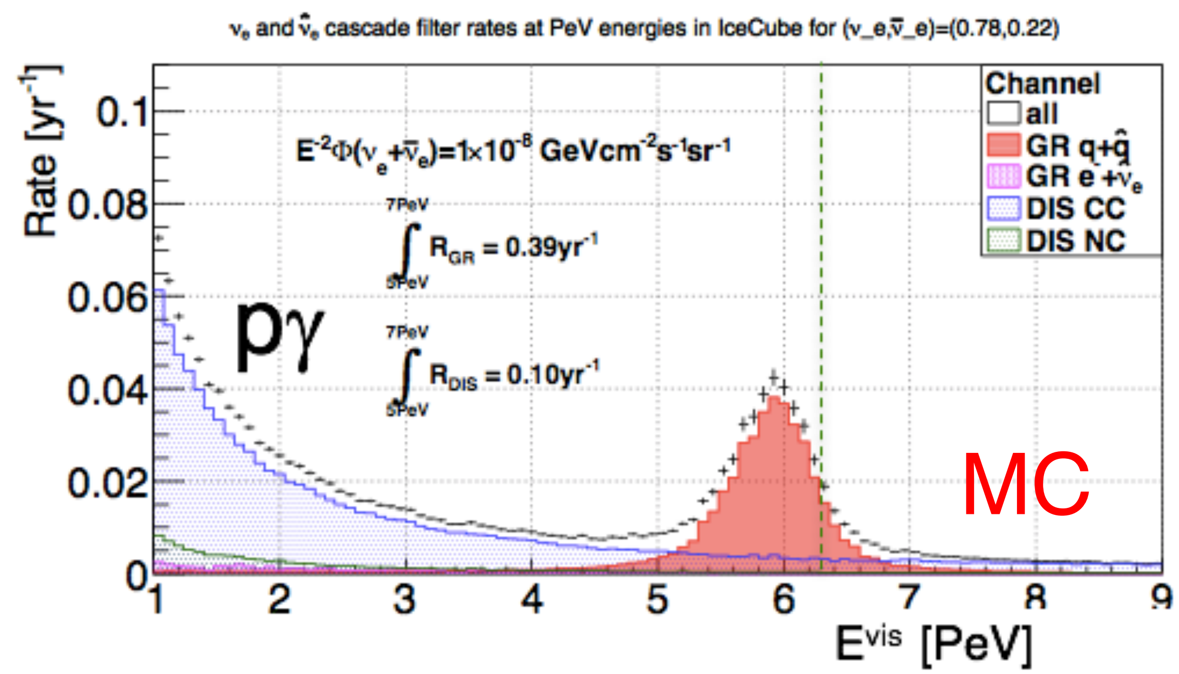
no anti-ν_e produced at source
at earth: anti-ν_e : ν_e = 0.22 : 0.78*

(*)ratios at earth from Bhattacharya et. al., arXiv:1108.3163

IceCube: PoS(ICRC2013) 0494

$$\overline{\nu_e} + e^- \rightarrow W^-$$





Astrophysical Neutrinos: Flavor composition

$(f_e : f_\mu : f_\tau)_S$ at Source:

□ (0 : 1 : 0)
○ (1 : 2 : 0)
△ (1 : 0 : 0)

"Models"

$$p+\gamma \rightarrow \Delta^+ \rightarrow n+\pi^+$$

$$p+p \rightarrow N\left[\pi^0+\pi^++\pi^-\right]+X$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow \left(e^+ + \boxed{\nu_e + \bar{\nu}_\mu}\right) + \boxed{\nu_\mu}$$

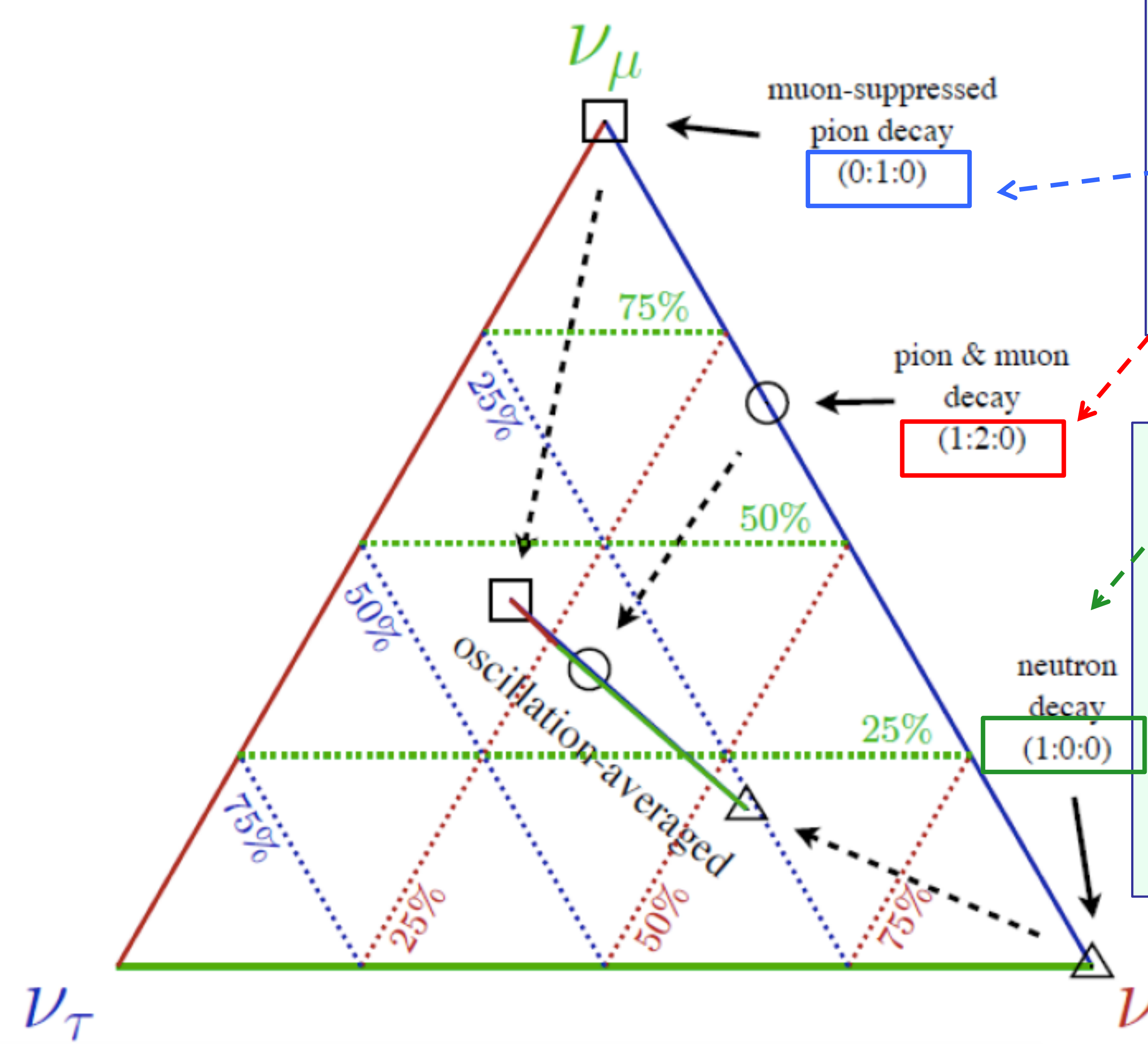
benchmark model $(f_e : f_\mu : f_\tau)_S = (1 : 2 : 0)$

