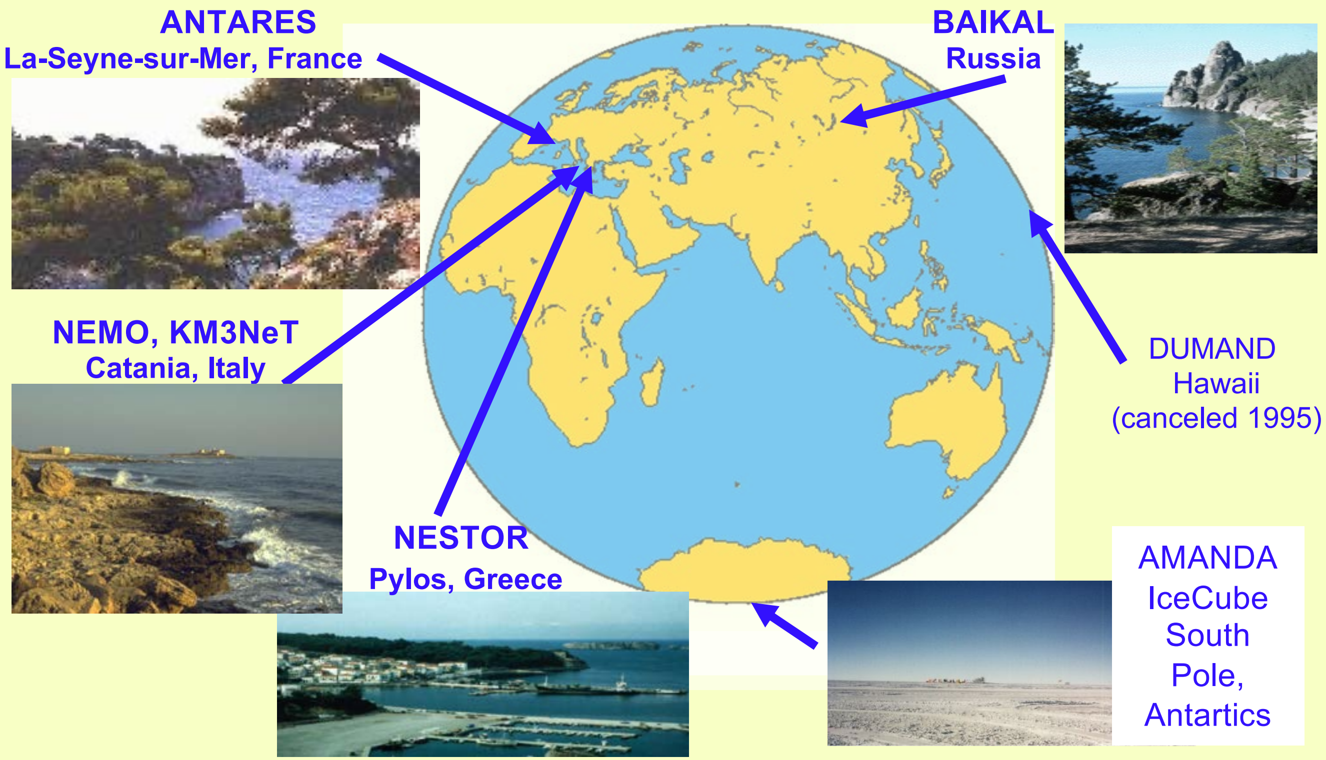
Lessons 17 and 18

- **First results from High Energy Astrophysical Neutrino Telescope (like BAIKAL, AMANDA, ANTARES, IceCube, KM3NeT…)**
  - **Measured cosmic diffuse neutrino fluxes: comparison with diffuse gamma fluxes (by Fermi)**
  - **Examples of multimessengers searches (GRBs, Pulsars, μQuasars, Gravitational waves, …)**
  - **A possible point-like neutrino source identified by multimessenger search**

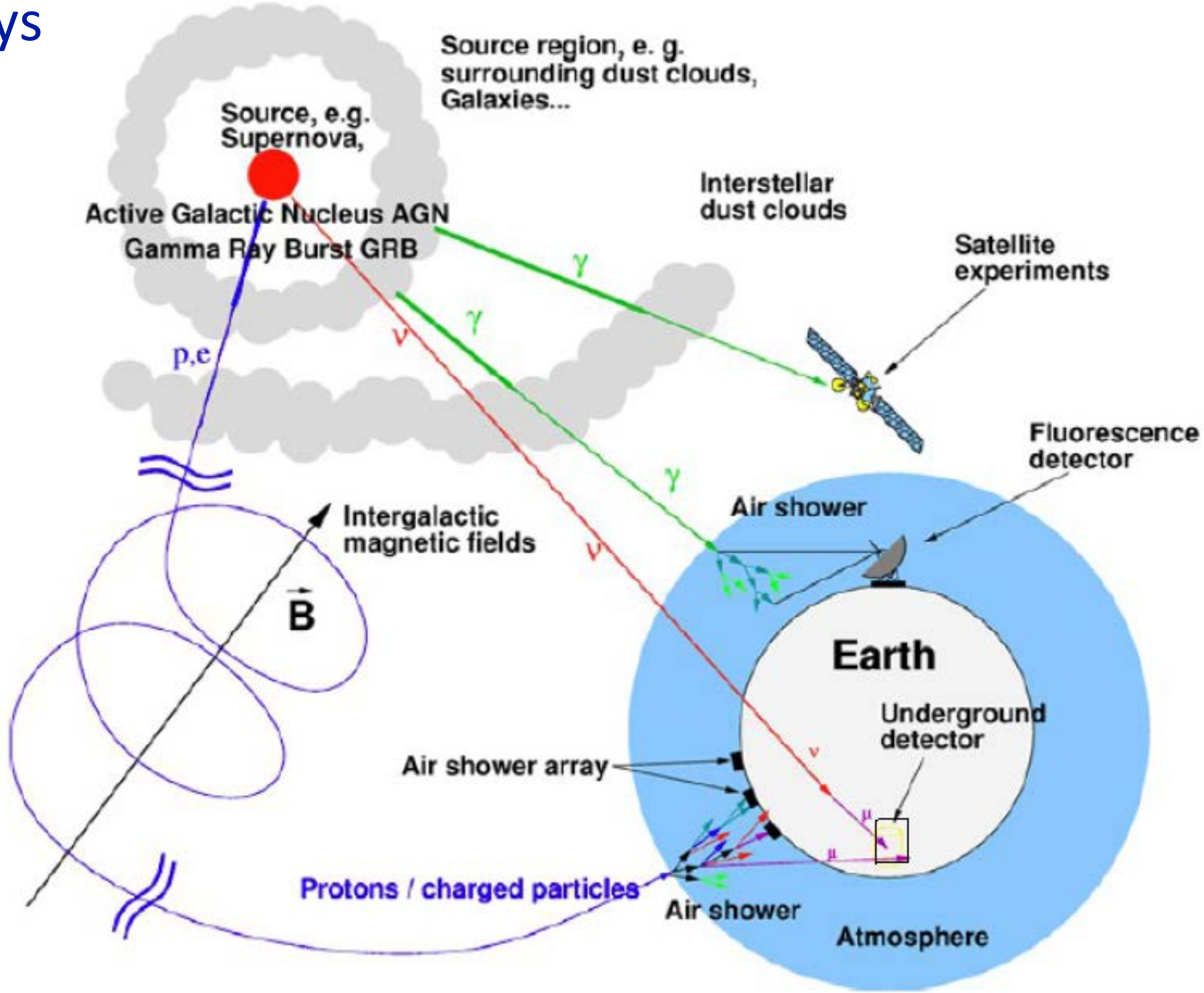
Present Cherenkov Neutrino Telescopes



Multi-messenger astronomy

- Cosmic rays
- Photons
- Neutrinos

Only ν propagate freely through the cosmos



Implications of astrophysical neutrinos

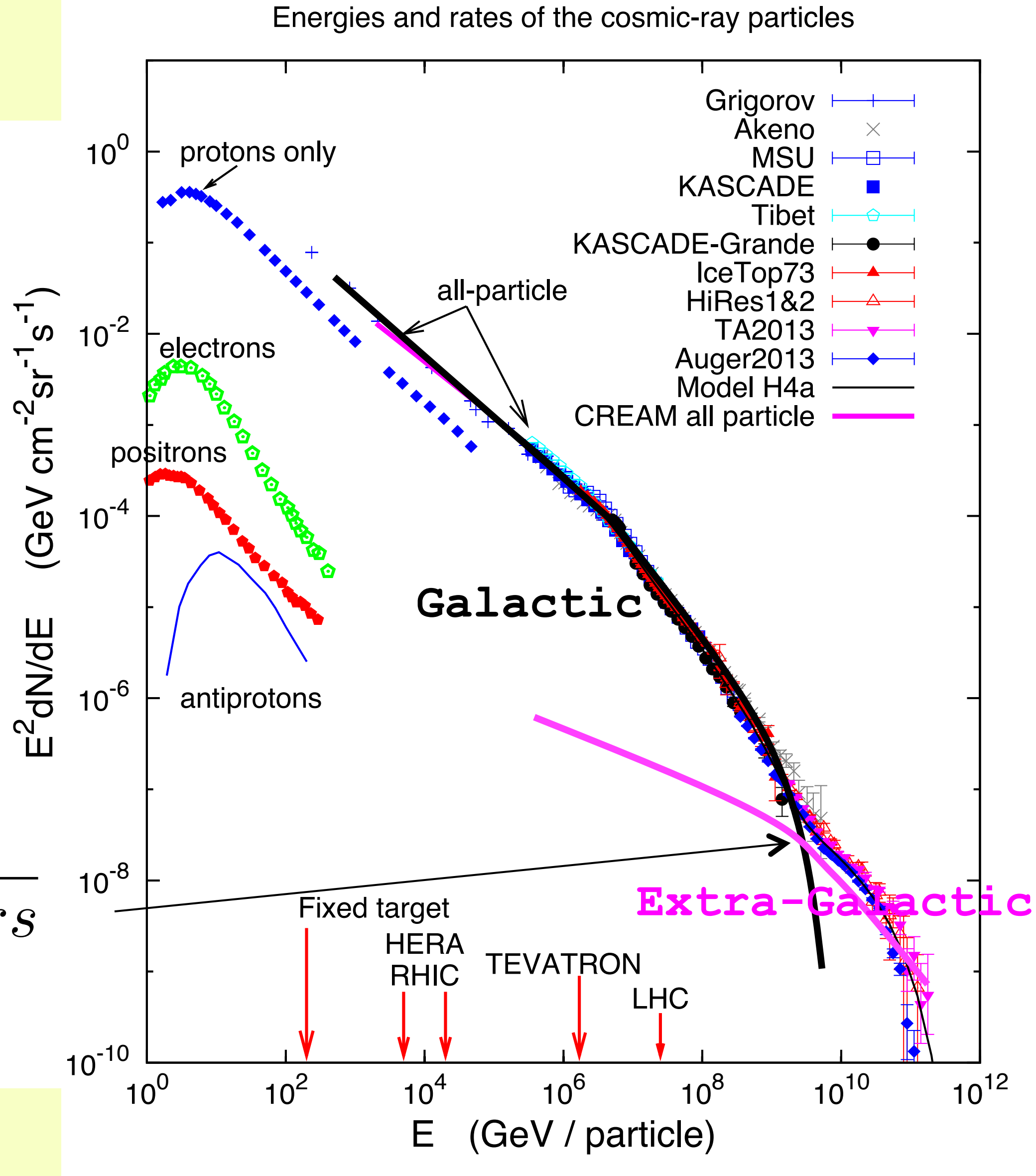
- Observations of γ–rays are often ambiguous
  – *Electrons radiate efficiently and usually explain the observations*
  – *Signatures of hadronic origin of photons are difficult to identify and prove*
- Neutrinos have a unique implication
  – *Observation of high energy extraterrestrial ν requires a hadronic origin*
  – *Neutrinos can emerge from deep inside a compact source without degradation by electromagnetic cascading*

Cosmic Rays …

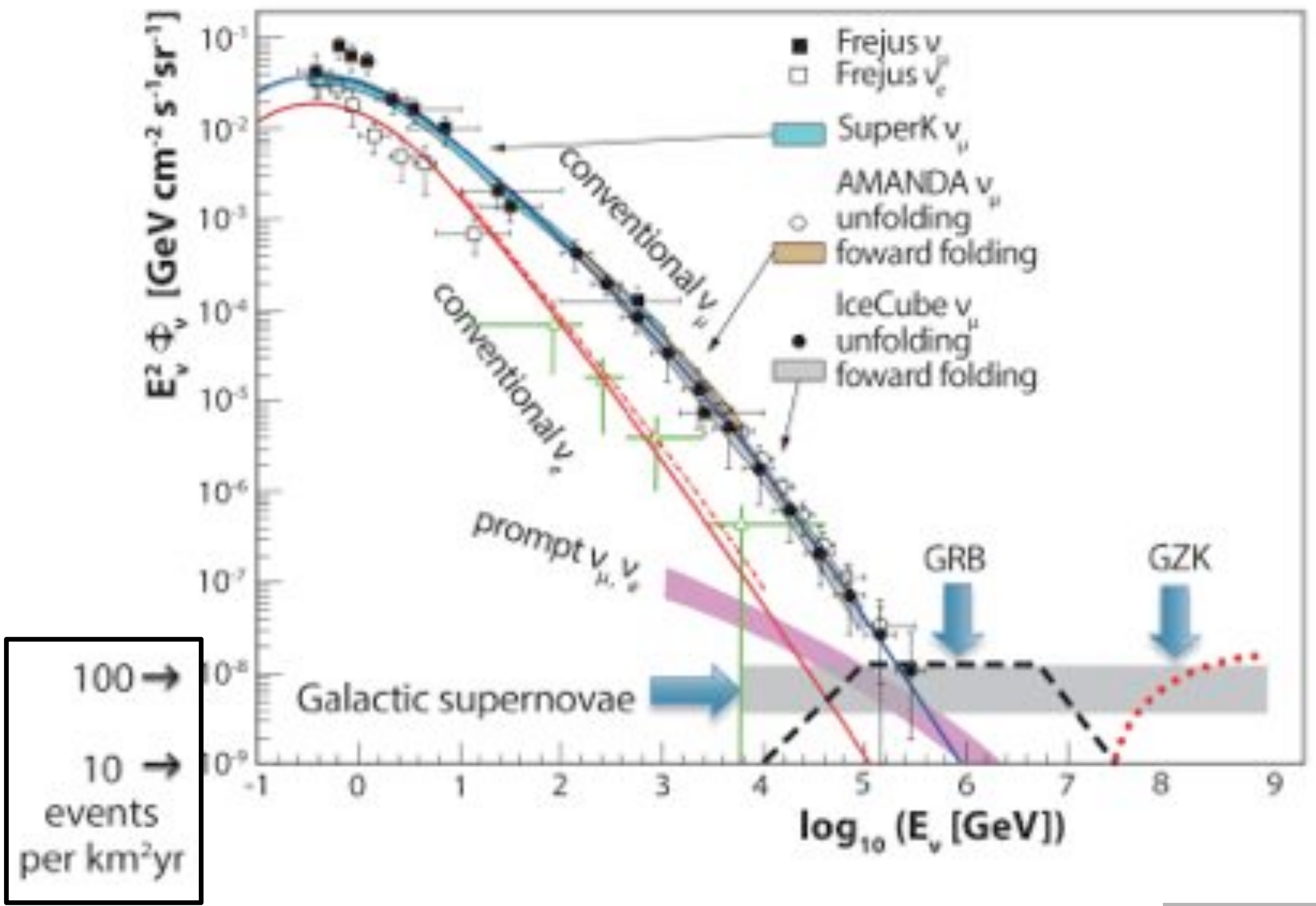
- Energy content of CR determines possible sources of neutrinos
- Extra-galactic origin is likely
- Location of transition from galactic to extra-galactic affects energy estimate

$$E\frac{dN}{d\ln E} \approx 3 \times 10^{-8} \frac{\text{GeV}}{cm^2 srs}$$

at 10^{10} GeV (10^{19} eV)



… and neutrinos



$$\Phi_\nu \equiv \frac{dN}{dE} \approx \frac{1}{E^2}$$

A 3-D cosmic-ray detector:

Two different kinds of events

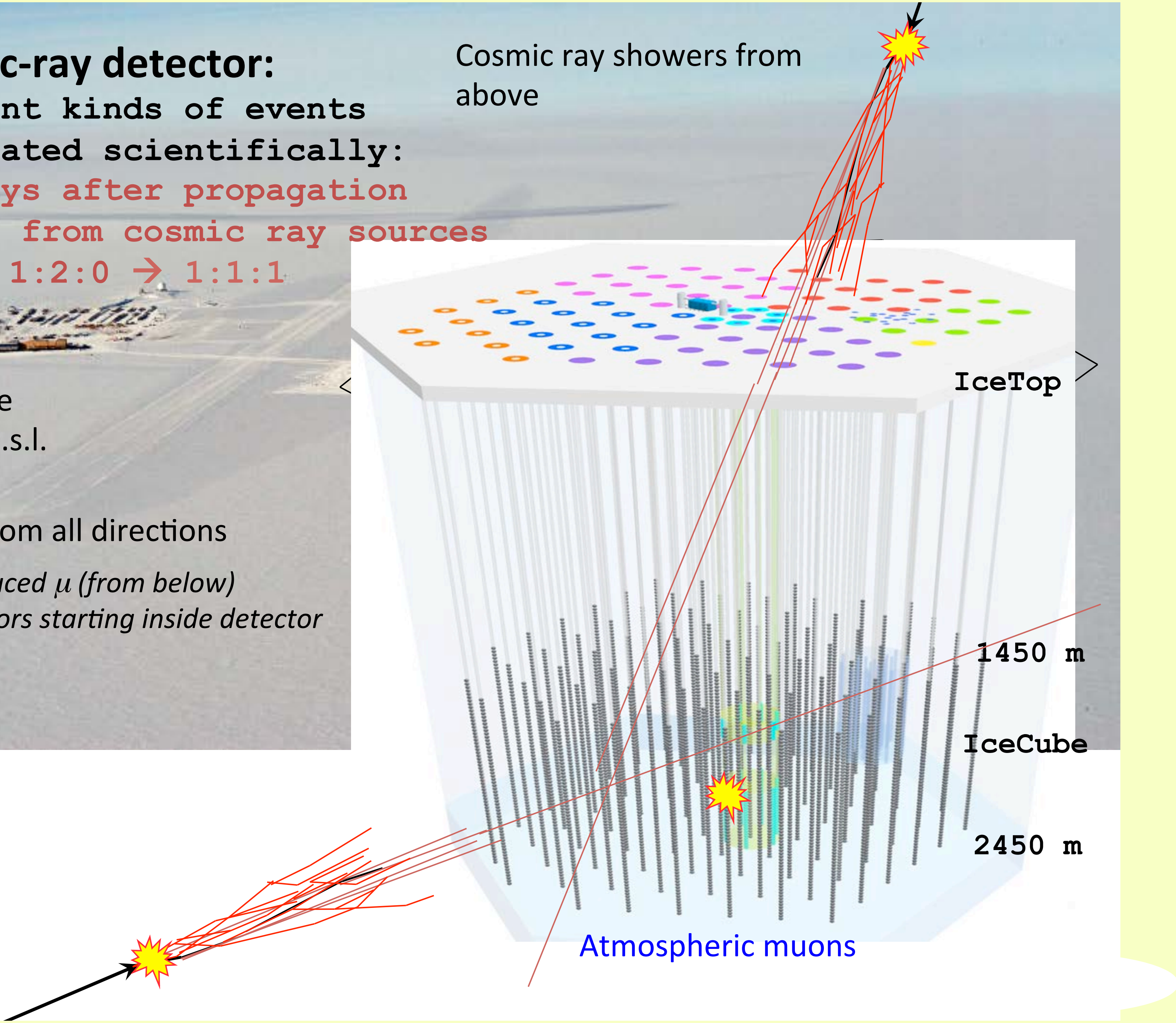
Closely related scientifically:

- Cosmic rays after propagation
- Neutrinos from cosmic ray sources
- $\nu_e:\nu_\mu:\nu_\tau$ = 1:2:0 → 1:1:1

South Pole
2835 m.a.s.l.

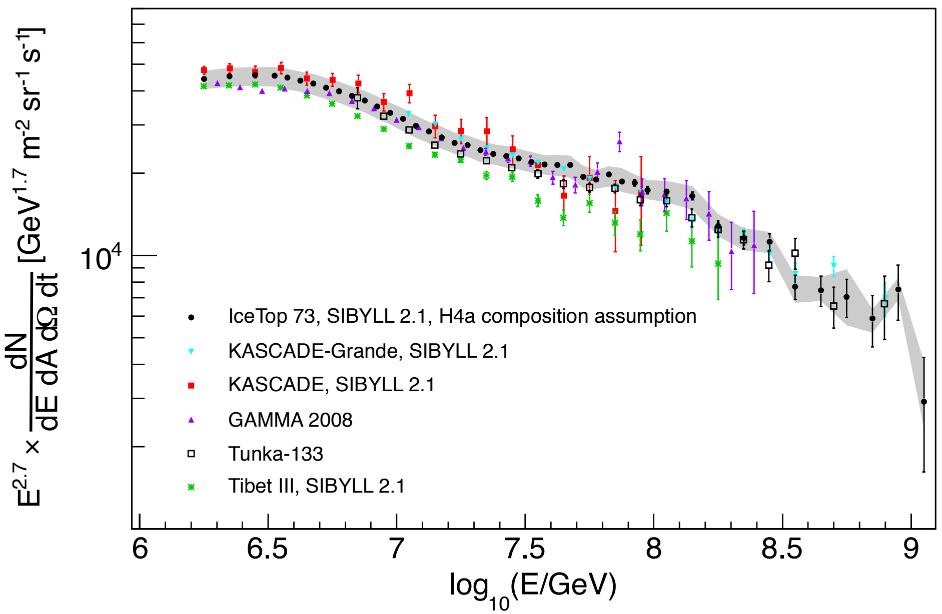
Neutrinos from all directions

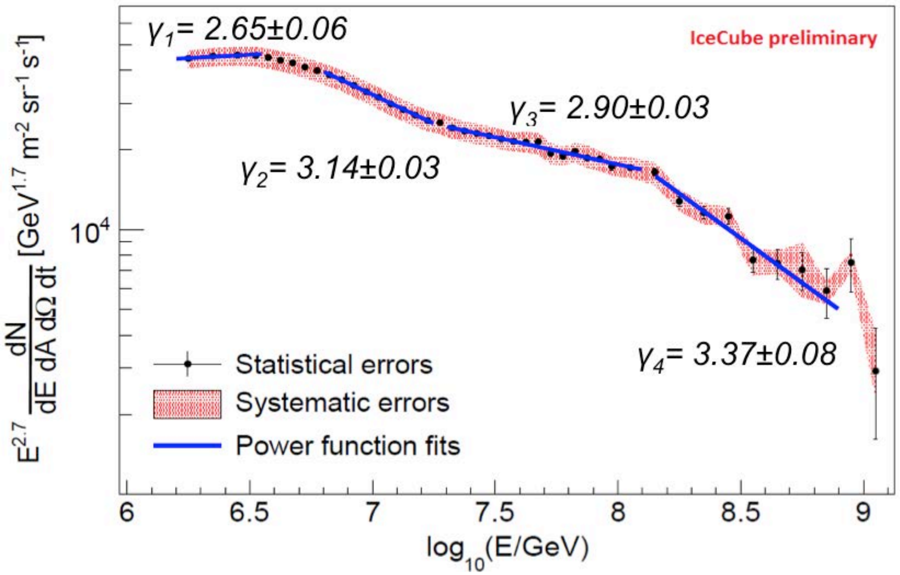
- *ν_μ-induced μ (from below)*
- *all flavors starting inside detector*



Primary spectrum from IceTop

Phys. Rev. D 88, 042004 (2013).





- $10^6 - 10^8$ GeV sets normalization for PeV ν
  - Directly for background atmospheric ν
  - At sources for astrophysical ν
- $10^7 - 10^9$ GeV: transition from galactic to extragalactic
  - Model dependent

Upward neutrinos in IceCube

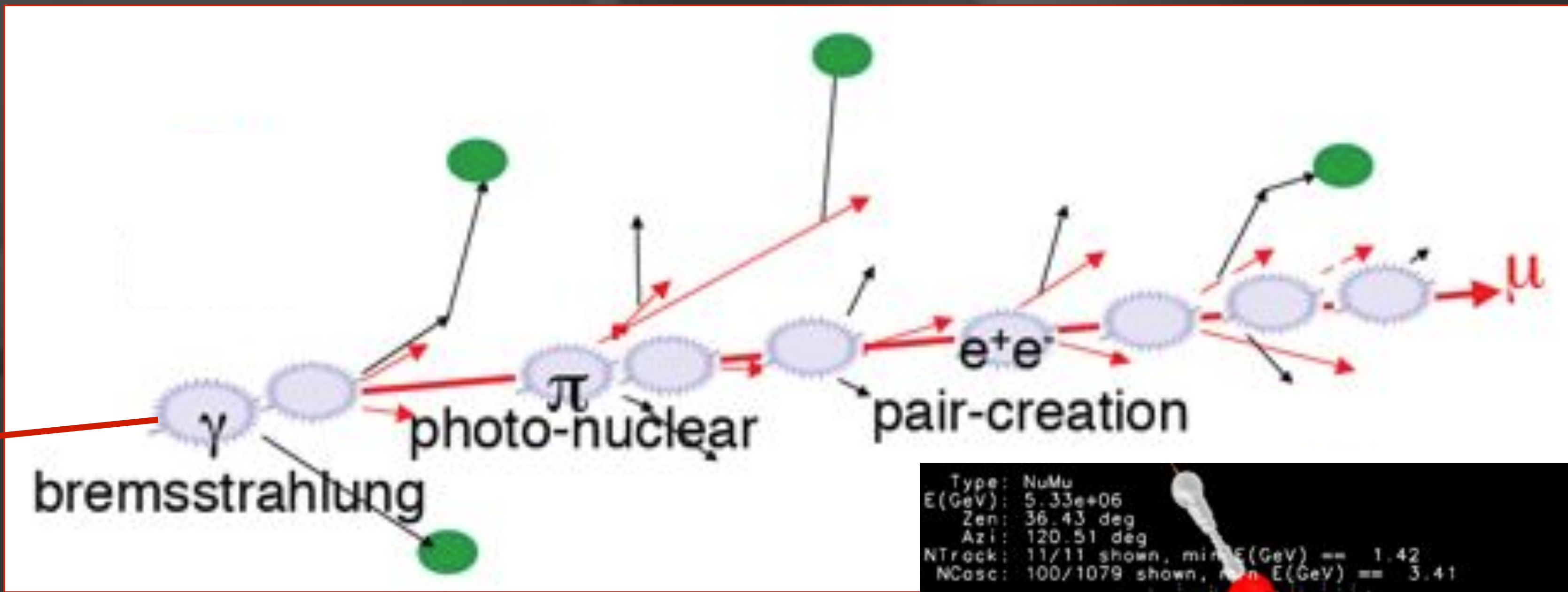
- Must have low enough energy to get through the Earth (depends on direction)
- Must produce a signal in the detector
  a. ν_μ – induced muon from neutrino interaction in the rock or ice below the detector (highest rate)
  b. Neutrino of any flavor interacts inside detector

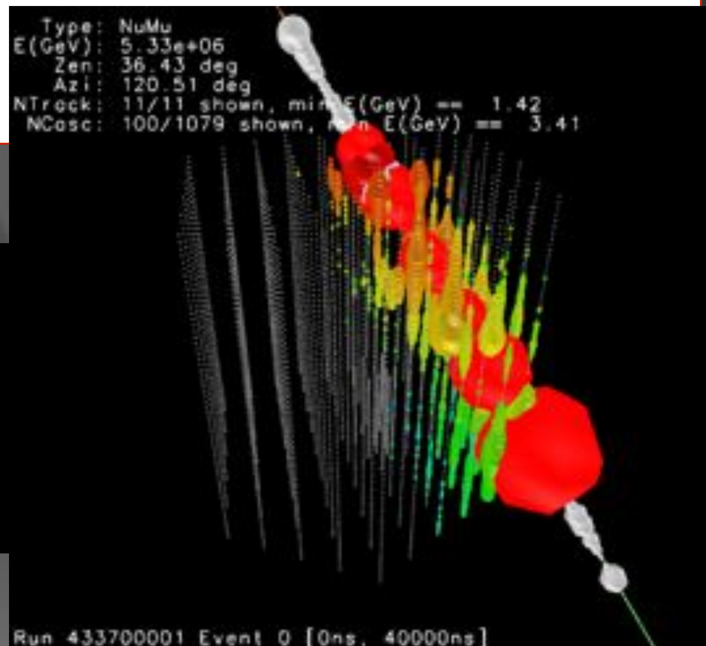
$$1\,\mathrm{km\,ice} = 0.91 \cdot 6 \times 10^{23} \cdot 10^{5} = 5 \cdot 10^{28}\,\mathrm{nucleons/cm}^2$$

$$\sigma_\nu \approx 2.6 \cdot 10^{-34}\,\mathrm{cm}^2 \text{ at } 10^5\,\mathrm{GeV}$$

Product ≈ 10^{-5} is fraction of ν of this energy that interact in detector

energy measurement (> 1 TeV)

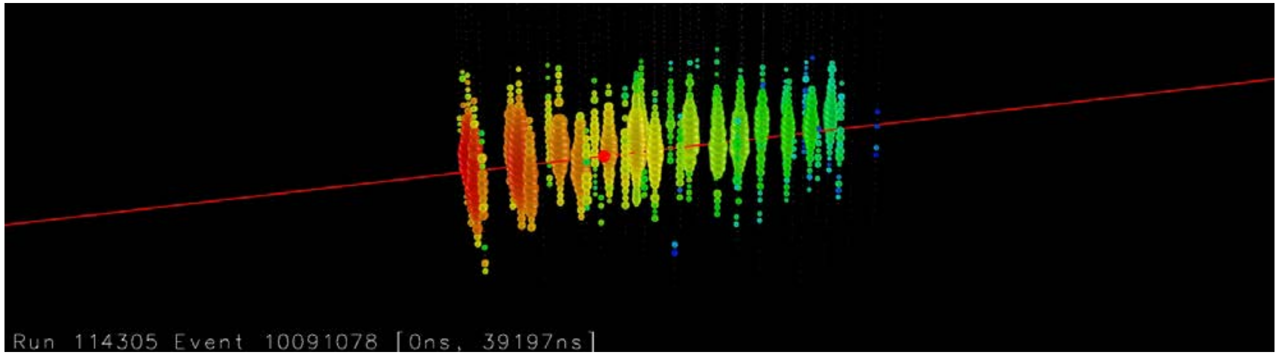




convert the amount of light emitted to measurement of the muon energy (number of optical modules, number of photons, dE/dx, …)

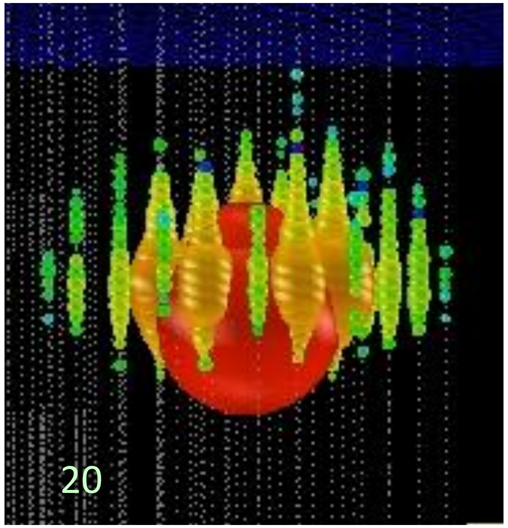
Neutrino Events

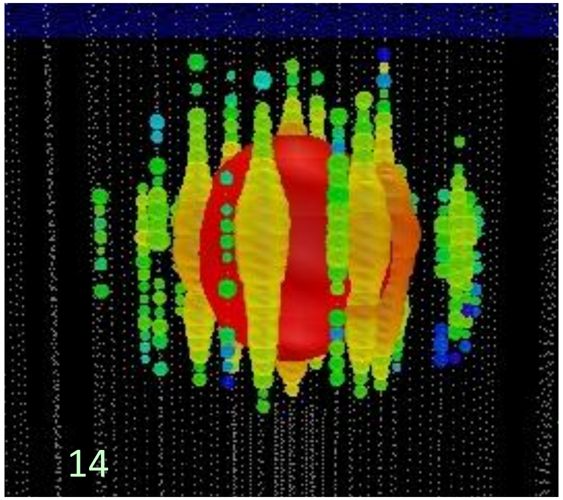
ν-induced μ entering from below



PeV = 10^6 GeV = 10^{15} eV. These are the highest energy neutrinos ever detected!

