Searching for Neutrino Sources with the ANTARES Telescope

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Aspen Summer Workshop
GeV & TeV Sources in the Milky Way

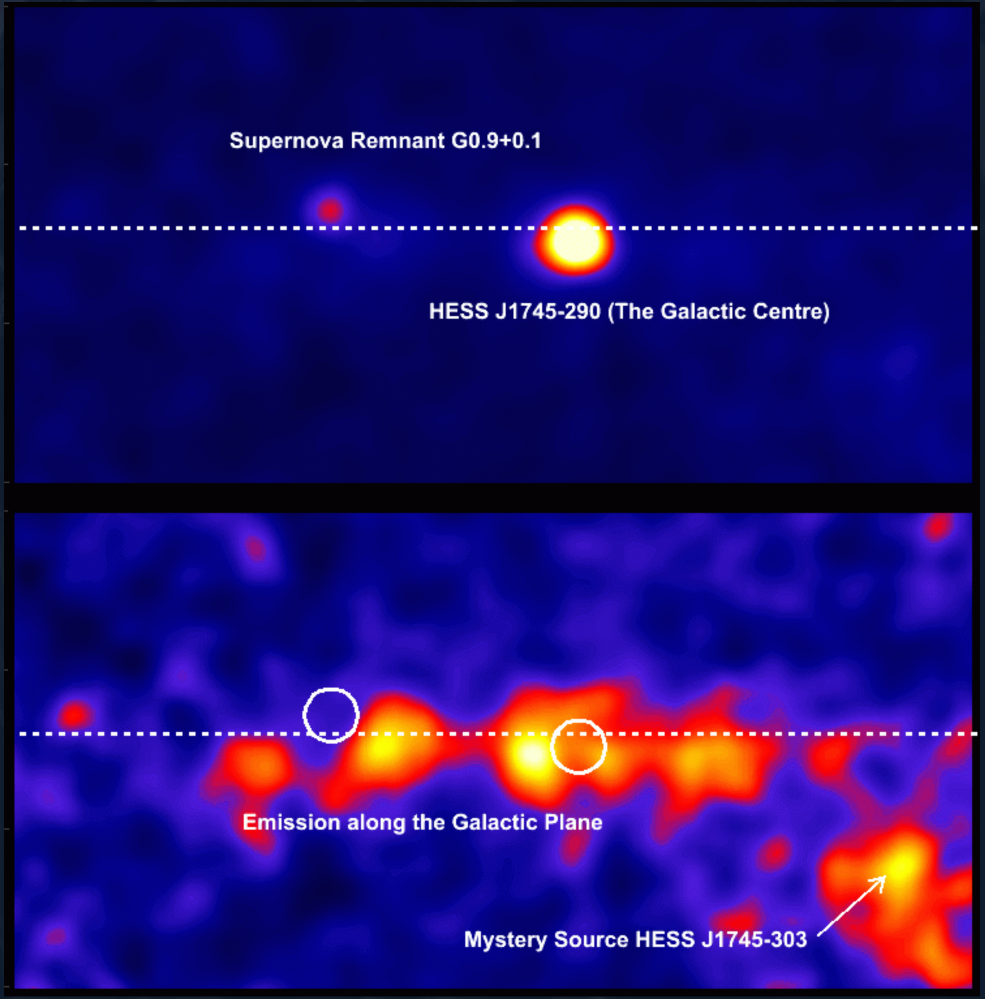
Neutrino Astronomy

High energy photon sources have been found

Produced how?

Leptonic interactions?

Hadronic interactions?



