Breaking News

Shigeru Yoshida
ICEHAP - Chiba university

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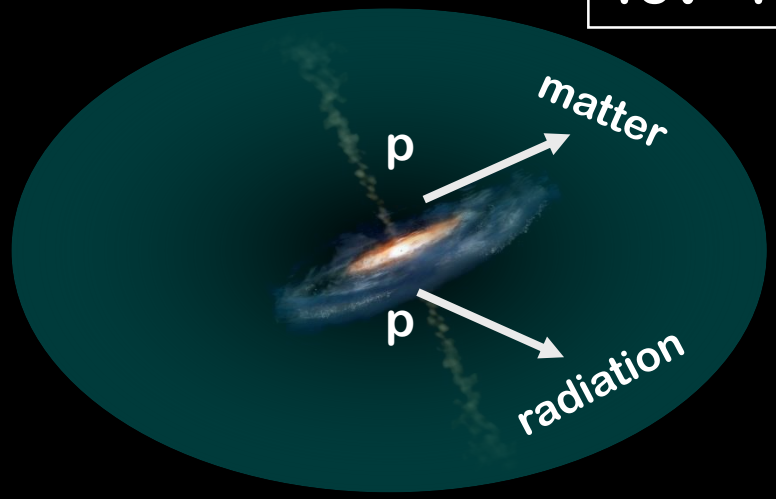
The Cosmic Neutrinos
Production Mechanisms

CHIBA UNIVERSITY

"On-source" ν

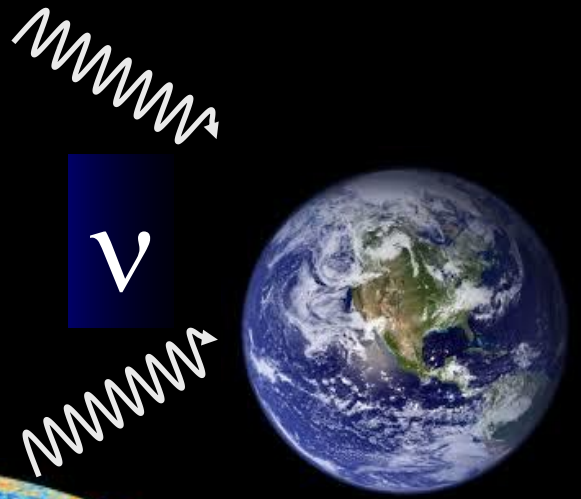
TeV - PeV



$pp \rightarrow \pi \rightarrow \nu$

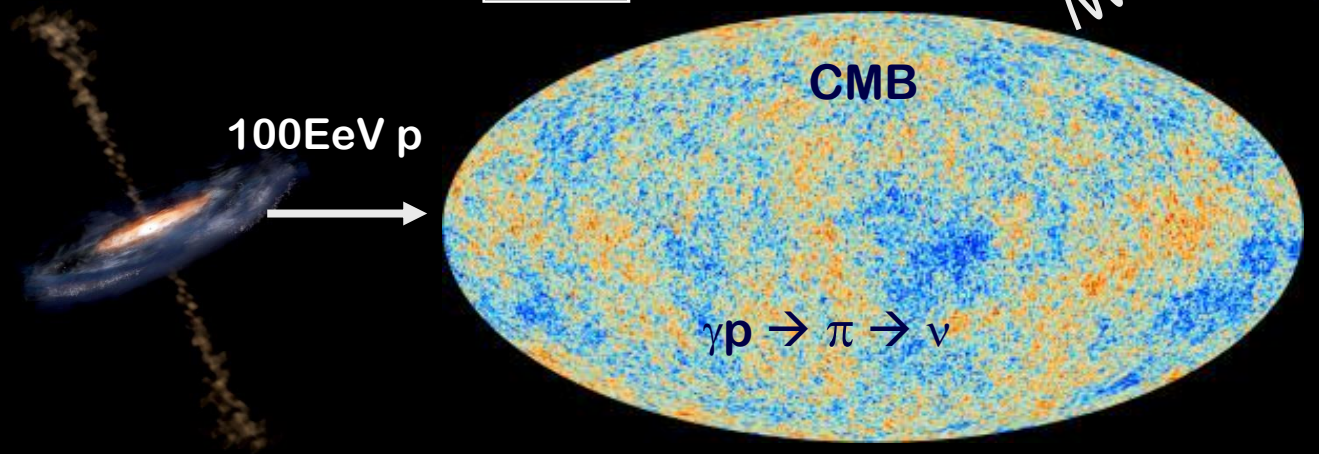
$\gamma p \rightarrow \pi \rightarrow \nu$

photopion production



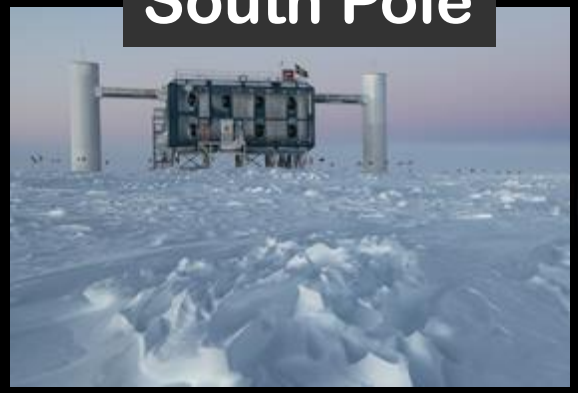
"GZK" cosmogenic ν

EeV



Realtime Multi-Messenger

South Pole



Northern Hemisphere

WIPAC
Wisconsin IceCube Particle Astrophysics Center

GCN-TAN

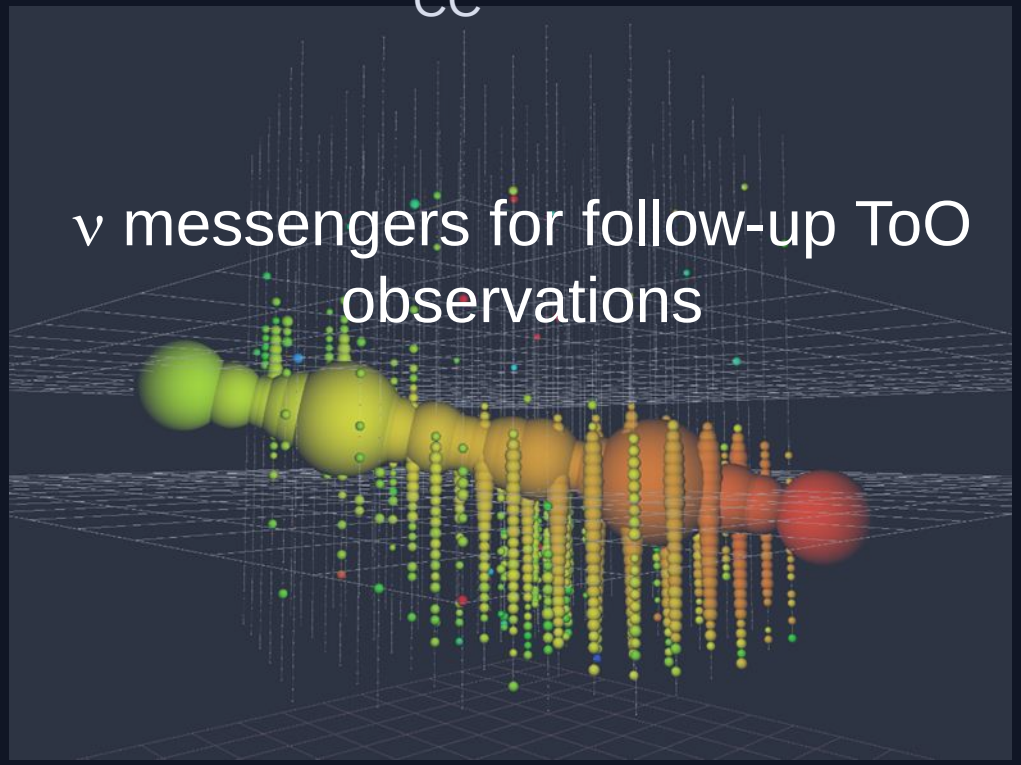
IceCube Event Topology

Track

$\nu_\mu \xrightarrow[CC]{} \mu$

$\nu_\tau \xrightarrow[CC]{} \tau$ (only at ultra-high energies)

Angular resolution
~ 0.5 degree

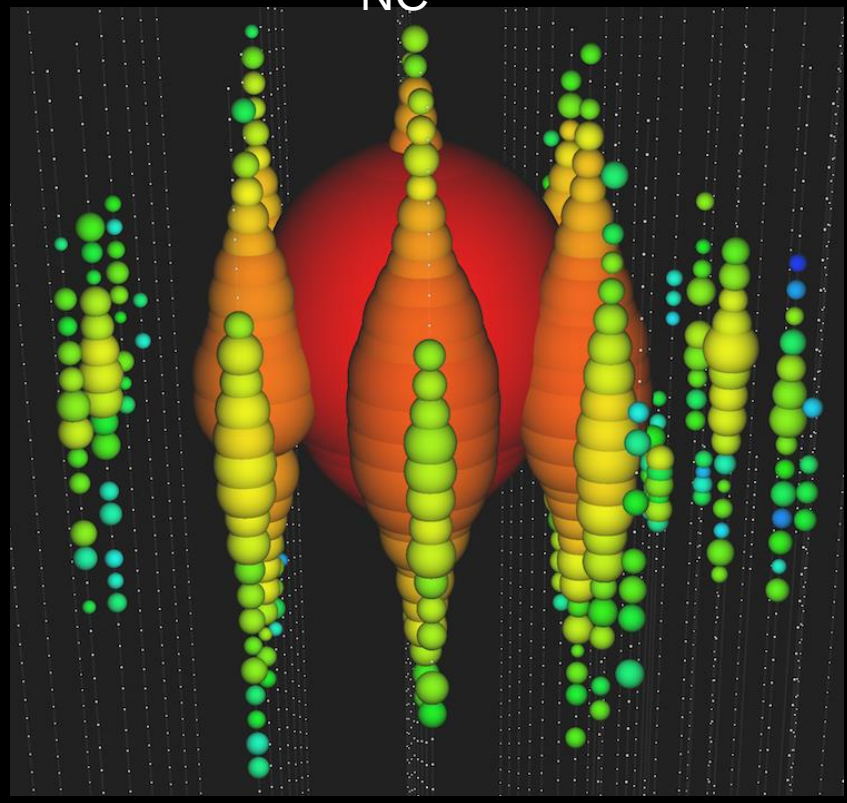


Cascade (shower)