$(f_e : f_\mu : f_\tau)_S = (0 : 1 : 0)$

$$n \rightarrow p + e + \boxed{\bar{\nu}_e}$$

Synchrotron cooling

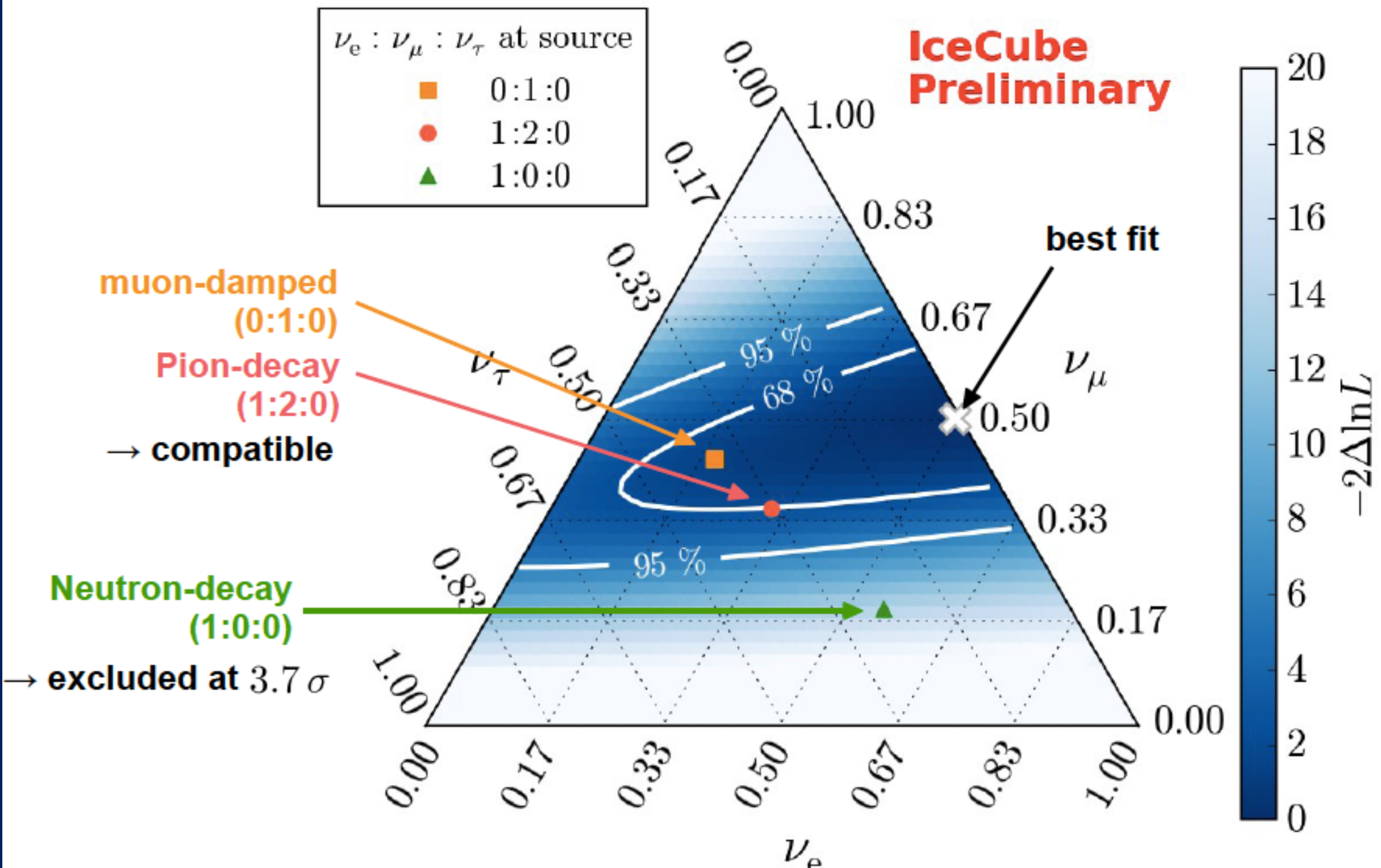
$(f_e : f_\mu : f_\tau)_S = (1 : 0 : 0)$



- Flavor composition likely energy dependent, may provide insight into energy losses of π's and μ's in the magnetic fields of cosmic accelerators
- New physics in neutrino propagation may modify flavor composition
- Assumption: flux $\nu \approx \bar{\nu}$ (true for pp only)

Astrophysical Neutrinos: Flavor composition

The exclusion regions for ν flavor ratios $(f_e:f_\mu:f_\tau)_\oplus$ at Earth



PoS(ICRC2015) 1066, ApJ 809 (2015), 98, PRL114 (2015) 17, 171102

The limits are consistent (at < 68% CL) with $(1:1:1)_\oplus$ flavor ratio at Earth, expected from the averaged oscillations of ν's produced by π's decay in astrophysical sources