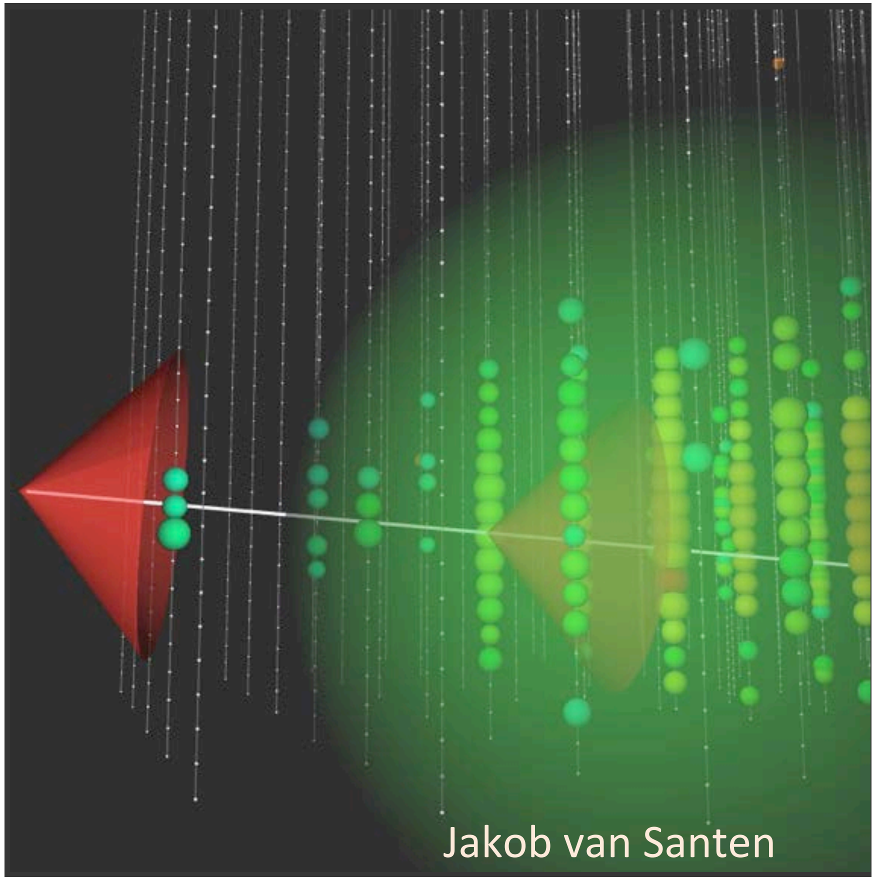
Two PeV cascades starting inside the detector
*PRL **111**, 021103 (2013)*
Large energy
→ atmospheric origin unlikely





Starting $\nu_\mu \rightarrow \mu$ events

- Event starts in fiducial volume
- Light from vertex spreads spherically with v=c/1.31
- Muon moves ahead with v = c
- ID confirmation by timing



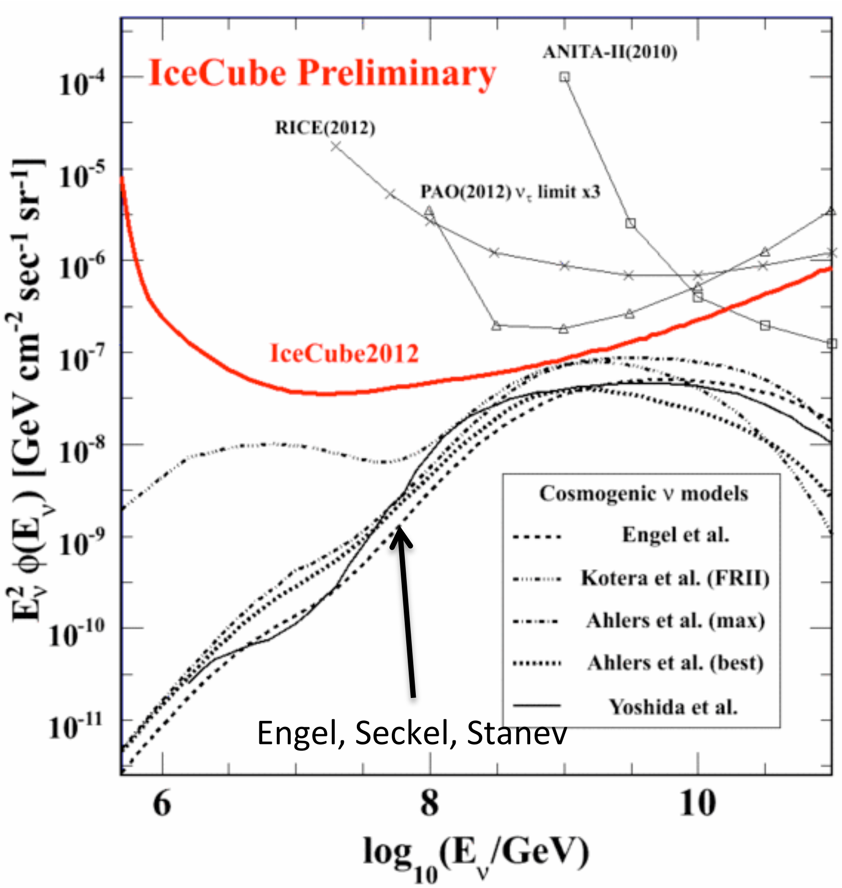
Search strategy for astrophysical neutrinos

1. Look for a hard, high-energy component above the atmospheric background
   - Upward ν_μ induced muons
     - Highest rate
   - Events starting in the detector
     - Lower rate, but
     - Atmospheric ν background is lower
2. Look for excess of events in the ν_μ skymap

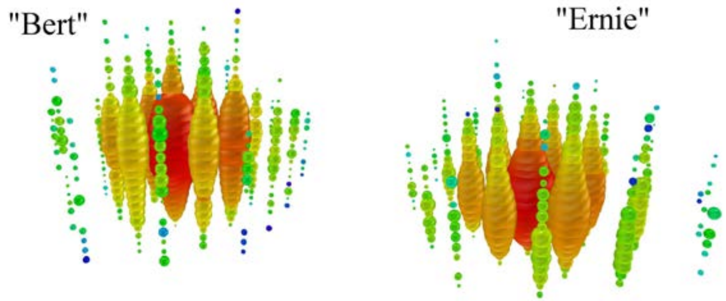
Search for cosmic neutrinos (also known as GZK ν)

$$p + \gamma_{\rm CMB} \rightarrow n + \pi^{+} \rightarrow n \; \mu^{+} \; \nu_{\mu}$$

Limits from IC-79 + IC-86, May 2010-May2012



This search discovered two PeV cascade events, each with just over 1 PeV deposited energy--lower than expected for cosmogenic neutrinos. The events were just at the threshold of the search.

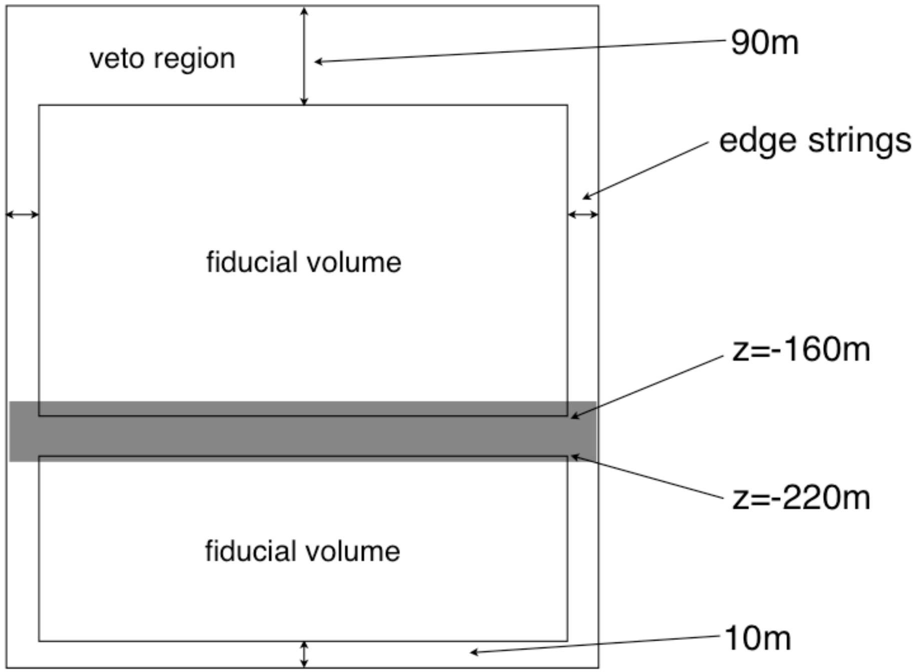


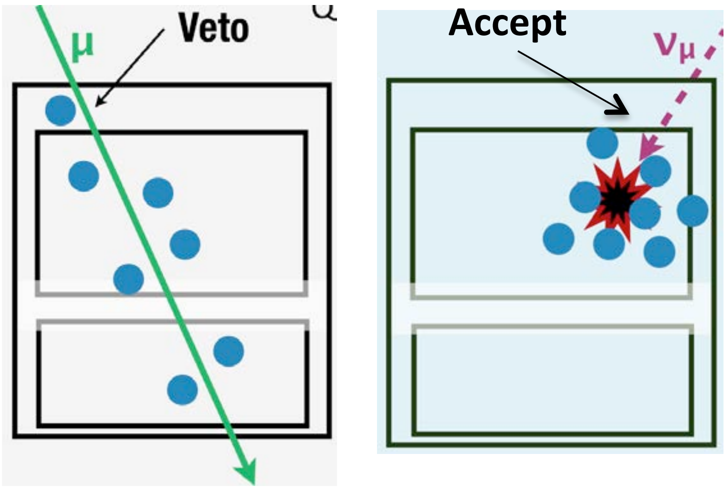
HESE: follow-up analysis of PeV events

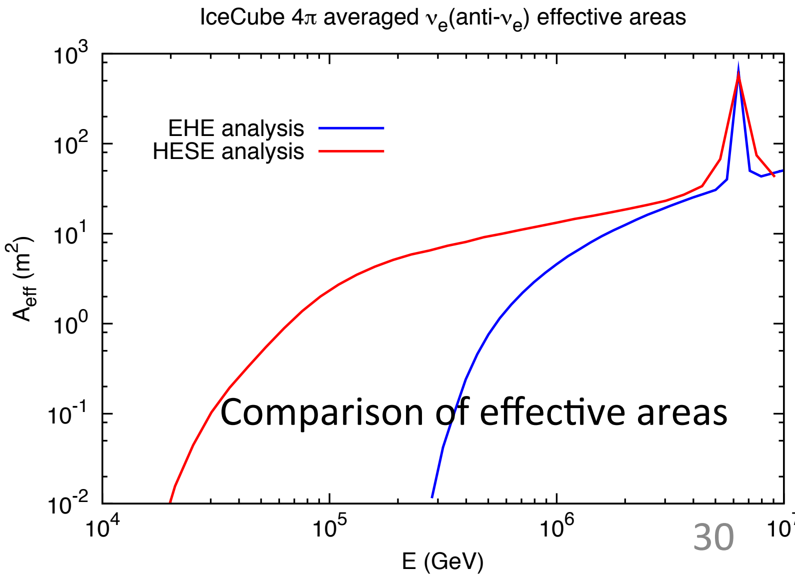
HESE = High Energy Starting Events

Looks at same 662 days of data (June 2010 – May 2012), Science, 22 Nov 2013

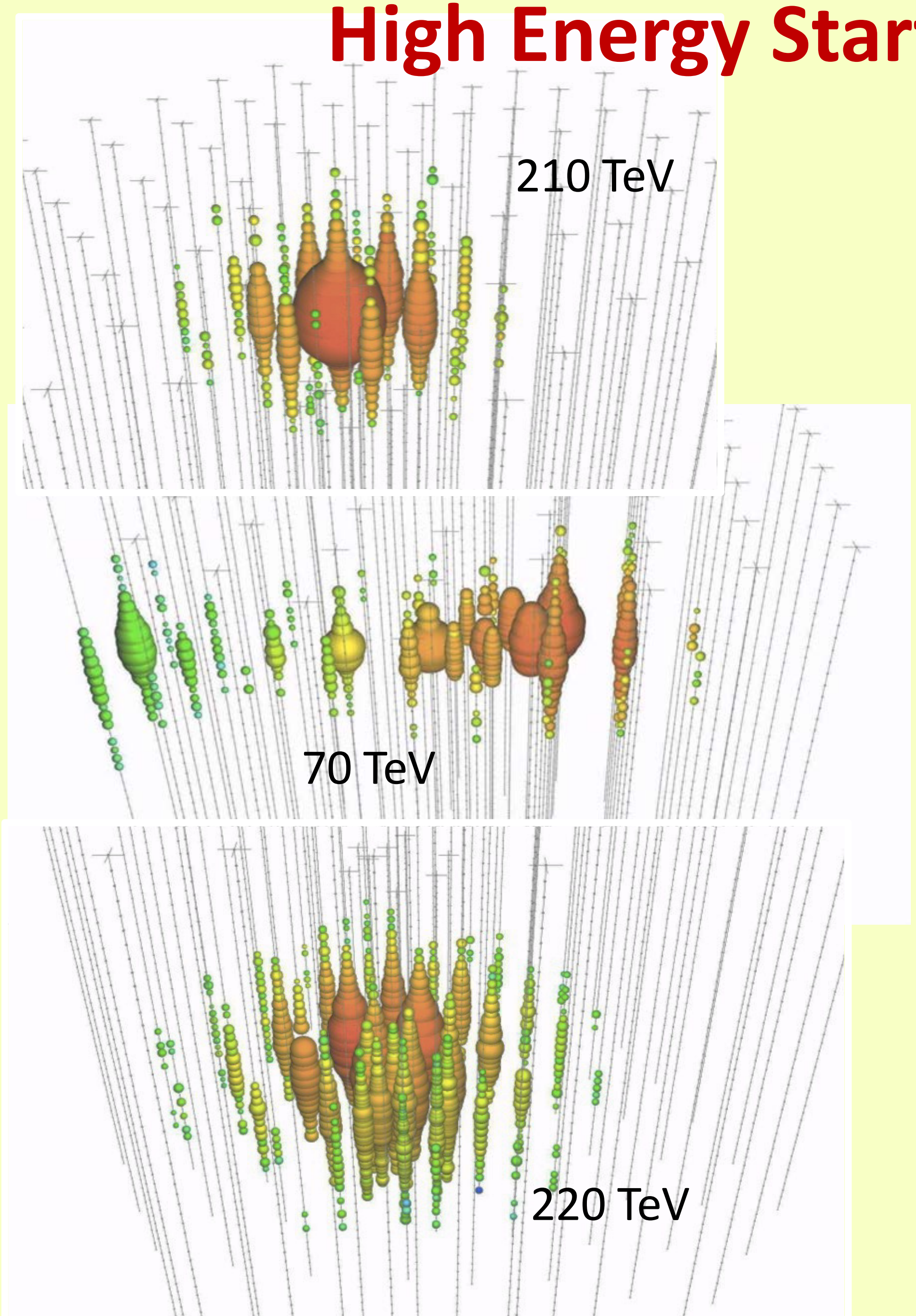
Require event to start inside fiducial volume
6000 p.e. threshold $\sim 30\,\mathrm{TeV}$ deposited energy,
lower than EHE search

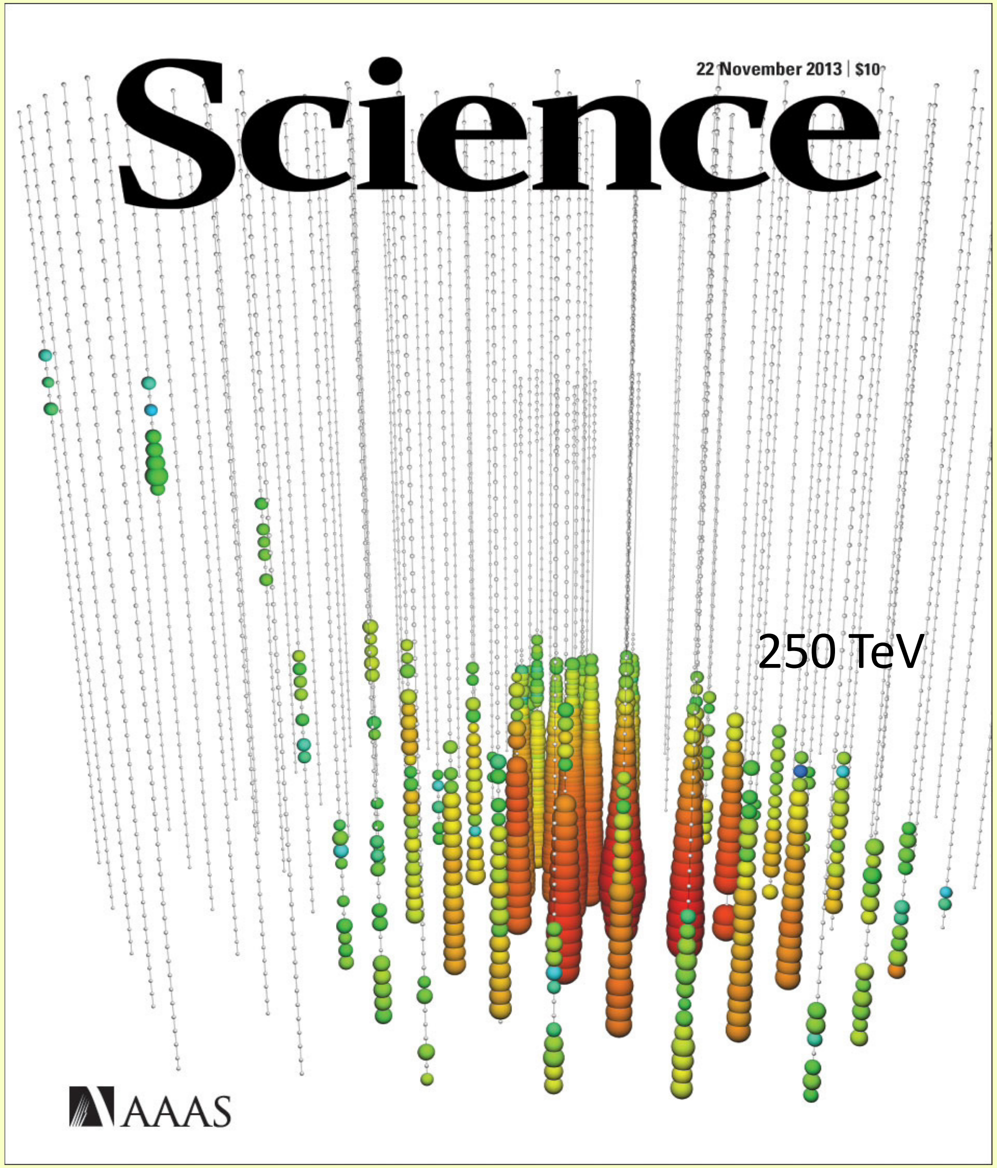




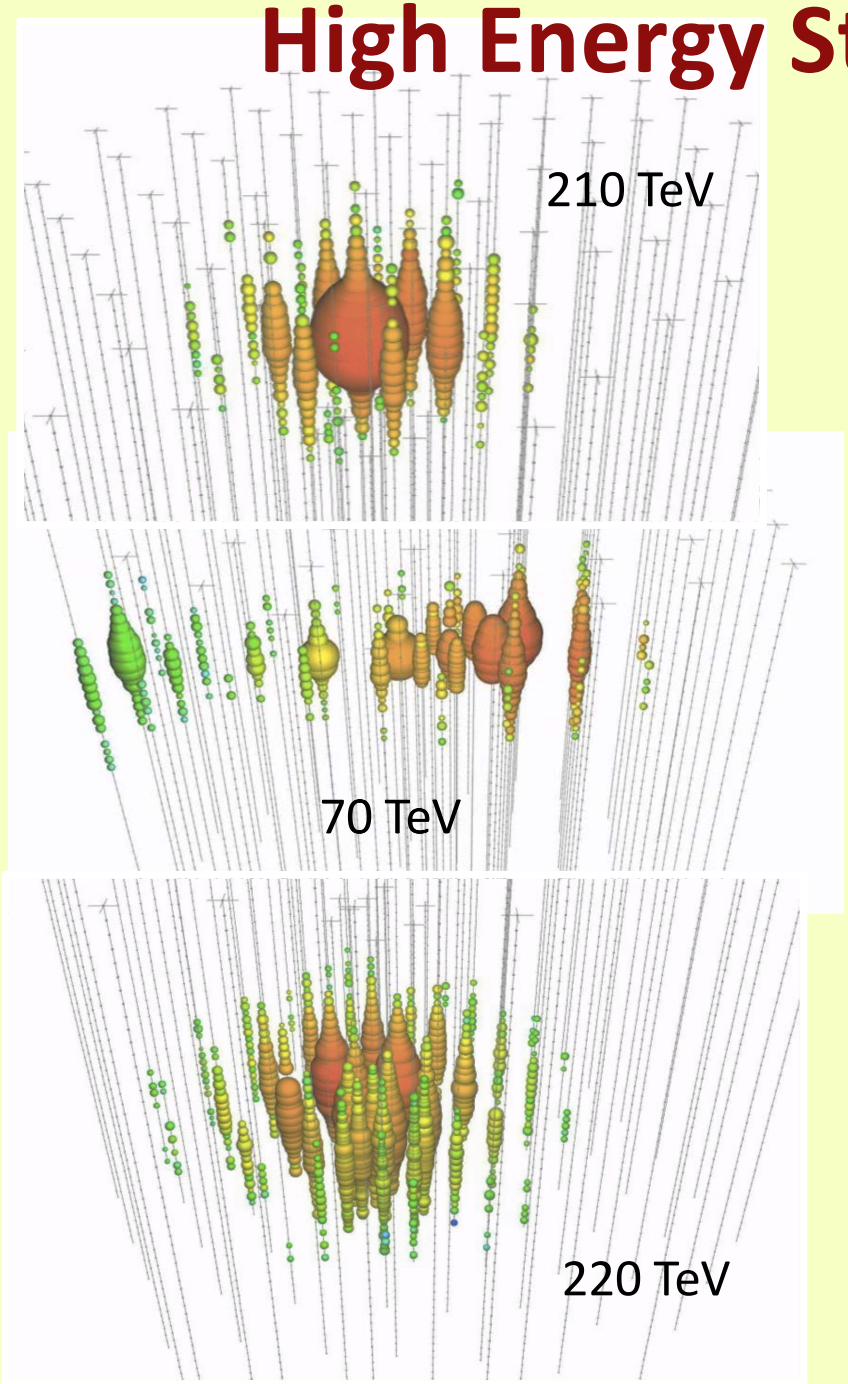


High Energy Starting Event Analysis



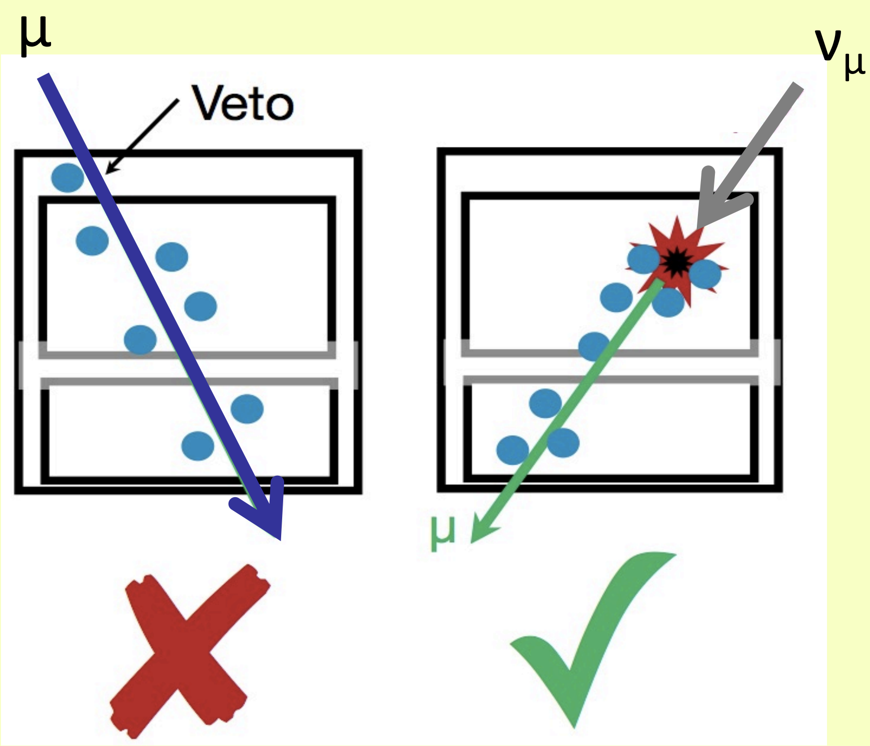


High Energy Starting Event Analysis



Require that event:

- Does not start in veto region
- Has at least 6000 photoelectrons

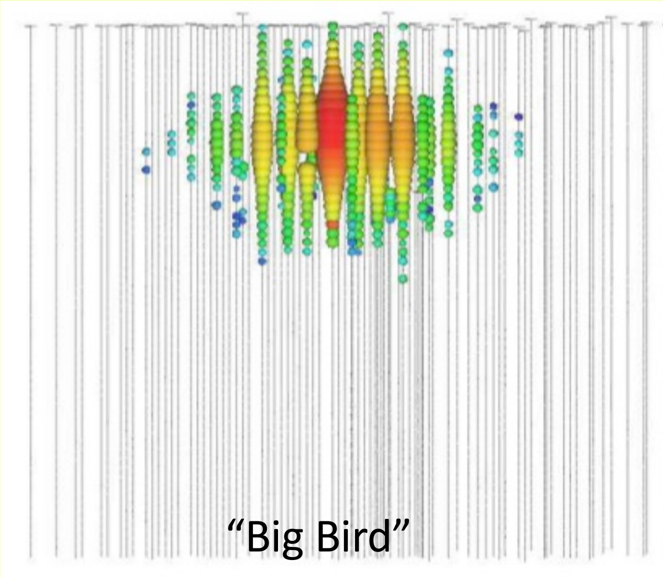


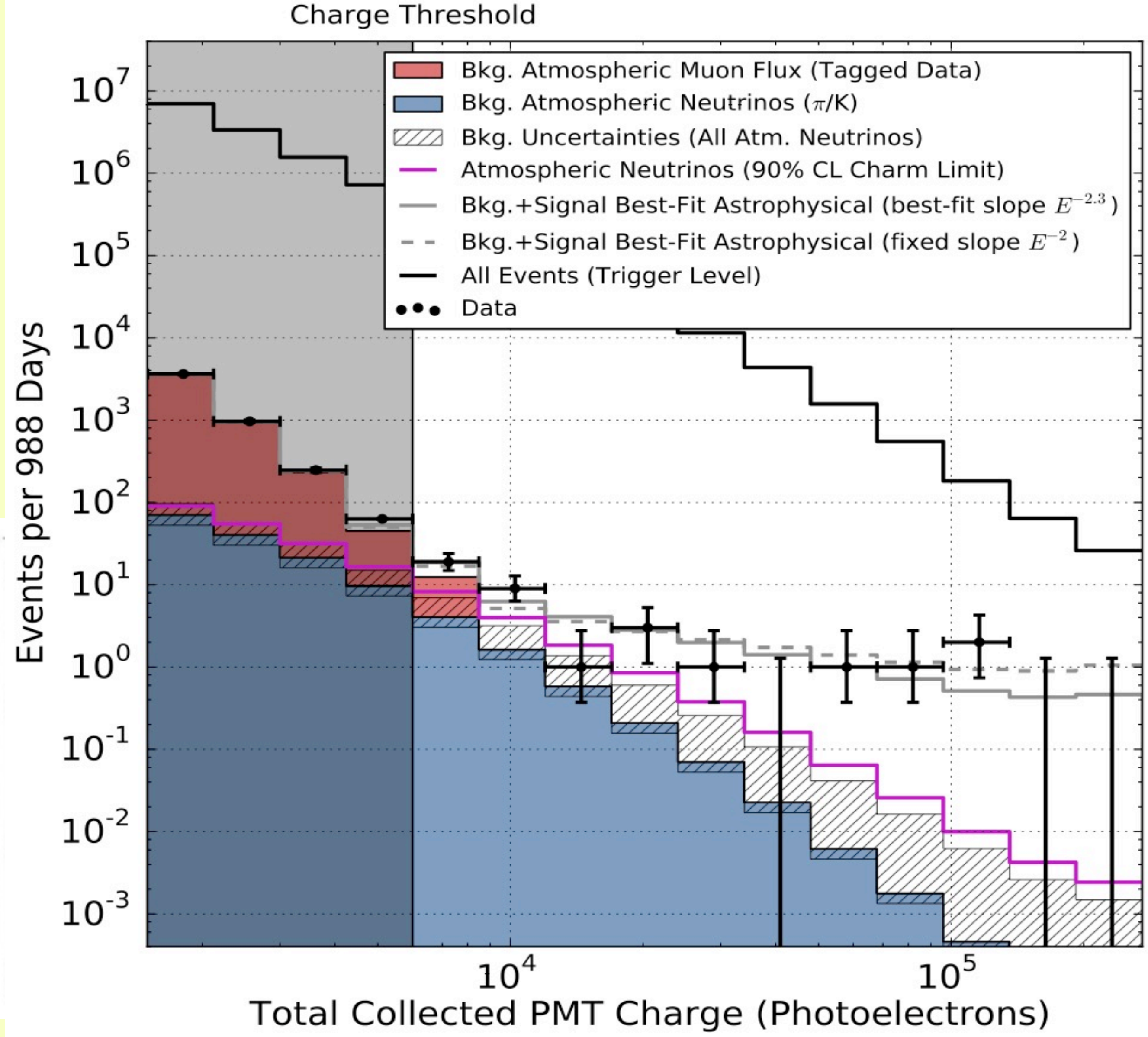
High Energy Starting Event Analysis

3-Year Analysis
PRL **113**, 101101 (2014)

36 events in 3 years

Three > PeV events seen in three years, including a 2-PeV neutrino





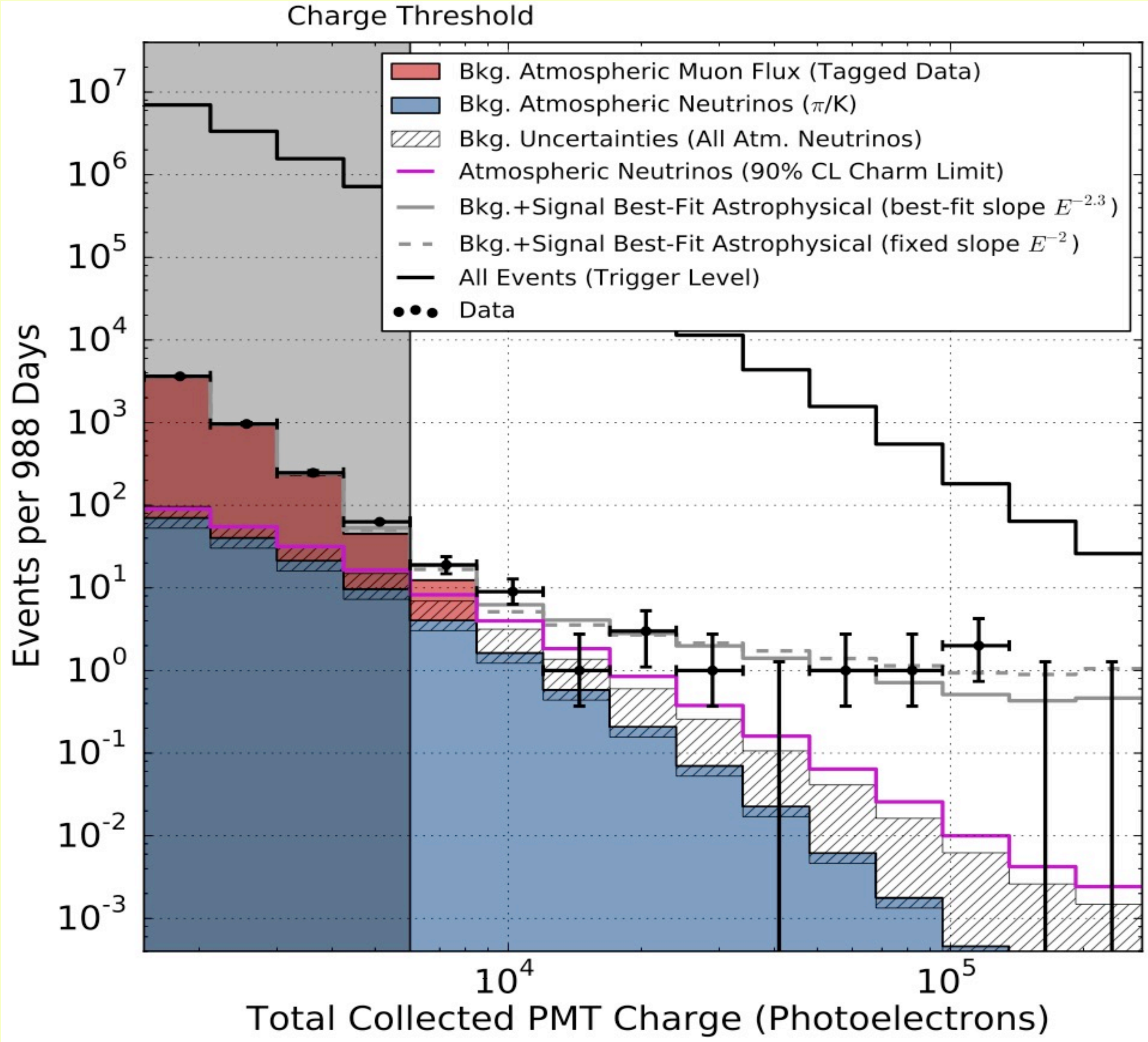
High Energy Starting Event Analysis

Significance of astrophysical flux: **5.7 σ**

Of the 36 events,
~ half are expected to be bkg (atm. muons and atm. neutrinos)

Astrophysical fit (and its significance) depends on **number, direction, and energy**

Shape (energy and zenith distribution) of signal and background is different…



Comments on backgrounds

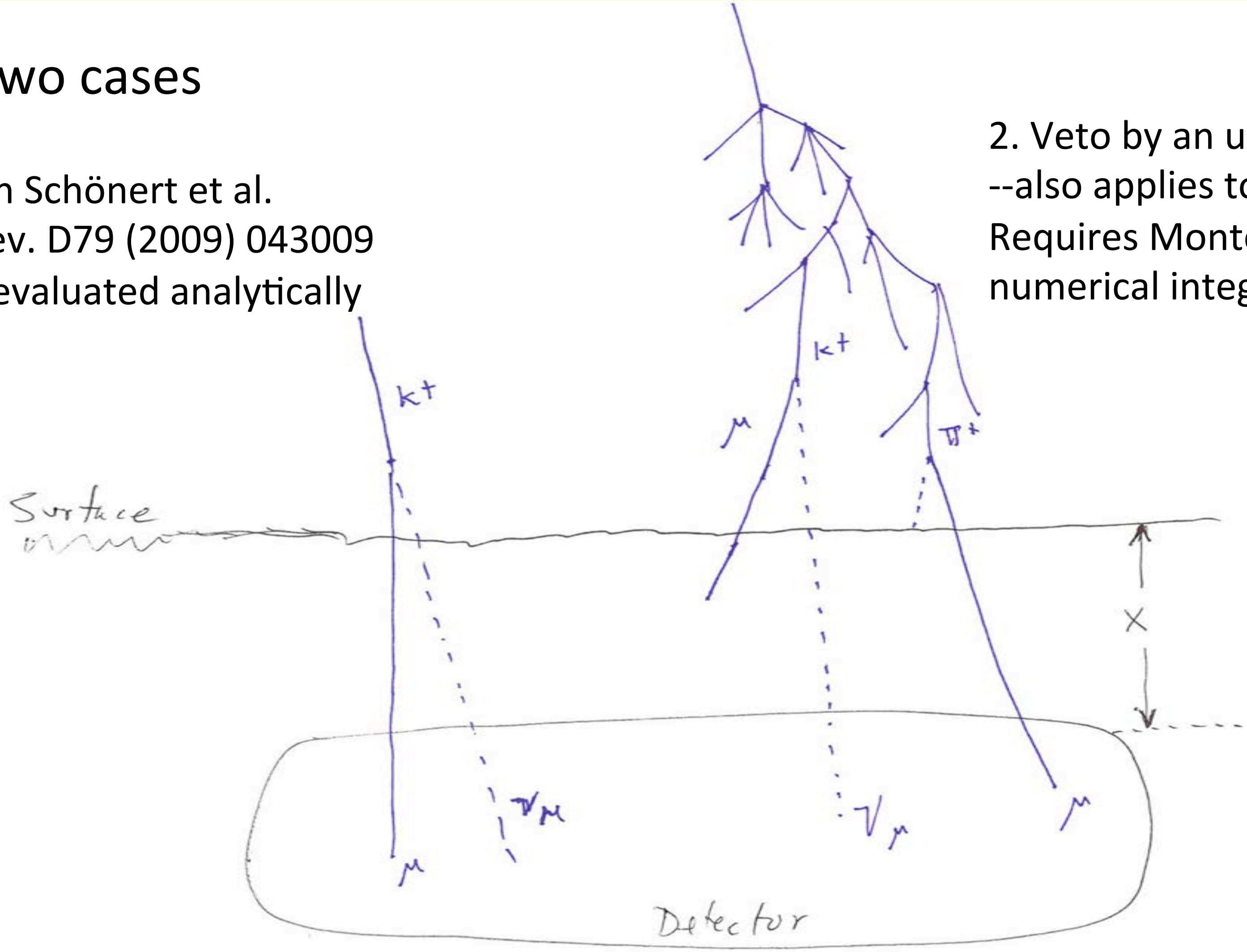
- Atmospheric muons passing the veto
  - This background is determined experimentally by defining a smaller, inner veto region and checking the rate at which tagged muons leak through
- Atmospheric neutrinos
  - "Conventional" ν (from K and π decay)
  - "Prompt" ν (from decay of charm)
  - Muons produced in the same shower as ν provide a partial self-veto in Southern sky

Atmospheric neutrino self veto

Two cases

1. Stefan Schönert et al.
Phys. Rev. D79 (2009) 043009
Can be evaluated analytically

2. Veto by an unrelated μ
--also applies to ν_e
Requires Monte Carlo or
numerical integration

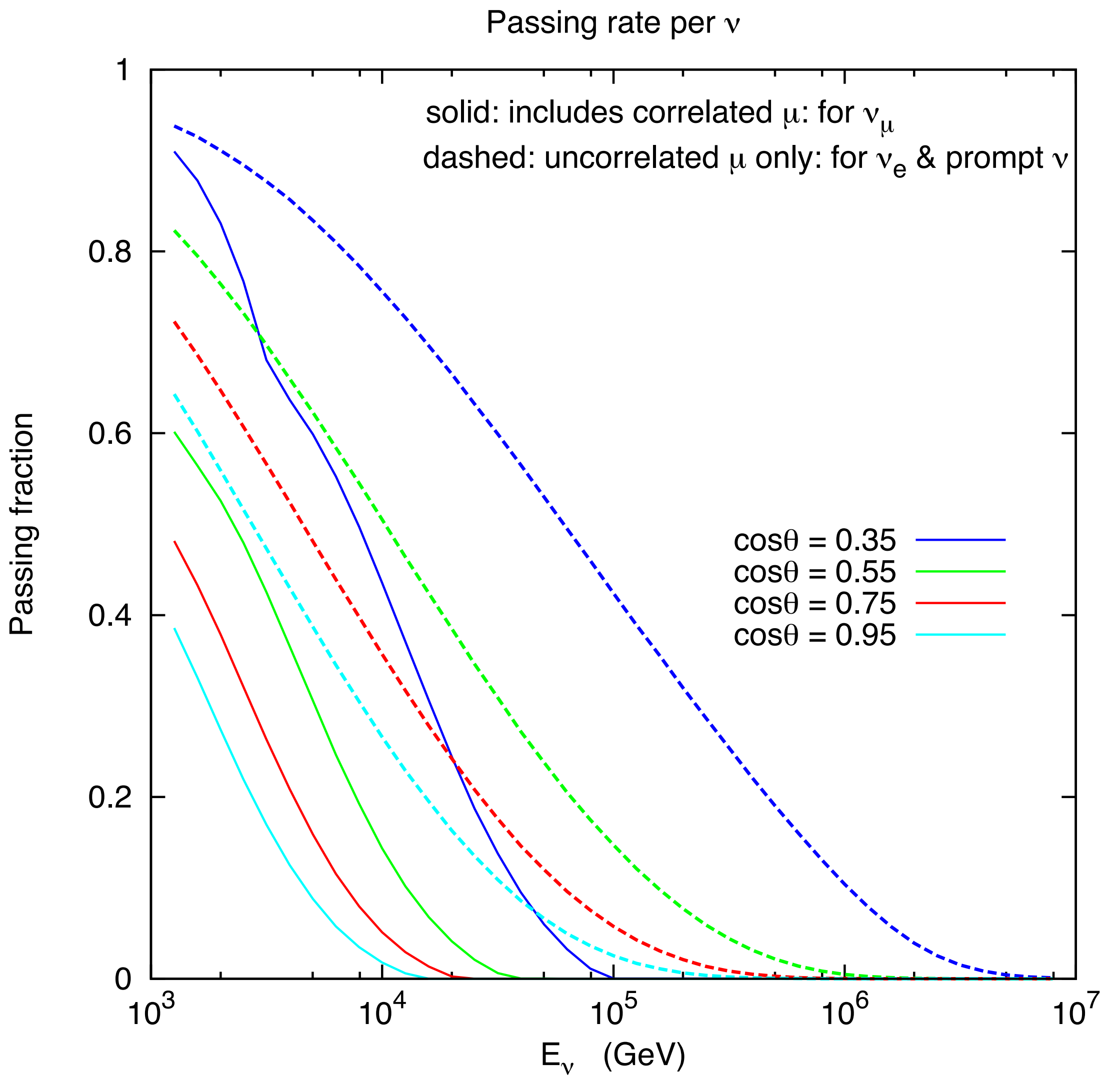


Tom Gaisser

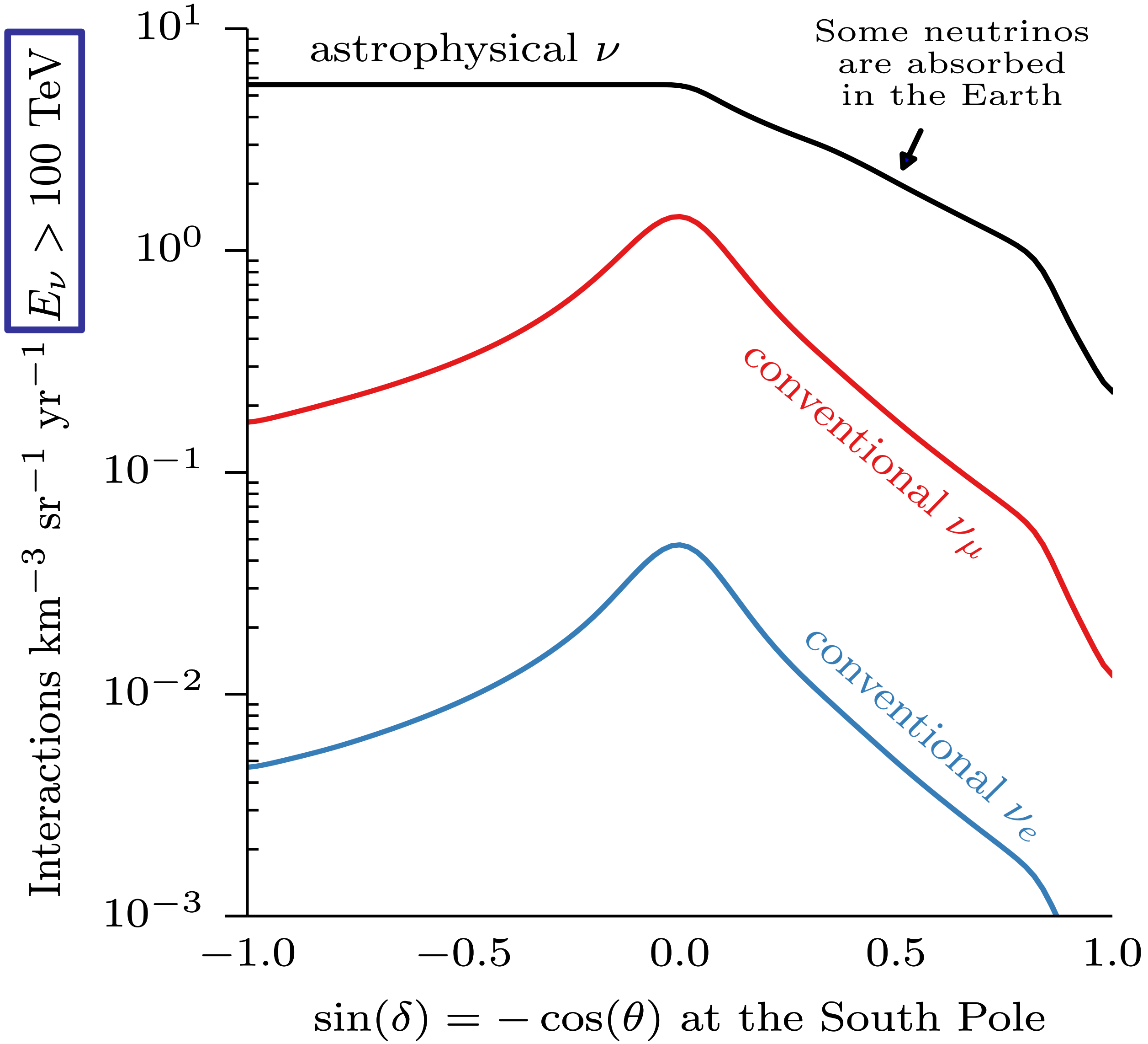
The rate of events passing the veto condition depends on ν flavor

Veto = 1 – Passing

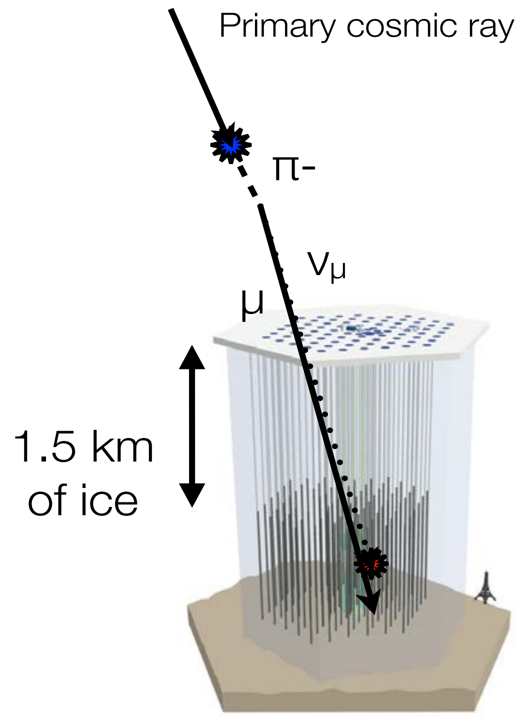
Veto is more effective for ν_μ than for ν_e and prompt ν



Atmospheric neutrino self-veto



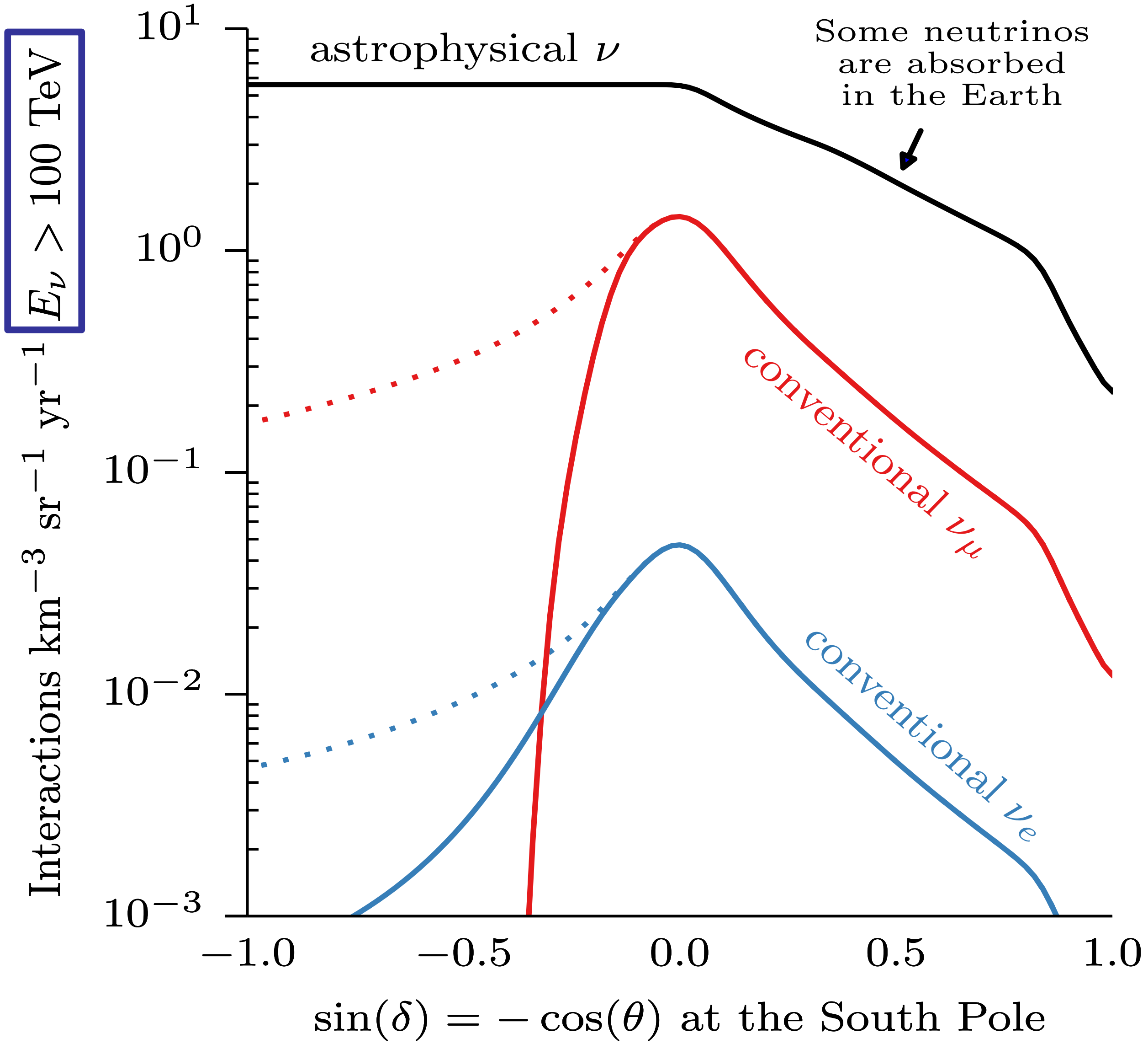
An active muon veto removes down-going atmospheric neutrinos.



Schönert, Resconi, Schulz, Phys. Rev. D, 79:043009 (2009)

Gaisser, Jero, Karle, van Santen, Phys. Rev. D, 90:023009 (2014)

Atmospheric neutrino self-veto



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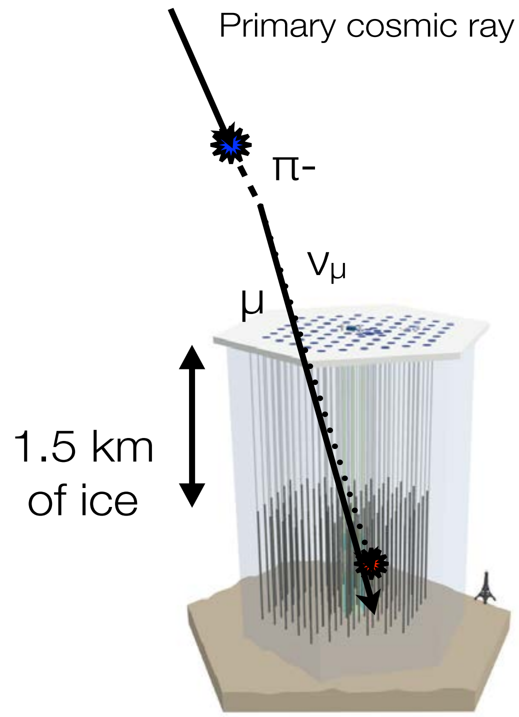

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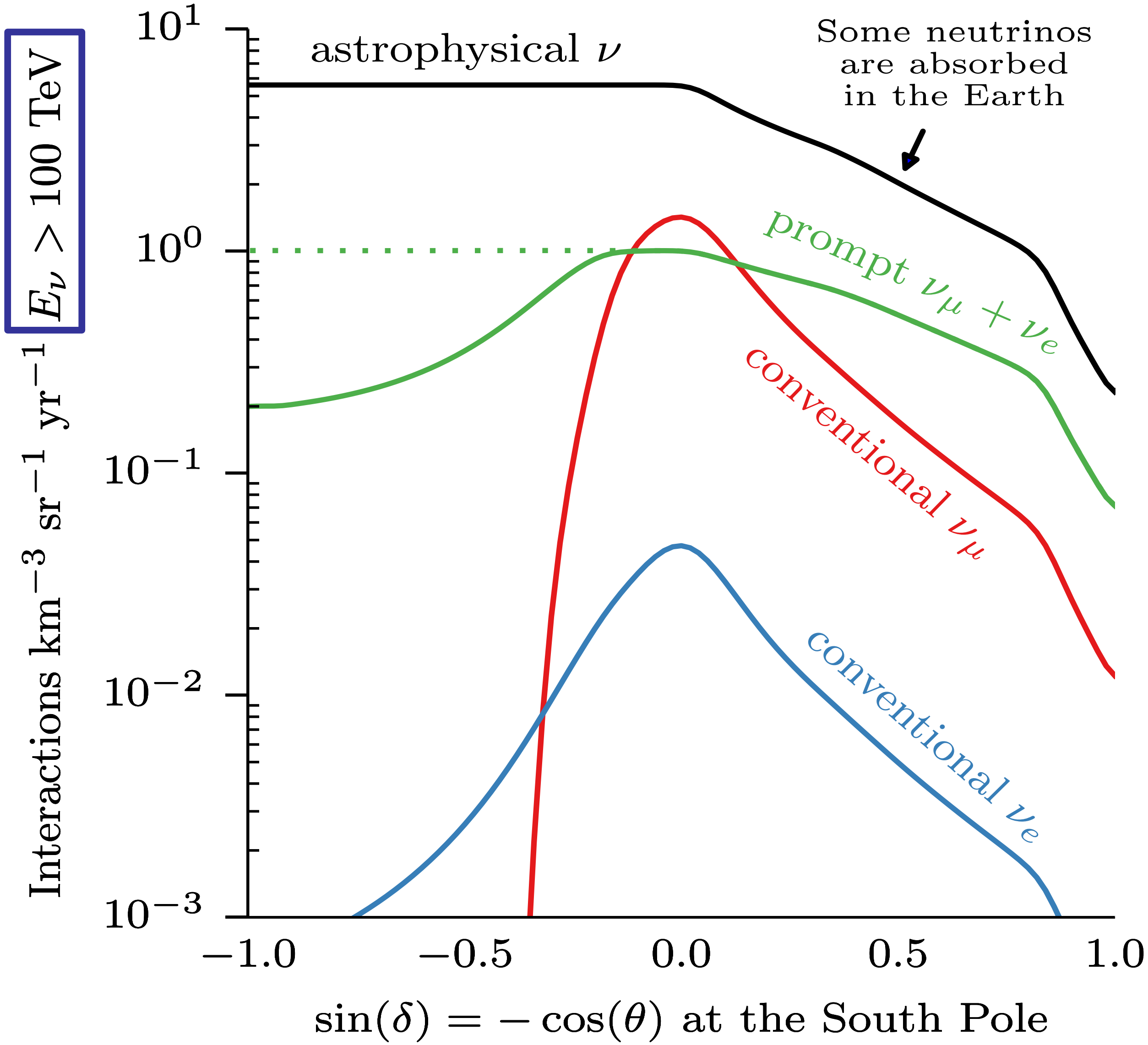
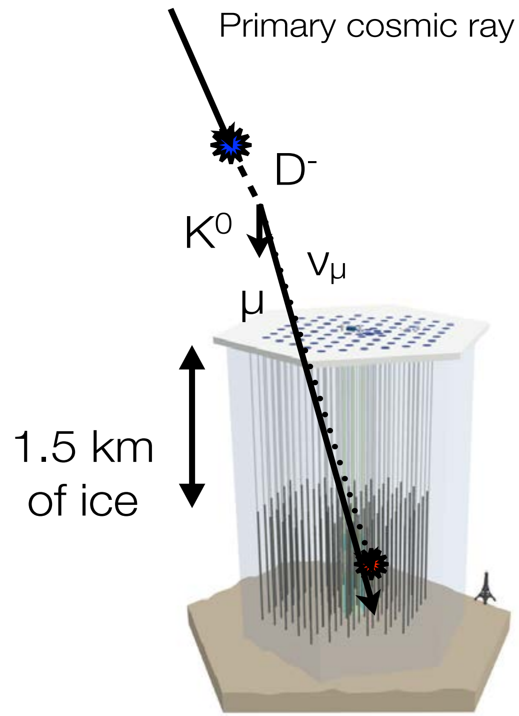


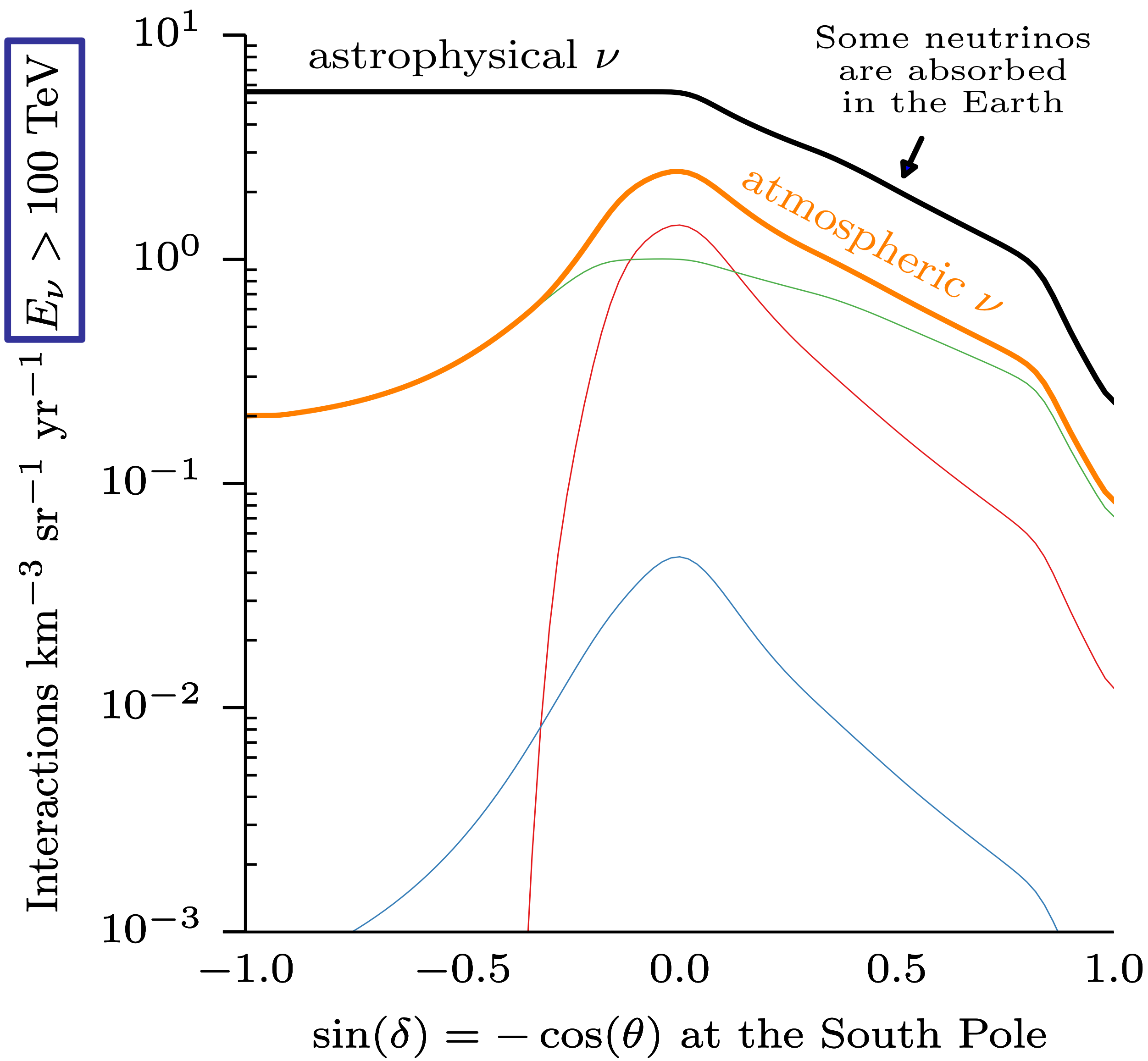
Prompt atmospheric neutrinos are vetoed, too.