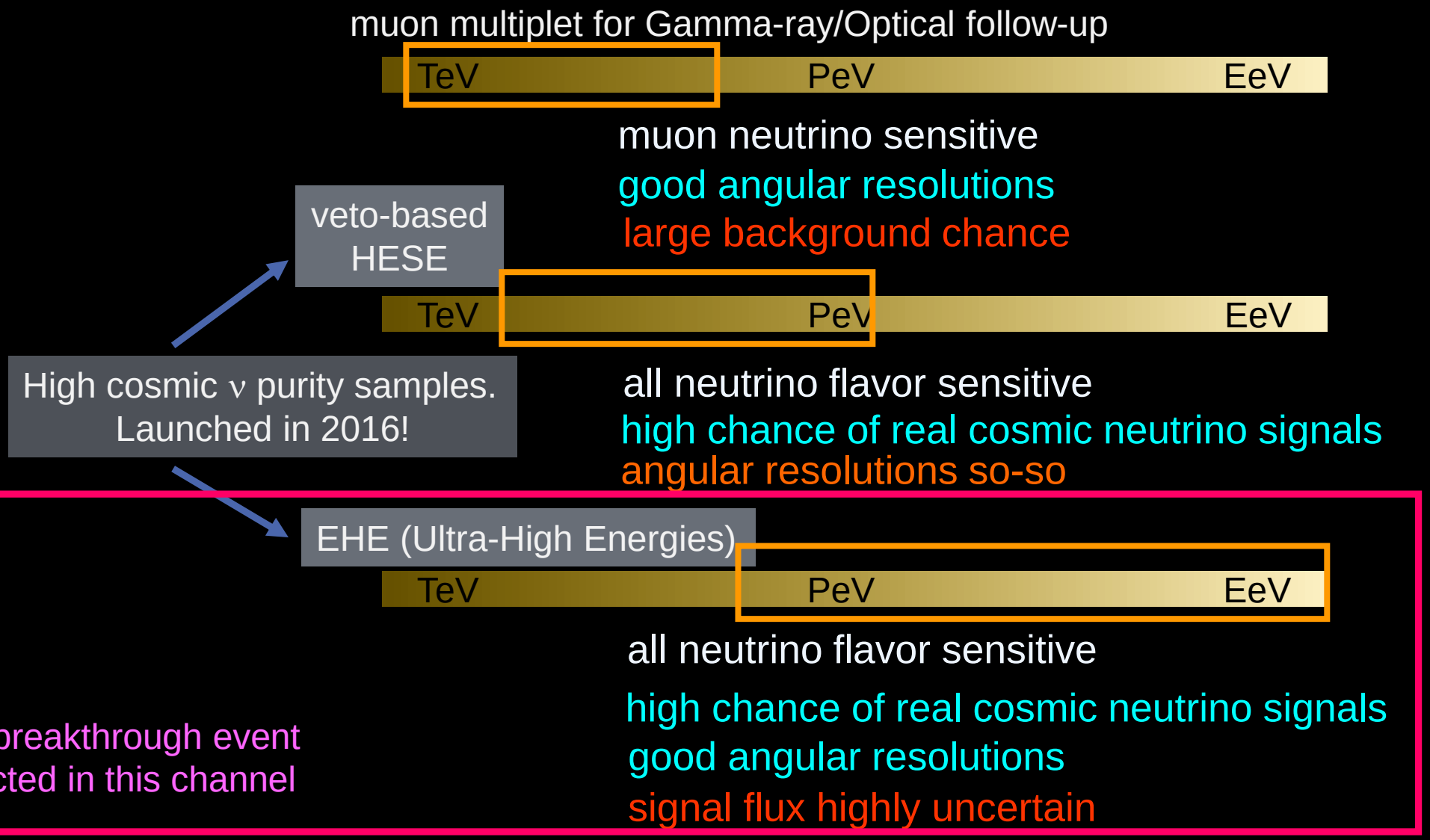
$\nu_e \xrightarrow[CC]{} e + X$

$\nu_x \xrightarrow[NC]{} x + X$ x=e, μ, τ

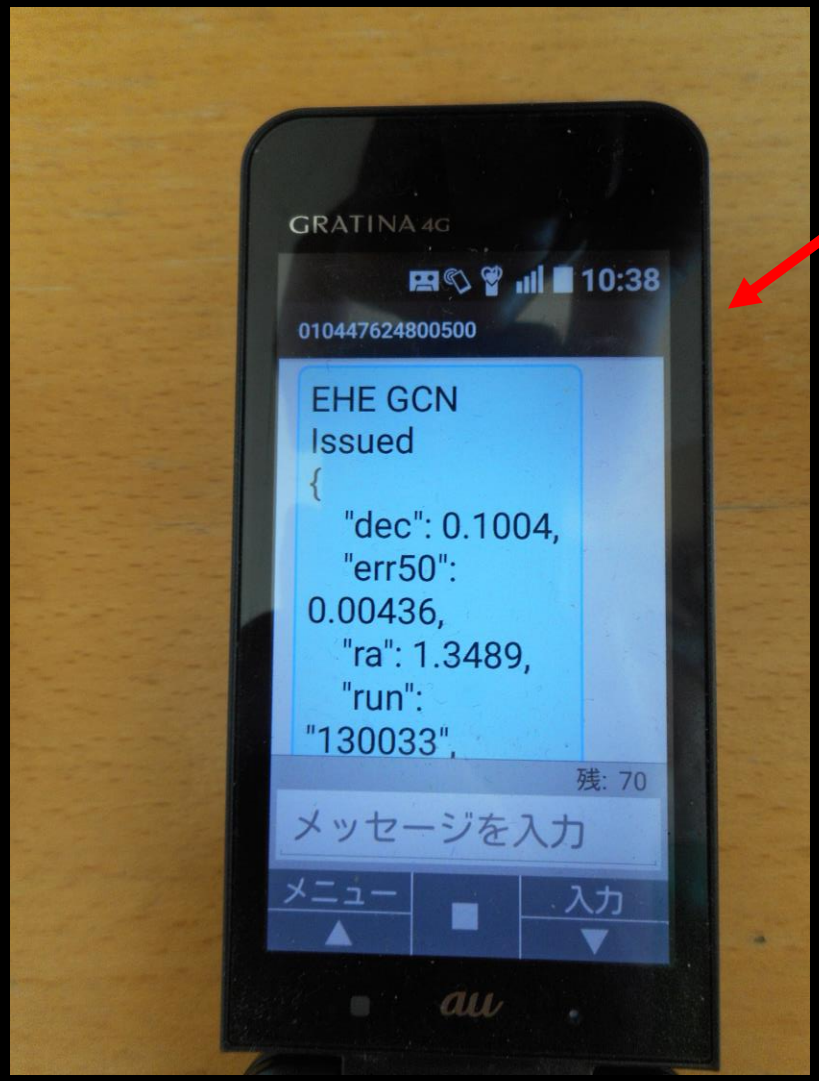
Angular resolution
~ 15 degree



IceCube Realtime Analysis Chain



And the story began here



SMS notice
pinged my (non-smart) cellphone

5:55 am, Saturday, September 23, JST

the greatest wakeup call I've ever had in Saturday morning

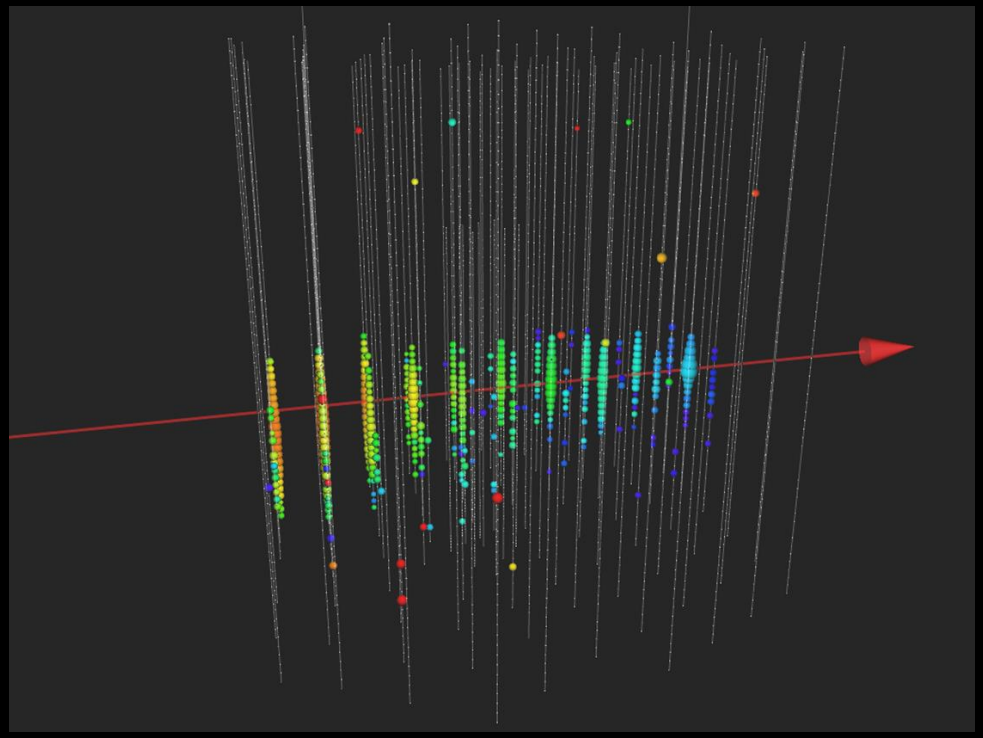
Numbers on IceCube 170922A

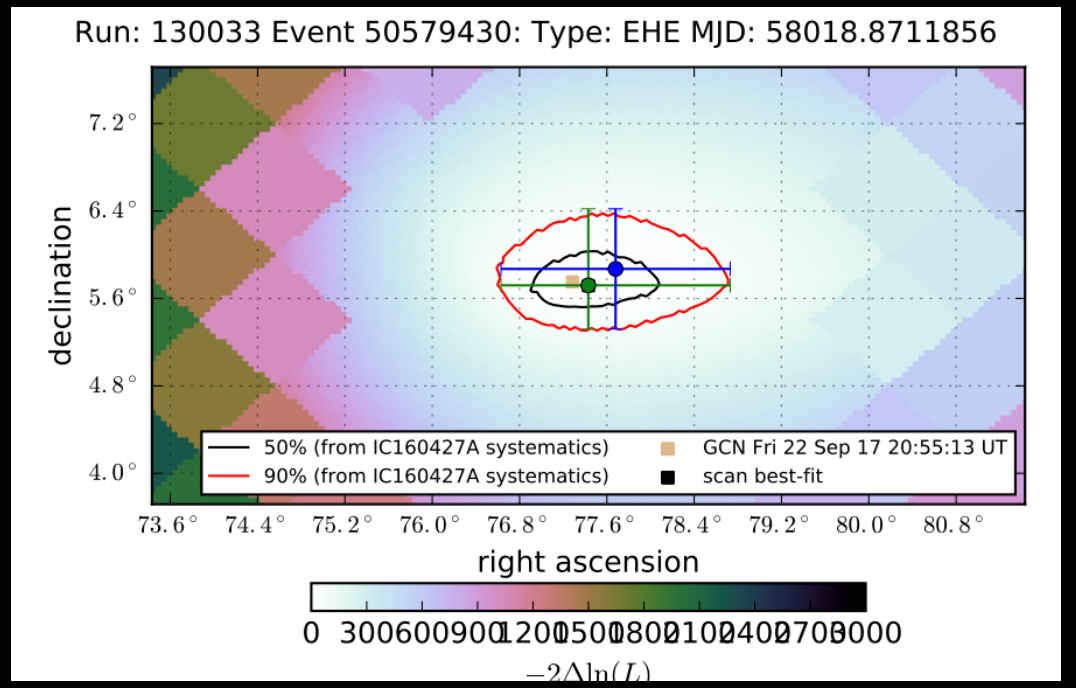
Identified by the EHE realtime stream

Date (UT):2017-09-22 20:54:30.436263 Run 130033 Evt 50579430

NPE:5785.94156

EHE linefit zenith 97.5 → Revised zenith 95.7 RA: 77.43 DEC: 5.72 (J2000)





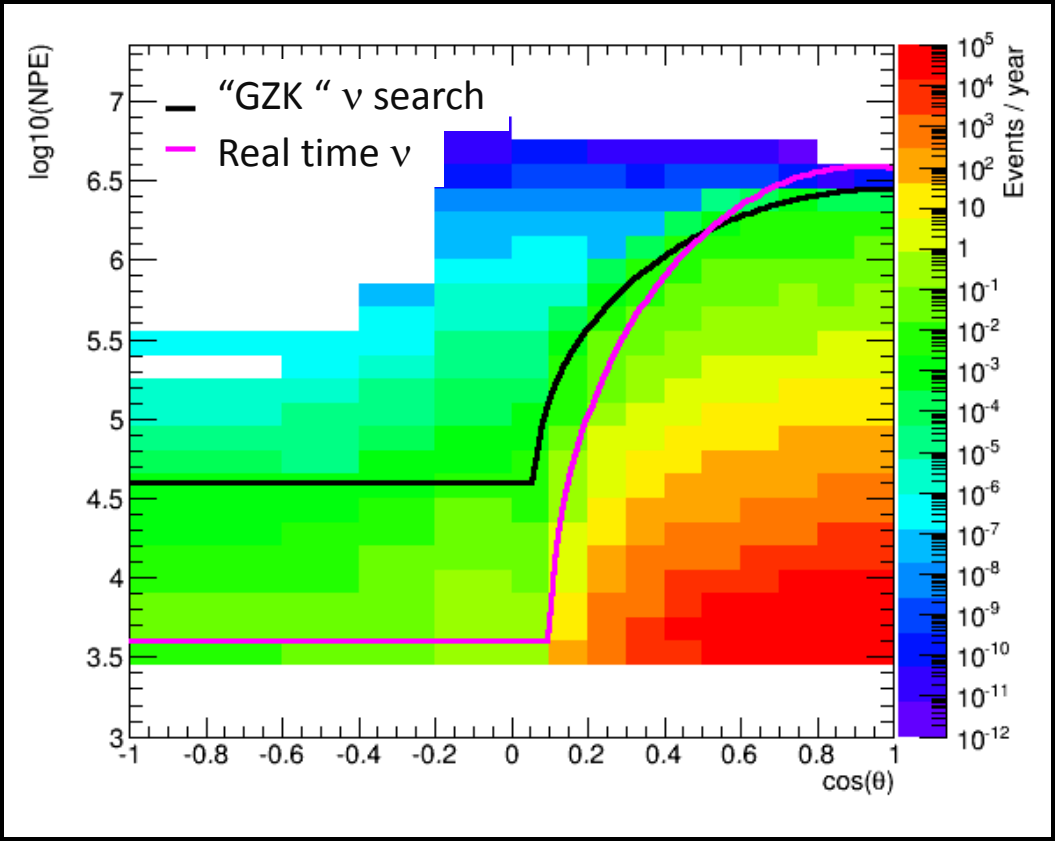
Provided by Claudio in the slack channel

Event selections for EHE real time stream

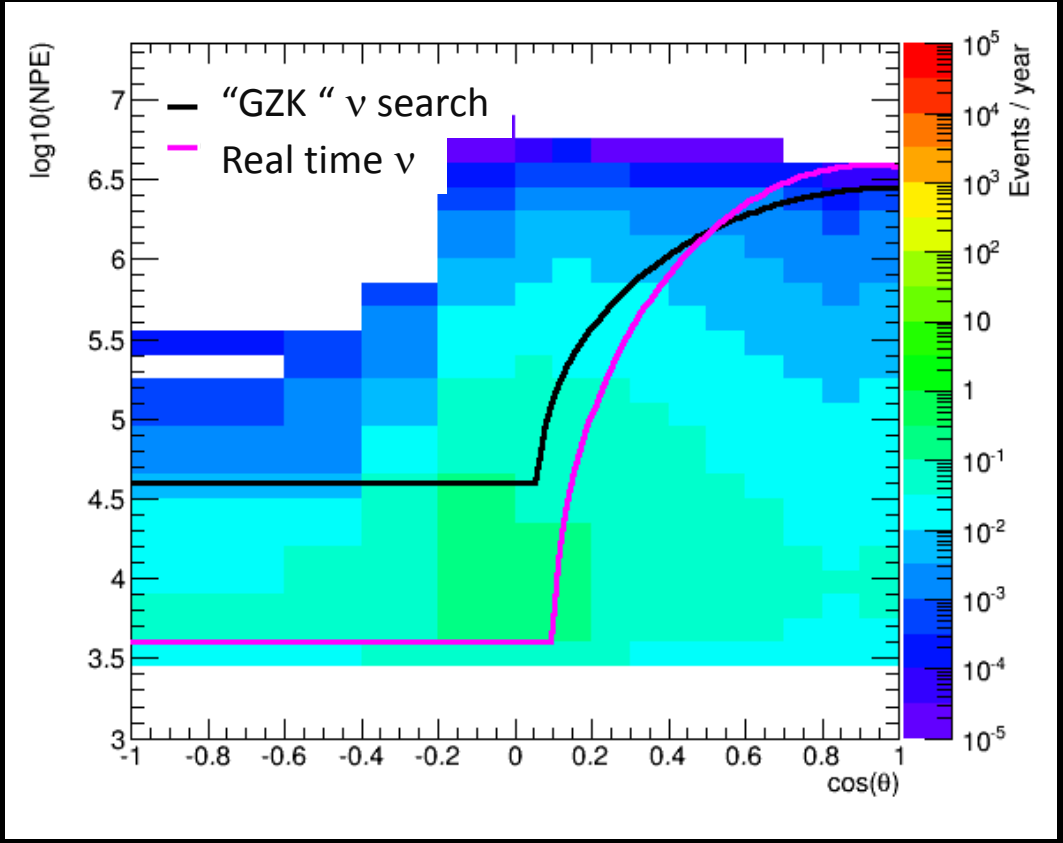
Relaxed cuts on NPE-cos(zenith) plane for track-like EHE L3