Antares: Astrophysical Neutrinos, Flux Results Comparison

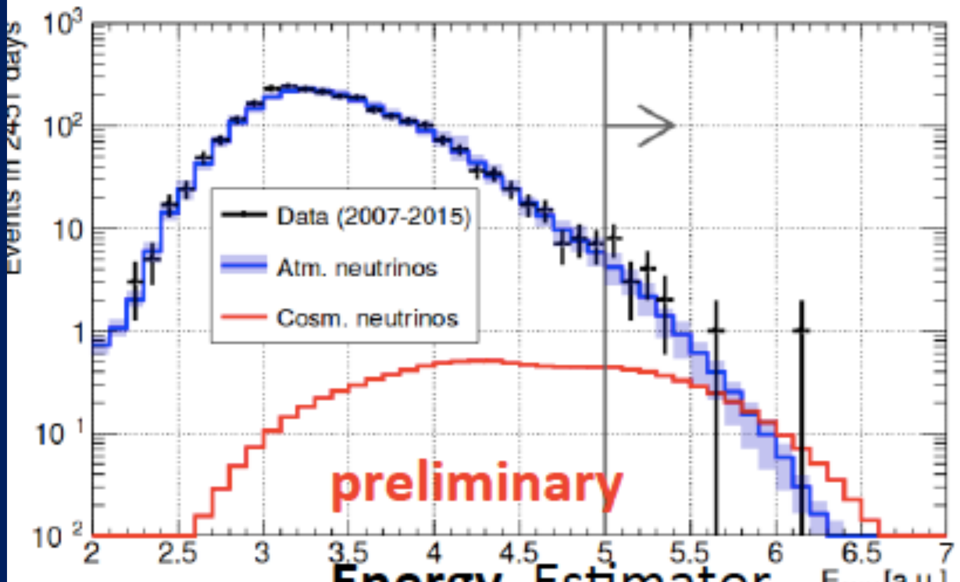
TRACKS

Data: 2007-2015 **(2451 livedays)**

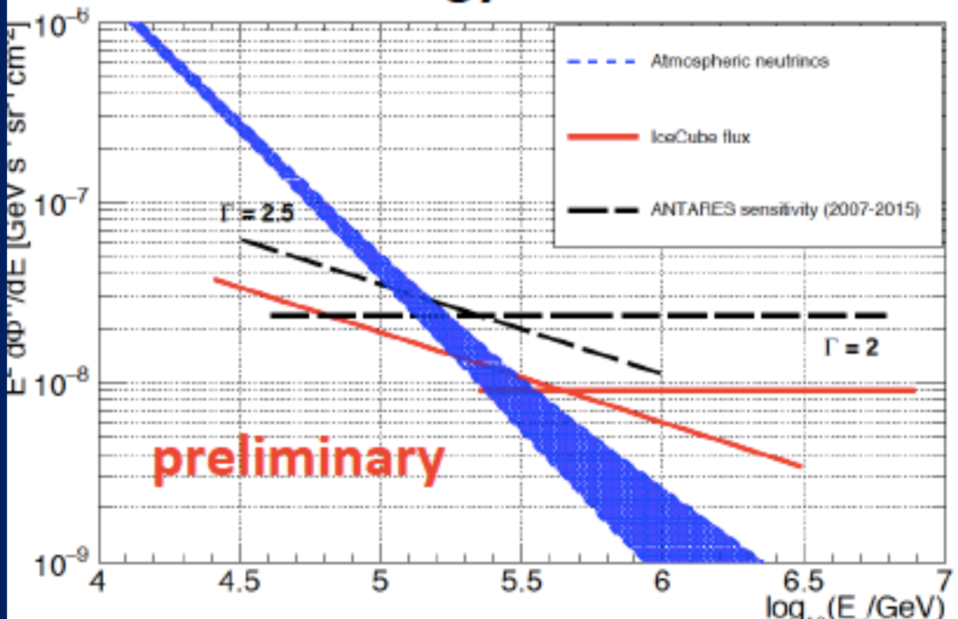
Above E_{cut}: Bkg: 13.5 ± 3 evts

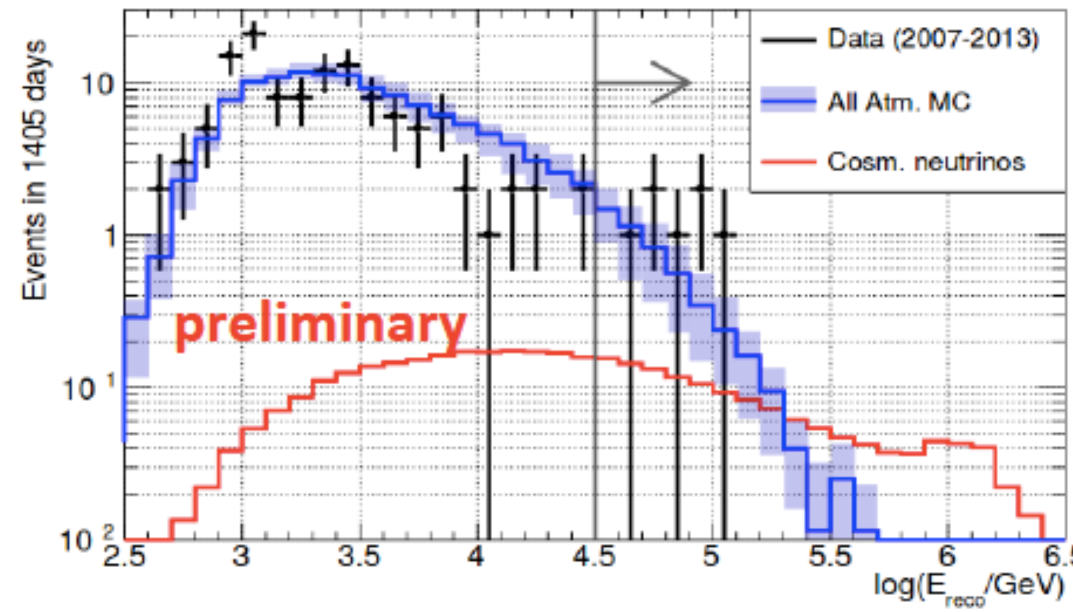
IC-like signal: 3 evts

Observed: **19 evts**



Energy Estimator





Reconstructed Energy

SHOWERS

Data: 2007-2013 **(1405 livedays)**

Above E_{cut}: Bkg: 5± 2 evts

IC-like signal: 1.5 evts

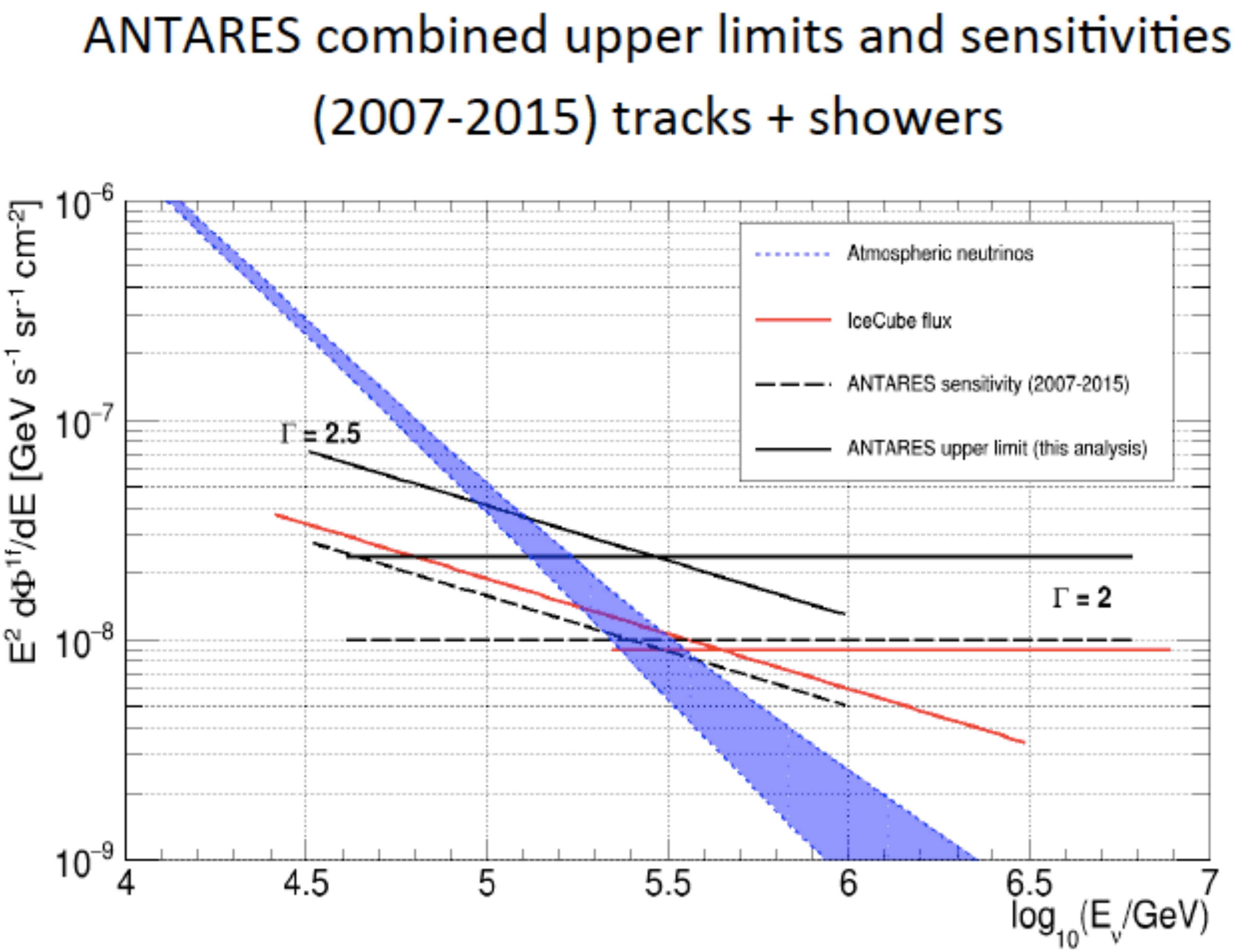
Observed: **7 evts**

NOW 2016 - Otranto

Highlights of ANTARES - A. Margiotta

Antares: A. Margiotta (NOW2016)

Antares: Astrophysical Neutrinos, Flux Results Comparison



Antares: A. Margiotta (NOW2016)

Multi-messenger astronomy

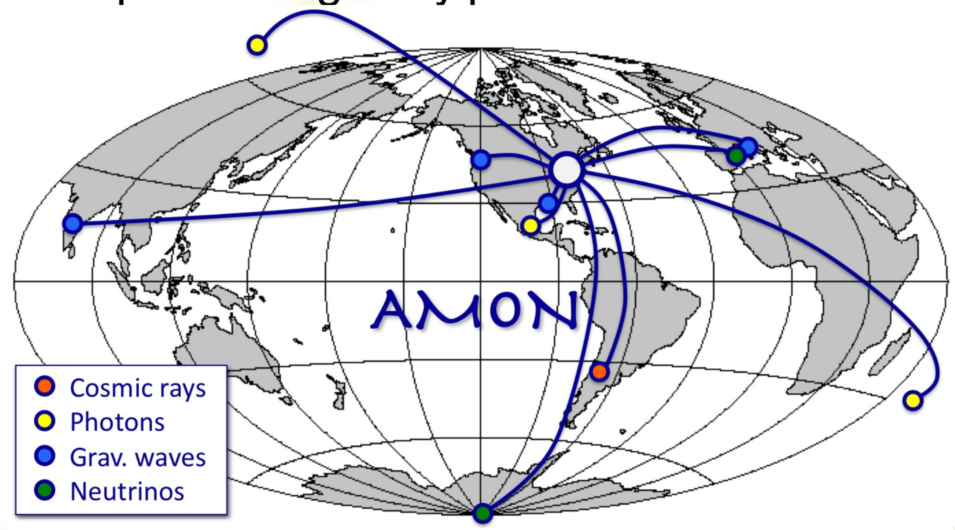
Goal: better understanding of physics mechanism

Individual MOU observatories:

- Swift XRT
- Palomar Transient Factory
- Magic Gamma Ray Telescope
- VERITAS
- HAWC
- HESS
- LIGO/VIRGO
- Murchison Widefield Array

Networks & public alerts:

http://amon.gravity.psu.edu



The Astrophysical Multimessenger Oberservatory Network:

Antares,IceCube, Auger,
Veritas,HAWC,Fermi,LMT,LCOGT,..