Schönert, Resconi, Schulz, Phys. Rev. D, 79:043009 (2009)

Gaisser, Jero, Karle, van Santen, Phys. Rev. D, 90:023009 (2014)

Atmospheric neutrino self-veto

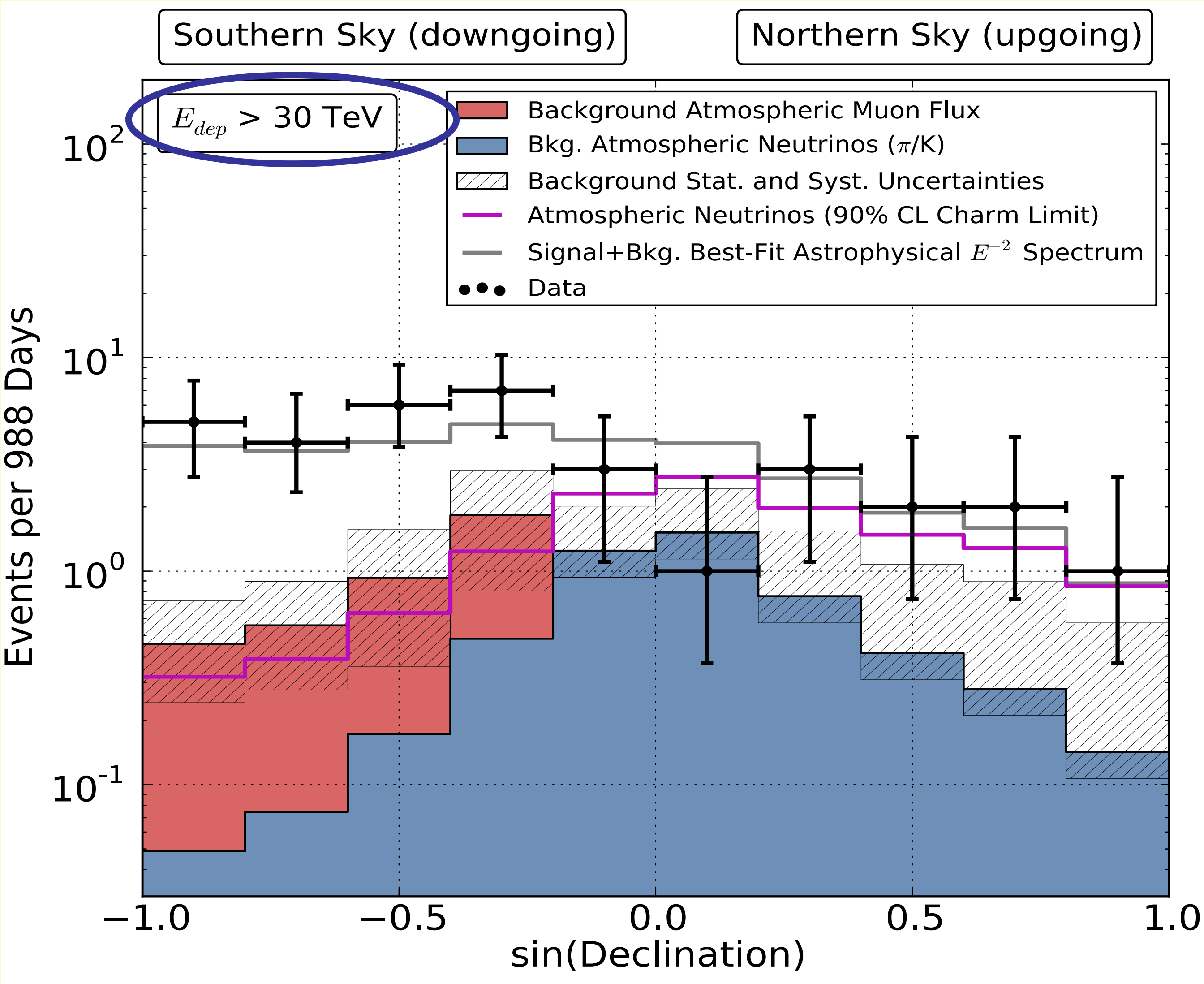


The zenith distributions of high-energy astrophysical and atmospheric neutrinos are fundamentally different.

Schönert, Resconi, Schulz, Phys. Rev. D, 79:043009 (2009)

Gaisser, Jero, Karle, van Santen, Phys. Rev. D, 90:023009 (2014)

3-Year
High Energy
Starting Event
Analysis



3-Year
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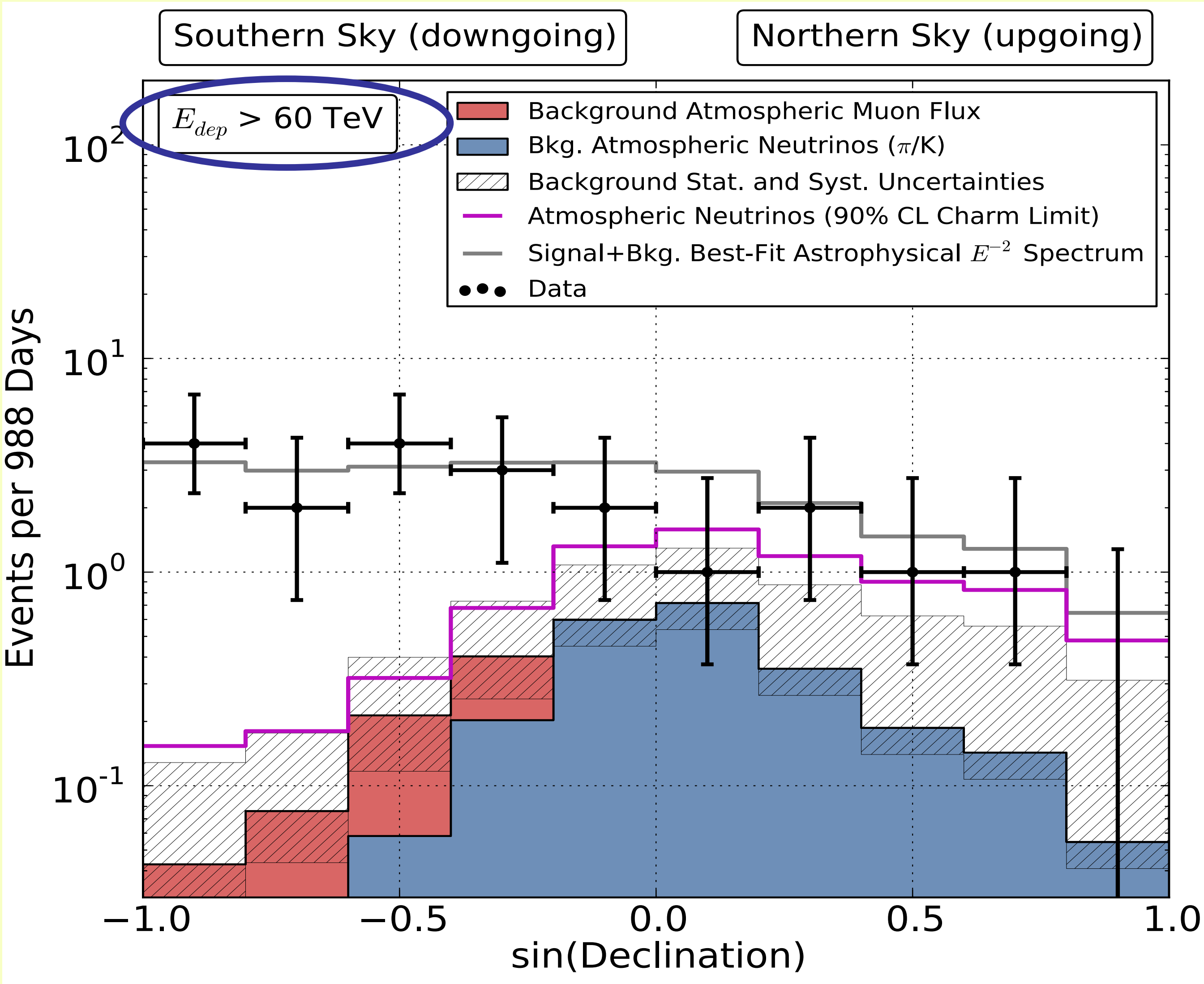

3-Year
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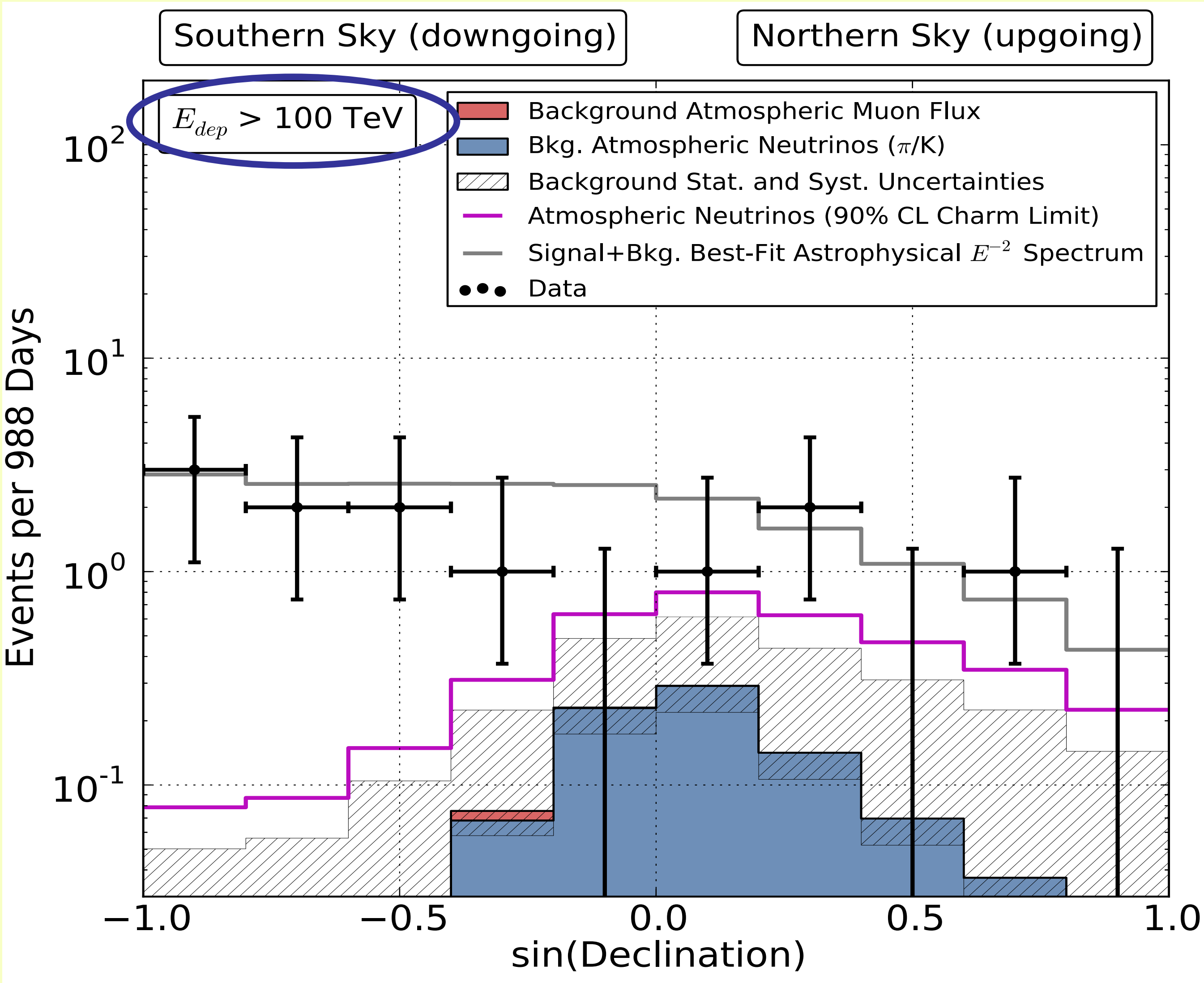
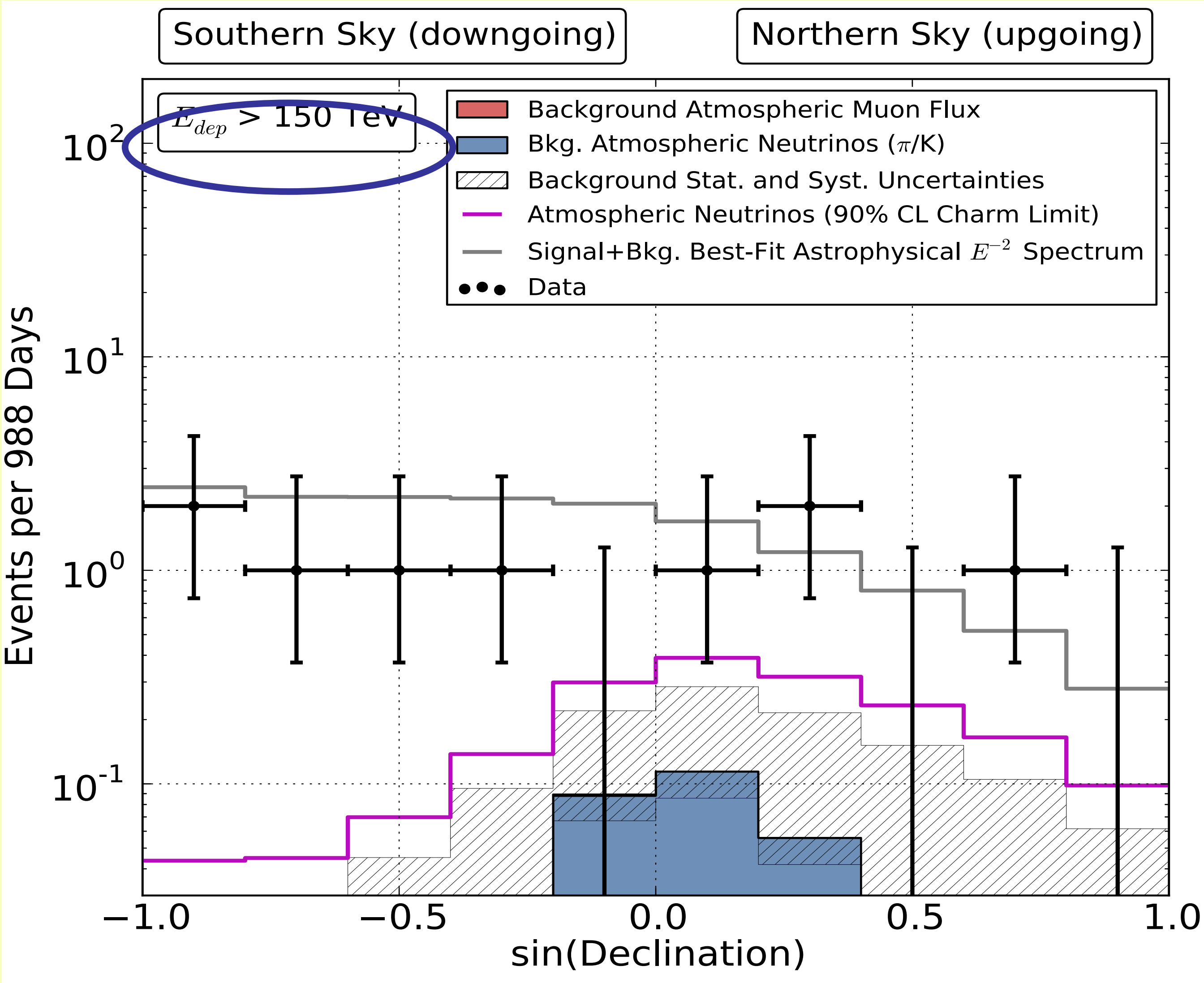
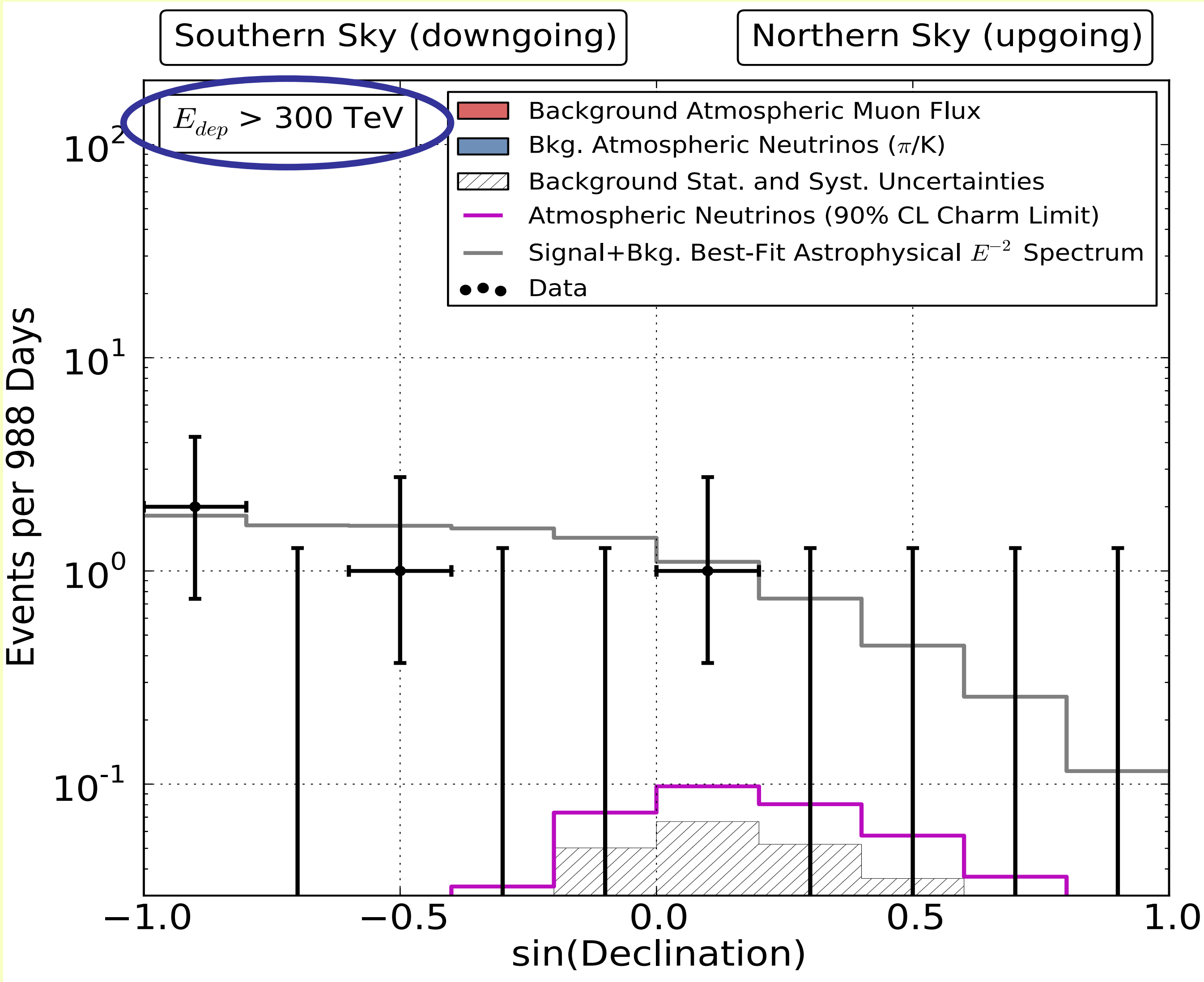


3-Year
High Energy
Starting Event
Analysis

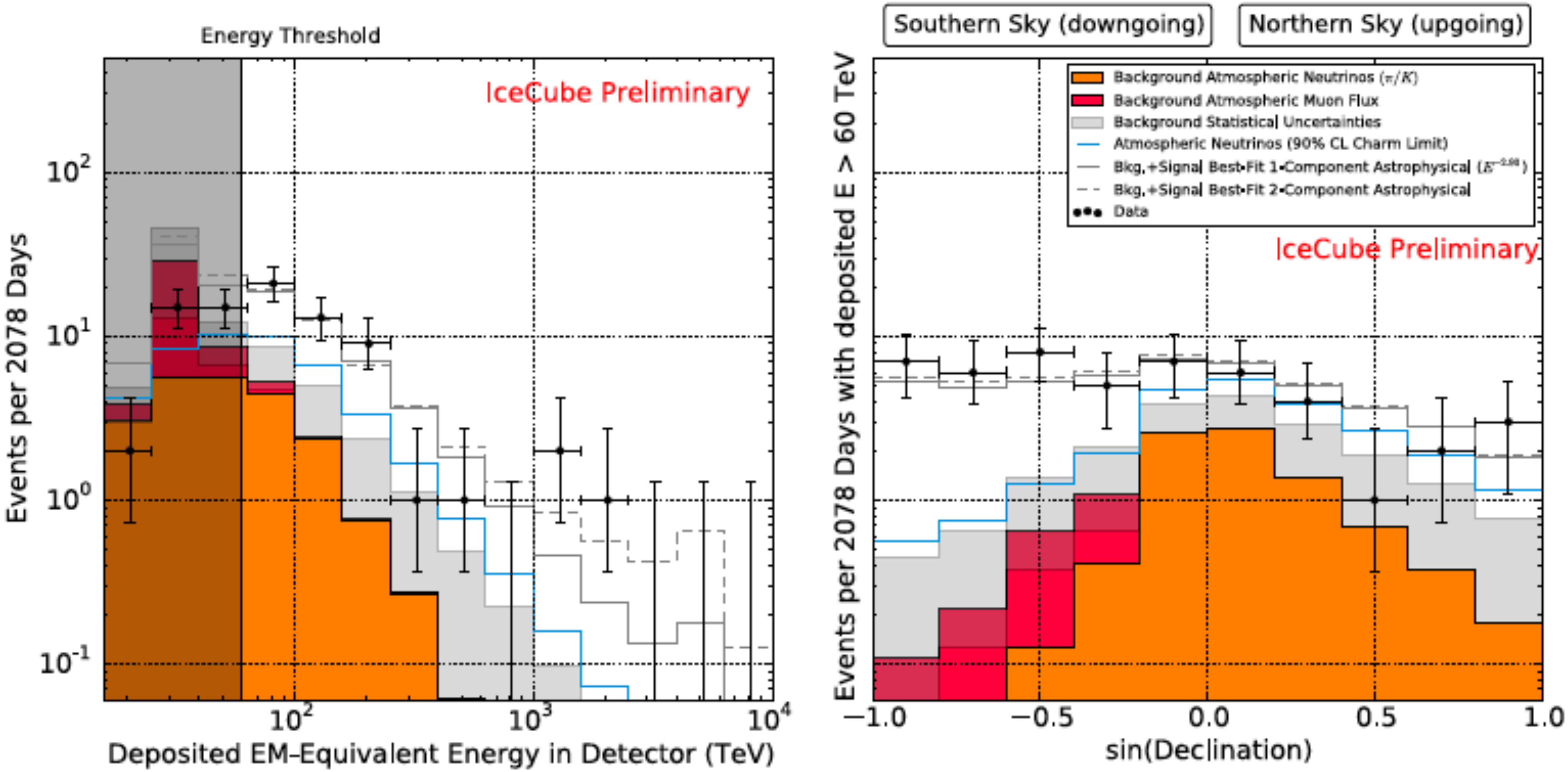


3-Year
High Energy
Starting Event
Analysis



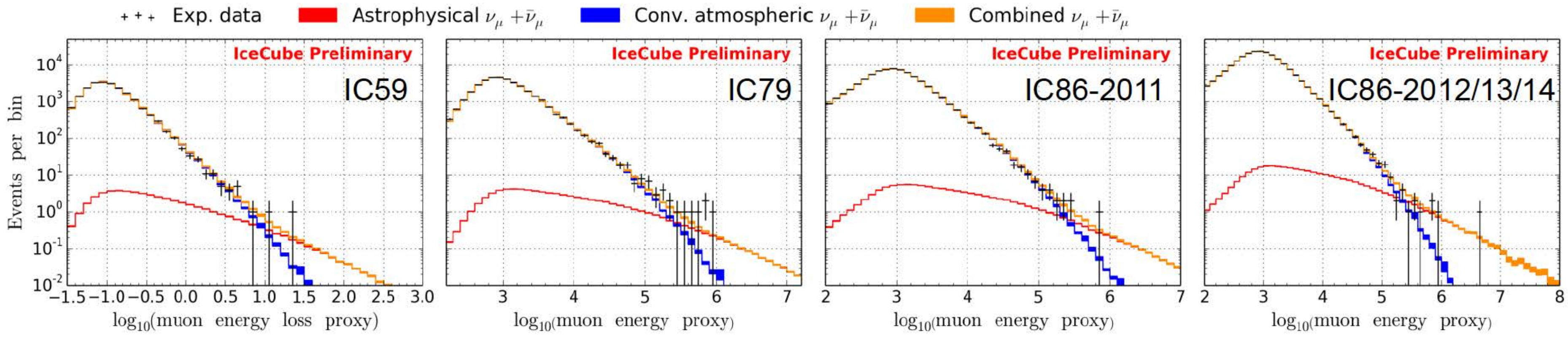
IceCube 2017 - High Energy Starting Event Analysis