$\chi^2_{\text{EHE trackfit}} < 80$

Atmospheric BG



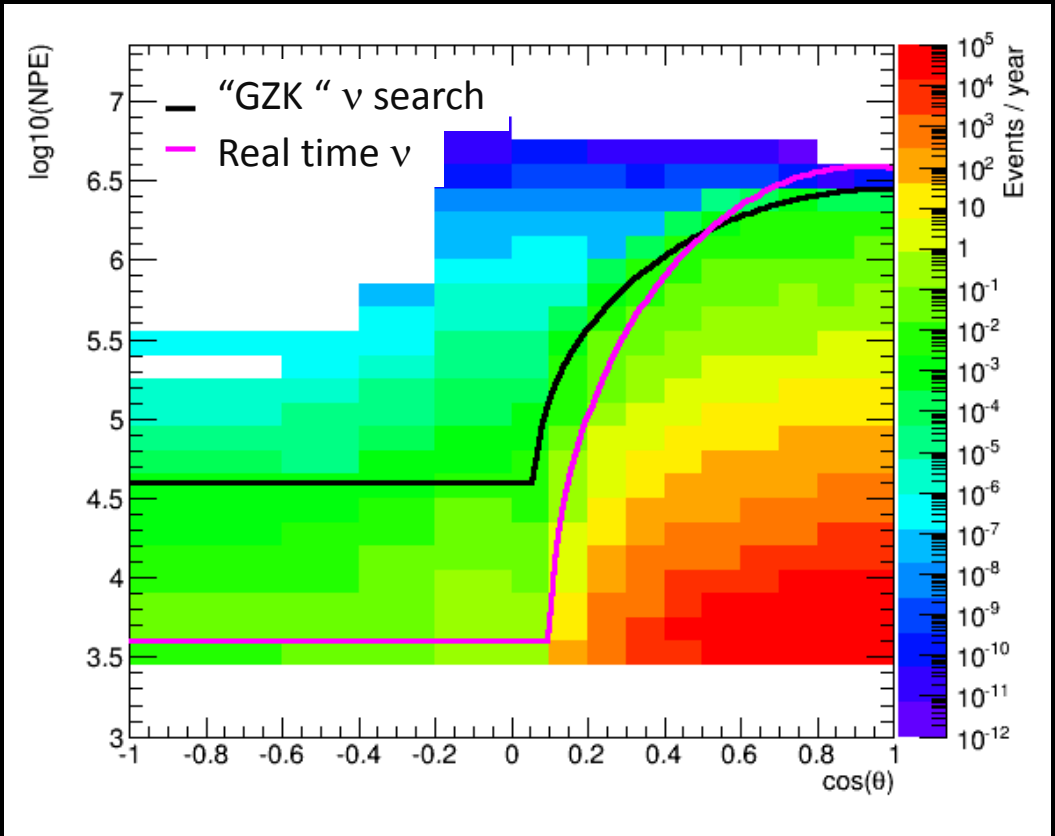
E^{-2} signal



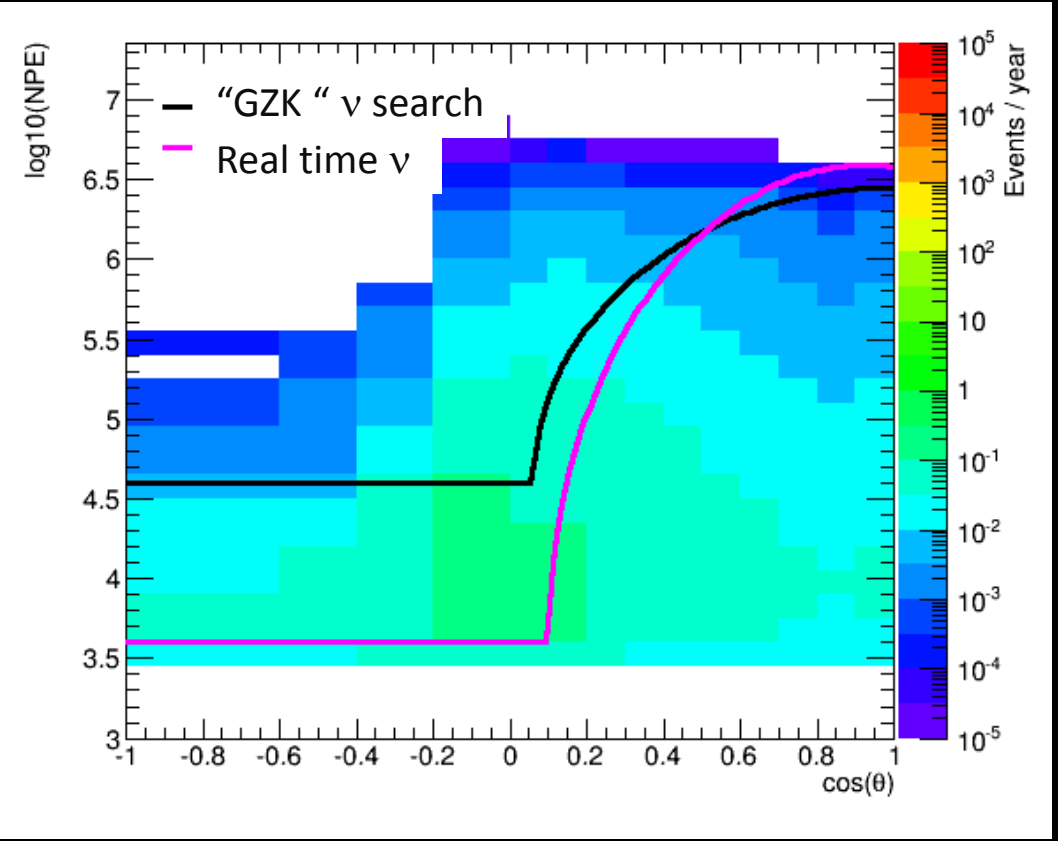
IceCube 170922A

NPE 5,786 cos(zenith) -0.13

Atmospheric BG



E^{-2} signal

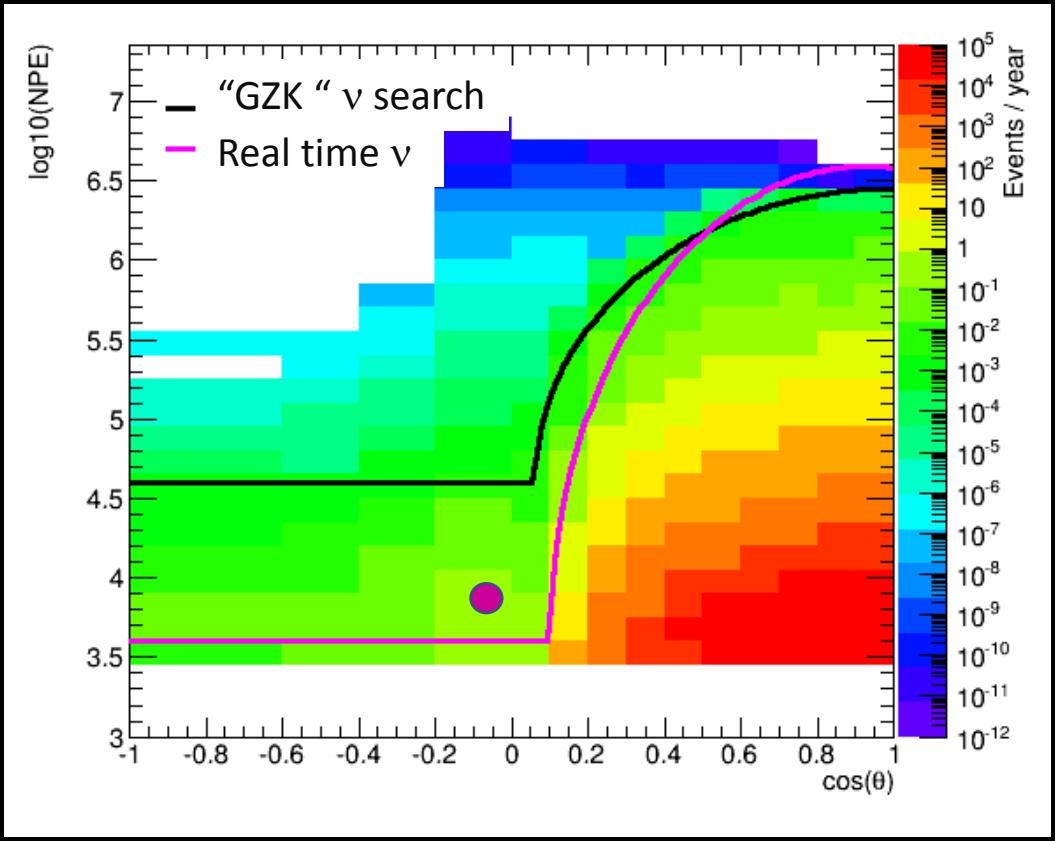


IceCube 170922A

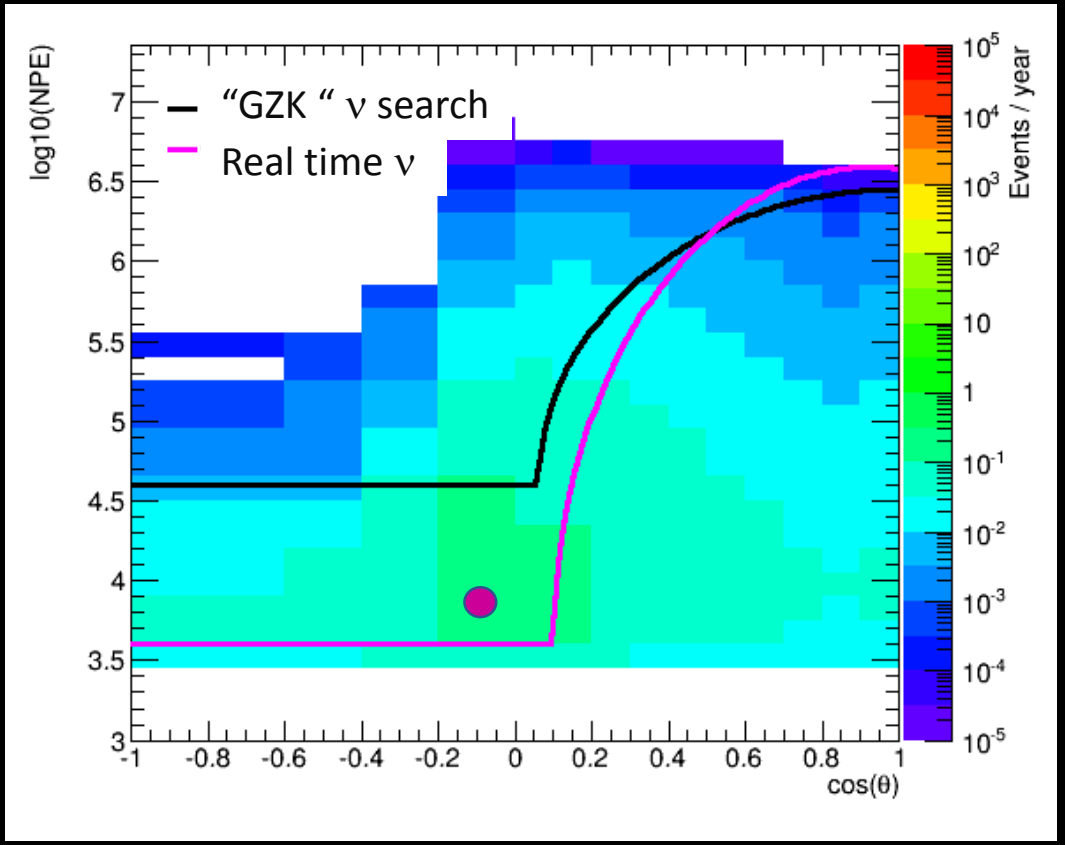
NPE 5,786 cos(zenith) -0.13

right on the “sweat spot” signalness : 56.5 %

Atmospheric BG



E^{-2} signal

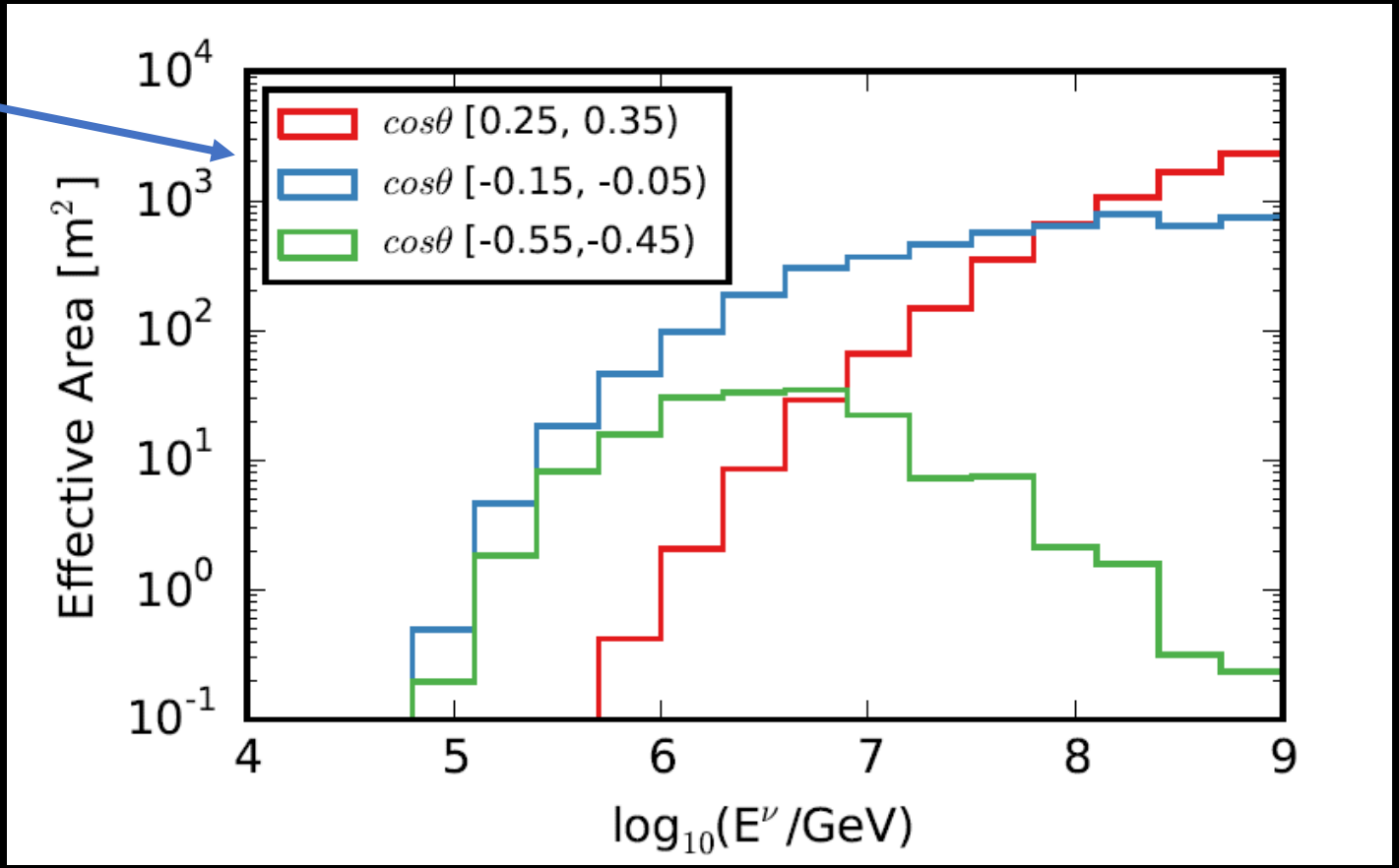


ν detection effective area

$$N = T \int d\Omega \int dE_\nu \phi_\nu(E_\nu)\, A_\nu(E_\nu)$$

# of events | time | solid angle | ν flux | ν effective area

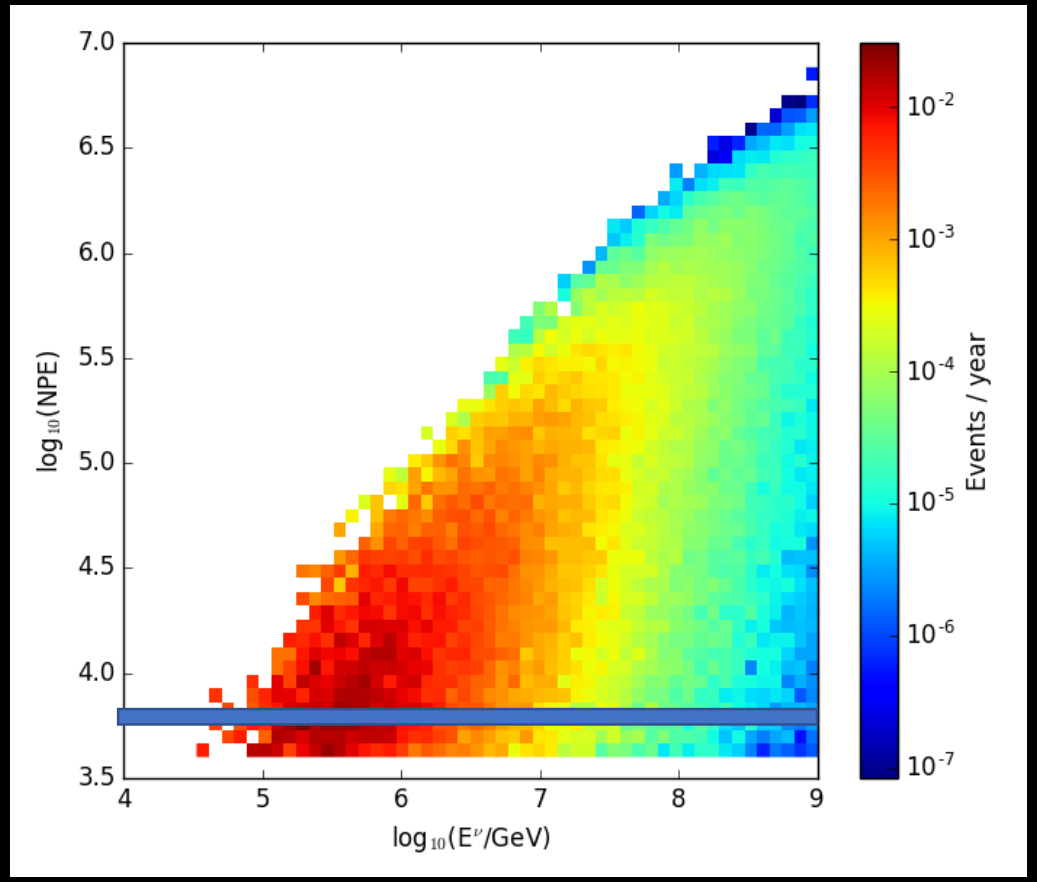
Zenith bin of this ν event



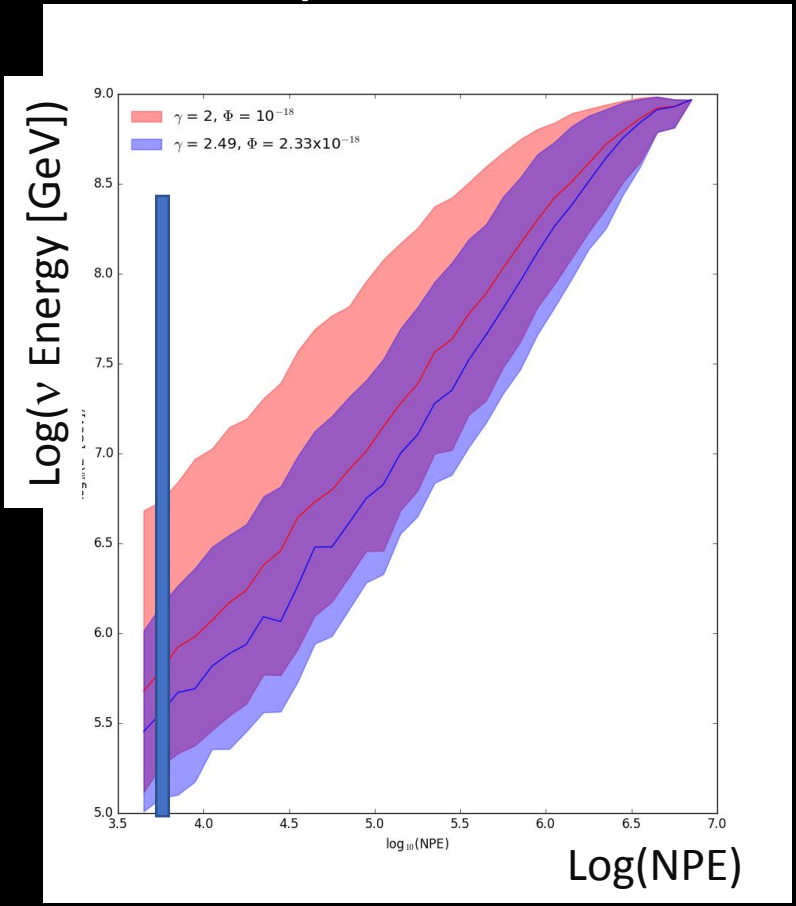
Neutrino Energy ?

Initial estimate reported in the GCN: 120 TeV

ν Energy Vs NPE ($E^{-2.5}$)



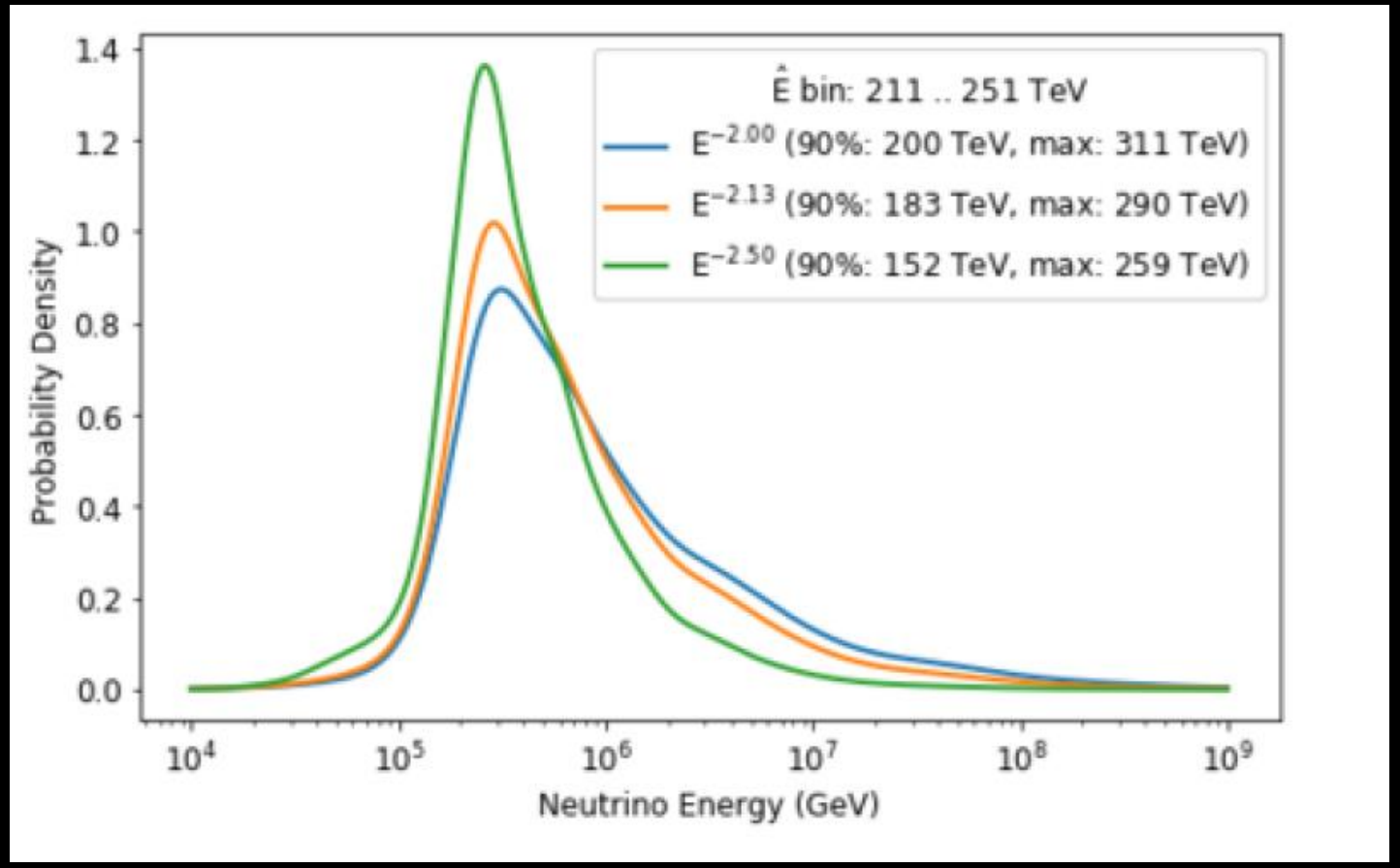
profile



Neutrino Energy ?

Energy deposit estimated : 21.6 TeV

→ ν_μ energy pdf at the earth surface



200TeV~ 7.5PeV

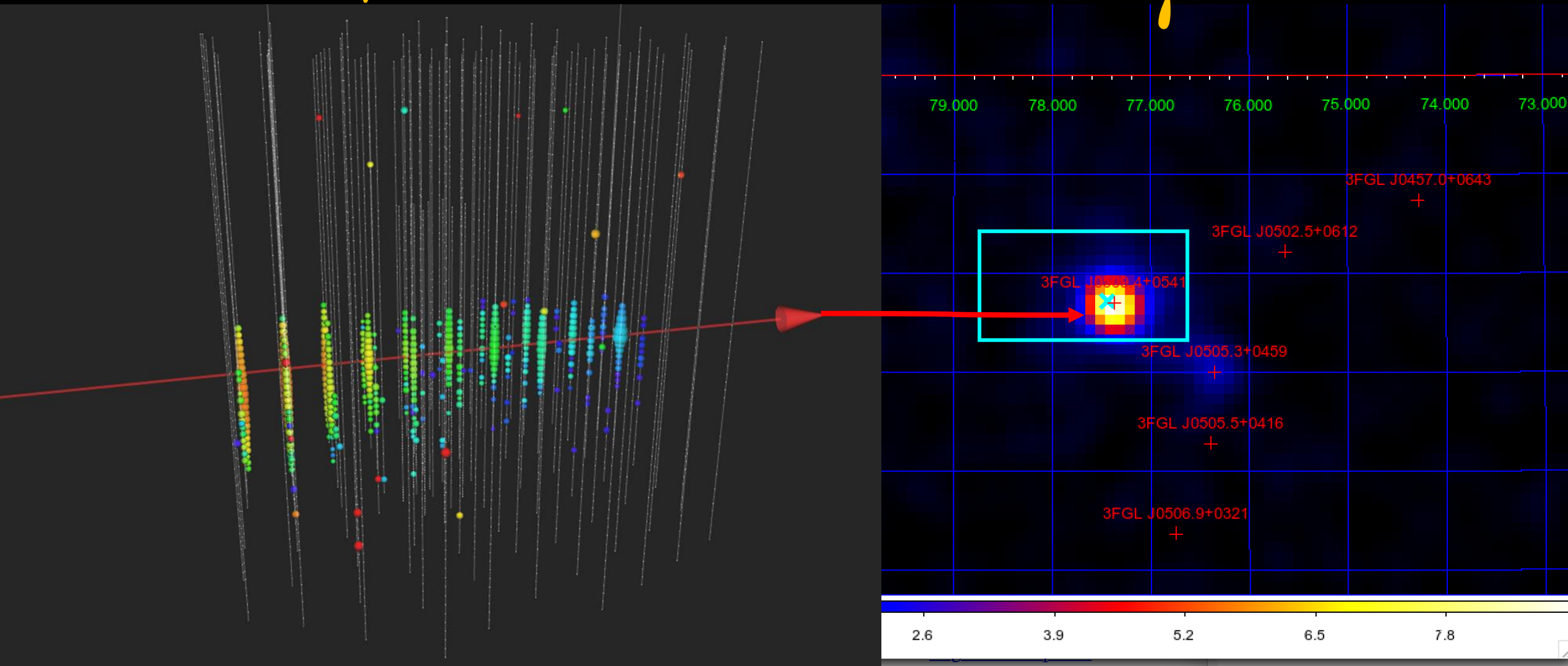
Summary of the follow-up observations