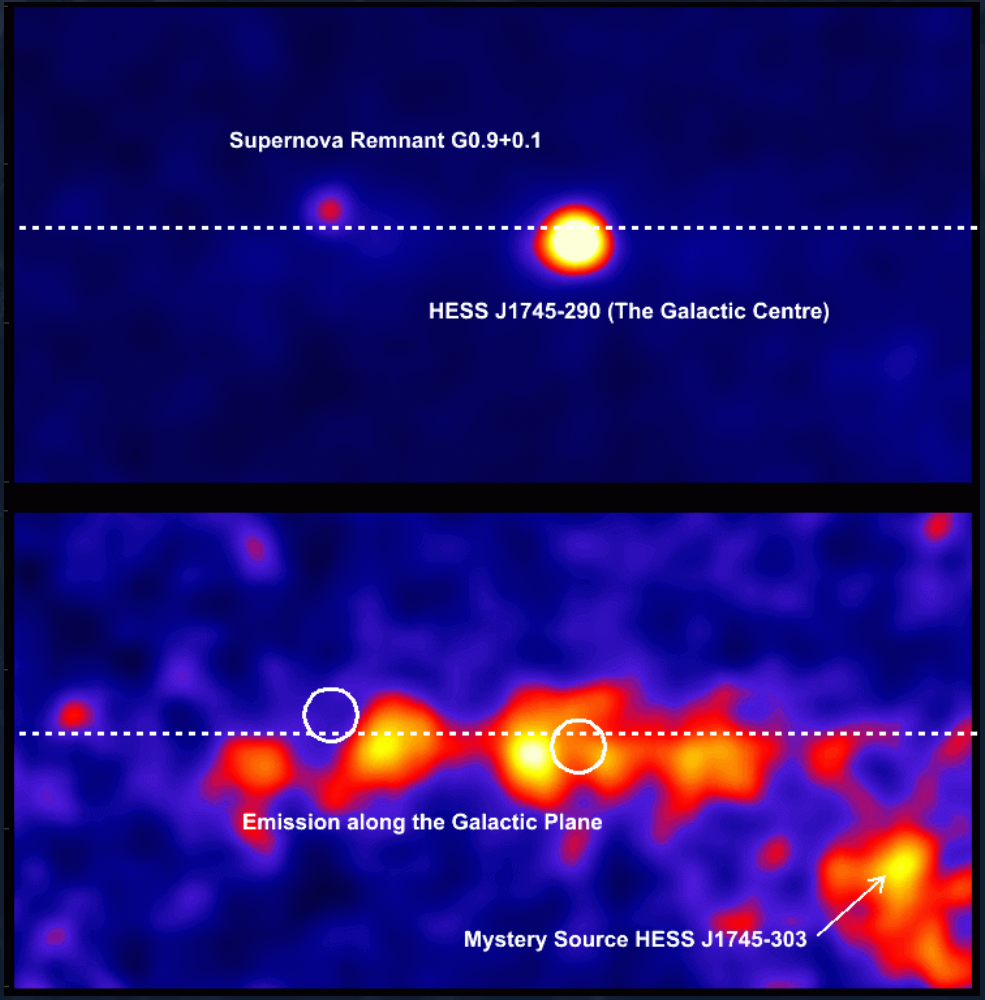
[From H.E.S.S Press Release]

Neutrino Astronomy

High energy photon sources have been found

Produced how?

If source emits HE neutrinos, it is accelerating hadrons!



[From H.E.S.S Press Release]

Neutrino Astronomy

Main goal

- Find cosmic neutrino sources
- Determine association with cosmic ray accelerators
  - GC, SNR, GRB, AGN, (unknown?)

But wait, there's more!

- Indirect dark matter searches
- Exotic particle searches
- Geophysical, biological sciences
- ...

Neutrino Astronomy

Benefit of (high energy) ν's

Neutrinos reveal their source

- Low cross section, no charge
- Photons: absorbed (in dust, etc.)
- Protons / ions: deflected by magnetic fields

Challenge of ν's

Hard to detect

- Low cross section, no charge

Neutrino Astronomy

Detection principle

Neutrino interacts
(with nucleus)