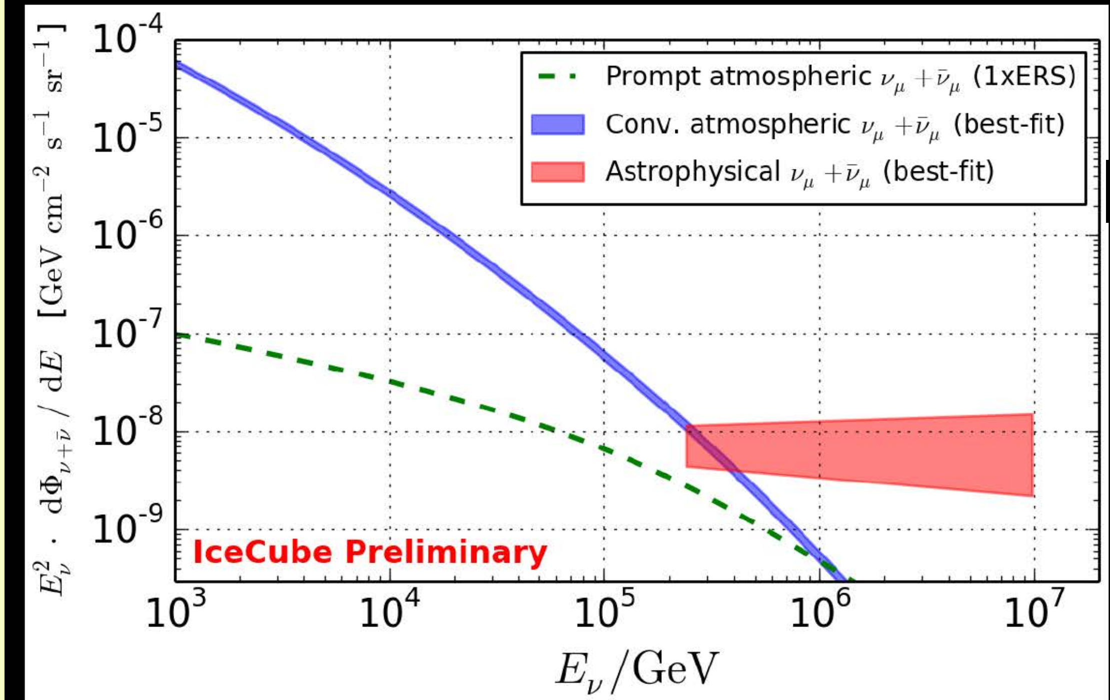
starting events: now 6 years → 8σ



IceCube today: diffuse ν_μ flux with up-going muons

after 7 years → 6.4 sigma





- Best-fit astrophysical normalization:

  0.97+.27-.25 $\times 10^{-18}$ GeV^{-1}cm^{-2}s^{-1}sr^{-1}

- Best-fit spectral index:

  γ_{astro} = 2.16 ± 0.11

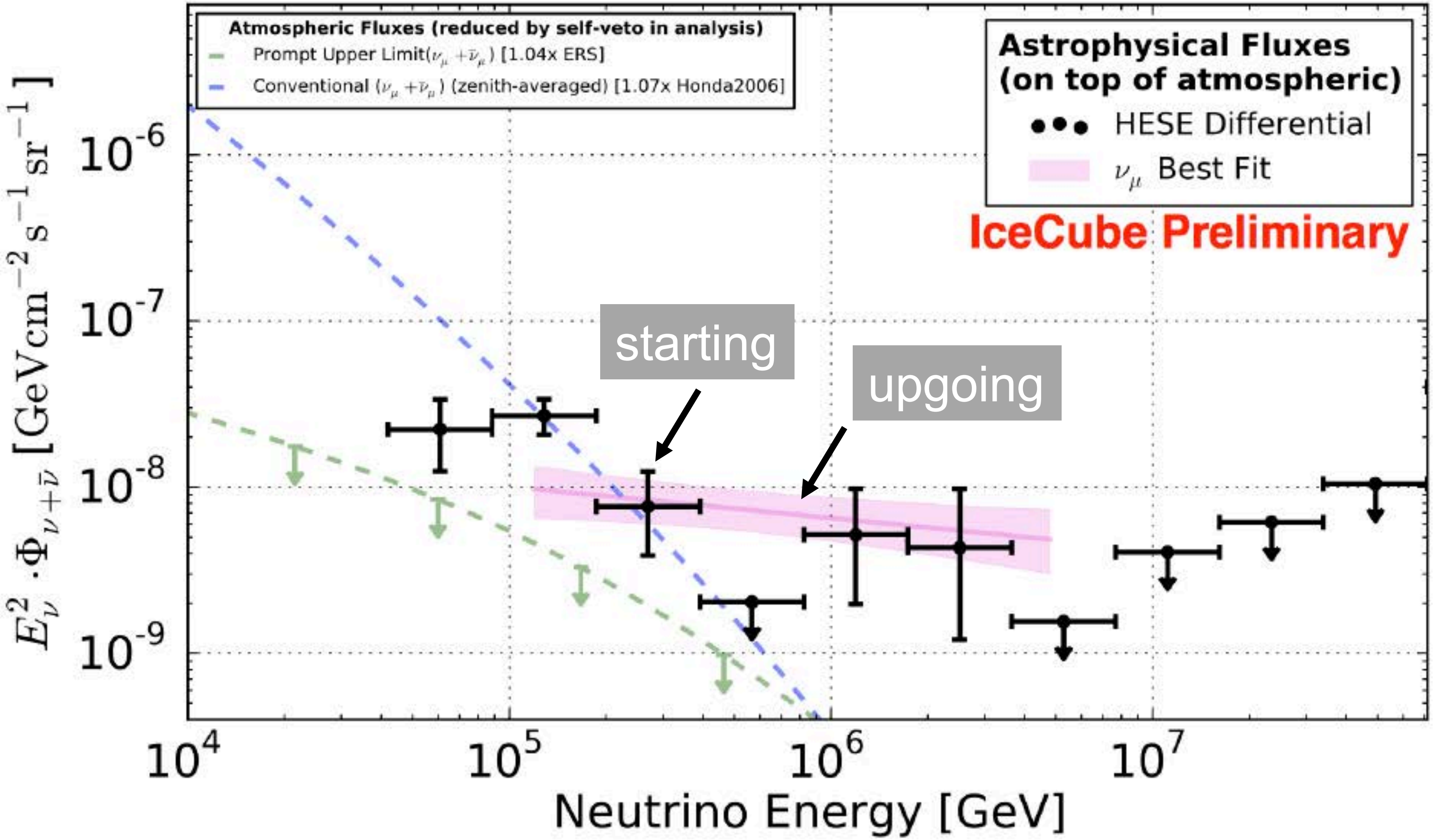
- Energy ranges:

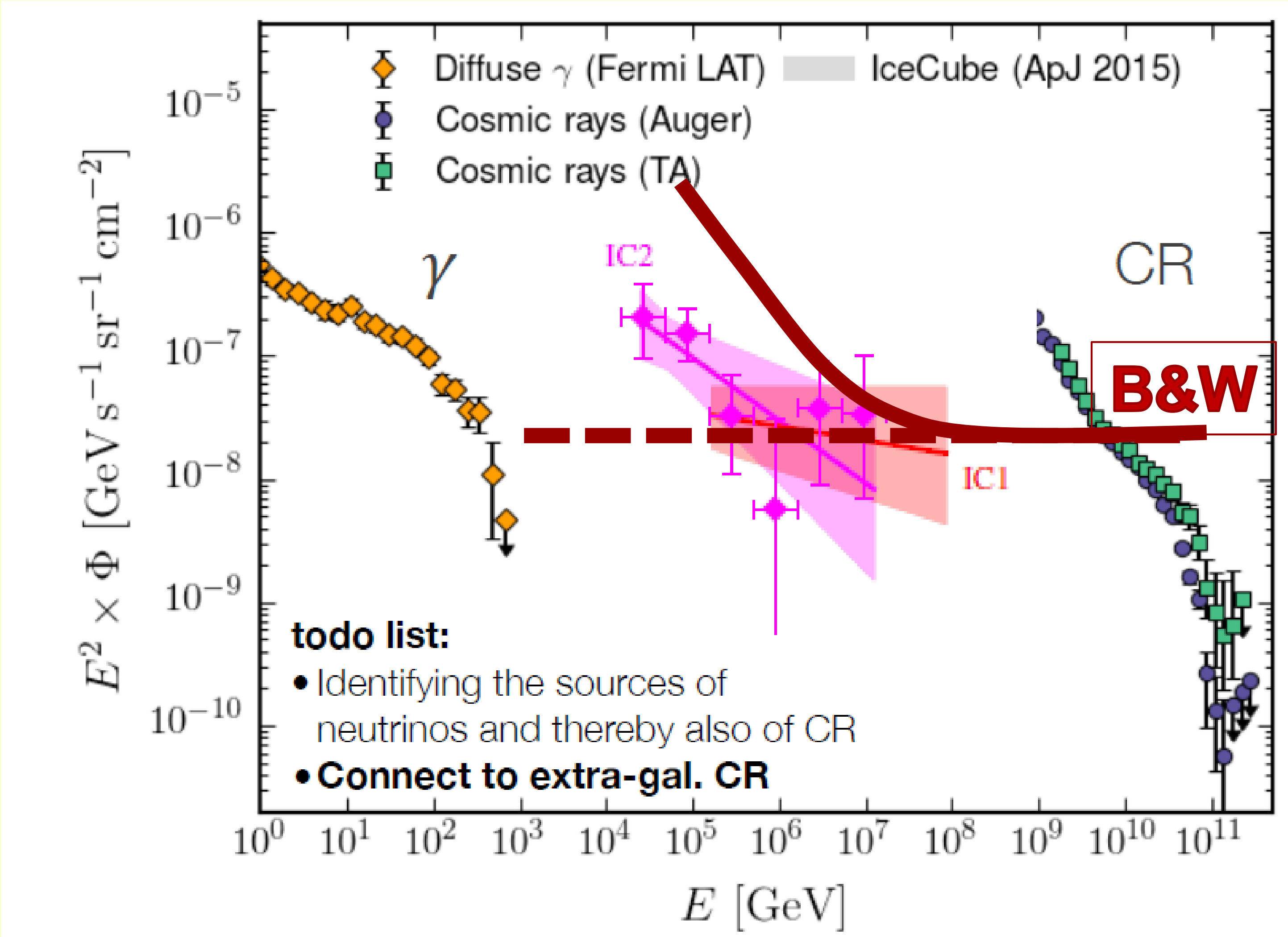
  240 TeV – 10 PeV

- Atmospheric-only hypothesis excluded by 6.0σ

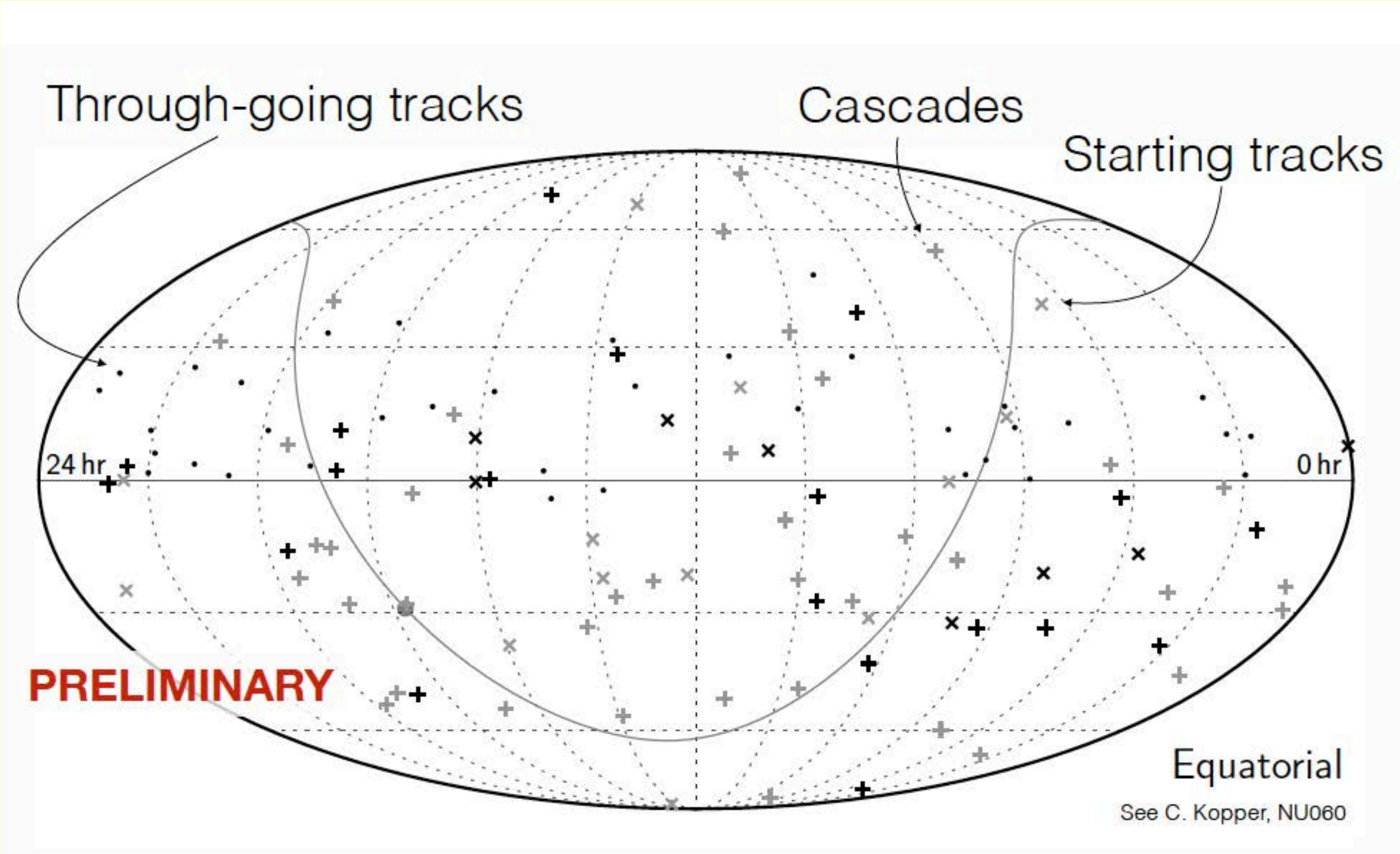
IceCube 2017

High Energy Staring events (showers) and up-going muons analyses give consistent results



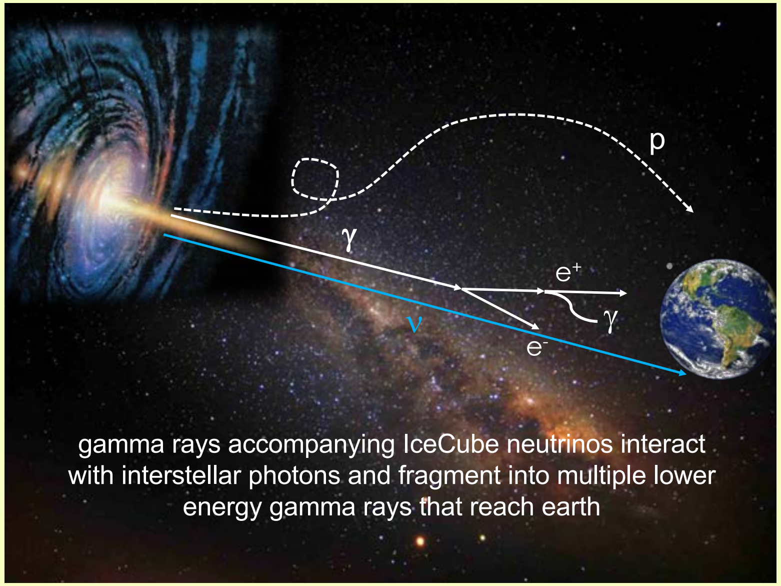

Diffuse γ (Fermi LAT)
IceCube (ApJ 2015)
Cosmic rays (Auger)
Cosmic rays (TA)
γ
IC2
IC1
CR
B&W
todo list:
• Identifying the sources of neutrinos and thereby also of CR
• Connect to extra-gal. CR
$E^2 \times \Phi$ [GeV s^{-1} sr^{-1} cm^{-2}]
E [GeV]

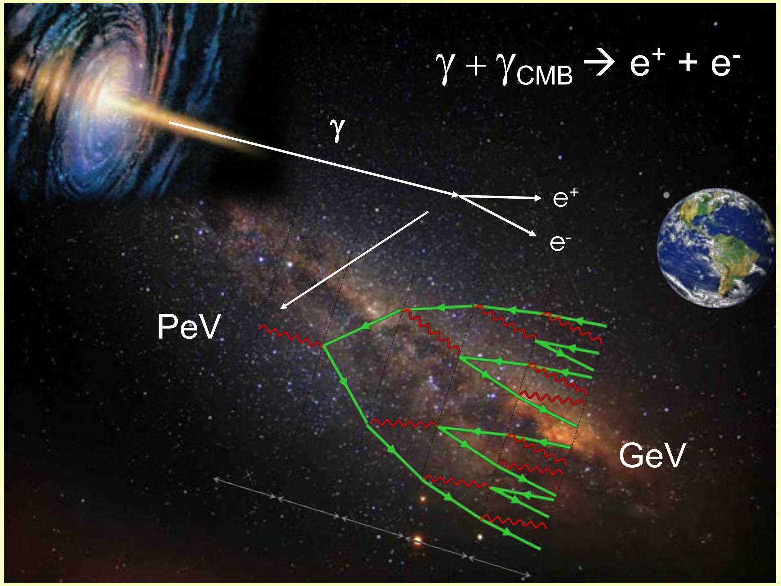
Where these neutrinos are coming from ??



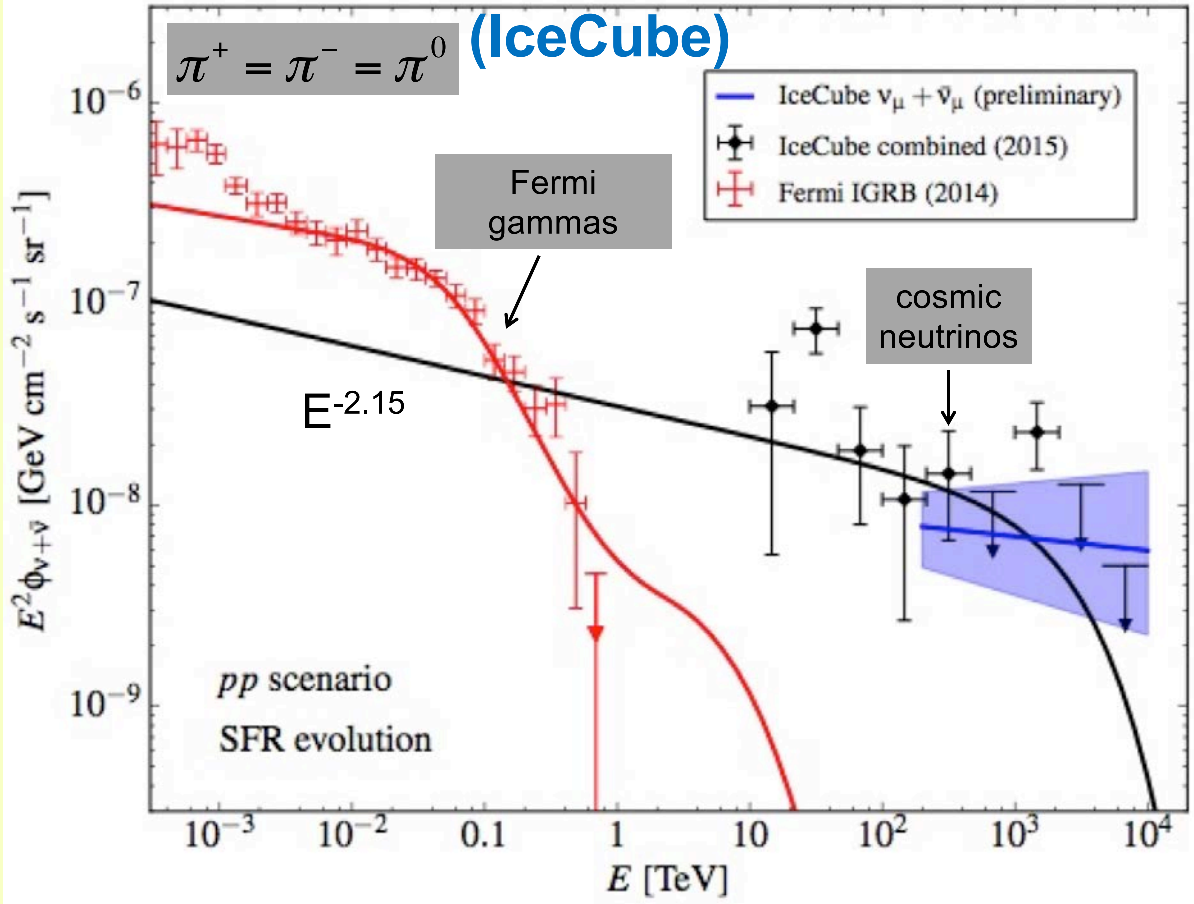
A diffuse flux from extragalactic sources
A subdominant Galactic component cannot be excluded

IceCube neutrinos and observed gammas (Fermi)



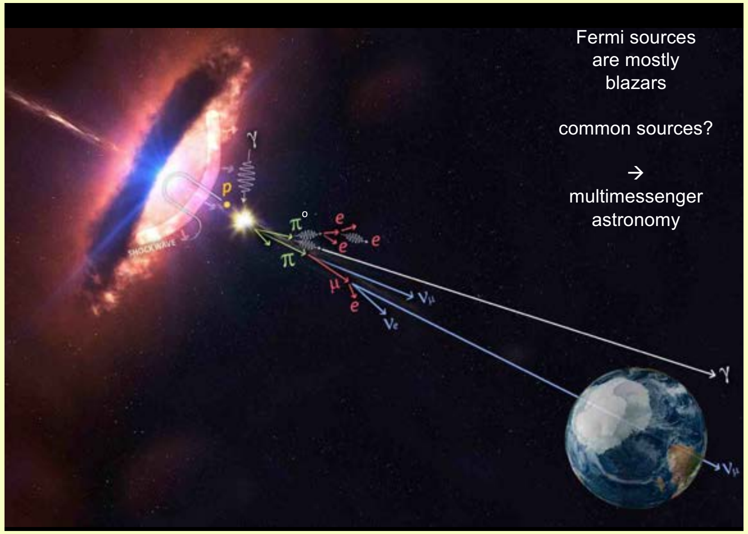


The Spectral Energy Density ($E^2\phi_{\nu+\bar{\nu}}$) for diffuse photons (Fermi) and neutrinos (IceCube)



Energy density of neutrinos in the non-thermal Universe is the same as that in gamma-rays

IceCube neutrinos and observed gammas (Fermi)



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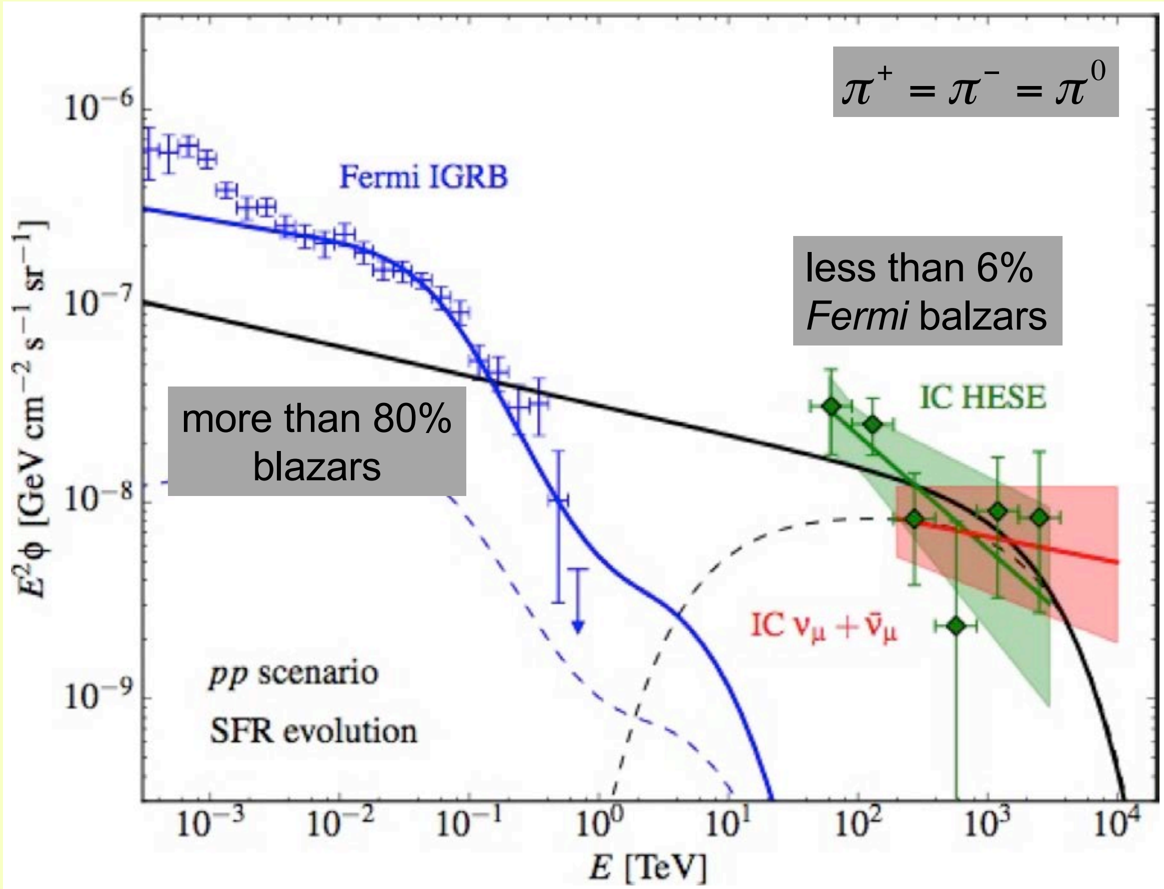
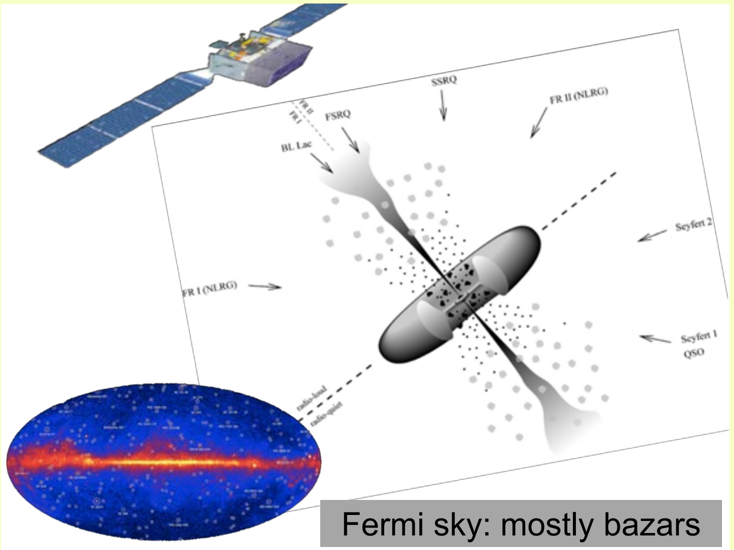


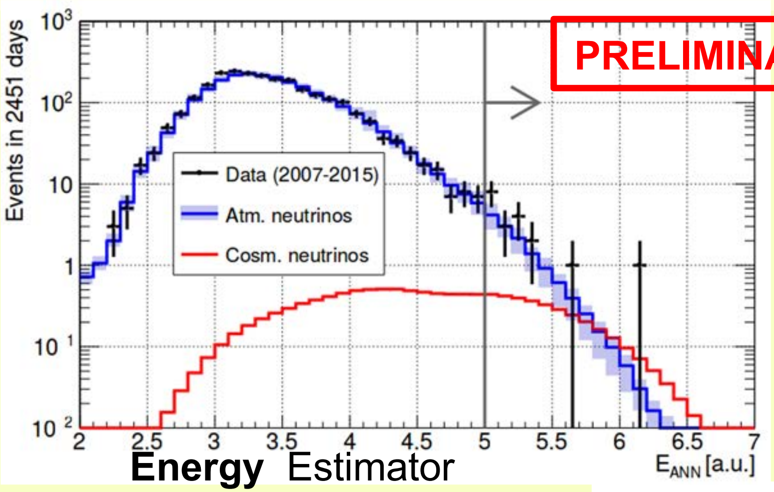


Origin of H.E. neutrinos events (>100TeV) from sources "opaque" for gamma-rays ??