Observatory	Observation Time	Detection	Source	Comments
Fermi-LAT	Sept 15-27	✓	TXS 0506+056 / 3FGL J0509.4+0541 / 3FHL J0509.4+0542	Flaring >800 MeV
Swift-XRT	Sept 28 00:09-22:42 UT Sept 27 18:52 UT, 5 ks Sept 30 – Oct 7, 2 ks	✓	1SXPS J050925.9+054134	Spectral softening/evolution
Liverpool	Sept 28, 900 s	✓	TXS 0506+056 (PMN J0509+0541)	Typical BL Lac spectrum "Bluer when brighter"
ASAS-SN	-50 days	✓	TXS 0506+056	~0.5 mag in V-band
AGILE	Sept 18 12:00 UT + 3 days ±6 days	✓	< 1° from 3FGL J0509.4+0541	Excess > 100 MeV
H.E.S.S.	Sept 28 01:05 UT, 1 hr Sept 24 03:10 UT, 1 hr	×		Set 90% CL UL on ν fluence
HAWC	Sept 15 09:04 UT - Sept 19 14:41 UT Sept 21 08:41 UT to Sept 27 14:10 UT	×		At T0, this location was not in HAWC's fov
ANTARES	±1 hr and ±1 day of T0	×		Set 90% CL UL on ν fluence
INTEGRAL	±300 s of T0	×		Set 3σ UL
IC multi-day	Sept 15 00:00 UT – Sept 29 00:00 UT	×		
VERITRAS	Sept 28, 1 hr + Sept 28-39, 5.5 hrs	×		~200 GeV

And many more!

and this is what happened

ν γ



Fermi Blazar TXS 0506+56

Right on top of IceCube 170922A

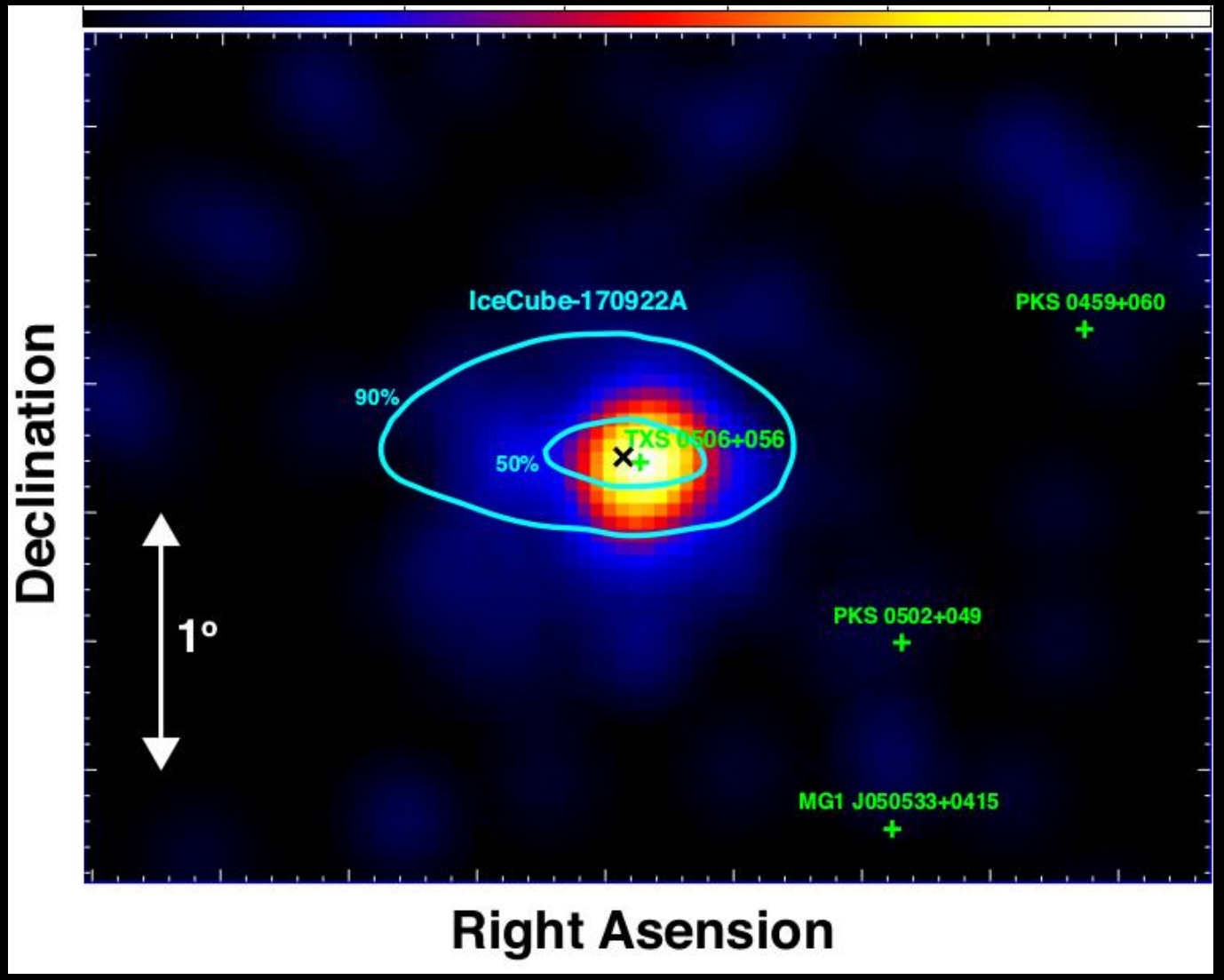
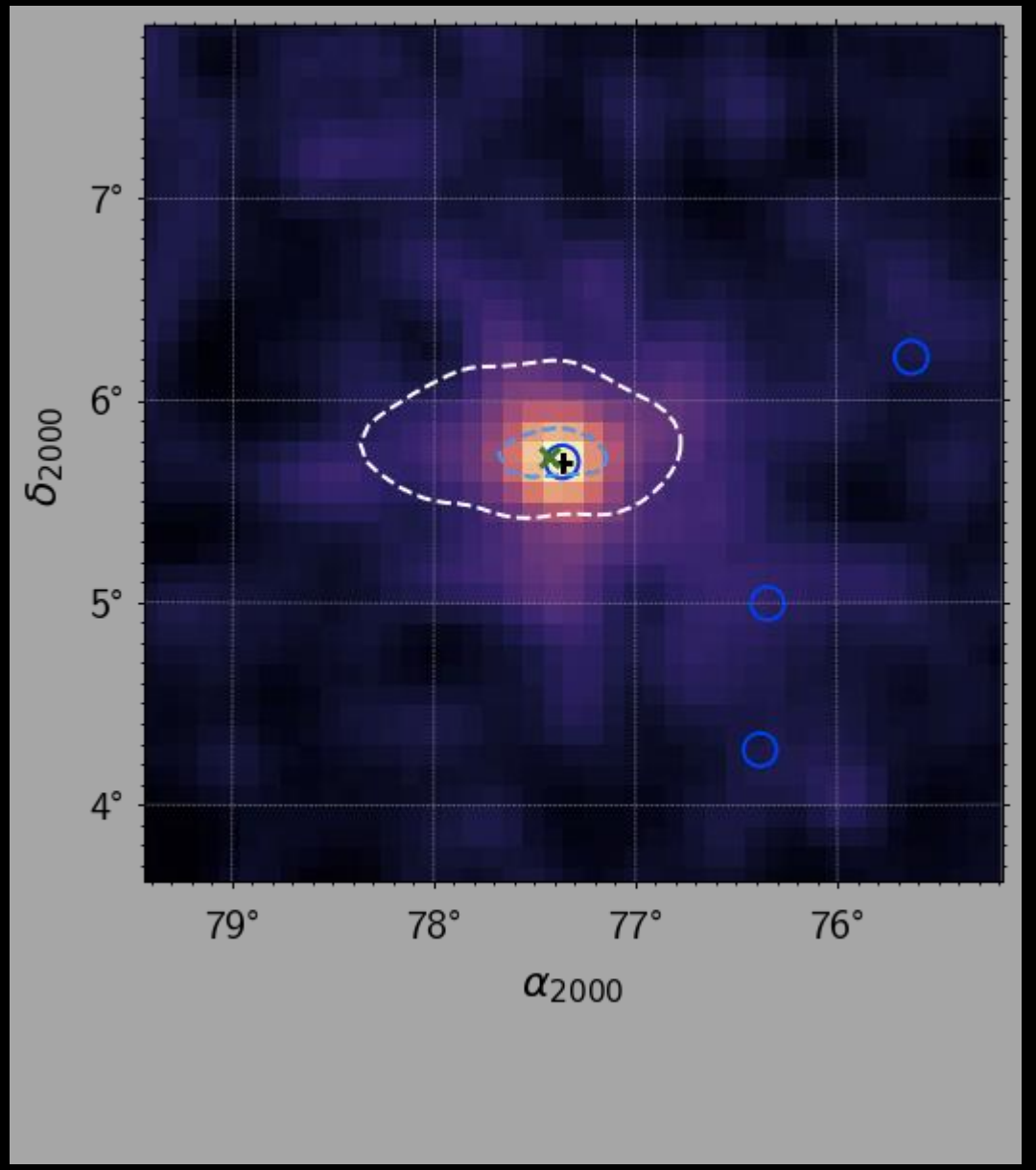