„The Astronomer's Telegram“

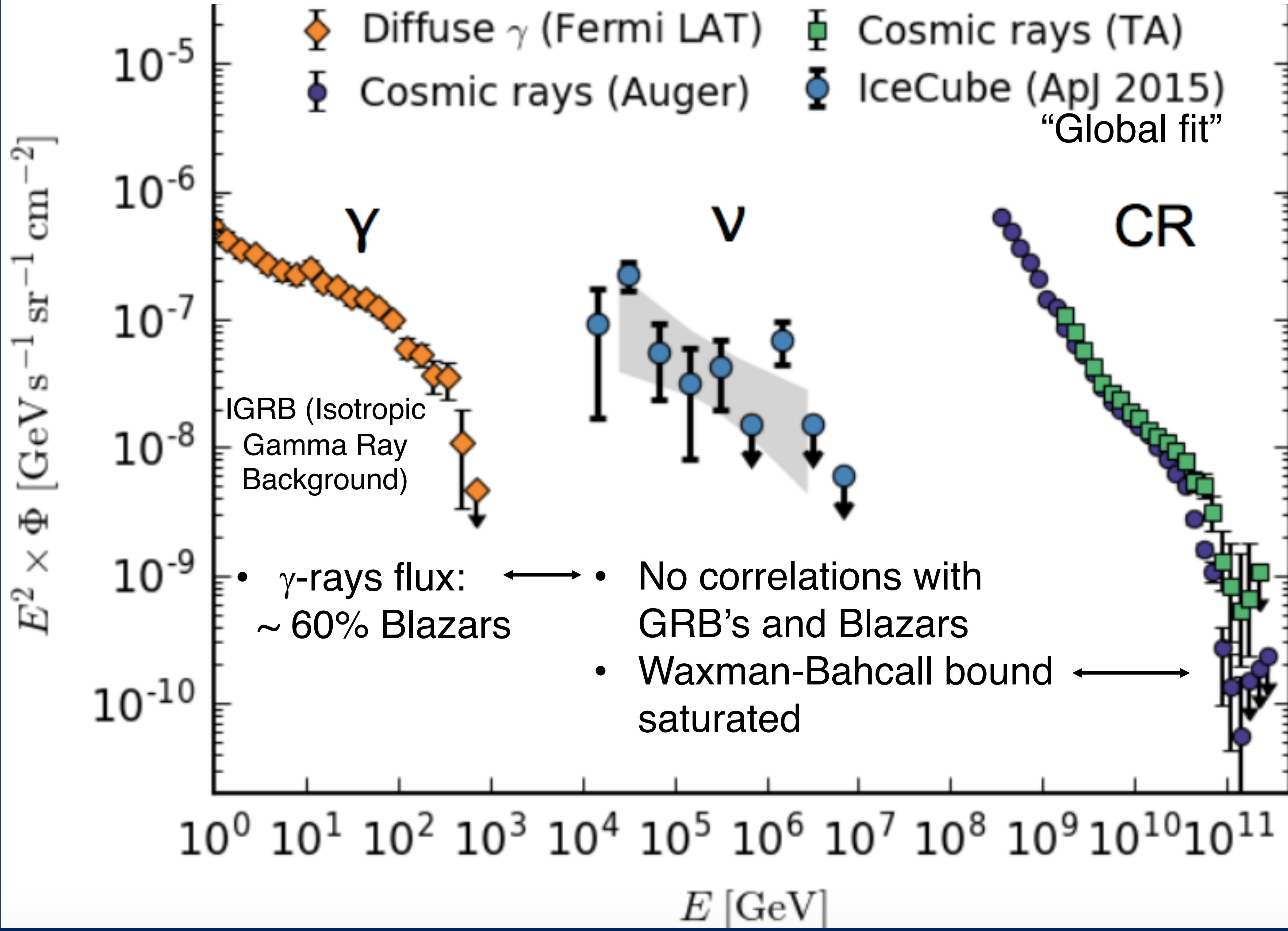
The Gamma-ray Coordinates Network

No significant correlations between ν (IceCube and Antares) events and γ / CR events found

Multi-messenger astronomy

Goal: better understanding of physics mechanism

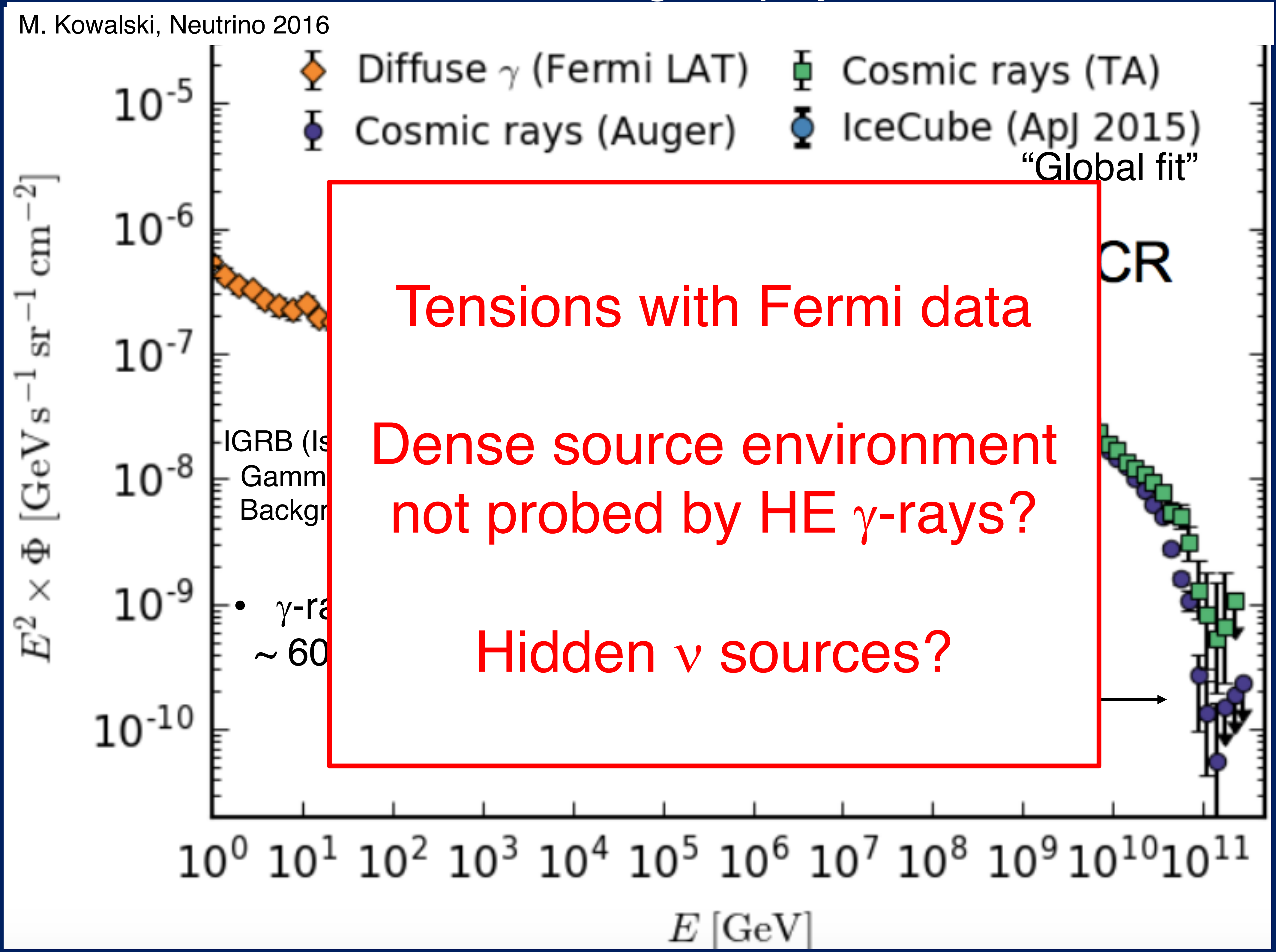
M. Kowalski, Neutrino 2016



Neutrino fluxes from blazars and star-forming galaxies are predicted by e.g. Kusenko et al. (2010), Murase et al. (2014) and Bechtol et al. (2015), respectively (small overall contribution to the flux)

Multi-messenger astronomy

Goal: better understanding of physics mechanism



Neutrino fluxes from blazars and star-forming galaxies are predicted by e.g. Kusenko et al. (2010), Murase et al. (2014) and Bechtol et al. (2015), respectively (small overall contribution to the flux)

Neutrino astronomy: many open questions
no identified (steady and transient) sources so far