Latest ANTARES results on the search for diffuse ν flux

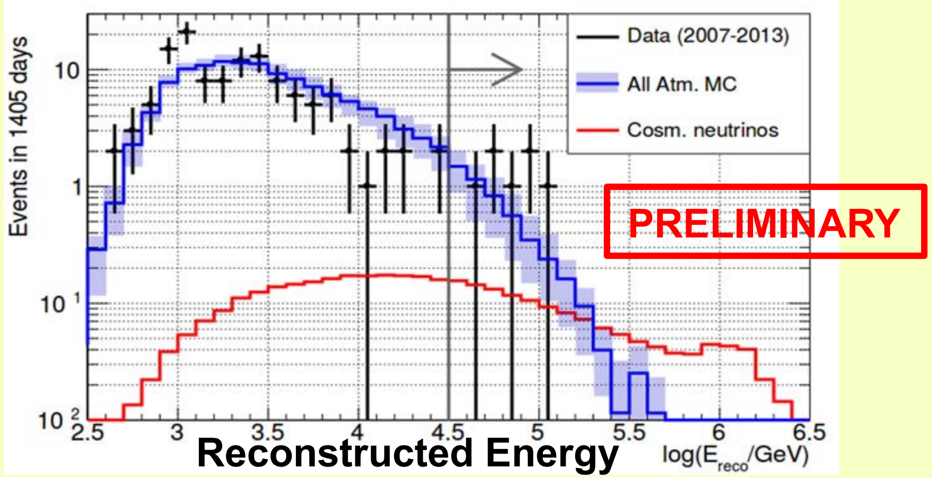
Tracks

Data: 2007-2015 **(2451 live-days)**
Above E_{cut}: Bkg: 13.5 ± 3 evts, IC-like signal: 3 evts
Observed: **19 evts**

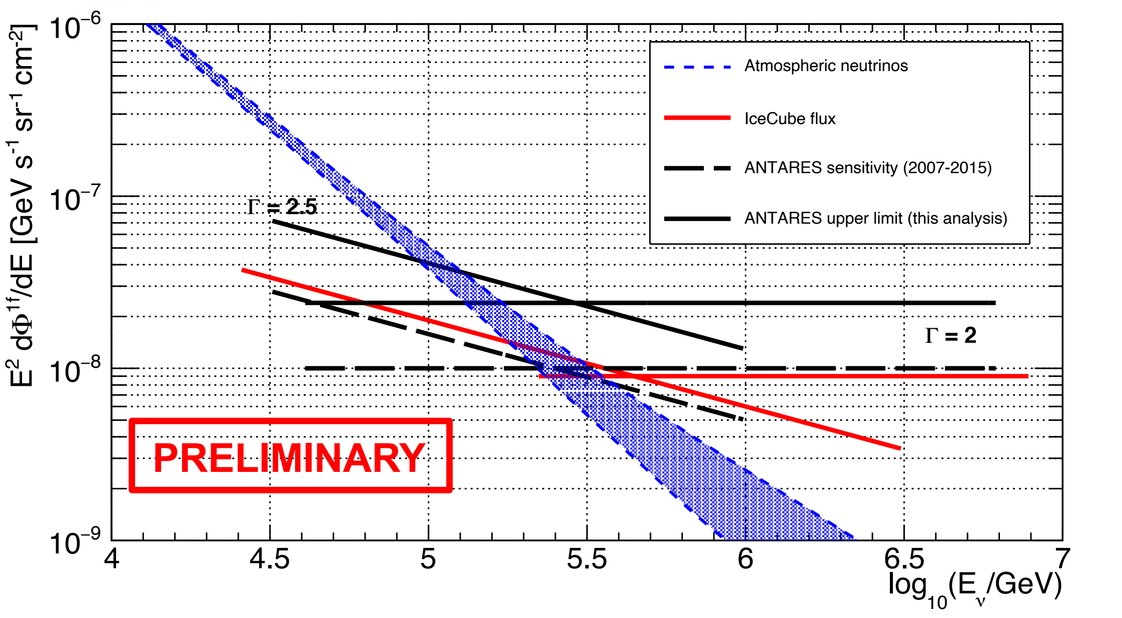


Cascades

Data: 2007-2013 **(1405 live-days)**
Above E_{cut}: Bkg: 5 ± 2 evts, IC-like signal: 1.5 evts
Observed: **7 evts**



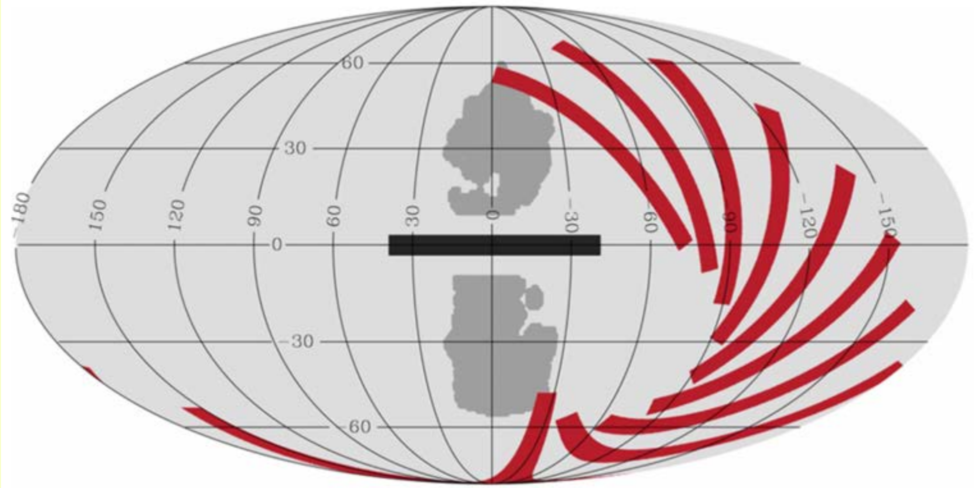
ANTARES
combined upper limits and sensitivities for 9 years data sample (2007-2015) tracks + cascades



Search for neutrinos from the Galactic ridge - 1

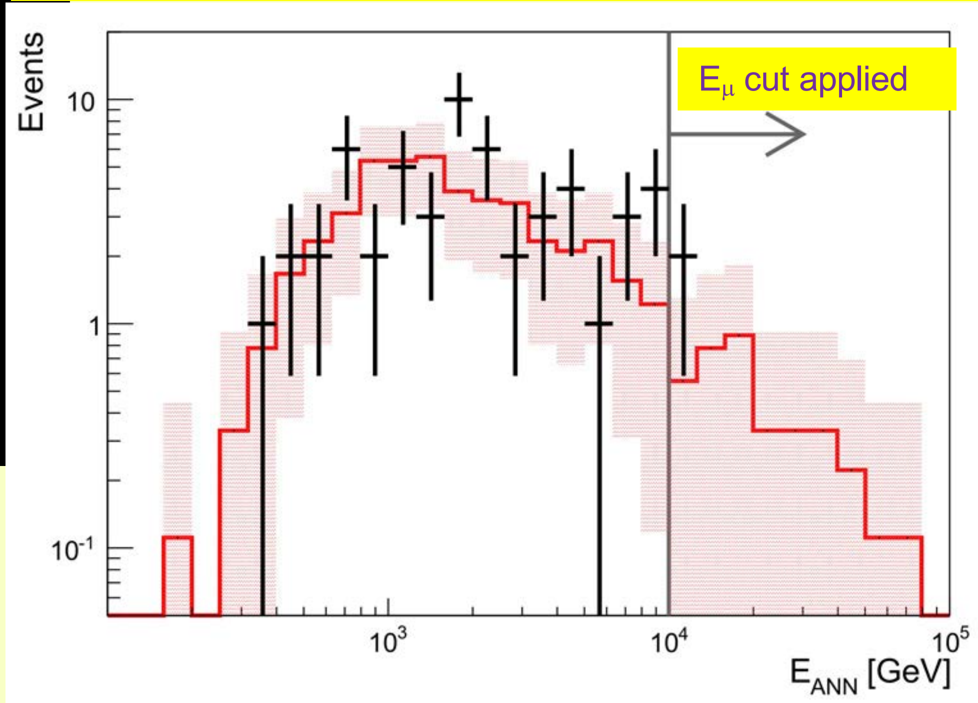
- ν's and γ-rays produced by CR propagation

$$p_{CR} + p_{ISM} \rightarrow \pi^0 \pi^\pm \ldots$$
$$\pi^0 \rightarrow \boldsymbol{\gamma\gamma(EM\ cascade)}$$
$$\pi^\pm \rightarrow \boldsymbol{\nu_\mu, \nu_e} \ldots$$



Physics Letters B 760 (2016) 143–148

- Search for ν_μ, data 2007-2013
- Search region |l|<30°, |b|<4°
- Cuts optimized for neutrino energy spectrum ~$E^{-\gamma}$ (γ=2.4-2.5)
- Counts in the signal/off zones
- No excess in the HE neutrinos
- 90% C.L. upper limits: 3<E_ν<300 TeV

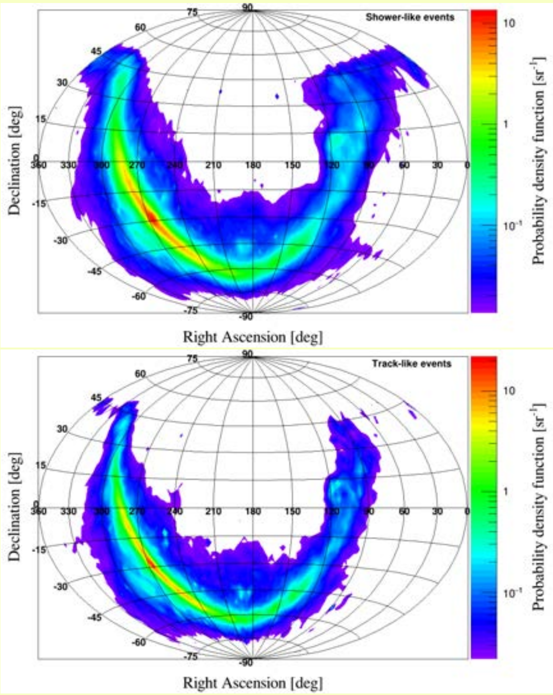


Distribution of the reconstructed E_μ of up-going muons in the Galactic Plane (black crosses) and average of the off-zone regions (red histogram).

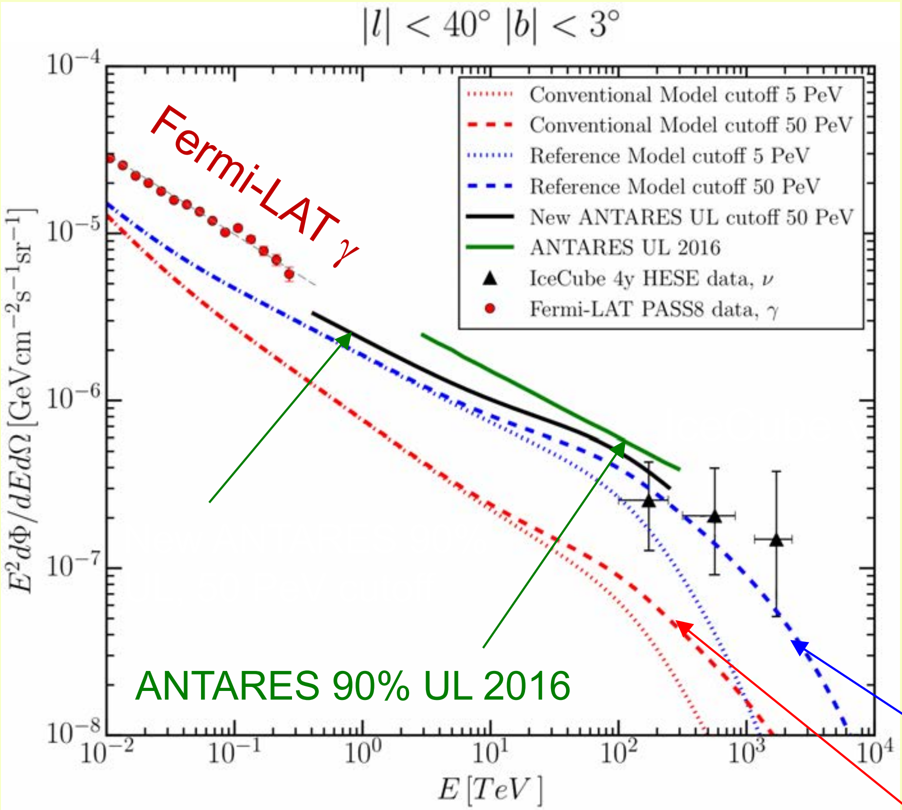
Search for neutrinos from the Galactic plane - 2

New analysis on tracks and showers, based on Max. Lik.

$$\mathcal{L}_{sig+bkg} = \prod_{\tau\in\{tr,sh\}} \prod_{i\in\tau} [\mu^{\tau}_{sig} \cdot pdf^{\tau}_{sig}(E_i, \alpha_i, \delta_i) + \mu^{\tau}_{bkg} \cdot pdf^{\tau}_{bkg}(E_i, \alpha_i, \delta_i)]$$



ANTARES arXiv:1705.00497v1
1 May 2017



KRA$_\gamma$ new model to describe the C.R. transport in our galaxy. It agrees with C.R. measurements (KASCADE, Pamela, AMS, Fermi-LAT, HESS). FERMI-LAT diffuse γ flux from along the galactic plane ($\pi^0 \rightarrow \gamma\gamma$) well explained above few GeV.

KRA$_\gamma$ allows to predict the ν flux by $\pi^{\pm}$ decays induced by galactic CR interactions

KRA$_\gamma$ 50PeV cut-off for CR
KRA$_\gamma$ 5PeV cut-off for CR

KRA$_\gamma$ assuming a neutrino flux ∝ $E^{-2.5}$ and a CR spectrum with 50 PeV cut-off can explain ~20% of the IceCube observed HESE.
ANTARES, with an good visibility of the Galactic Plane well suited to observe these fluxes or to put competitive limits: no signal found → set 90%C.L. upper limits.

Neutrinos from “FERMI Bubbles” ??

Search from a Mediterranean Cherenkov ν Telescope

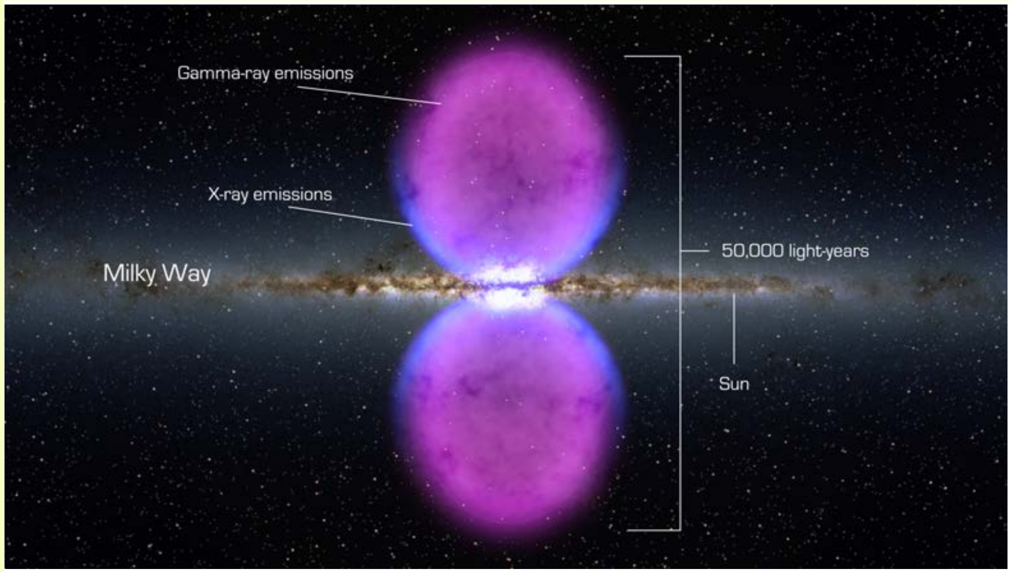
- FERMI detected hard γ emission (E^{-2}) up to 100 GeV in extended “bubbles” around Galactic Center, hard spectrum not compatible with Inverse Compton mechanism, M.Su et al., Ap.J.724 (2010).
- Models involving hadronic processes (e.g. Crocker & Aharonian, PRL 2011) predict significant neutrino fluxes.

$$\Phi_\nu \approx 0.4 \cdot \Phi_\gamma \Rightarrow \quad E_\nu^2 \frac{dN_{\nu_\mu + \bar{\nu}_\mu}}{dE_\nu} \approx 1.2 \div 2.4 \cdot 10^{-7}\, GeV\ cm^{-1} s^{-1} sr^{-1} = A_{theory}$$

- Estimates for the neutrino flux:

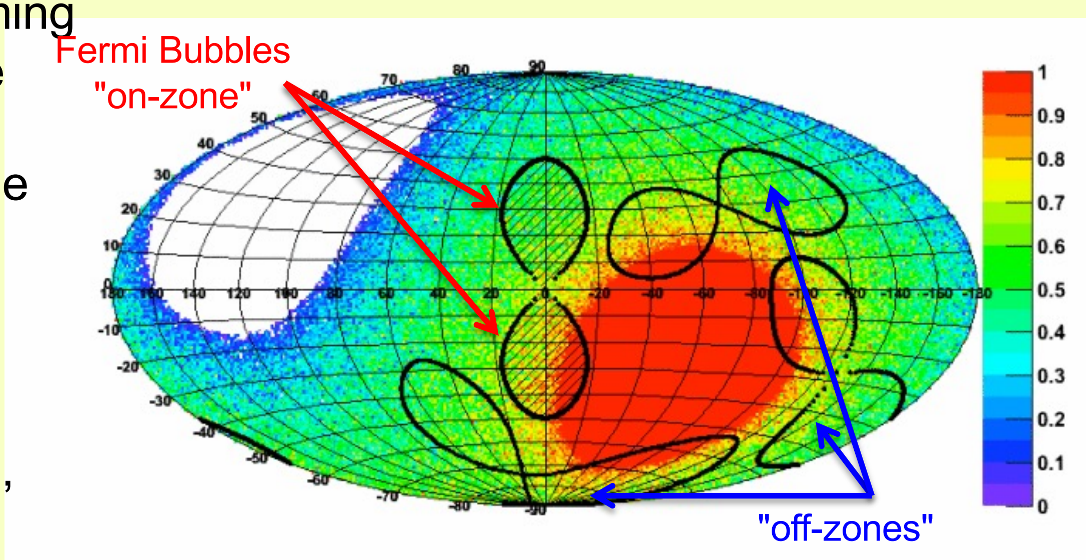
$$E_\nu^2 \frac{dN_{\nu_\mu + \bar{\nu}_\mu}}{dE_\nu} = A_{theory} e^{-\frac{E}{E_\nu^{cutoff}}}$$

- An exponential energy cut-off could affect the flux
- ANTARES, the present Mediterranean ν Telescope, searched for these neutrinos.



Search for a diffuse ν_μ flux from "FERMI Bubbles"

Compare the neutrino-like events coming from 3 "off-zones" (with the same size and shape as the Fermi Bubbles "on-zone") with the events coming from the Fermi Bubbles



Events selected as up-going and well reconstructed tracks.
Data sample, in the period 2008-2011, includes 806 days

In the 3 off-zones observed:

n_{bkg} = 9, 12 and 12 events

In the Fermi-Bubble **region**

n_{obs} = 16 events (1.2σ excess)

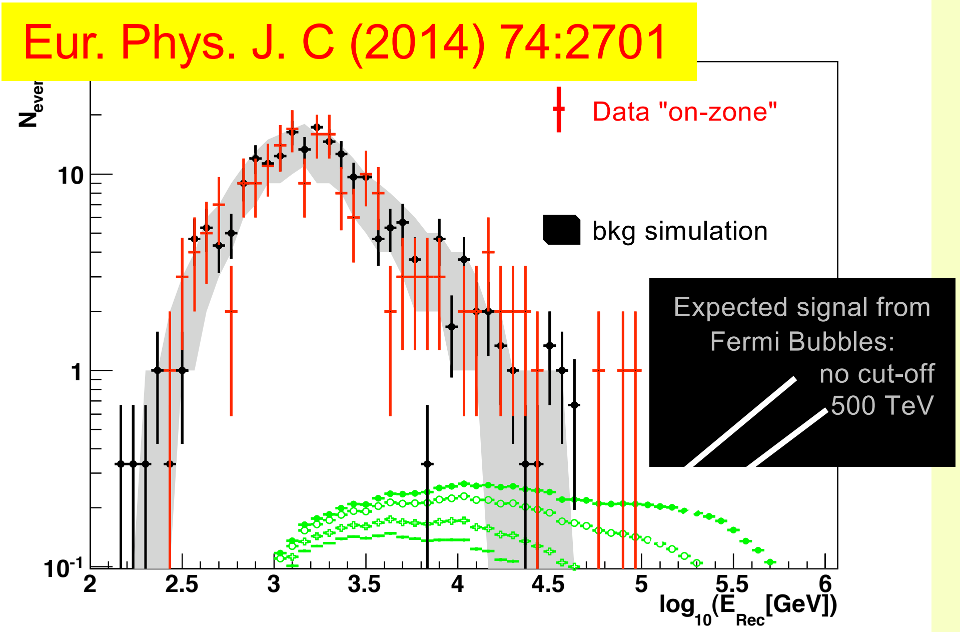
No statistically consistent signal observed

Assuming no cut-off

$E^2\Phi(E)_{90\%C.L.}$= 5.7•10^{-7} GeV cm^{-2} s^{-1} sr^{-1}

Assuming 500 TeV cut-off

$E^2\Phi(E)_{90\%C.L.}$= 8.7•10^{-7} GeV cm^{-2} s^{-1} sr^{-1}

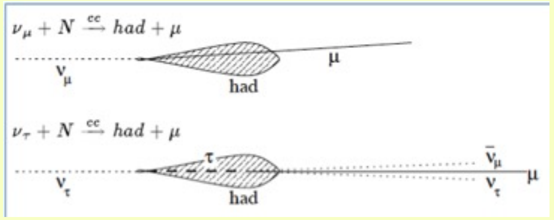


It's mandatory now !!!!

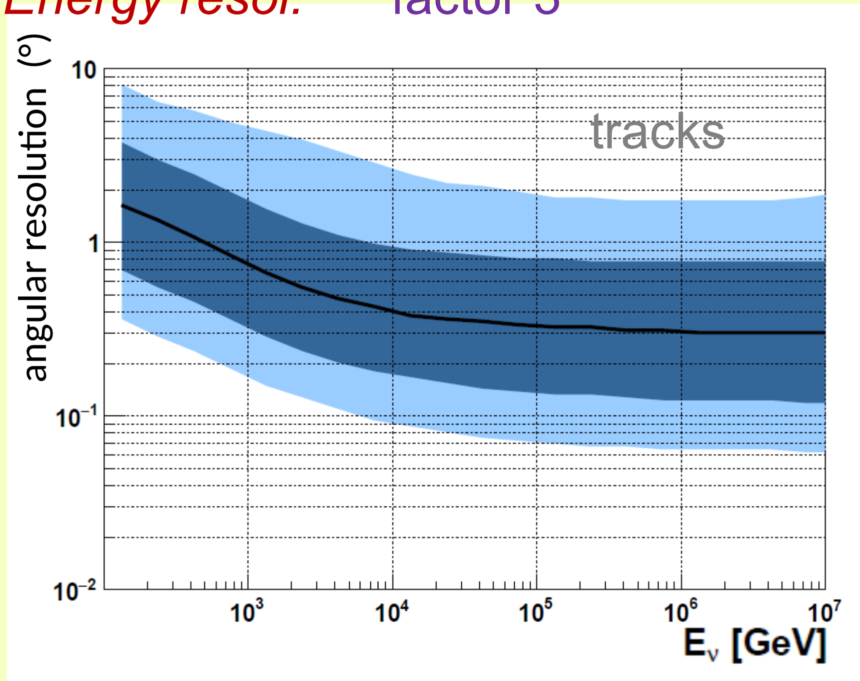
- **Let search for neutrino point like sources:**
  - Large size detector required (very small fluxes expected)
  - Very good accuracy in angular reconstruction (high background, the irreducible atmospheric background has to be subtracted statistically)

The ANTARES search for point-like ν sources based on two kind of events

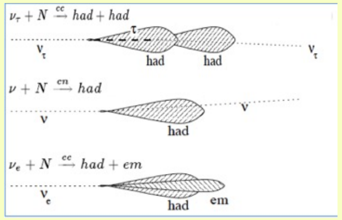
- Tracks: CC ν_μ or $\nu_\tau \rightarrow \mu$



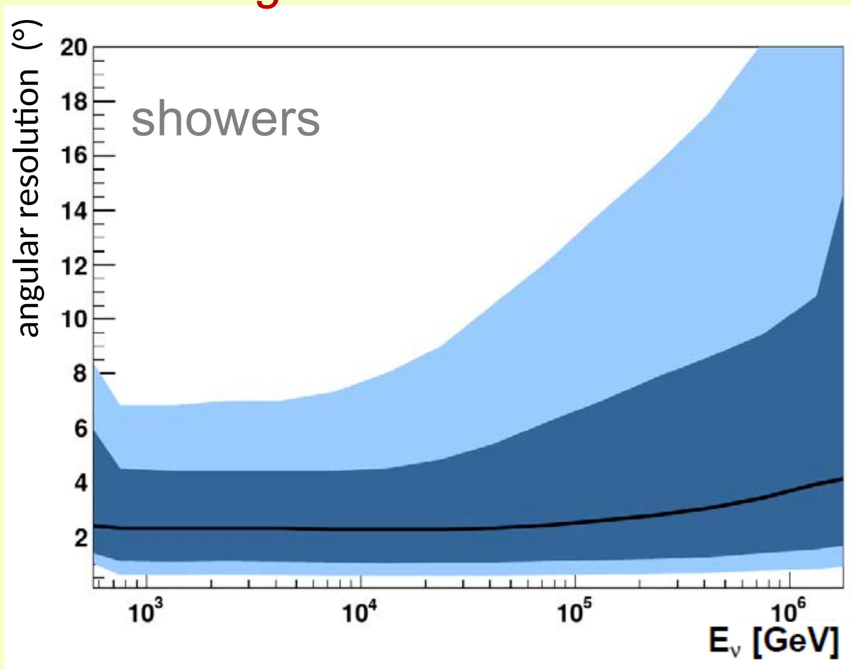
- Interaction can occur far from the detector providing a large *Effective Volume*
- *Angular resol*. $< 0.4°$ for $E_\nu > 10\ TeV$
- *Energy resol.* ~ factor 3



- Electronic or hadronic showers: NC and CC ν_e or $\nu_\tau \rightarrow$ showers



- Events contained in the detector: smaller *Effective Volume,*
- *Energy resolution ~ 5-10%*
- *Median angular resolution* $\sim 3°$

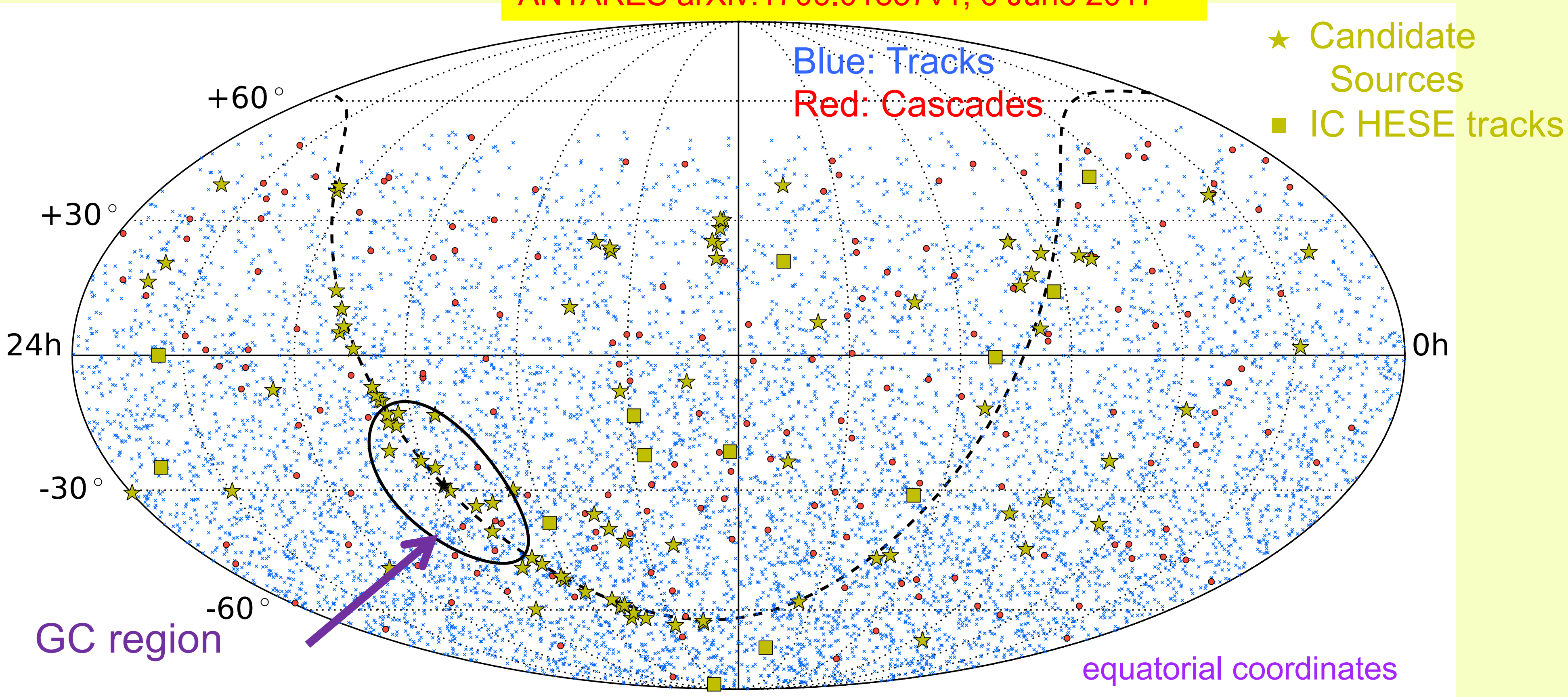


ANTARES Search for point-like cosmic ν Sources

9 years of ANTARES data searching for all neutrino flavours:
7629 "tracks" + 180 "shower" events passed the selection criteria

$$\log\mathcal{L}_{sig+bkg} = \sum_{S=tr.,sh.}\sum_{\tau=S} \log[\mu^{\tau}_{sig}\cdot\mathcal{F}^{\tau}_{sig}(\delta)\cdot\mathcal{P}^{\tau}_{sig,i}(E_i) + \mathcal{N}^{\tau}\cdot\mathcal{B}^{\tau}_{i}\cdot\mathcal{P}^{\tau}_{bkg,i}(E_i)] - \mu_{sig}$$