image made
by Masaaki Hayashida
(Fermi)

Fermi Blazar TXS 0506+56

Redshift unknown (0.15<z<1.6 (0.58))

categorized as ISP-BL Lac by Fermi
(but the classification does not mean
we understand the type of this blazar)



The source images in multi-wavelength bands

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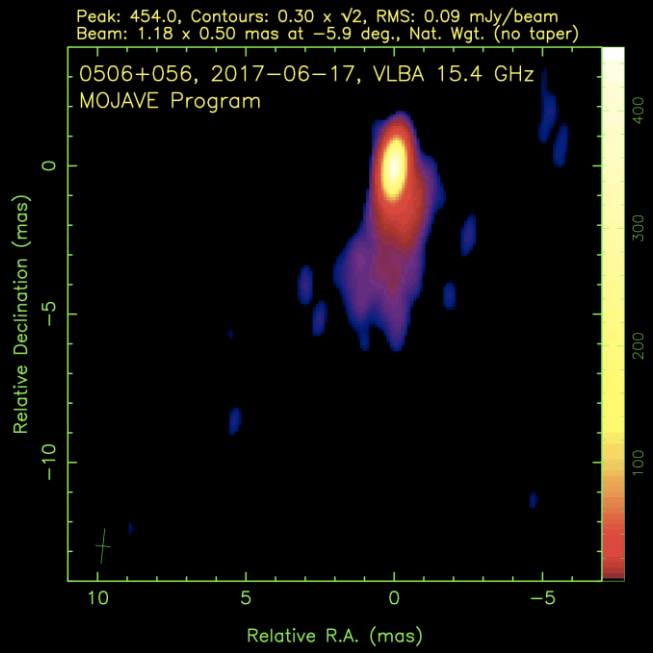
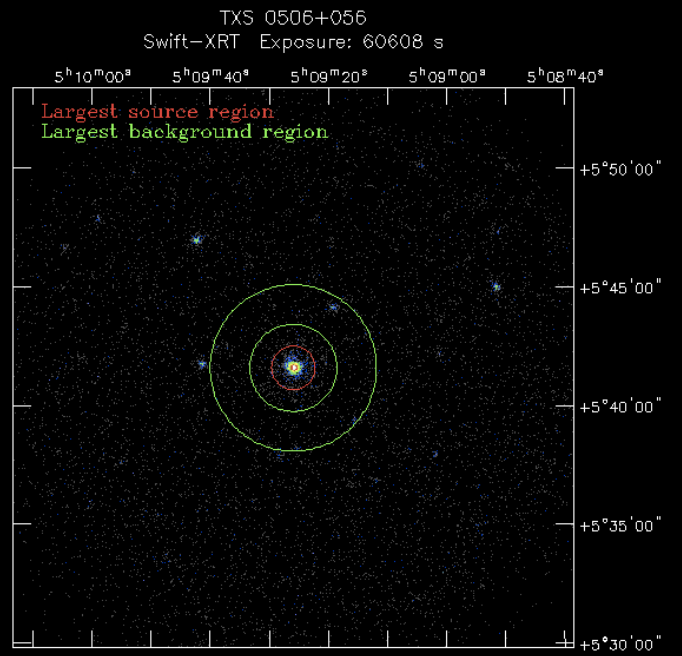
radio

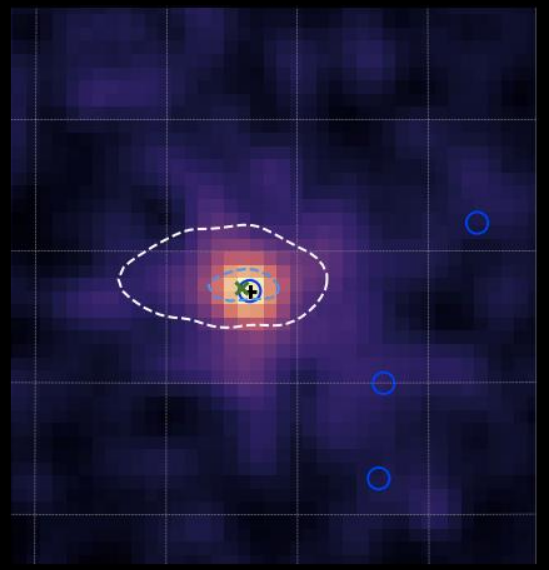


optical

x-ray



γ-ray



We are on the road to checkmate a cosmic ray origin

chess

Japanese “Shogi”

TeV PeV EeV

No Blazars as major sources

Blazar stacking analysis

THE CONTRIBUTION OF *FERMI*-2LAC BLAZARS TO DIFFUSE TEV–PEV NEUTRINO FLUX

M. G. Aartsen[1], K. Abraham[2], M. Ackermann[3], J. Adams[4], J. A. Aguilar[5], M. Ahlers[6], M. Ahrens[7], D. Altmann[8], K. Andeen[9], T. Anderson[10]

Show full author list

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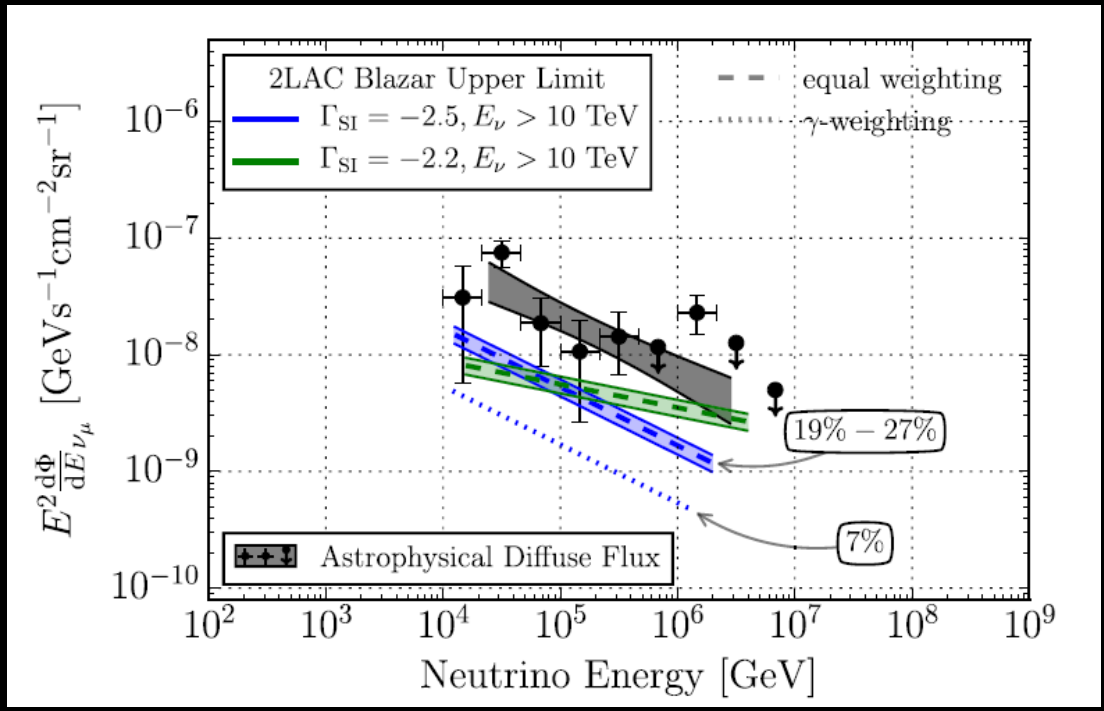
The Astrophysical Journal, Volume 835, Number 1

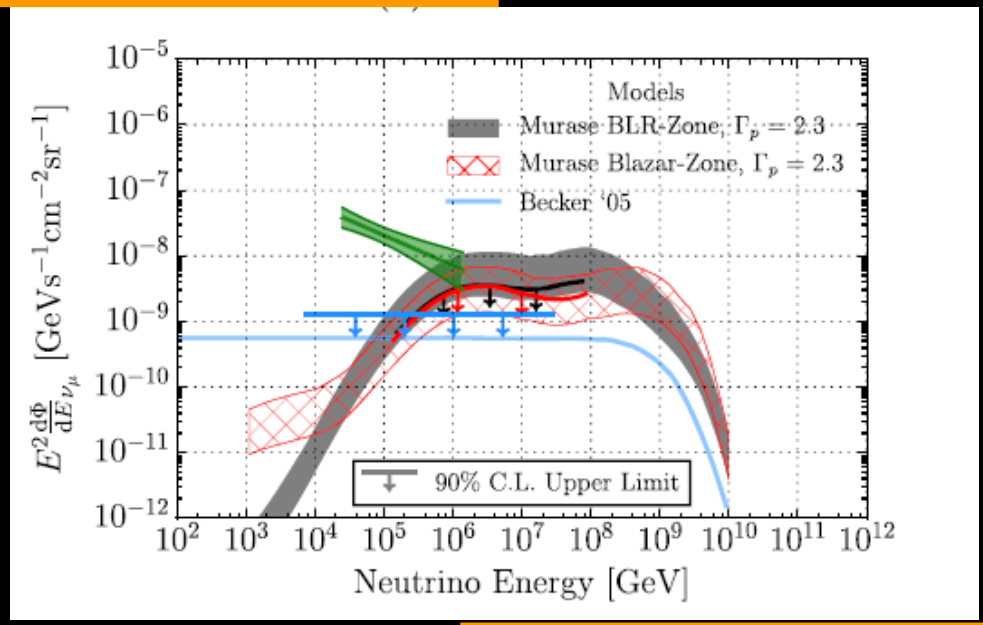


Search for a cumulative ν excess from 862 2LAC blazars

Model dependent constraints on Blazars

TeV PeV EeV

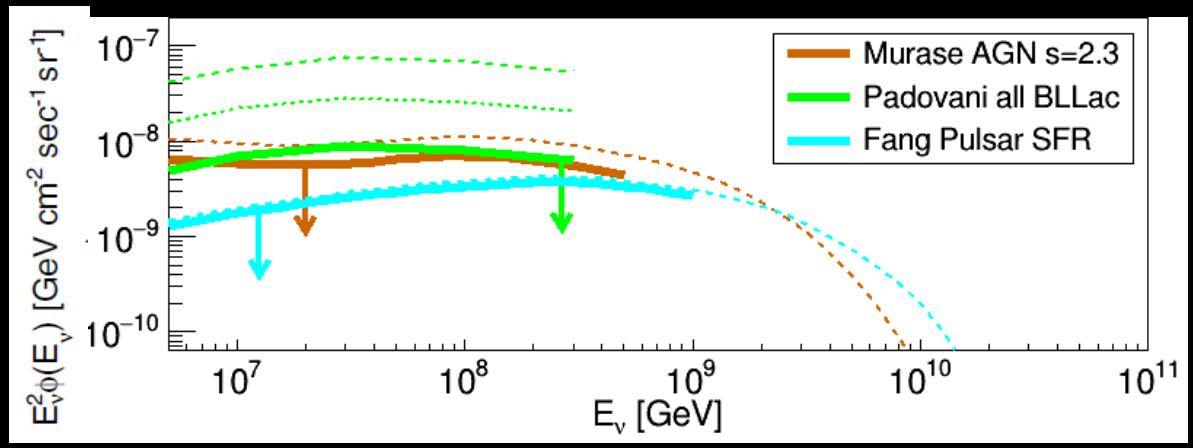
IceCube Collaboration
ApJ 835 no.1 45 (2017)