Call for future larger detectors

Km3Net, Lake Baikal-GVD and IceCube-Gen2

High Energy Neutrinos: Future

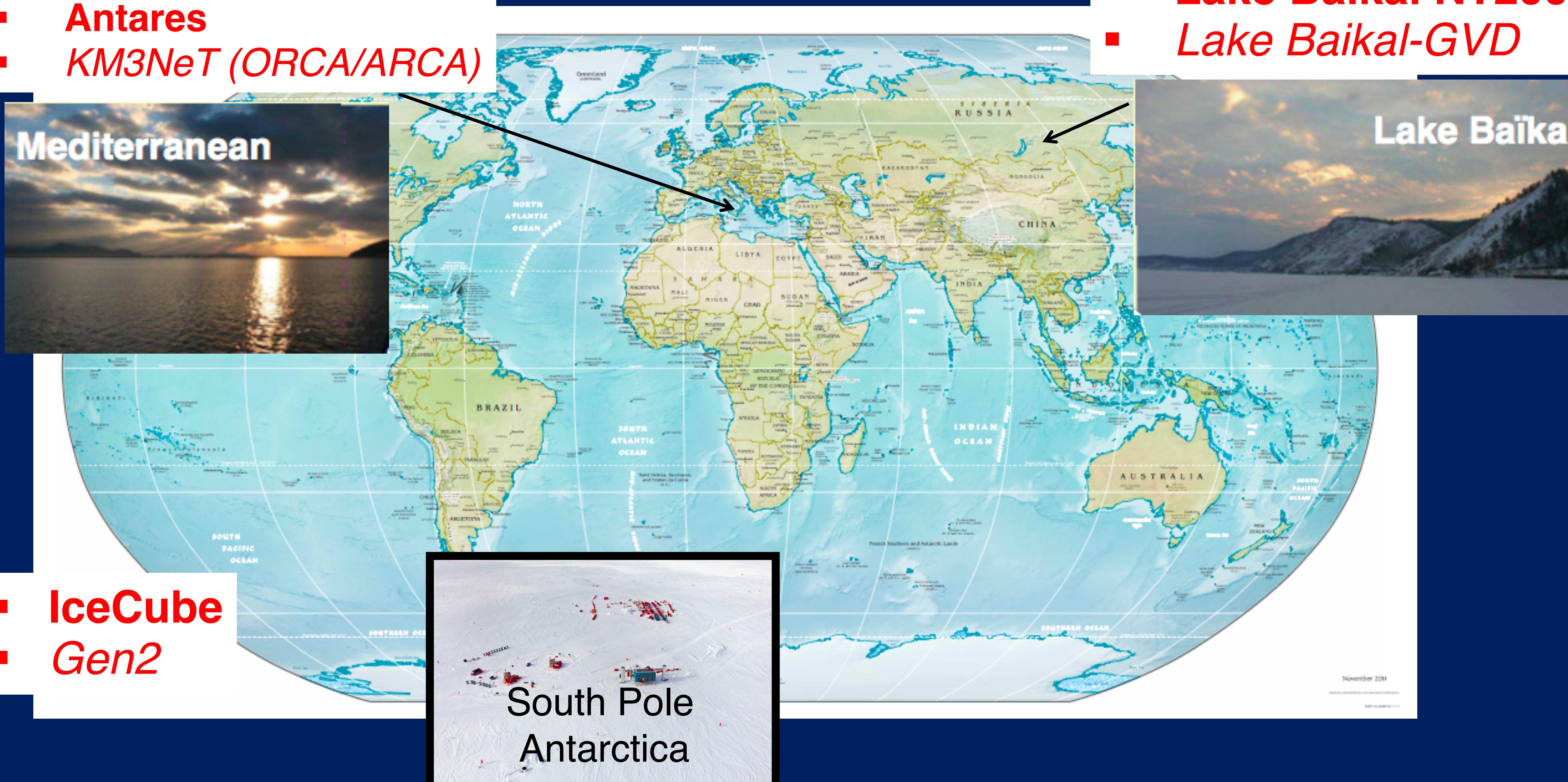
Neutrino telescopes main goal(s):

- **ν source searches**
- **diffuse/unresolved ν flux measurements**

Techniques: optical detection

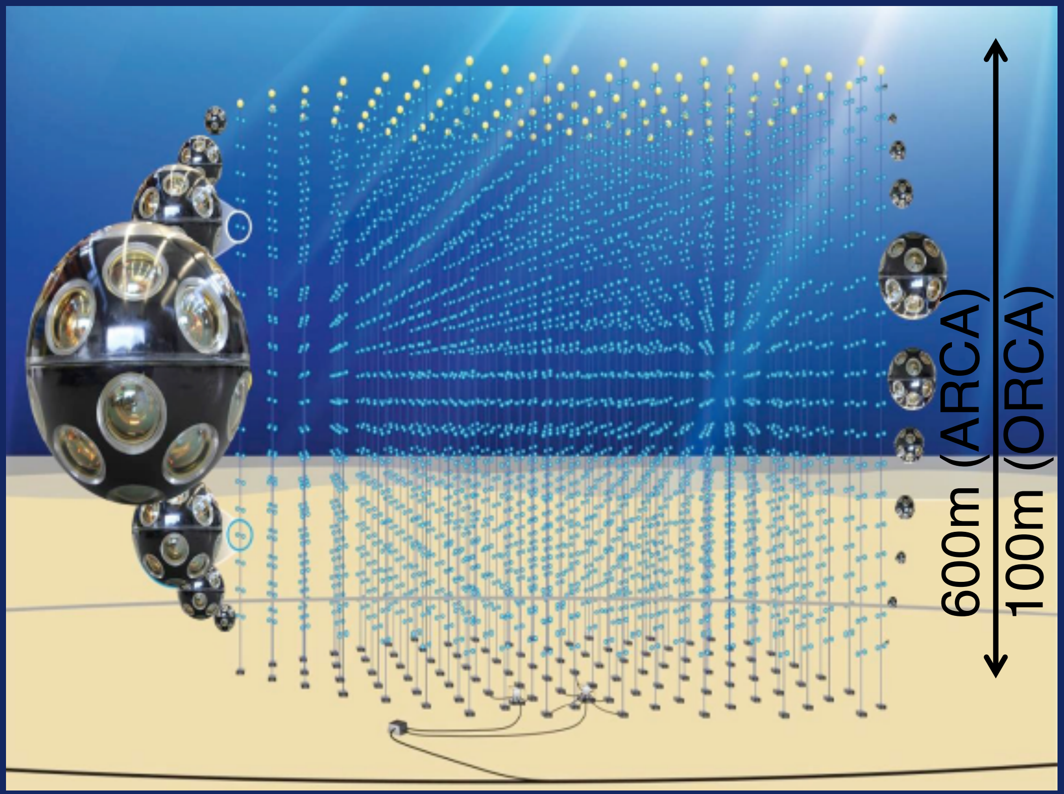
- **Antares**
- *KM3NeT (ORCA/ARCA)*

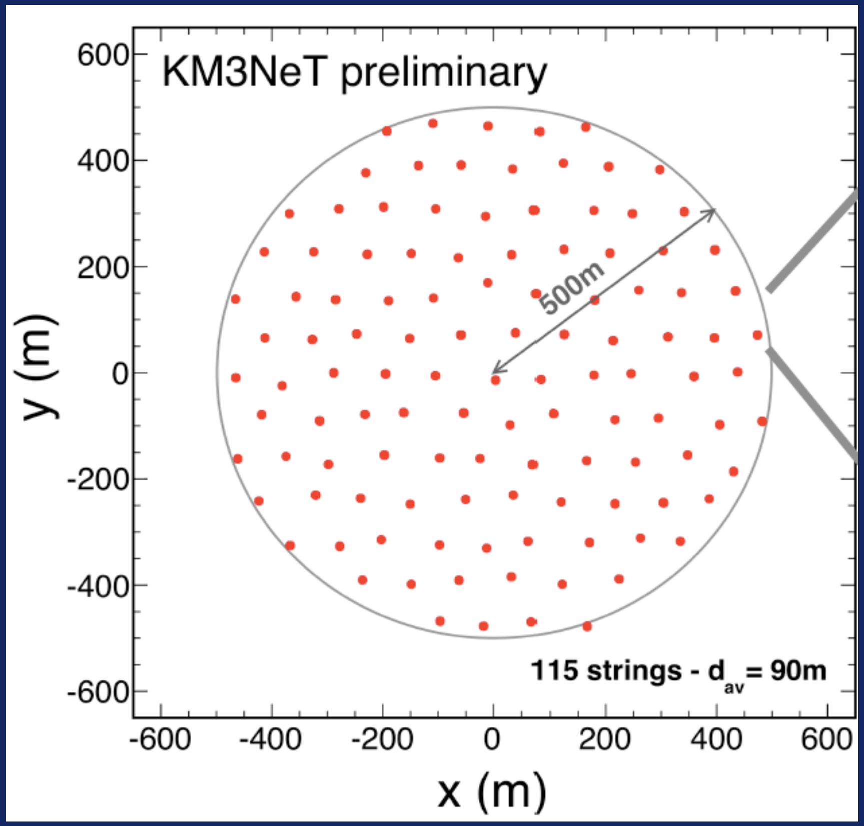
- **Lake Baikal NT200+**
- *Lake Baikal-GVD*