ANTARES arXiv:1706.01857v1, 6 June 2017

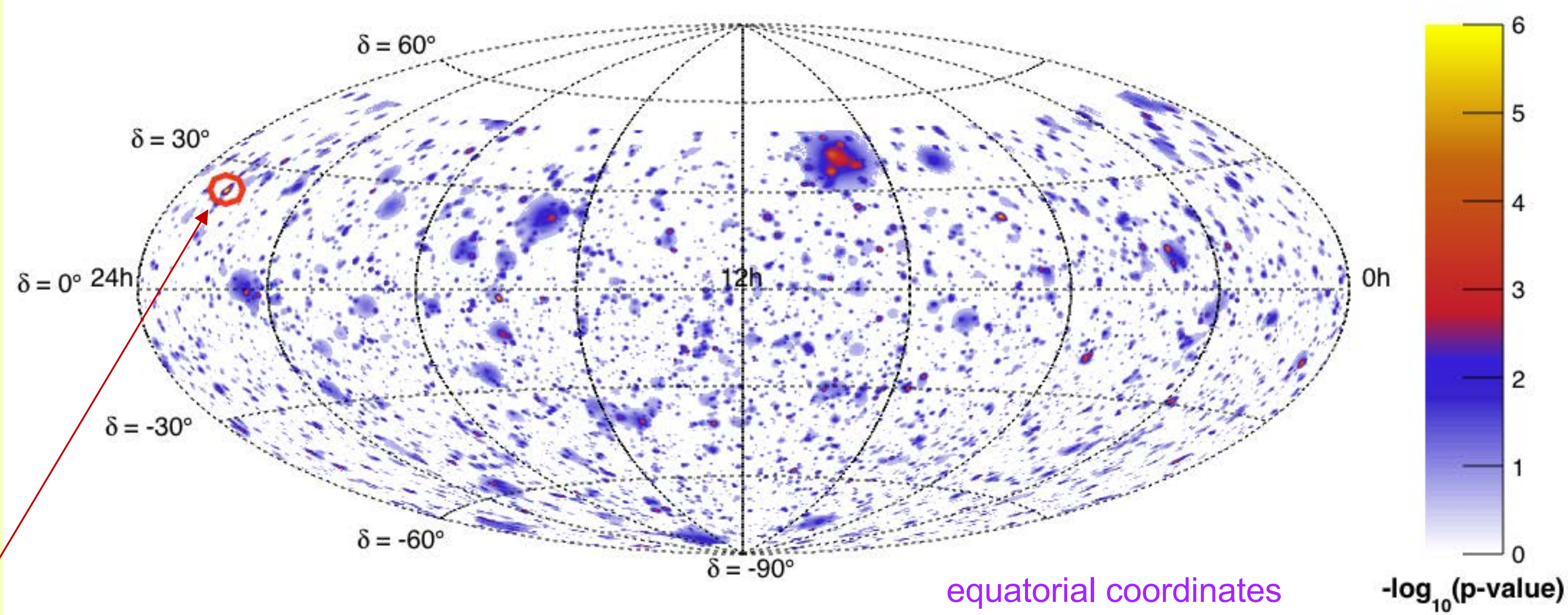


so far …. no significant excess has been found

ANTARES results: "full sky search" of ν sources

The visible sky of ANTARES divided on a $1^0 \times 1^0$ (r.a x decl.) boxes.
Maximum Likelihood analysis searching for clusters

ANTARES arXiv:1706.01857v1, 6 June 2017

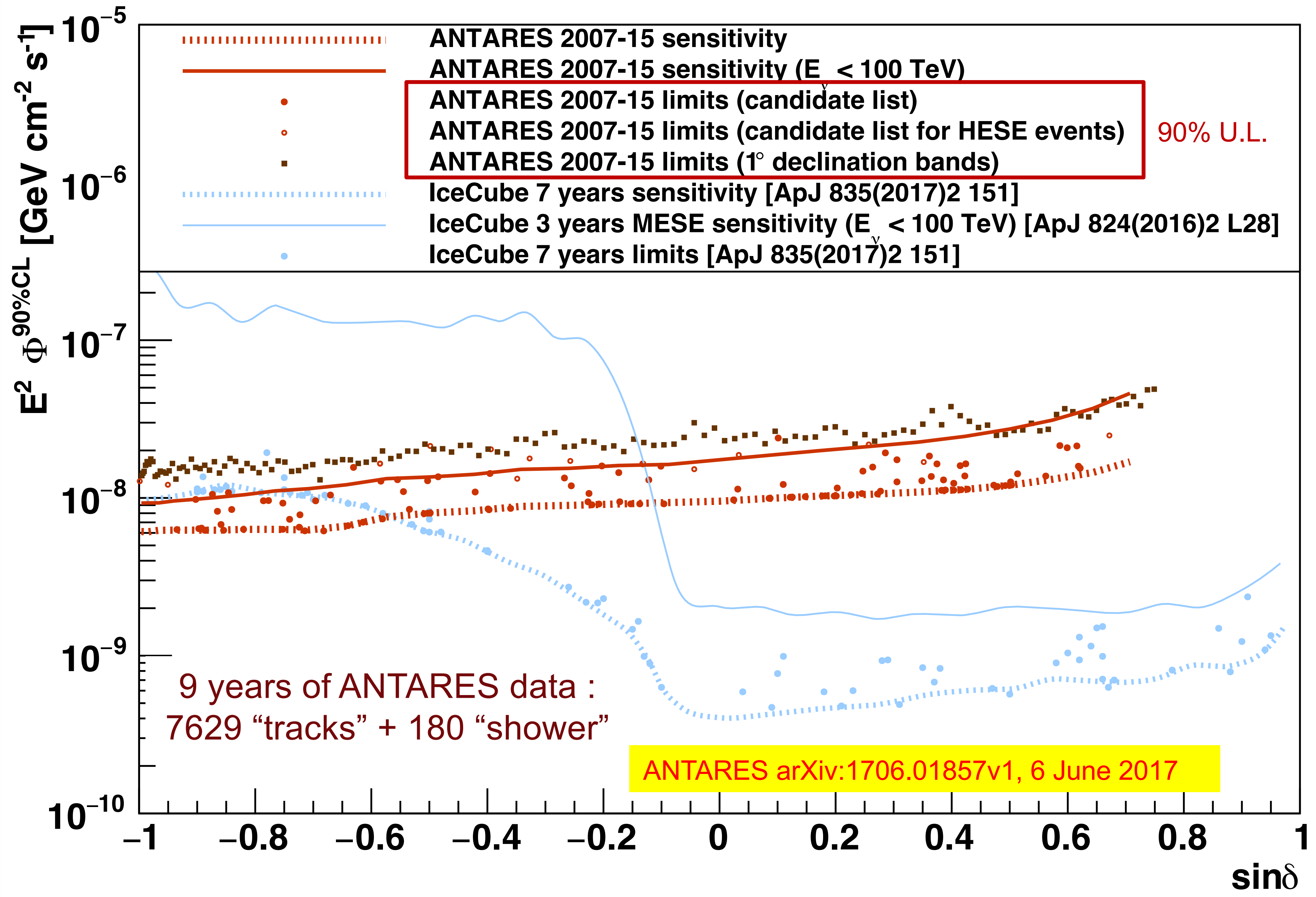


equatorial coordinates

The most significant cluster: decl. $\delta = 23.5^0$, r.a. $\alpha = 343.8^0$ has a pre-trial p-value of 3.84×10^{-6}

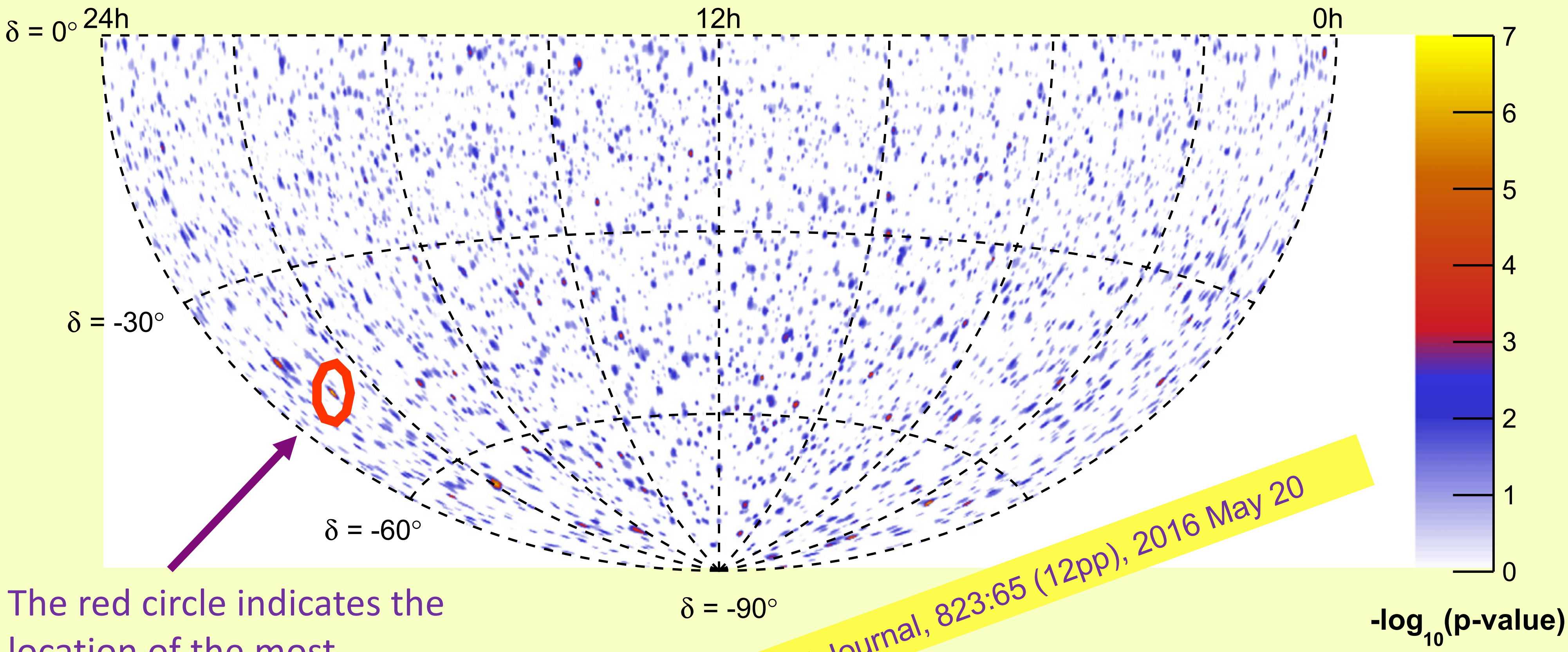
→ U. L. from this sky location $E^2 \frac{d\Phi}{dE} = 3.8 \times 10^{-8}$ GeV cm^{-2} s^{-1}

ANTARES results: "full sky search" of ν sources



Joint IceCube + ANTARES search for ν sources

Skymap of pre-trial p-values for the combined ANTARES 2007/12 and IceCube 40, 59, 79 point-source analyses.



The red circle indicates the location of the most significant cluster:
(0.7σ post-trial significance)

The Astrophysical Journal, 823:65 (12pp), 2016 May 20

The Multi-Messenger Search Programme with ANTARES

Neutrinos trigger others

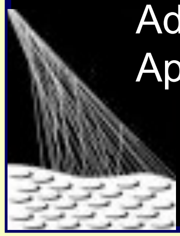
Others trigger neutrinos

ANTARES ⟺ VIRGO LIGO

common working group (GWHEN)
S. Adrián-Martínez et al.,
JCAP 06 (2013) 008

ANTARES ⟺ AUGER

Adrian-Martinez et al.,
ApJ 774 (2013) 008



TAToO
(Telescopes – ANTARES Target of Opportunity)

Optical follow-up of neutrino alerts for transient source search (GRBs, SNae).
Analysis in progress!

ANTARES ⟺ **Optical Telescopes** TAROT & ROSTE + more

Ageron *et al.*, *Astrop.Phys* 35 (2012) 530-536

Flaring Sources
(ν emission from γ-flaring blazars/μQuasars)

ANTARES ⟺ Gamma-Rays X-Rays

blazars: APP 36 (2012) 304;
μQuasars: JHEAp, 3-4 (2014) 9-7

GCN (Gamma-ray Coordination Network)

ANTARES ⟺ GCN

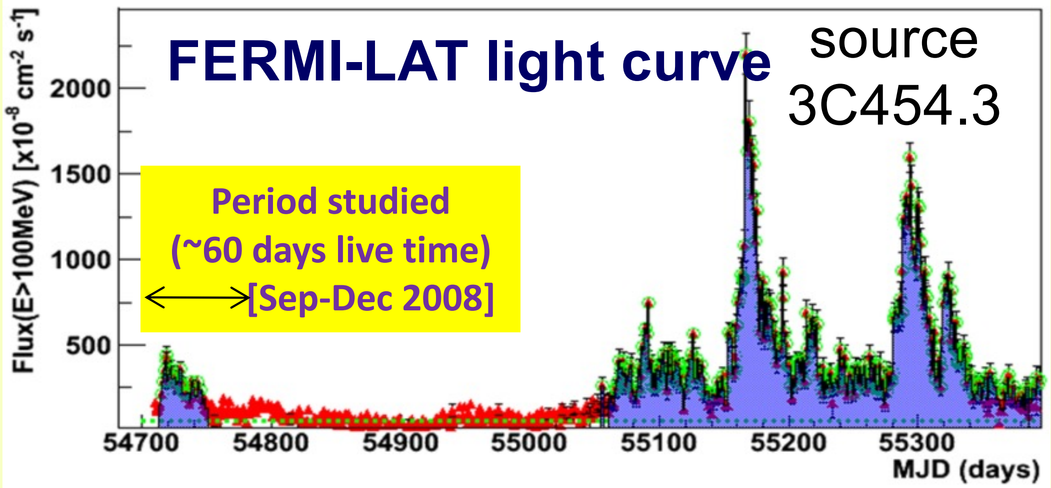
A&A 559, A9 (2013),
JCAP 1303 (2013) 006

Search for ν from flaring AGN - 2008

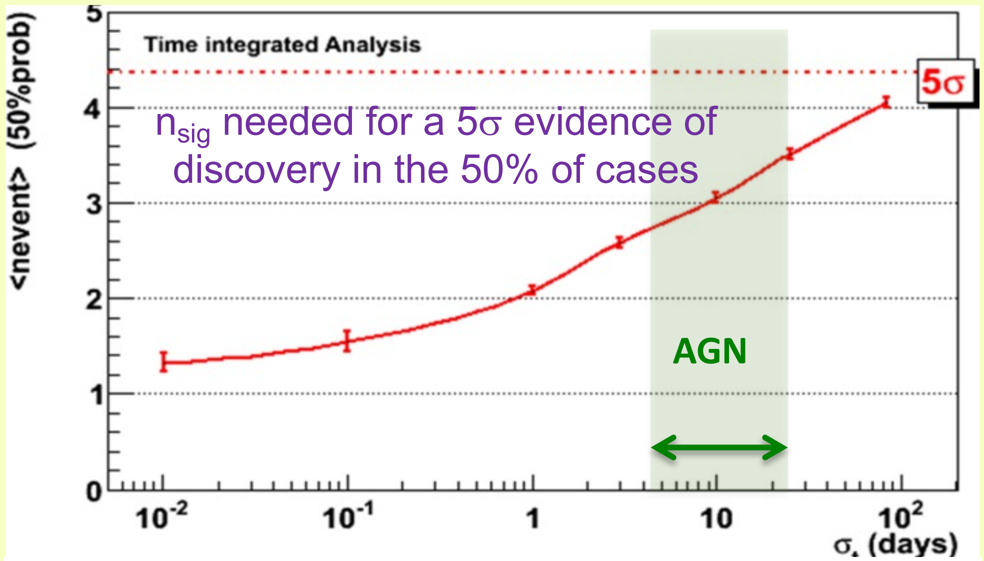
ν emission from γ-flaring blazars

Astropart. Phys. 36 (2012) 204–210, arXiv:1111.3473 [astro-ph.HE]

ANTARES ⇔ FERMI



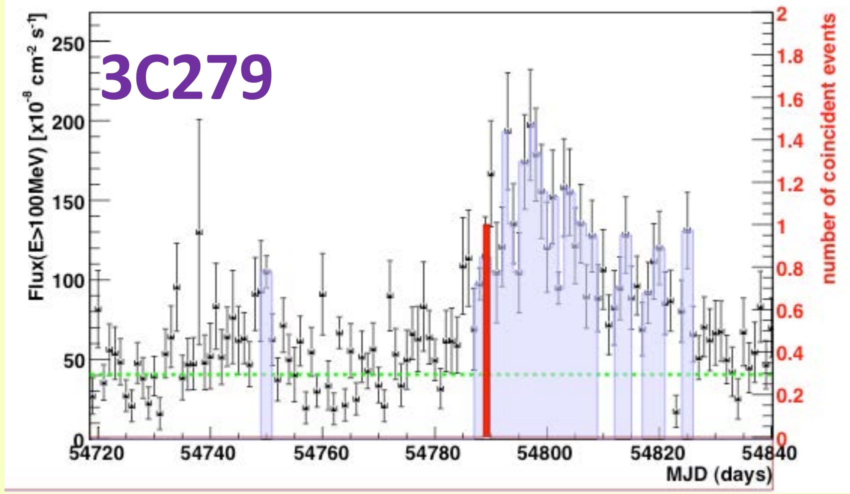
10 sources selected from the FERMI/LAT catalogue, showing a large variability (flaring state) in the period studied for this analysis.



Performance of the time-dependent analysis

RESULTS

- **1 neutrino candidate event compatible with the time/space distribution (Δα=0.56°) of 3C279 with probability (p-value) = 1% (but post trial probability = 10%)**
- **Fluence Upper Limits**
- **RESULTS ARE VERY PROMISING, new analisys going on with 2008-2011 FERMI data**



Search for ν from flaring AGN – 2008-2011

[40 sources, 86 flaring periods] (ANTARES ⟺ FERMI)

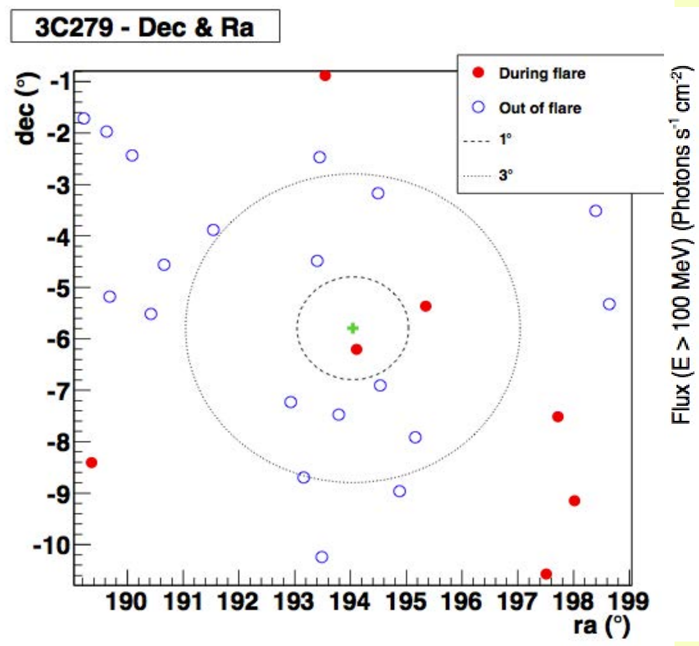
…to be extended to IACT blazars (HESS, MAGIC, VERITAS)

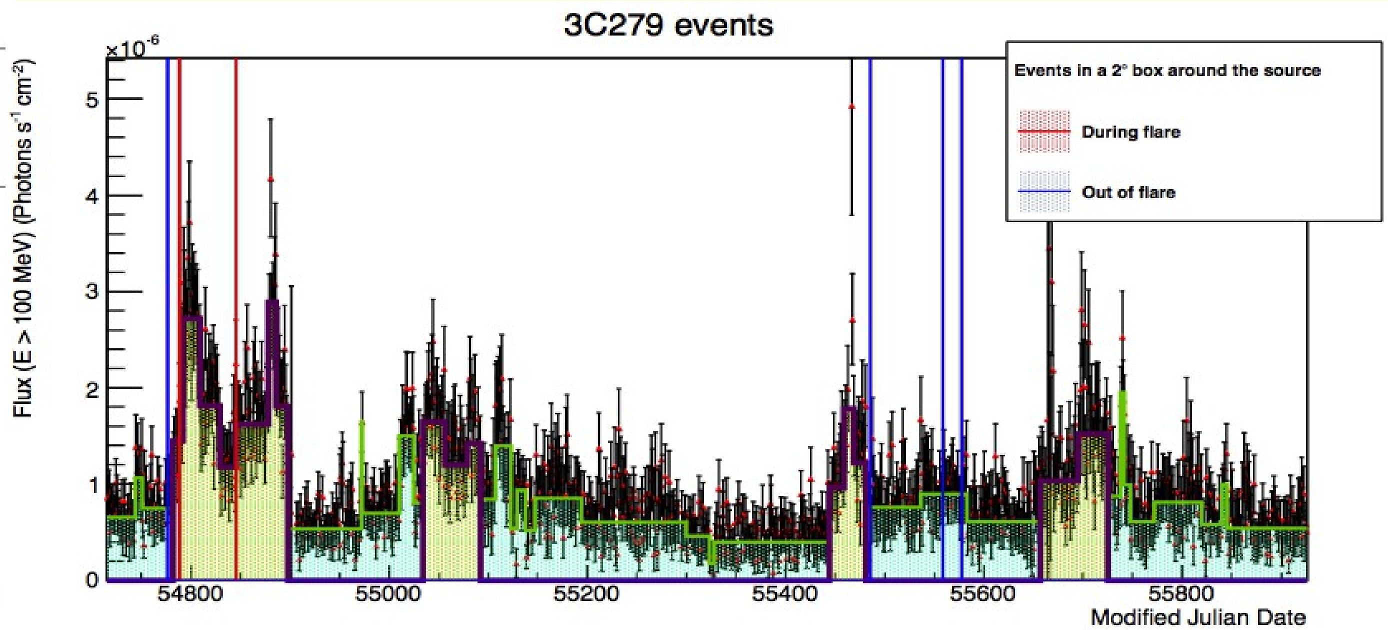
PRELIMINARY

6 specially significant flares

p-values (Pre-trial/Post-trial)				
Source	E^{-1}	E^{-2}	$E^{-2}exp^{-E/10TeV}$	$E^{-2}exp^{-E/1TeV}$
3C 279	**0.17%/9.91%**	0.33%/14.5%	5.31%/73.5%	6.68%/89.4%
PKS 1124-186	1.94%/54.3%	**1.07%/41.29%**	1.68%/55.1%	3.85%/82.2%
PKS 1830-211	2.67%/69.5%	**1.43%/52.8%**	3.08%/72.6%	6.64%/91.6%
3C 454.3	**3.53%/67.7%**	—	—	—
4C +21.35	**3.68%/68.9%**	—	5.31%/73.5%%	—
CTA 102	—	**4.62%/86.5%**	—	—

(—) Those cases have a fitted signal $n_{sig} \lesssim 0.001$ and p-value∼100%

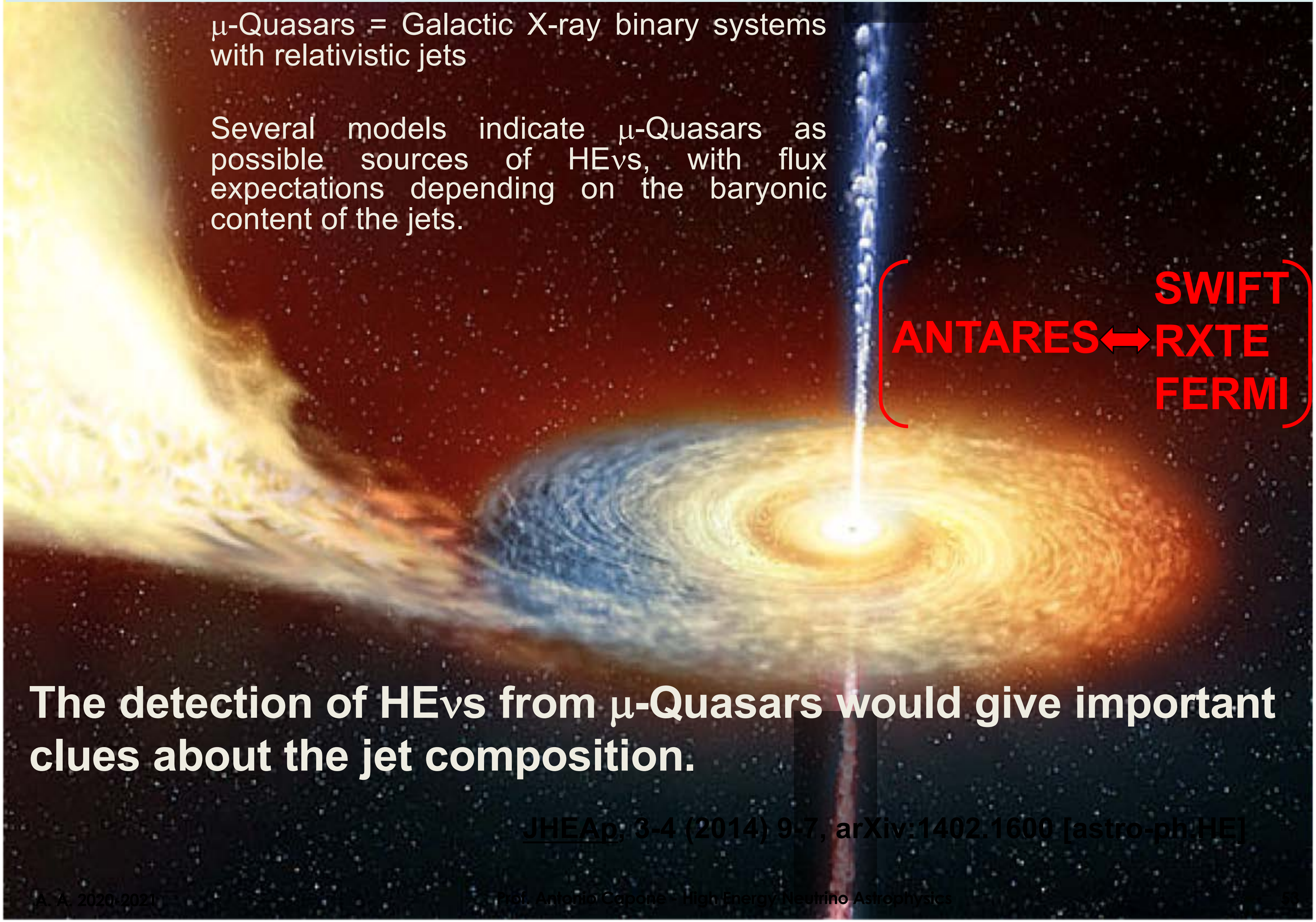




ANTARES and ν from μ-Quasars

μ-Quasars = Galactic X-ray binary systems with relativistic jets

Several models indicate μ-Quasars as possible sources of HEνs, with flux expectations depending on the baryonic content of the jets.



ANTARES ⟺ SWIFT / RXTE / FERMI

The detection of HEνs from μ-Quasars would give important clues about the jet composition.

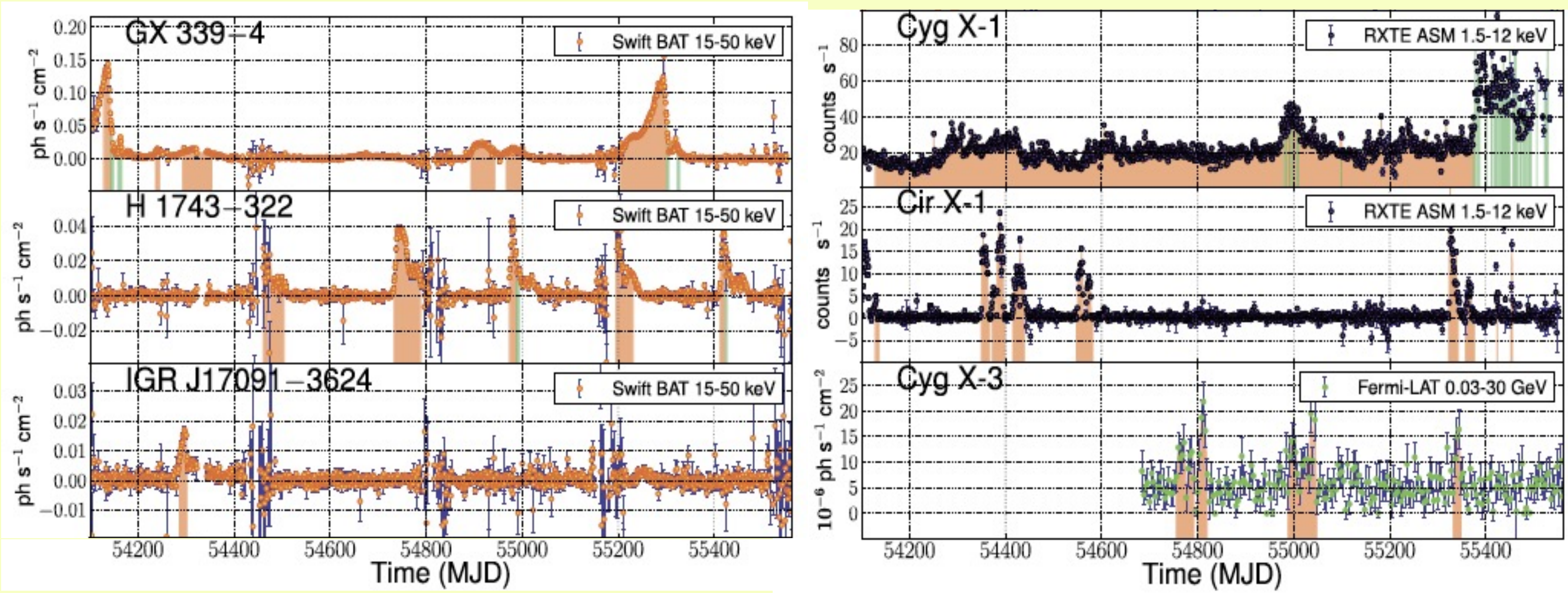
JHEAp, 3-4 (2014) 9-7, arXiv:1402.1600 [astro-ph.HE]

ANTARES and ν from μ-Quasars

ANTARES data set: 2007-2010 → 6 sources selected, with requisites:

- -in the ANTARES visible sky;
- -showing an outburst in the period 2007-2010.