ν_μ only

TeV PeV EeV

IceCube Collaboration
PRL 117 241101 (2016)



all flavor sum

Global Ultra-High Energy (UHE) Diffuse fluxes

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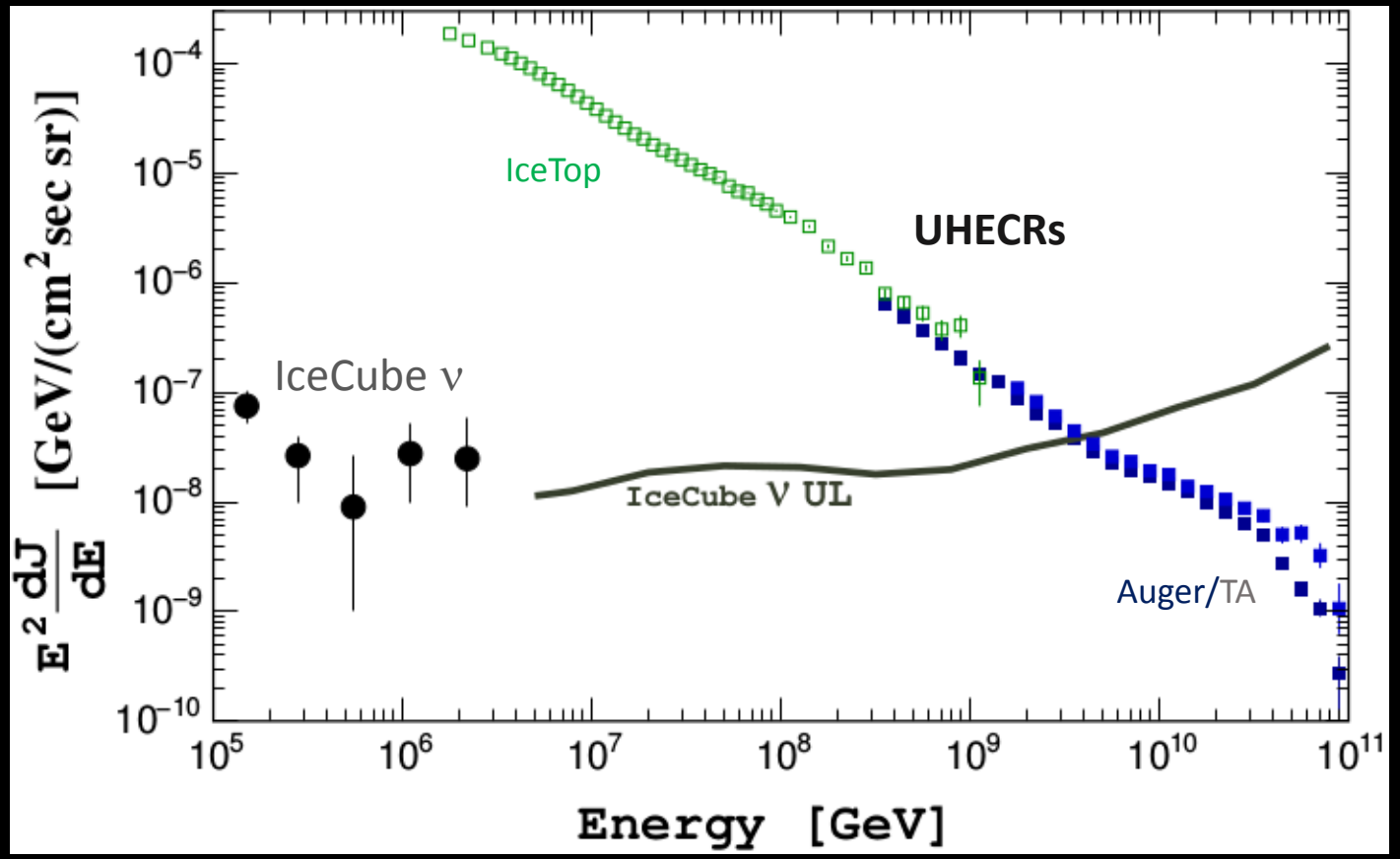
The (yet-unknown) UHE cosmic ray (UHECR) sources are also the origin of IceCube TeV ν?



Energy flux

IceCube ν ~ UHECRs

Is this just a coincidence?

UHECR-IceCube ν Unified Model

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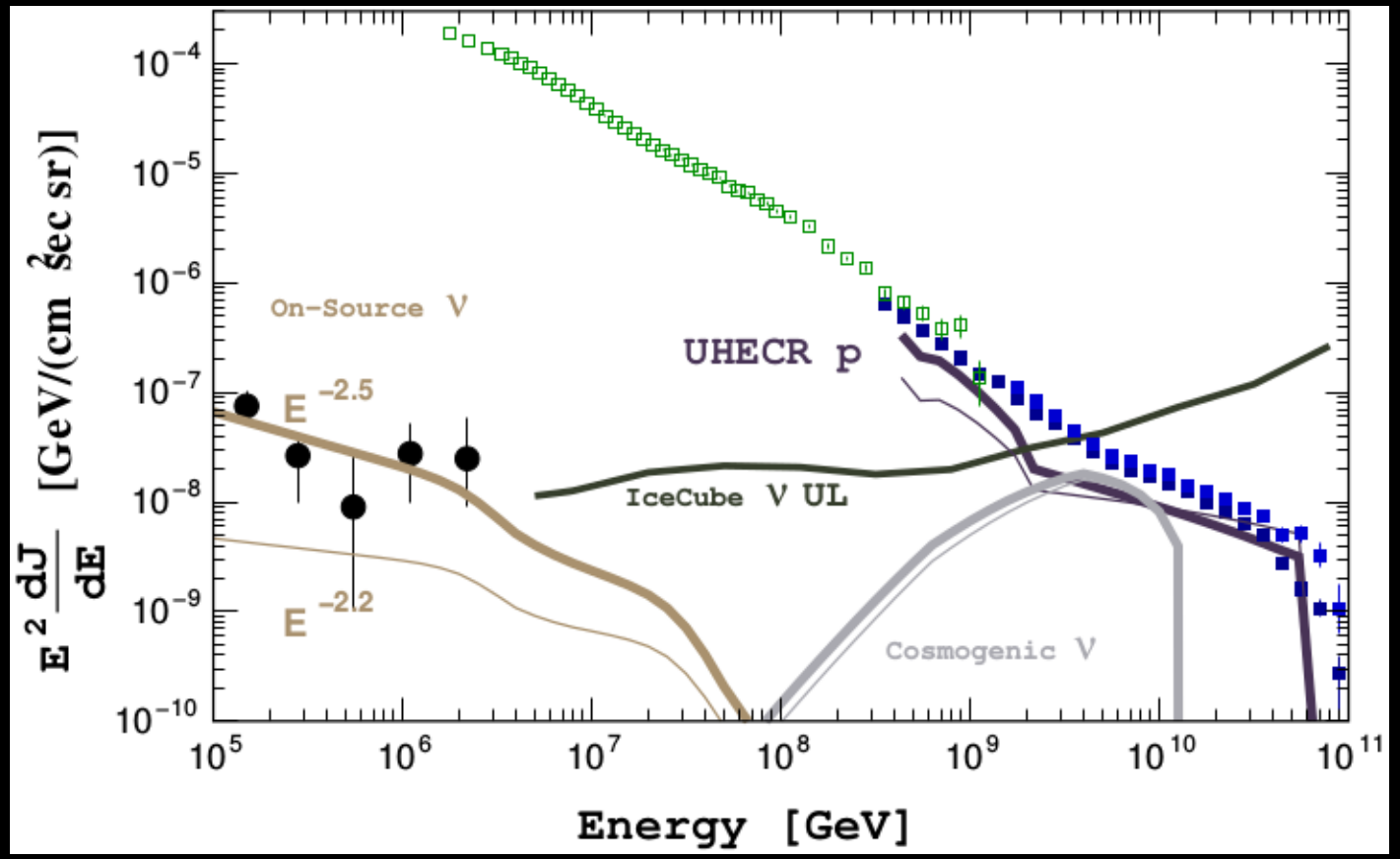
The (yet-unknown) UHECR sources are also the origin of IceCube TeV ν?



A genetic analytical model

- Optical Depth 0.1
- SFR-like evolution

Can be consistent with UHECR data and ν UL at higher energies

taking the formula from

Yoshida & Takami PRD 2014

Yoshida & Ishihara PRD 2012

UHECR-IceCube ν Unified Model

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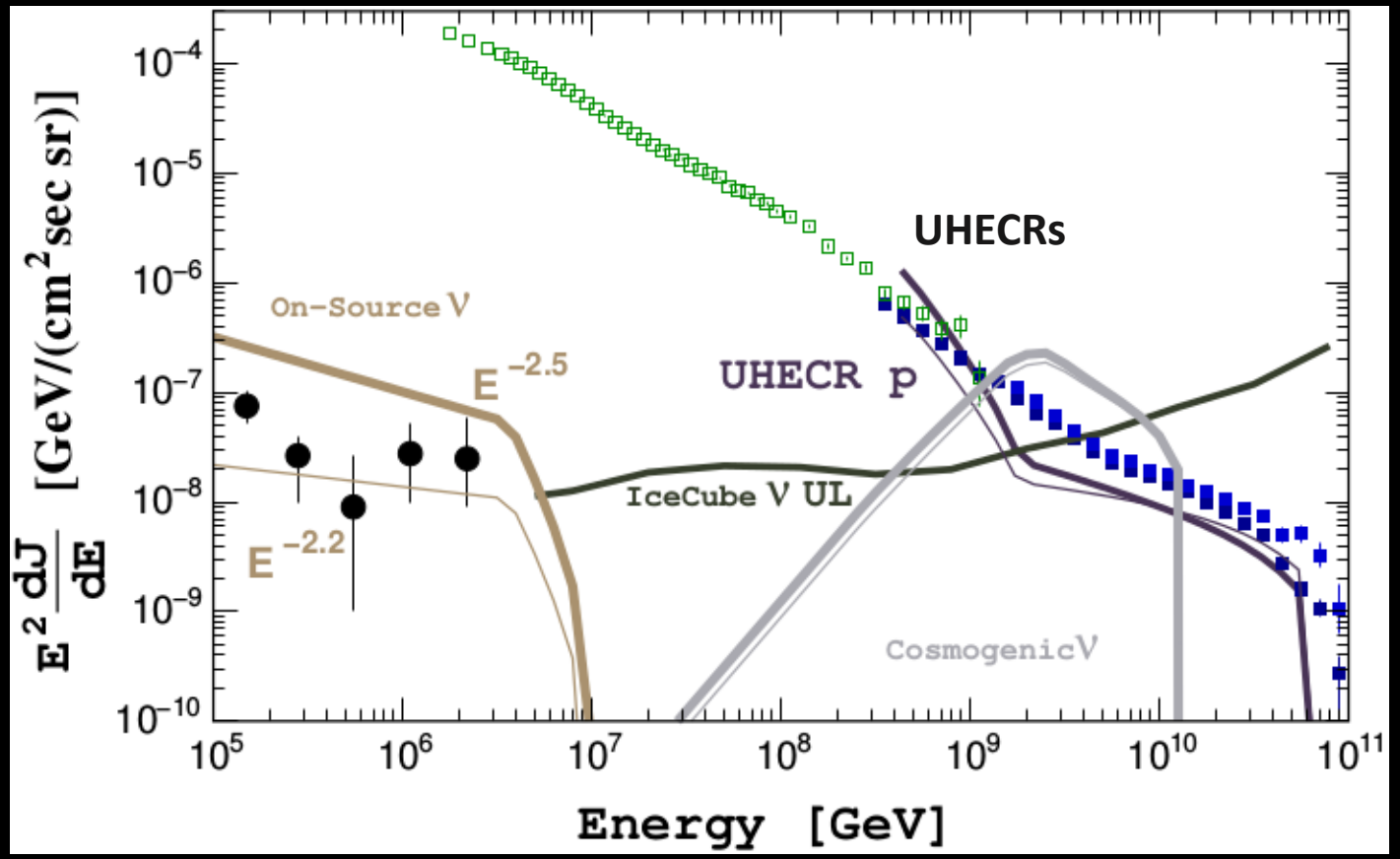
The (yet-unknown) UHECR sources are also the origin of IceCube TeV ν?



A genetic analytical model

- Optical Depth 0.1
- FSRQ-like evolution

Inconsistent with
ν UL at higher energies

taking the formula from

Yoshida & Takami PRD 2014

Yoshida & Ishihara PRD 2012

Tracing *history* of the particle emissions with ν flux

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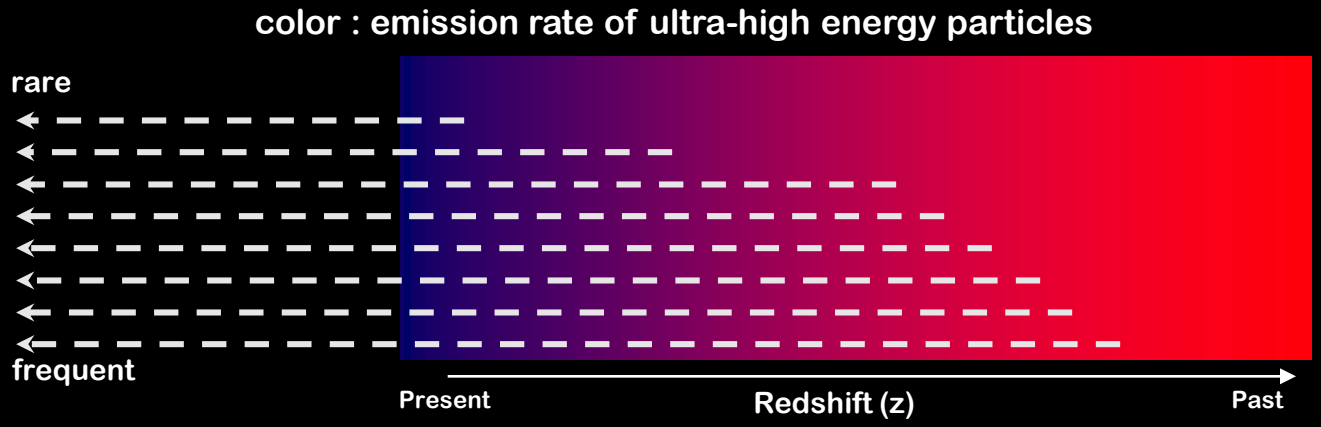
Intensity gets higher if the emission is more active in the past

because ν beams are penetrating over cosmological distances

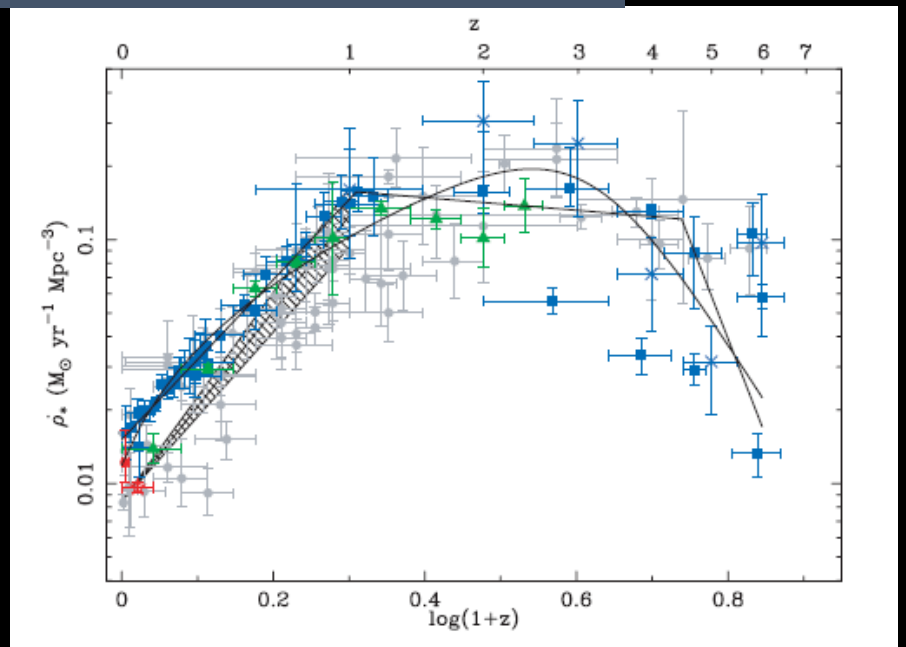


Hopkins and Beacom, Astrophys. J. **651** 142 (2006)

The cosmological evolution

Many indications that the past was more active.