- **IceCube**
- *Gen2*

KM3NET 'building block'





- 115 lines
- 18 OMs per line

- <u>ARCA</u>
  - ✓ 90m horizontal
  - ✓ 36m vertical

- <u>ORCA</u>
  - ✓ 20m horizontal
  - ✓ 6m vertical

Timeline

Phase	Blocks	Primary deliverables
1	0.2	Proof of feasibility and first science results;
2	2	Measurement of the neutrino signal reported by IceCube; All flavour neutrino astronomy;
	1	Determination of the neutrino mass hierarchy;
3	6	Neutrino astronomy including Galactic sources;

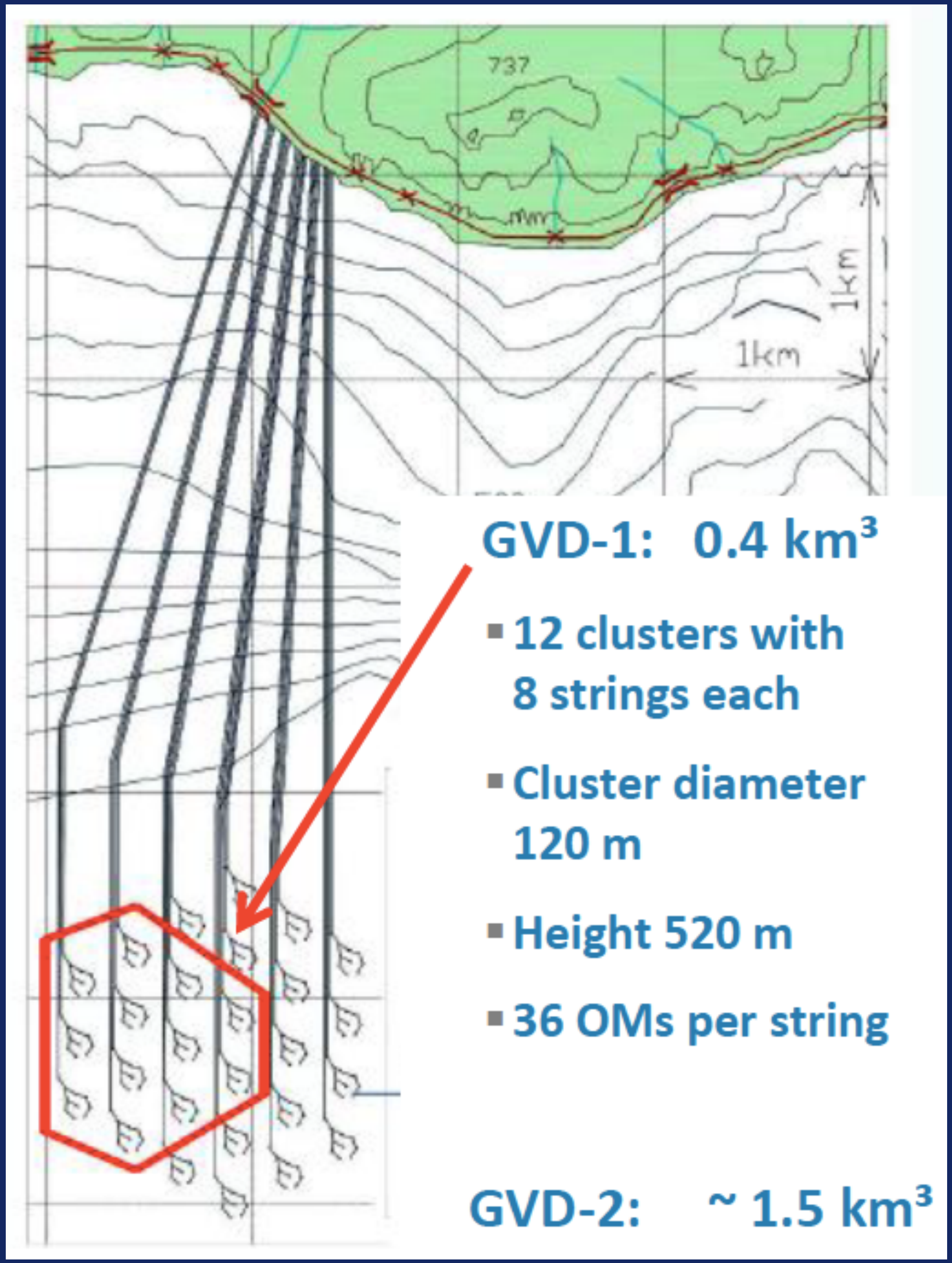
Table 1: Summary of the phased implementation of the KM3NeT research infrastructure.

10% ARCA
5% ORCA
funded, 2017

100% ARCA
100% ORCA
2020 (completion)

Lake Baikal-GVD (Gigaton Volume Detector)

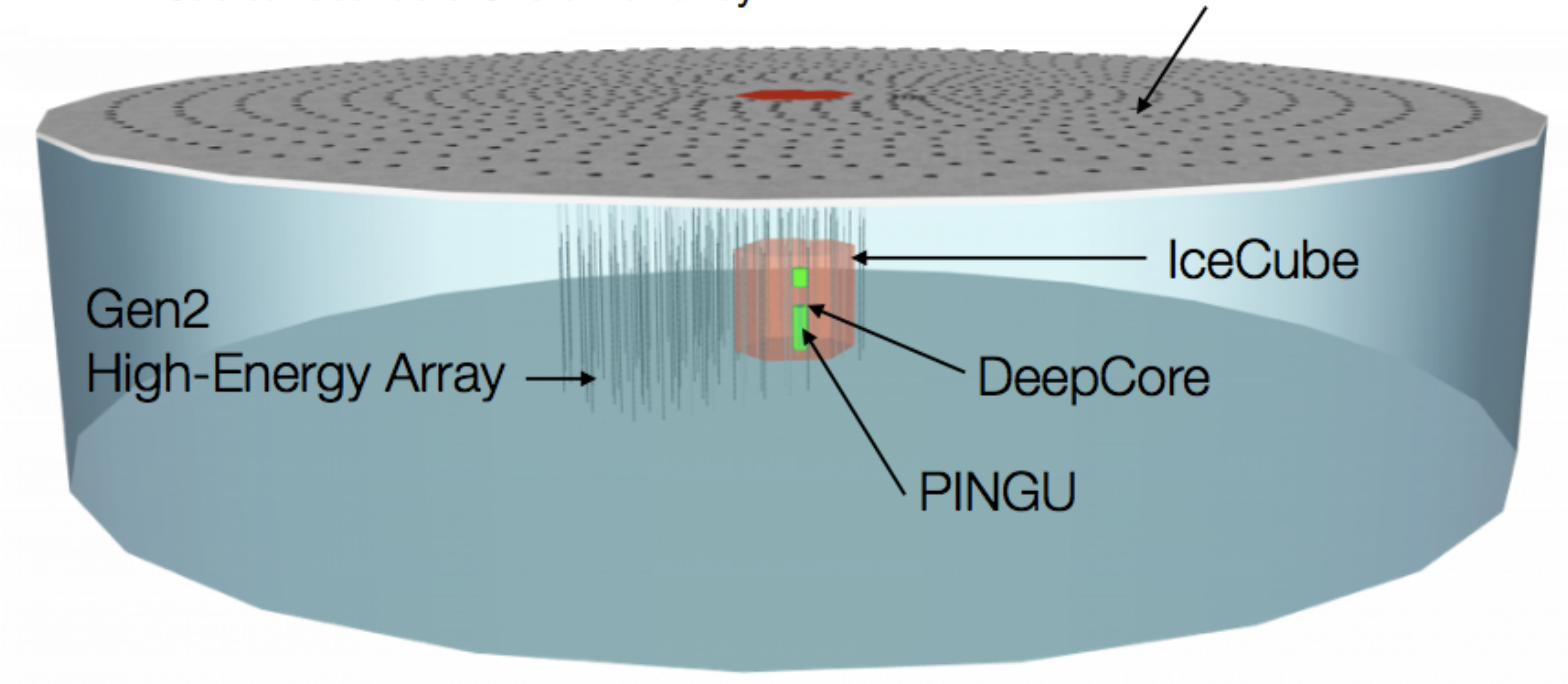
- The most northern location allows observing the Galactic Center 18 hours per day through the Earth
- 2016: The first cluster, in operation
  ✓ sensitive to 1 cascade event with E > 100 TeV of IC flux
- Completion of the Baikal-GVD with 2304 OMs (GVD-1) with ~ 0.4 km^3 effective volume for cascade detection is expected in 2020
- GVD-2 with ~ 1.5 km^3 effective area (~ 2025)