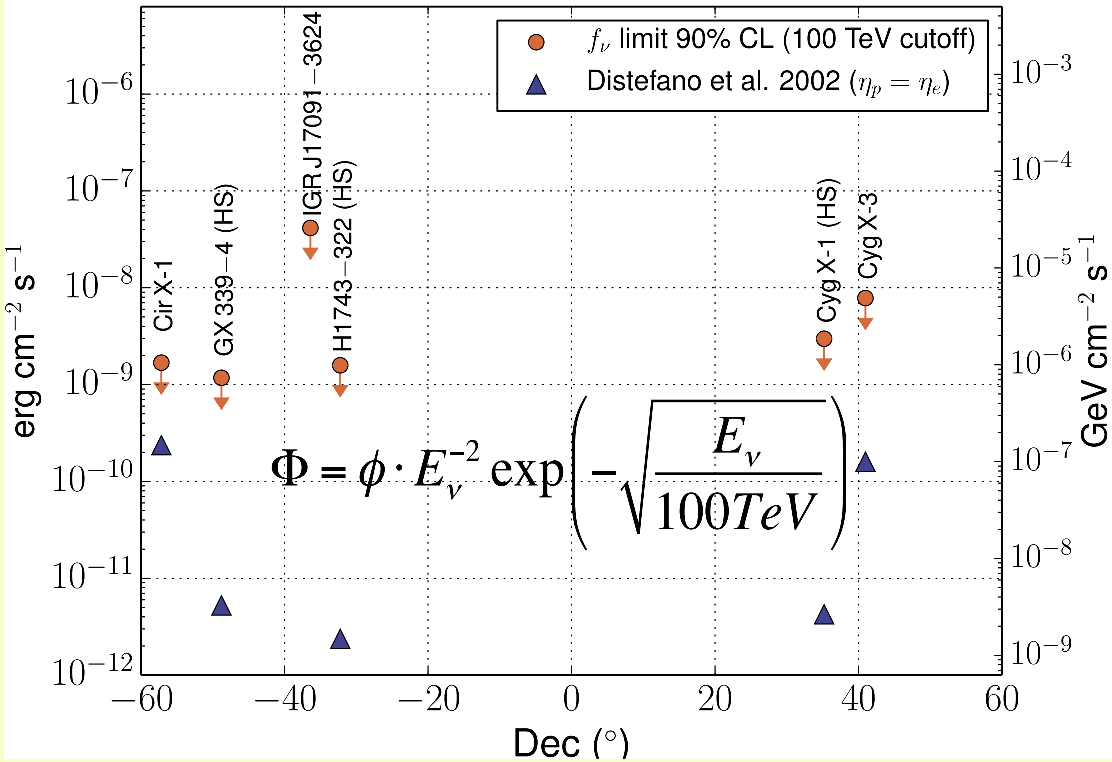
Time-Dependent Analysis: for each source, the data analysis has been restricted to the flaring time periods, selected in a multi-wavelength approach (X-rays/γ-rays) and with a dedicated outburst selection algorithm (+ additional criteria, customized for the features of each μQ).



ANTARES and ν from μ-Quasars

Data Analysis & Results

JHEAp, 3-4 (2014) 9-7, arXiv:1402.1600 [astro-ph.HE]



[systematic uncertainties included]

METHOD

- unbinned search
- likelihood ratio test statistic
- quality cuts optimized for 5σ discovery

RESULTS

- no statistically significant excess above the expected atmospheric bkg

90% C.L. upper limits on the flux normalization ϕ

…assuming a neutrino spectrum following:

- a power-law
- a power-law with expo. cut-off

→ **INFER INFORMATION on JET COMPOSITION: constraints on η_p/η_e = ratio of proton to electron luminosity in the jet**

A Multi-Messenger Search of ν from GRB

GCN alerts trigger the recording of all the low level triggers. A continuous buffer ensures the availability of the data before the alert

GCN=Gamma Ray Burst Coordination Network

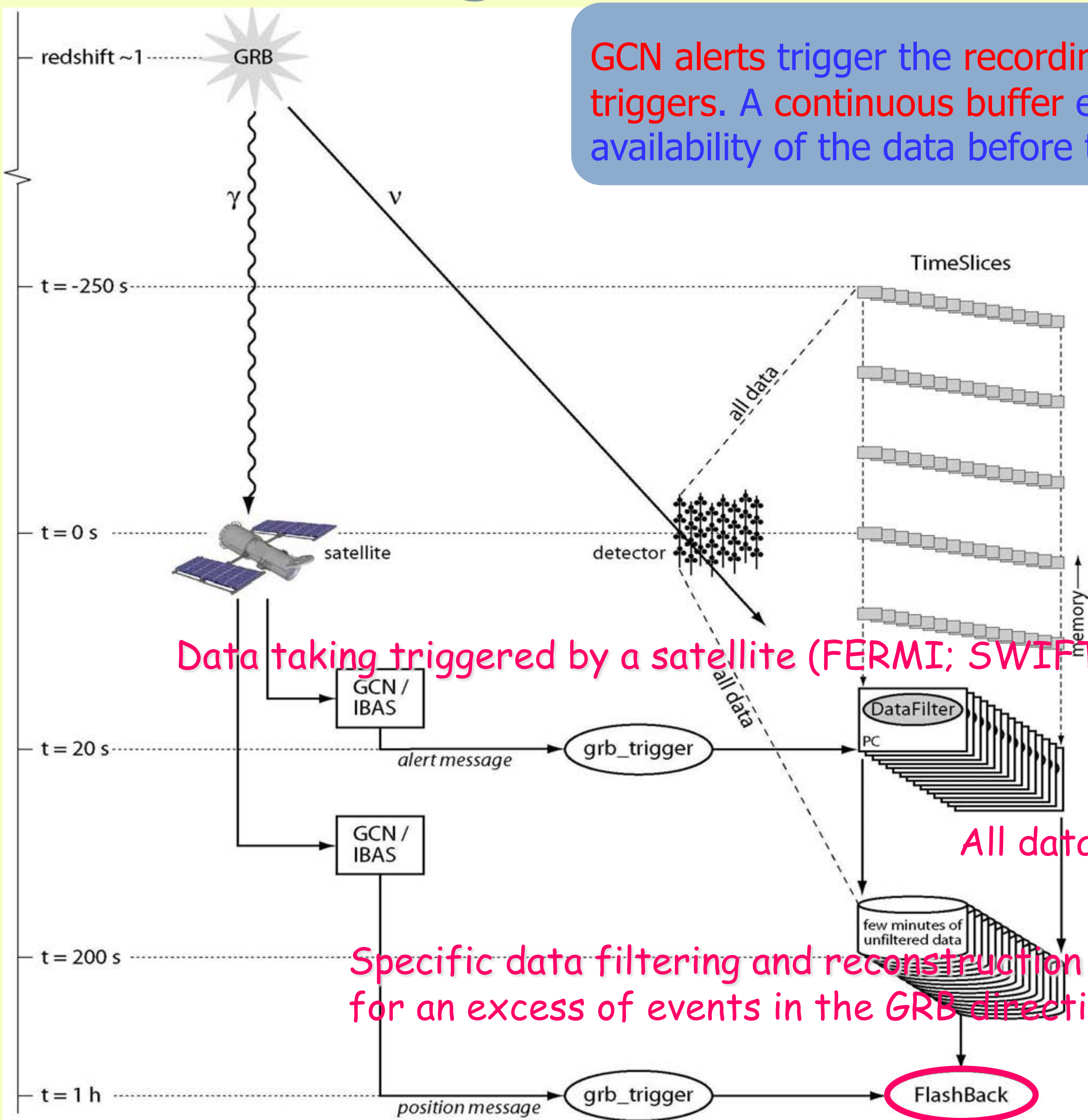
t =-250 s

t = 0 s

t = 20 s

t = 200 s

t = 1 h



Data taking triggered by a satellite (FERMI; SWIFT, INTEGRAL)

All data written to disk

Specific data filtering and reconstruction by searching for an excess of events in the GRB direction (offline)

ANTARES Multi-messenger program:
search for ν_μ from very bright GRB sources

The search was performed for 4 bright GRBs:

GRB080916C, GRB 110918A, GRB 130427A and GRB 130505A)

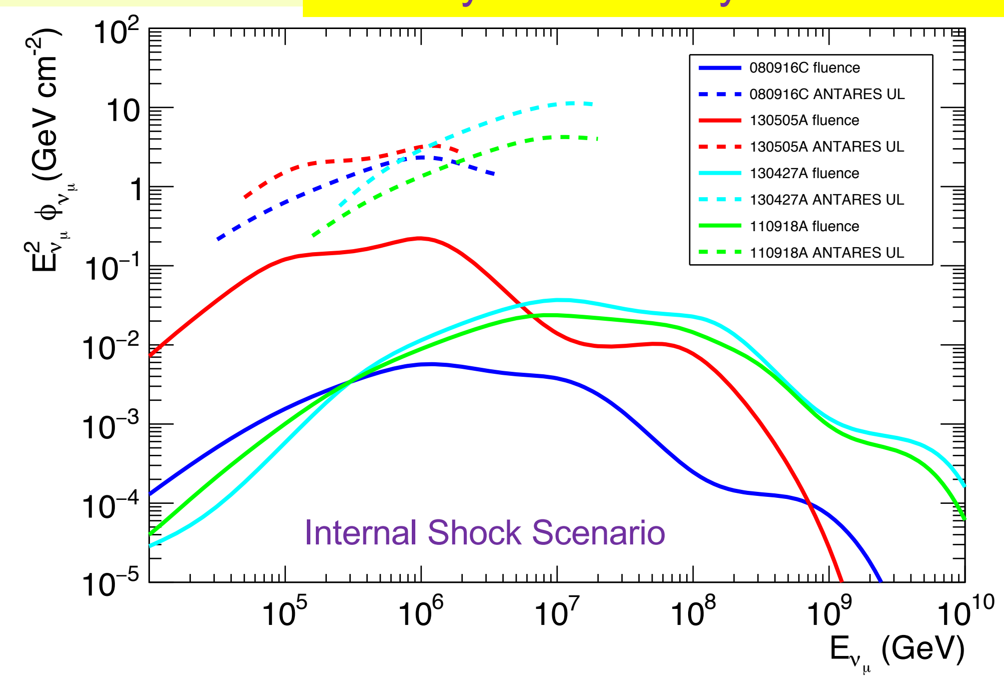
observed between 2008 and 2013.

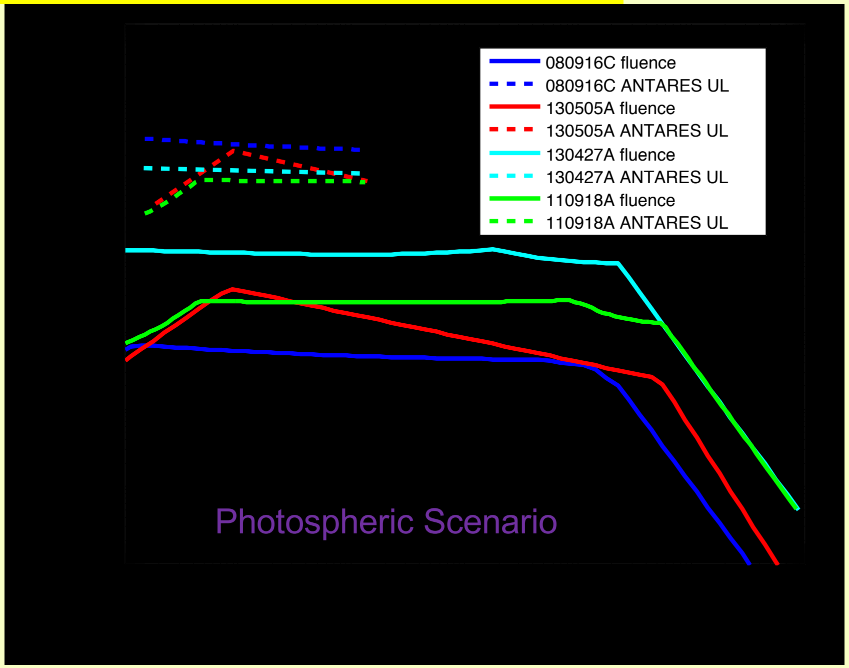
The expected neutrino fluxes evaluated in the framework of:

- the fireball model have with the internal shock scenario ($E_\nu \geq 100TeV$)
- the photospheric scenario ($E_\nu < 10TeV$)

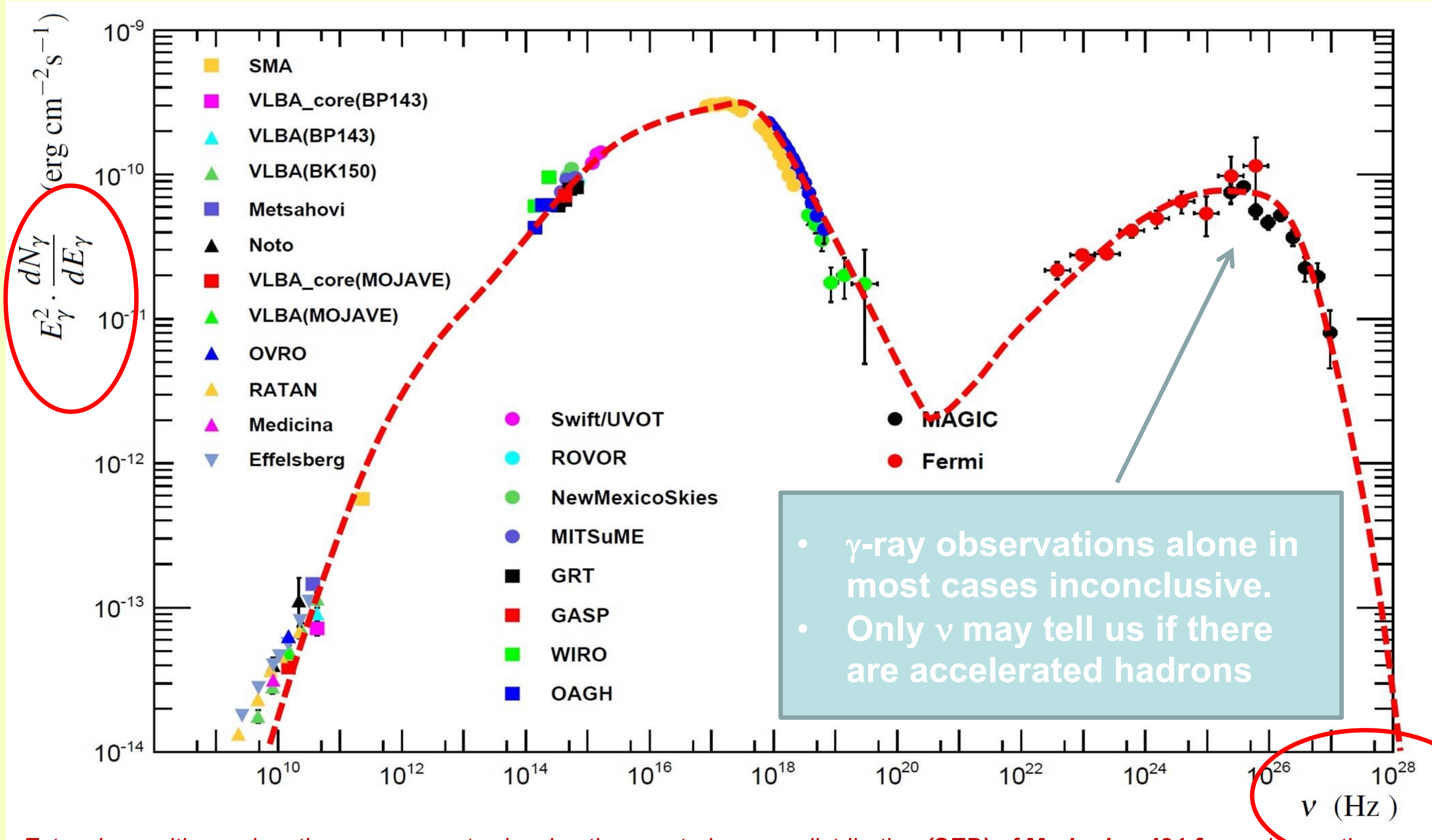
No events have been found: 90% C.L. upper limits to the neutrino fluence.

Monthly Notices Royal Astronomical Society (2017) 469 (1): 906-915.





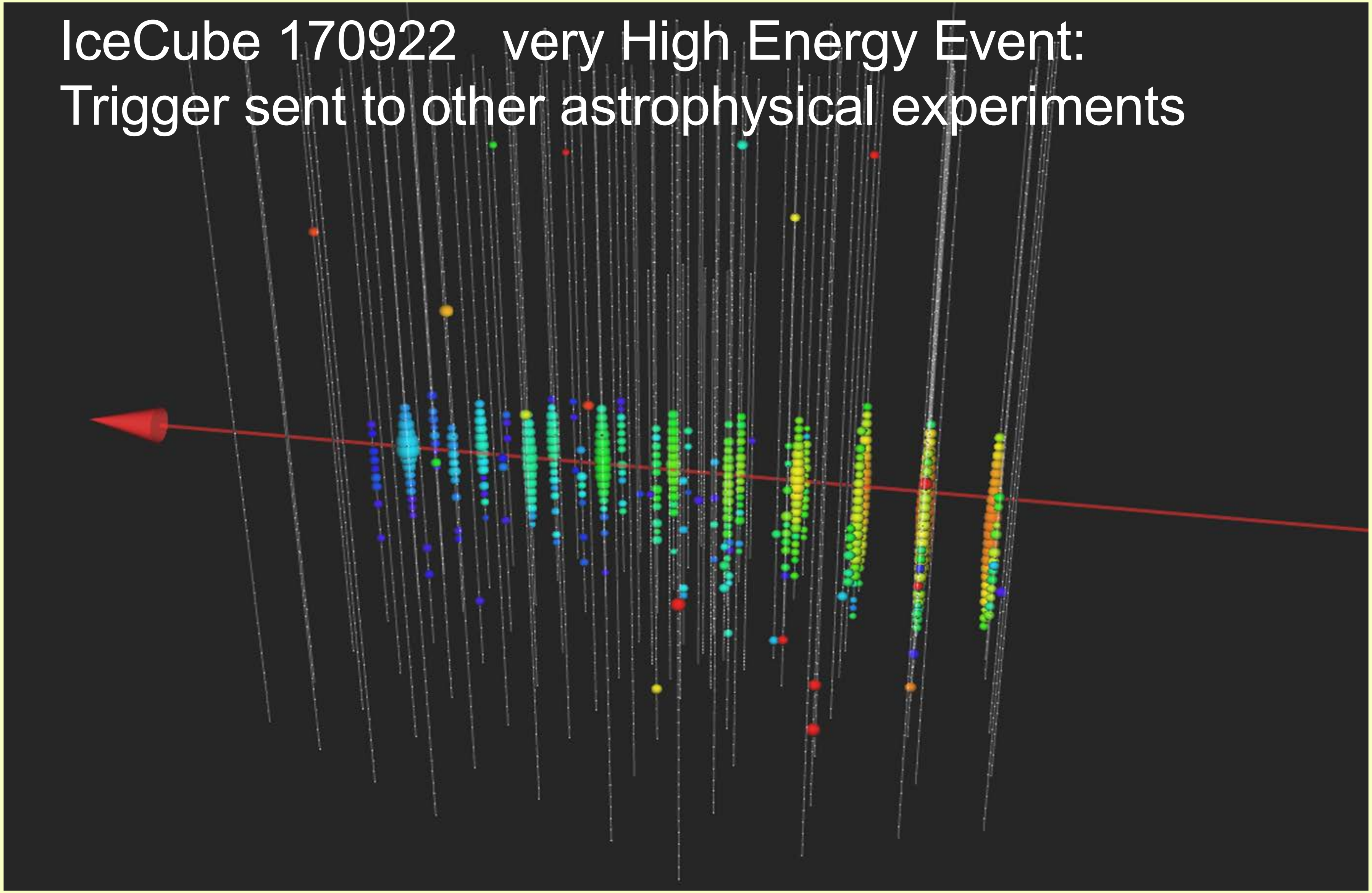
Multi-wavelength observation: Mrk421
an example



- γ-ray observations alone in most cases inconclusive.
- Only ν may tell us if there are accelerated hadrons

*Extensive multi-wavelength measurements showing the spectral energy distribution **(SED)** of **Markarian 421 from** observations made in 2009. The dashed line is a fit of the data with a leptonic model. Abdo et al. ApJ 736(2011) 131 for the references to the data*

Triggering on Neutrino Telescopes site



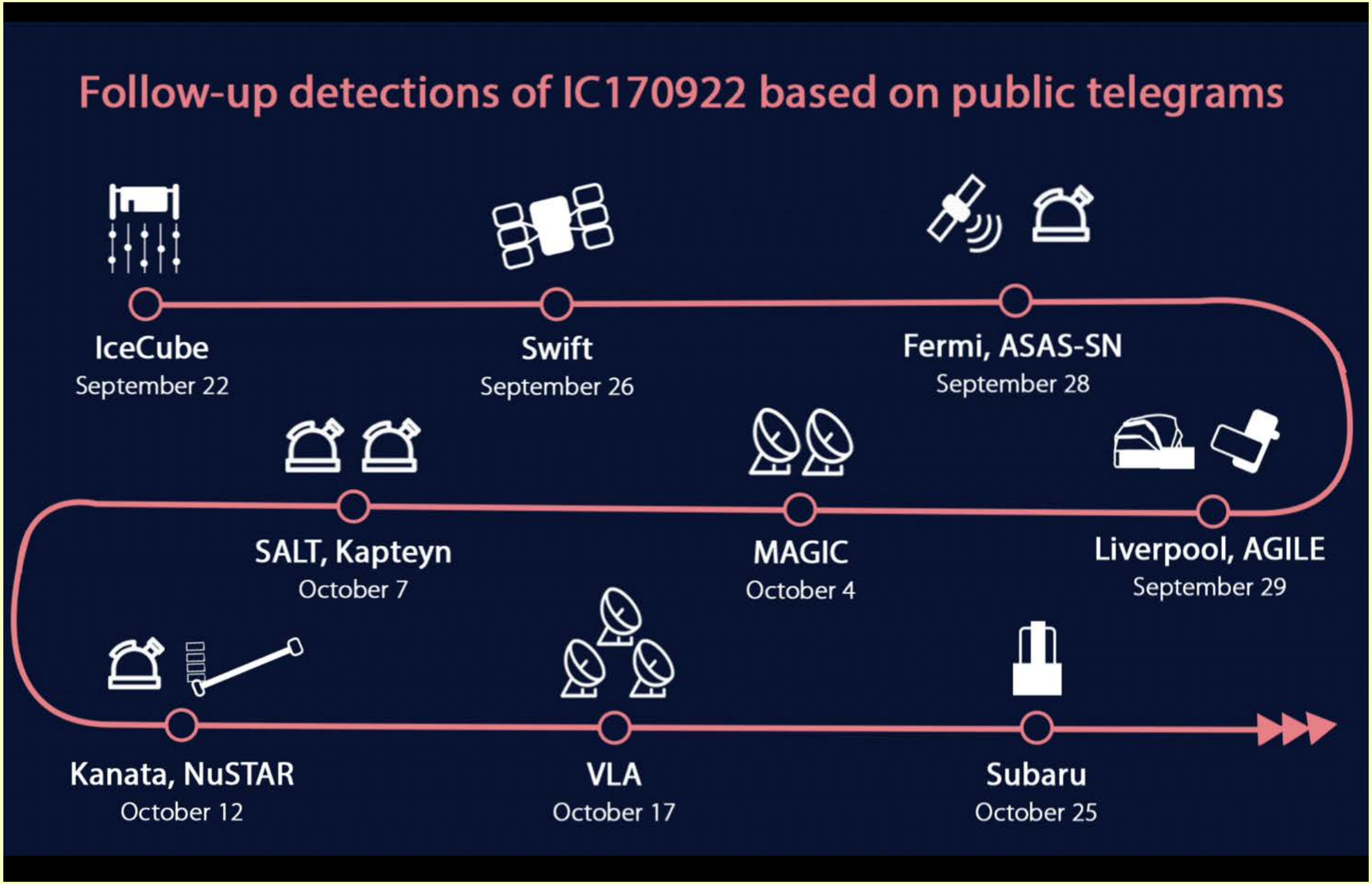
Triggering on Neutrino Telescopes site

IceCube Trigger

43 seconds after trigger, GCN notice was sent

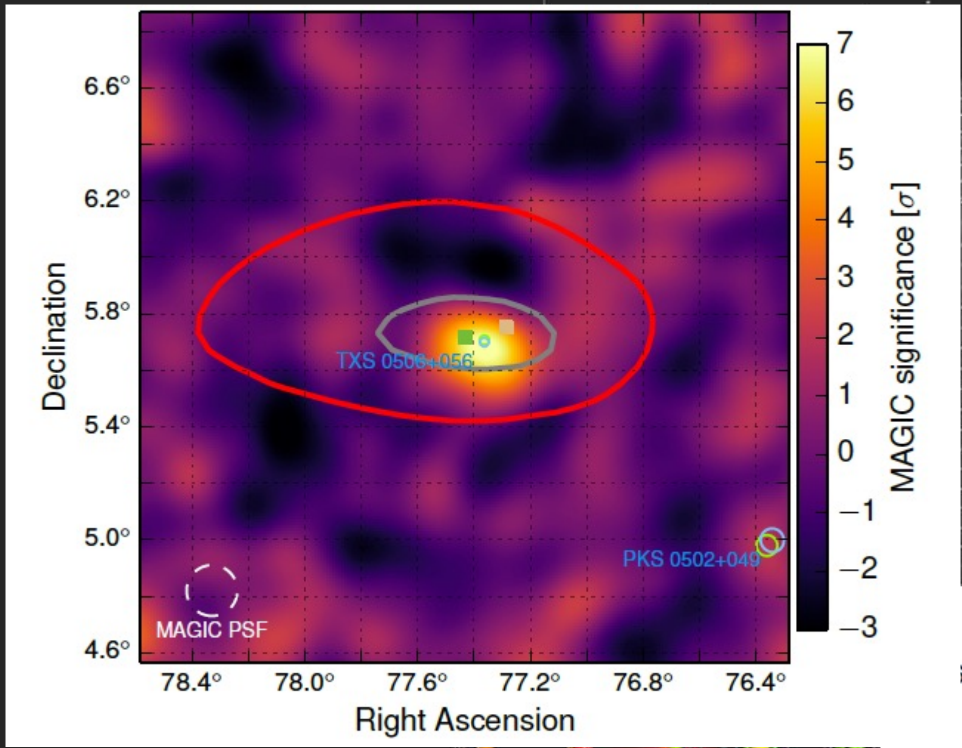
```
//////////////////////////////////////////////////////////////////////
TITLE:            GCN/AMON NOTICE
NOTICE_DATE:      Fri 22 Sep 17 20:55:13 UT
NOTICE_TYPE:      AMON ICECUBE EHE
RUN_NUM:          130033
EVENT_NUM:        50579430
SRC_RA:            77.2853d {+05h 09m 08s} (J2000),
                   77.5221d {+05h 10m 05s} (current),
                   76.6176d {+05h 06m 28s} (1950)
SRC_DEC:           +5.7517d {+05d 45' 06"} (J2000),
                   +5.7732d {+05d 46' 24"} (current),
                   +5.6888d {+05d 41' 20"} (1950)
SRC_ERROR:        14.99 [arcmin radius, stat+sys, 50% containment]
DISCOVERY_DATE:   18018 TJD;   265 DOY;   17/09/22 (yy/mm/dd)
DISCOVERY_TIME:   75270 SOD {20:54:30.43} UT
REVISION:         0
N_EVENTS:         1 [number of neutrinos]
STREAM:           2
DELTA_T:          0.0000 [sec]
SIGMA_T:          0.0000e+00 [dn]
ENERGY :          1.1998e+02 [TeV]
SIGNALNESS:       5.6507e-01 [dn]
CHARGE:           5784.9552 [pe]
```

Triggering on Neutrino Telescopes site

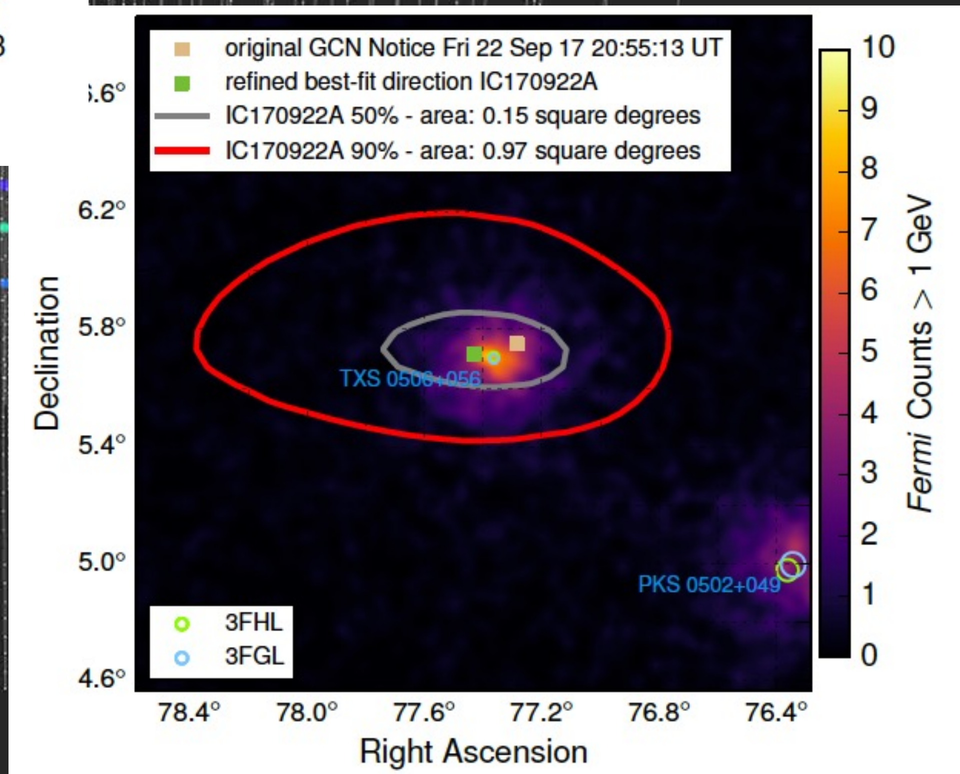


IceCube 170922

Fermi
detects a flaring blazar within 0.06°



MAGIC
detects emission of > 100 GeV gammas



multiwavelength campaign launched by IC 170922

IceCube, *Fermi* –LAT, MAGIC, Agile, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kapteyn, Kanata, KISO, Liverpool, Subaru, *Swift*, VLA, VERITAS

- neutrino: time 22.09.17, 20:54:31 UTC
  energy 290 TeV
  direction RA 77.43^o Dec 5.72^o
- Fermi-LAT: flaring blazar within 0.06^o (7x steady flux)
- MAGIC: TeV source in follow-up observations
- follow-up by 12 more telescopes
- → IceCube archival data (without look-elsewhere effect)
- → Fermi-LAT archival data