Star formation rate→



The spectral emission rate

$\rho(z) \sim (1+z)^m$

m= 0 : No evolution

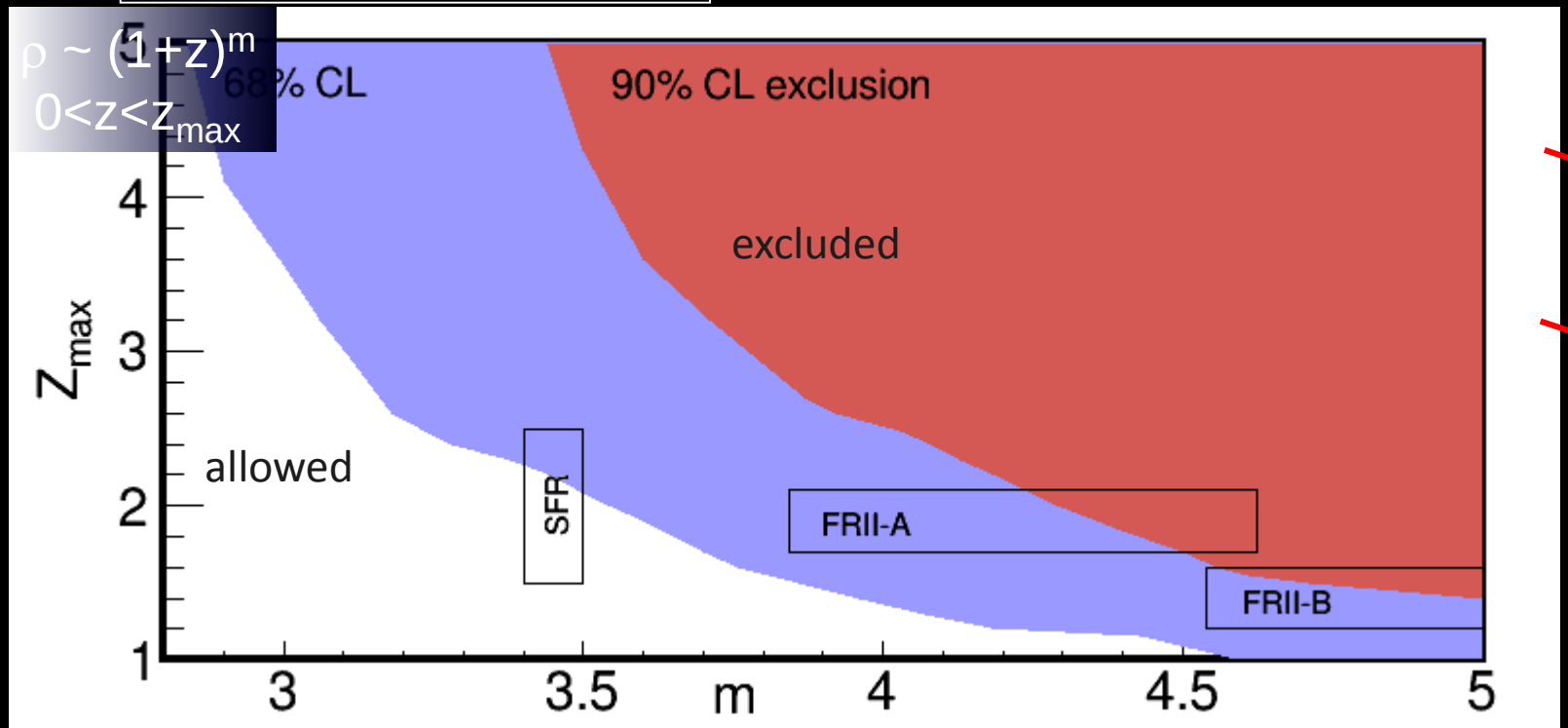
TeV PeV EeV

The Constraints on evolution (emission history) of UHE cosmic ray sources

IceCube collaboration
Phys.Rev.Lett.**117** 241101(2016)

UHECR source
is cosmologically
LESS evolved

Any sources with evolution
compatible or stronger than
star formation rate are disfavored



FRII (FSRQs)

GRBs

UHECR-IceCube ν Unified Model

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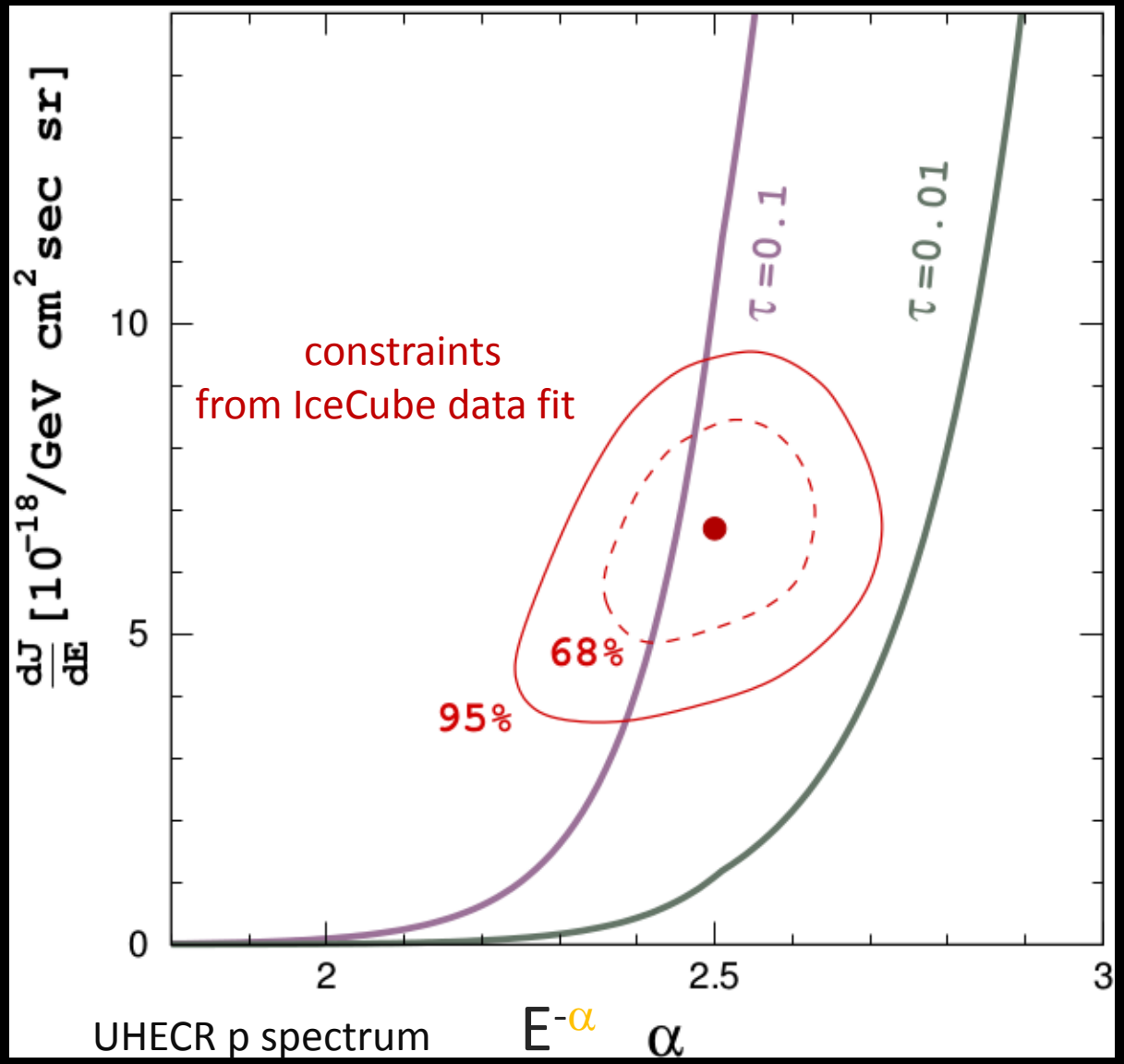

prediction from the unified model

There are not many astronomical objects to meet these criteria

Optical depth> 0.01 if soft spectrum

Optical depth~ 1 if hard spectrum

evolution weaker or compatible to SFR

UHECR-IceCube ν Unified Model

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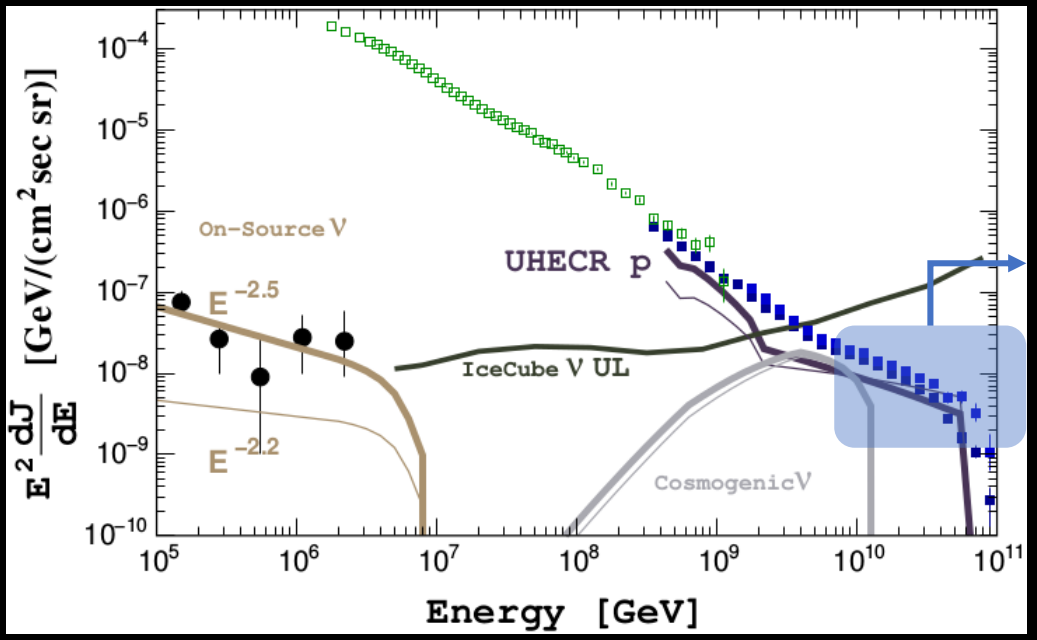
Energetics requirements



Source luminosity with SFR-like evolution

	$E^{-2.2}$	$E^{-2.5}$
E>10 EeV	~4×10^{44} erg/Mpc^3 yr	~2×10^{44} erg/Mpc^3 yr
extrapolate ↓		
E>10 PeV	~2×10^{48} erg/Mpc^3 yr	~6×10^{48} erg/Mpc^3 yr

c.f. GRB $L_\gamma \sim 10^{44}$ erg/Mpc^3 yr FSRQ $L_\gamma \sim 10^{46}$ erg/Mpc^3 yr

UHECR-IceCube ν Unified Model

genetic requirements to UHECR sources

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cosmological evolution compatible or weaker than star formation rate

IceCube bounds on GZK ν

Fermi extra-galactic diffuse γ-ray bound

optical depth $\tau >\sim 0.01$ if $E^{-2.6}$, $\tau>0.1$ if $E^{-2.3}$ or harder

IceCube TeV-PeV ν flux

c.f. GRB internal shock $\tau\sim0.1$, afterglow $O(10^{-3})$, BL Lac $O(10^{-6})$