IceCube-Gen2
A Vision for the Future of Neutrino Observatory in Antarctica

White paper,arXiv:1412.5106

- Surface air shower/veto array
- Sub-surface radio Cherenkov array



IceCube-Gen2: Facility
A Vision for the Future of Neutrino Observatory in Antarctica

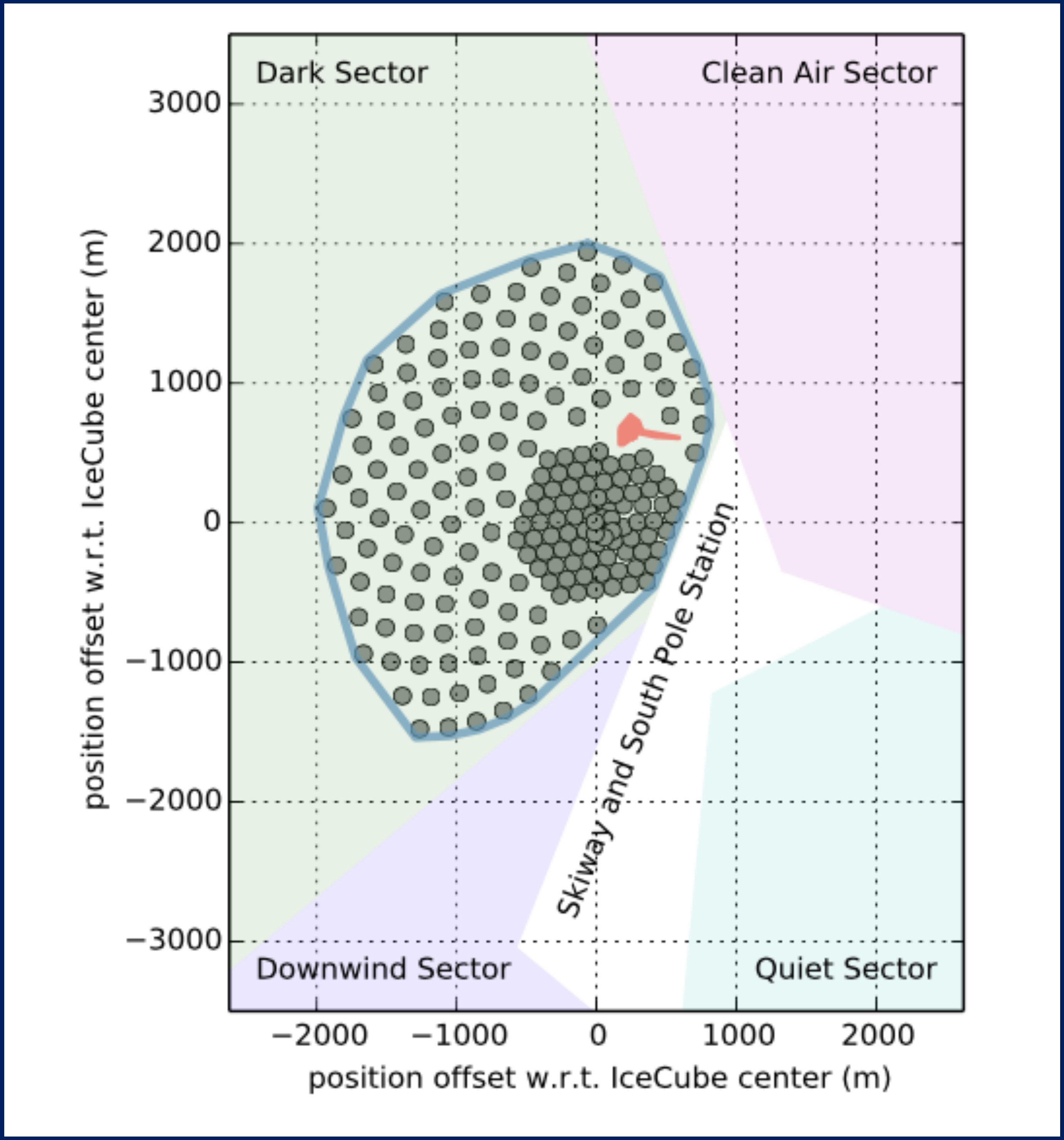
arXiv:1412.5106

Benchmark geometry:

- instrumented volume ~10 km^3
- 120 strings, length 1.25km
- 240 m string spacing
- 80 DOMs/string

- 10 x IC volume for contained event analysis above 200 TeV

- Surface veto (CR physics, atm. neutrino veto)



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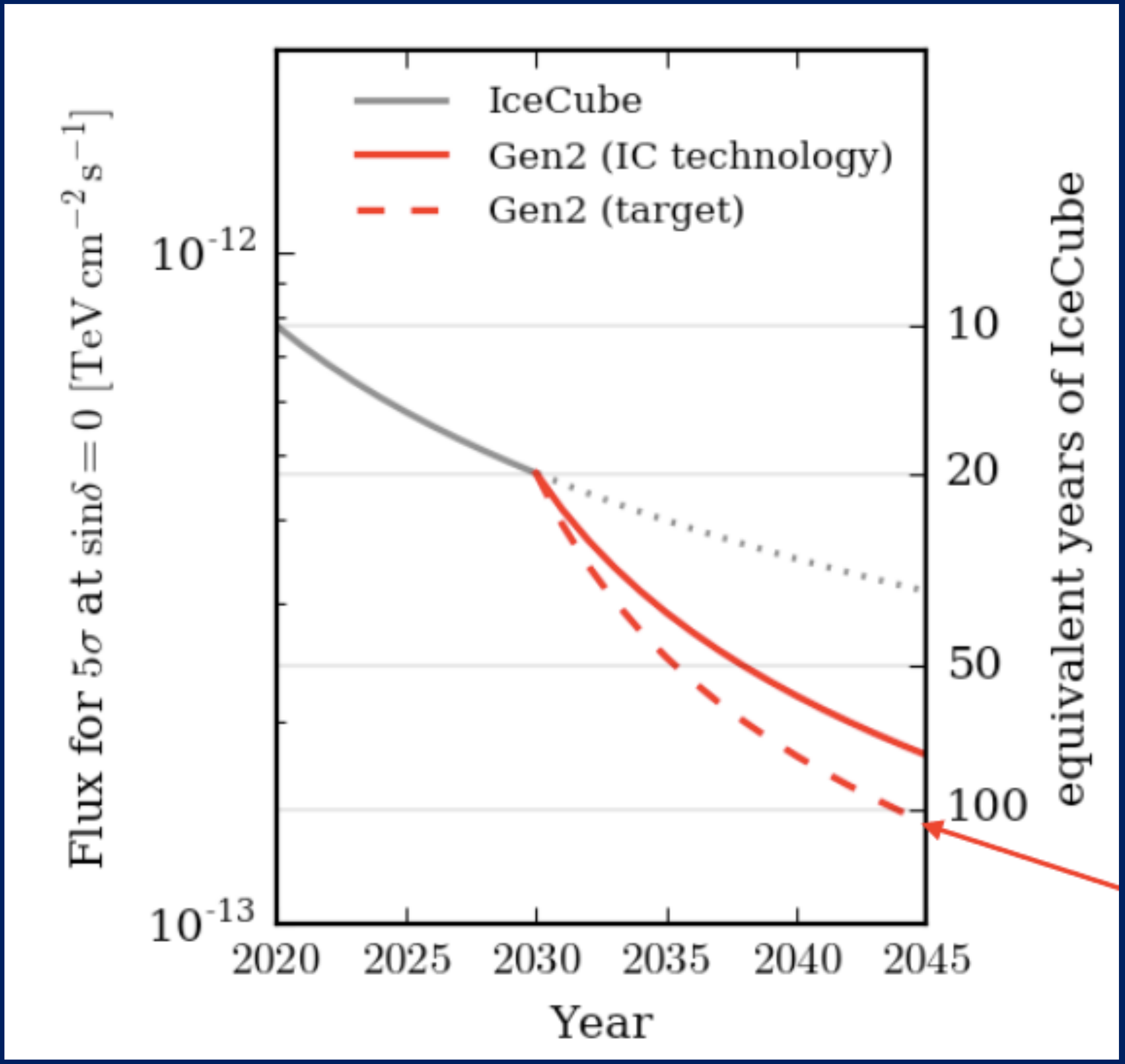
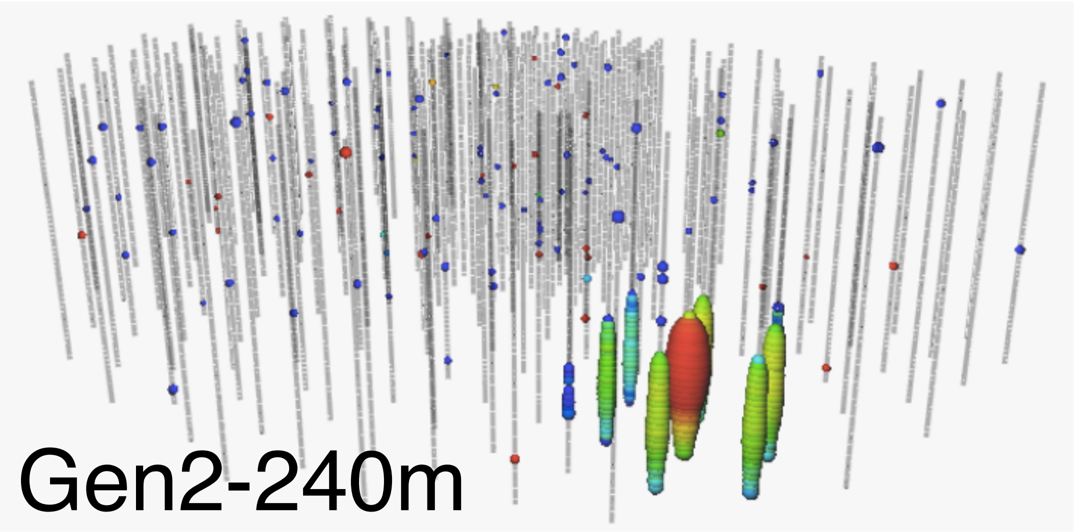


IceCube-Gen2: Facility
A Vision for the Future of Neutrino Observatory in Antarctica

arXiv:1412.5106

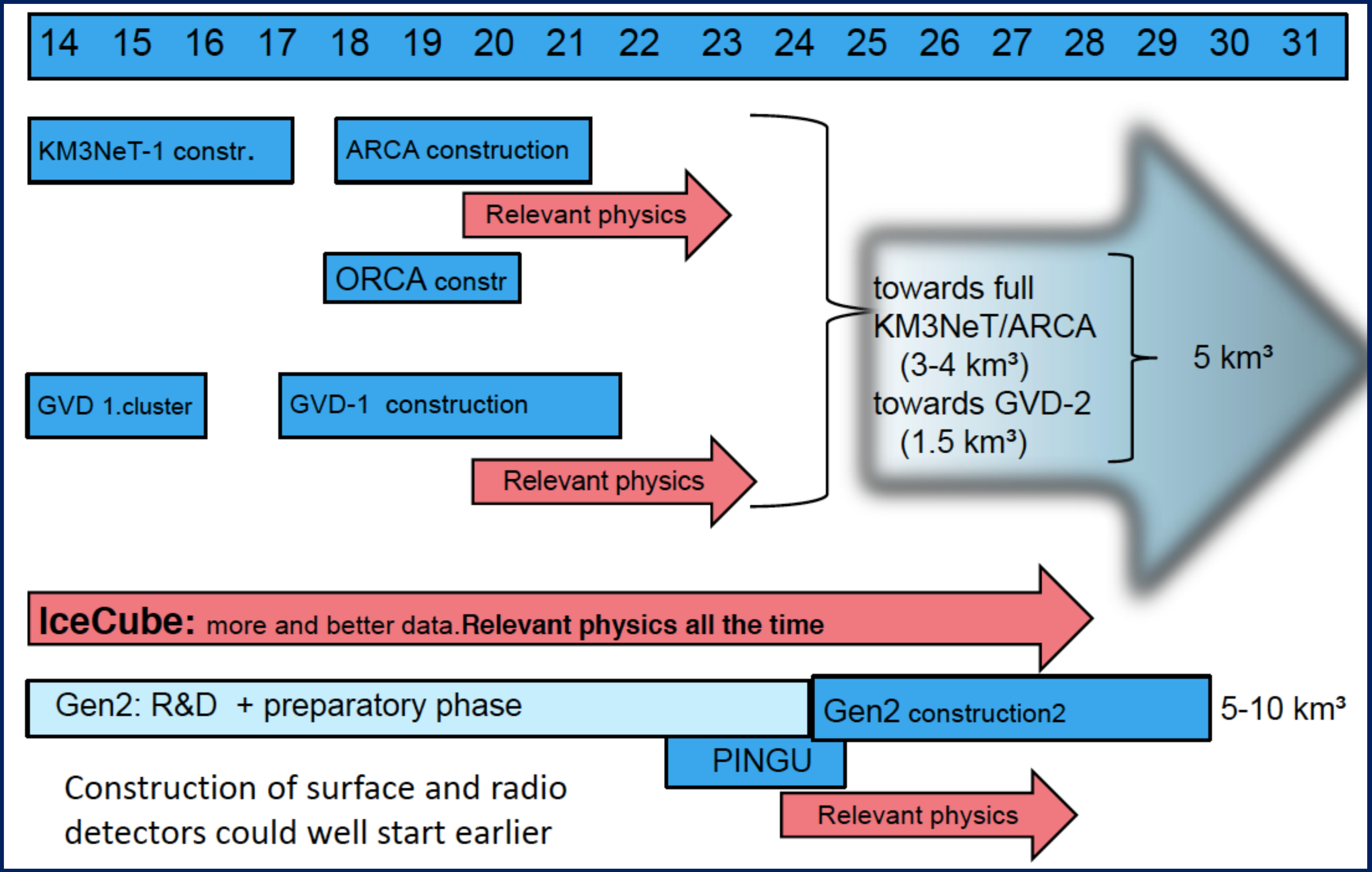


Glashow Resonance
Expected Rate / Year
5 PeV < E_{vis} < 7 PeV

Φ_{ν_e} $[\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}]$	interaction type	pp source IC-86	240m	360m
$1.0 \times 10^{-18}(E/100\,\mathrm{TeV})^{-2.0}$	GR	$\boxed{0.88}$	$\boxed{7.2}$	16
	DIS	0.09	0.8	1.6
$1.5 \times 10^{-18}(E/100\,\mathrm{TeV})^{-2.3}$	GR	0.38	3.1	6.8
	DIS	0.04	0.3	0.7
$2.4 \times 10^{-18}(E/100\,\mathrm{TeV})^{-2.7}$	GR	$\boxed{0.12}$	$\boxed{0.9}$	2.1
	DIS	0.01	0.1	0.2

TABLE I. Expected number of contained neutrino-induced cascades per year with 5 PeV < E_{vis} < 7 PeV in IceCube in its current 86-string configuration and in an extended detector with a string spacing of 240 m (360 m shown for comparison) assuming a source dominated by p-p interactions. For every event Cherenkov light is required to be detected by optical modules on at least 3 strings.

High Energy Neutrinos: Future



Ch. Spiering (NOW2016)

Era of km^3 neutrino astronomy has begun

IceCube Discovery ⇨ *Measurements* ⇨ *Models testing*

Diffuse signal ⇨ *First source* ⇨ *Catalog!*

Astrophysical neutrinos have been discovered by IceCube
Diffuse flux characteristics started (IceCube + theoretical models + multi-messenger)
Origin: Lot's of possible interpretations
Cosmic accelerator source searches continue …..

Call for a larger detectors!

Stay tuned!