Energy luminosity $O(10^{48})$ erg/Mpc^3 yr @ E>10 PeV

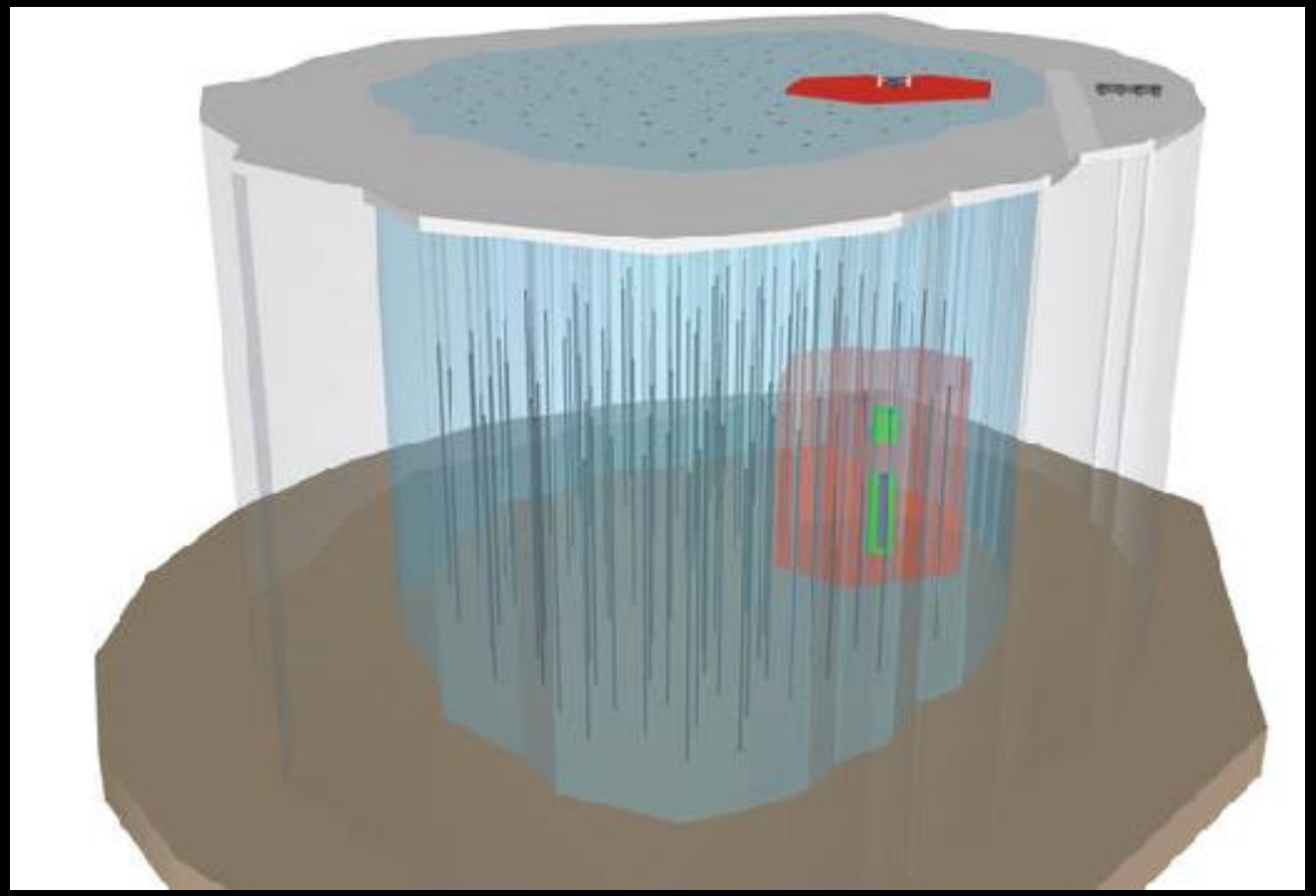
extrapolated from UHECR luminosity

BL Lac, GRB internal shocks, FSRQs all unlikely

A *major class* of (UHE) cosmic ray sources is yet unknown

The solution

IceCube-Gen2



IceCube-Gen2
the staging strategy

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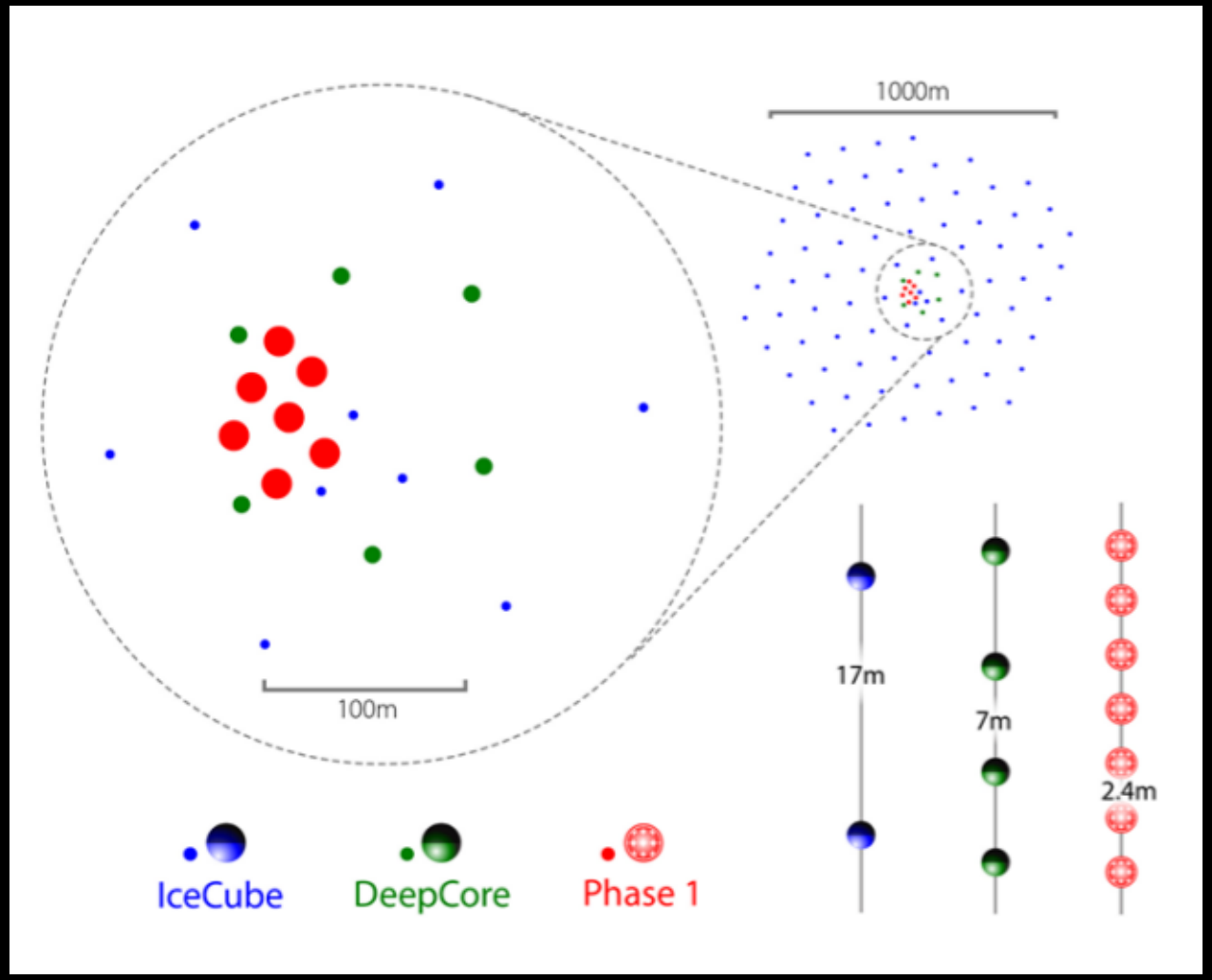
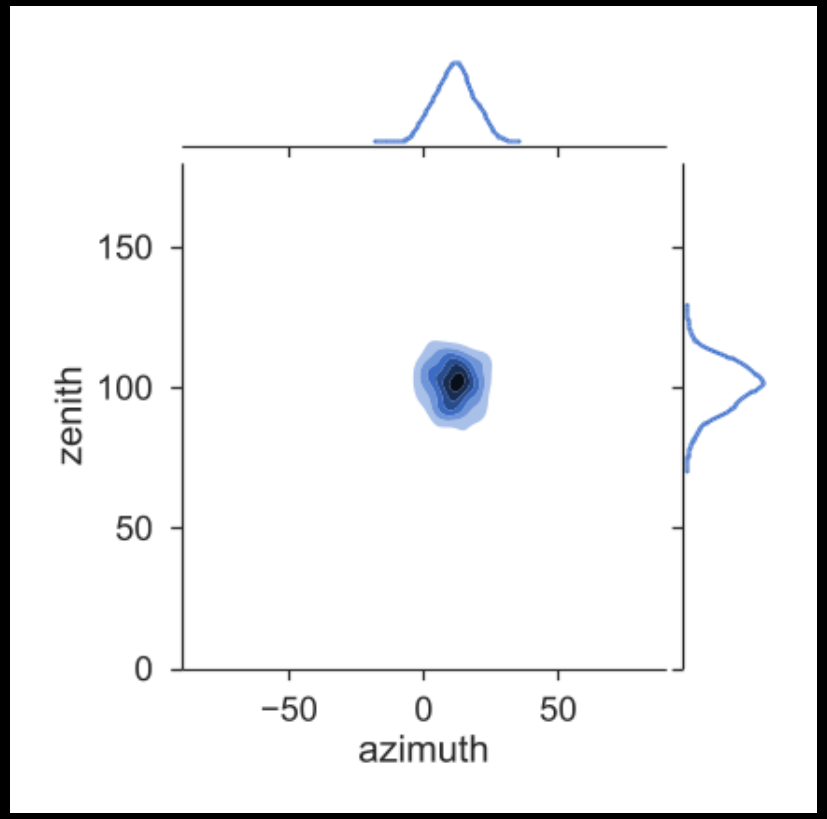
IceCube-Gen2 Phase1

towards precise measurements
of ice's optical characteristics



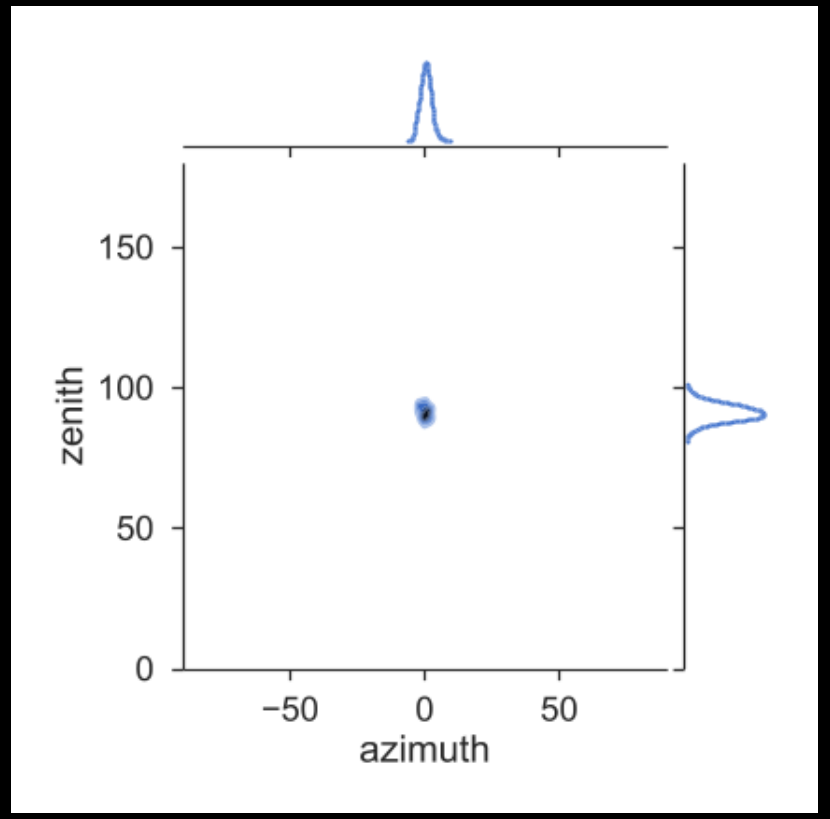
Improving the angular resolutions of ν-induced *shower* events for multi-messenger astronomy

The present – 15 degree error



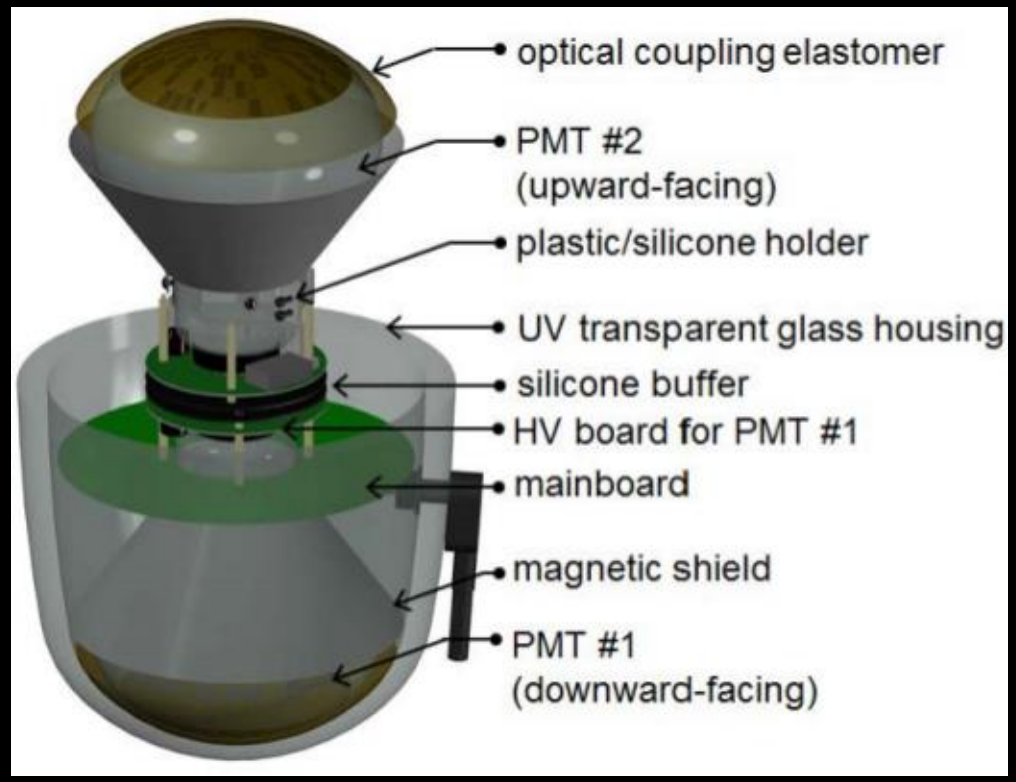
With better understandings of **C light scattering**

Yes we can! 4 degree error



D-Egg detectors map out Ice

D-Egg schematics



D-Egg prototypes

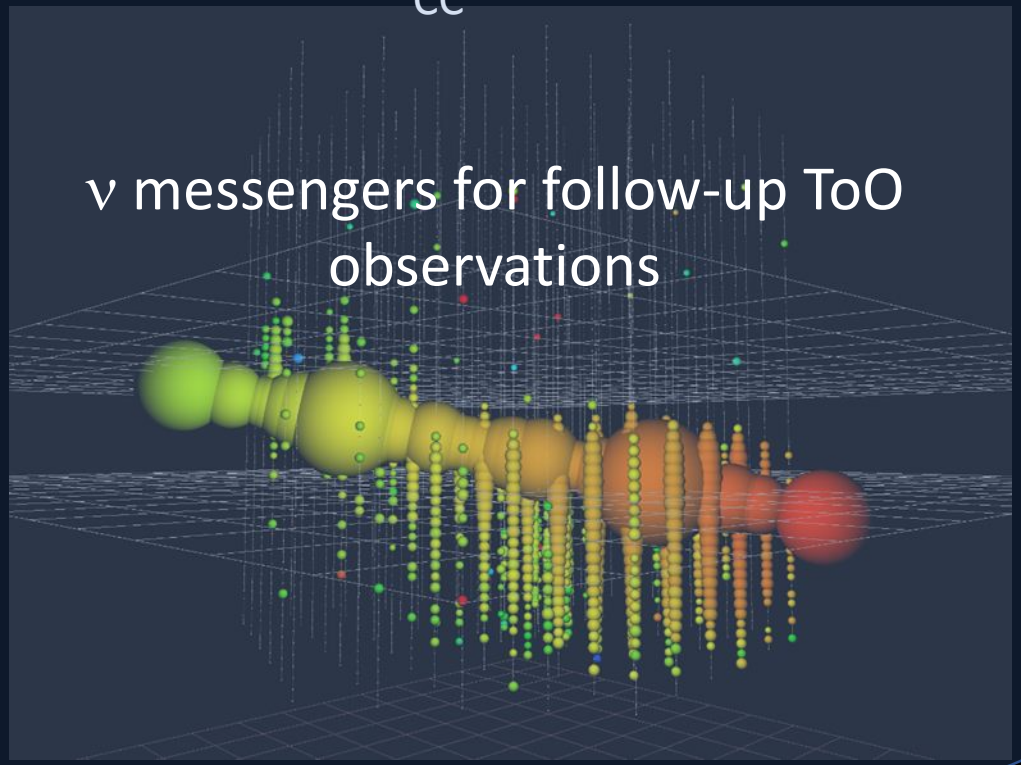
IceCube Event Topology

Track

Angular resolution
~ 0.5 degree

$\nu_\mu \xrightarrow[CC]{} \mu$

$\nu_\tau \xrightarrow[CC]{} \tau$ (only at ultra-high energies)



ν messengers for follow-up ToO observations

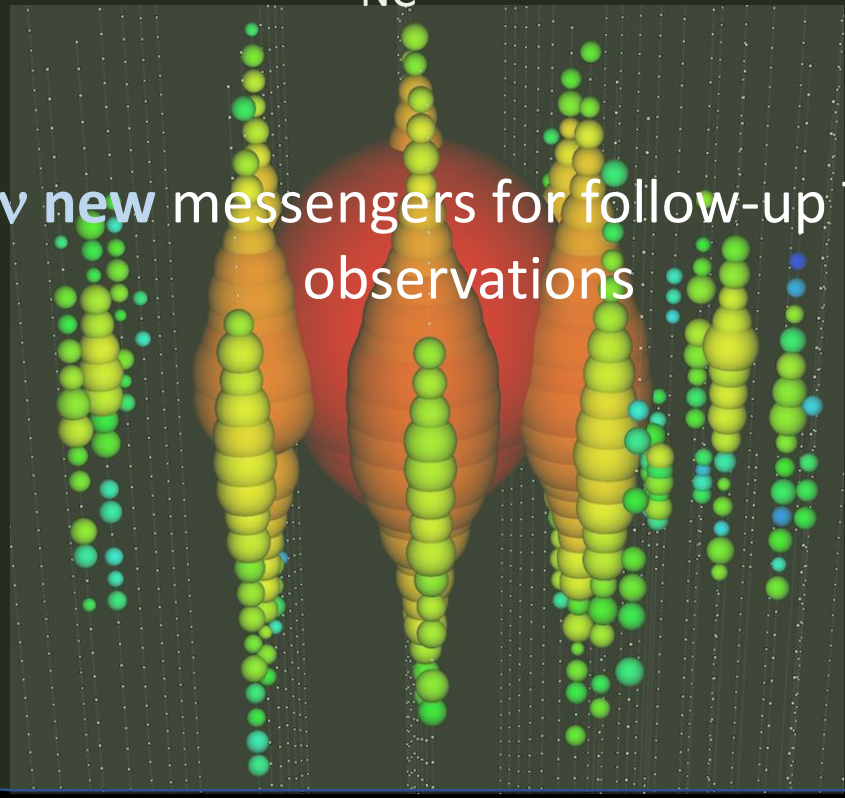
Cascade (shower)

Angular resolution
~ 4 degree

$\nu_e \xrightarrow[CC]{} e + X$

$\nu_x \xrightarrow[NC]{} x + X$

x=e, μ, τ



ν **new** messengers for follow-up ToO observations