Neutrino Astronomy

Detection principle

Fast lepton produced

Neutrino Astronomy

Detection principle

Cherenkov radiation measured

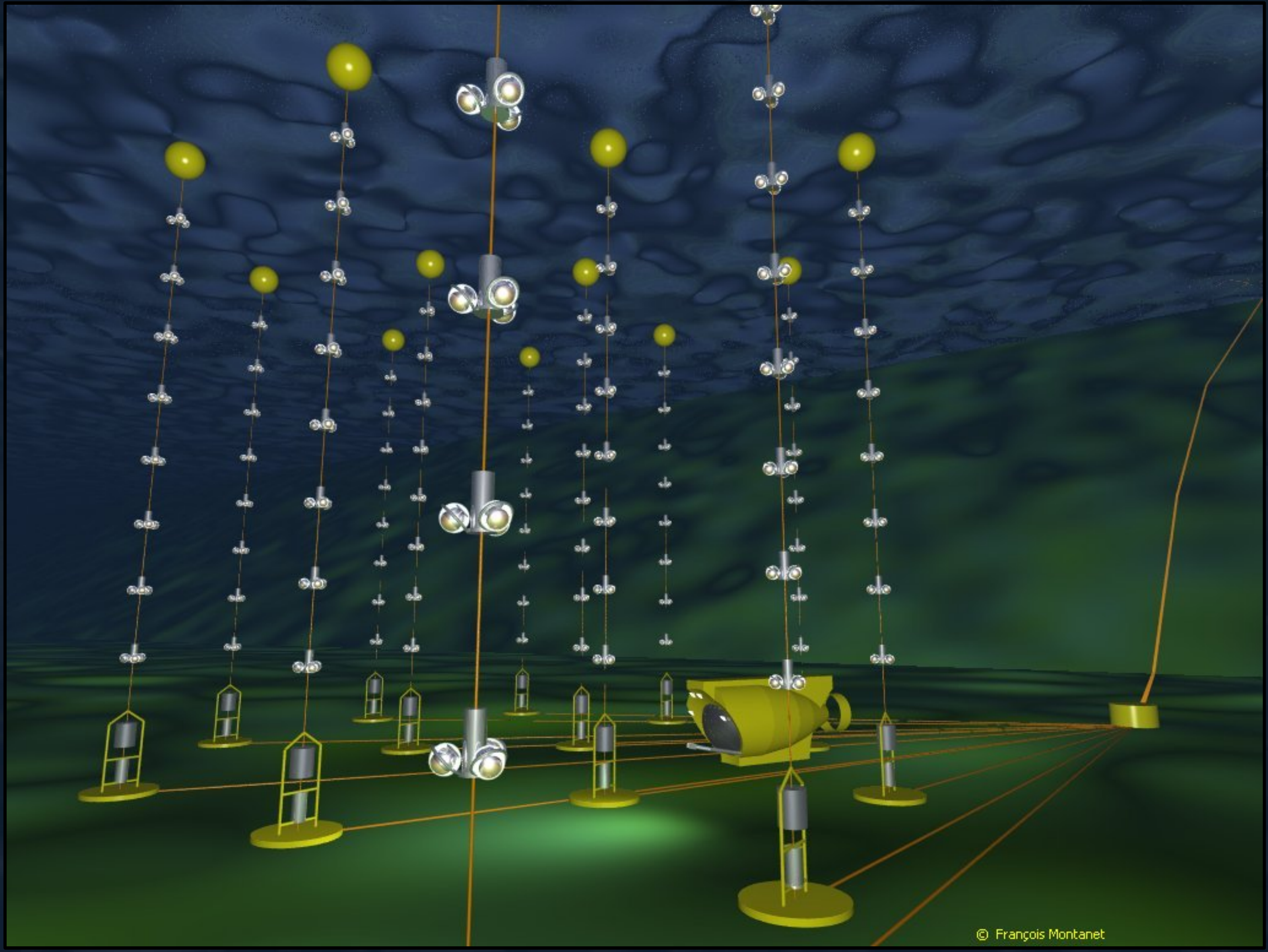
Neutrino Astronomy

Mediterranean Sea

- Cherenkov medium
- Large target volume
- Long scattering length for blue light
- View of southern sky & galactic center

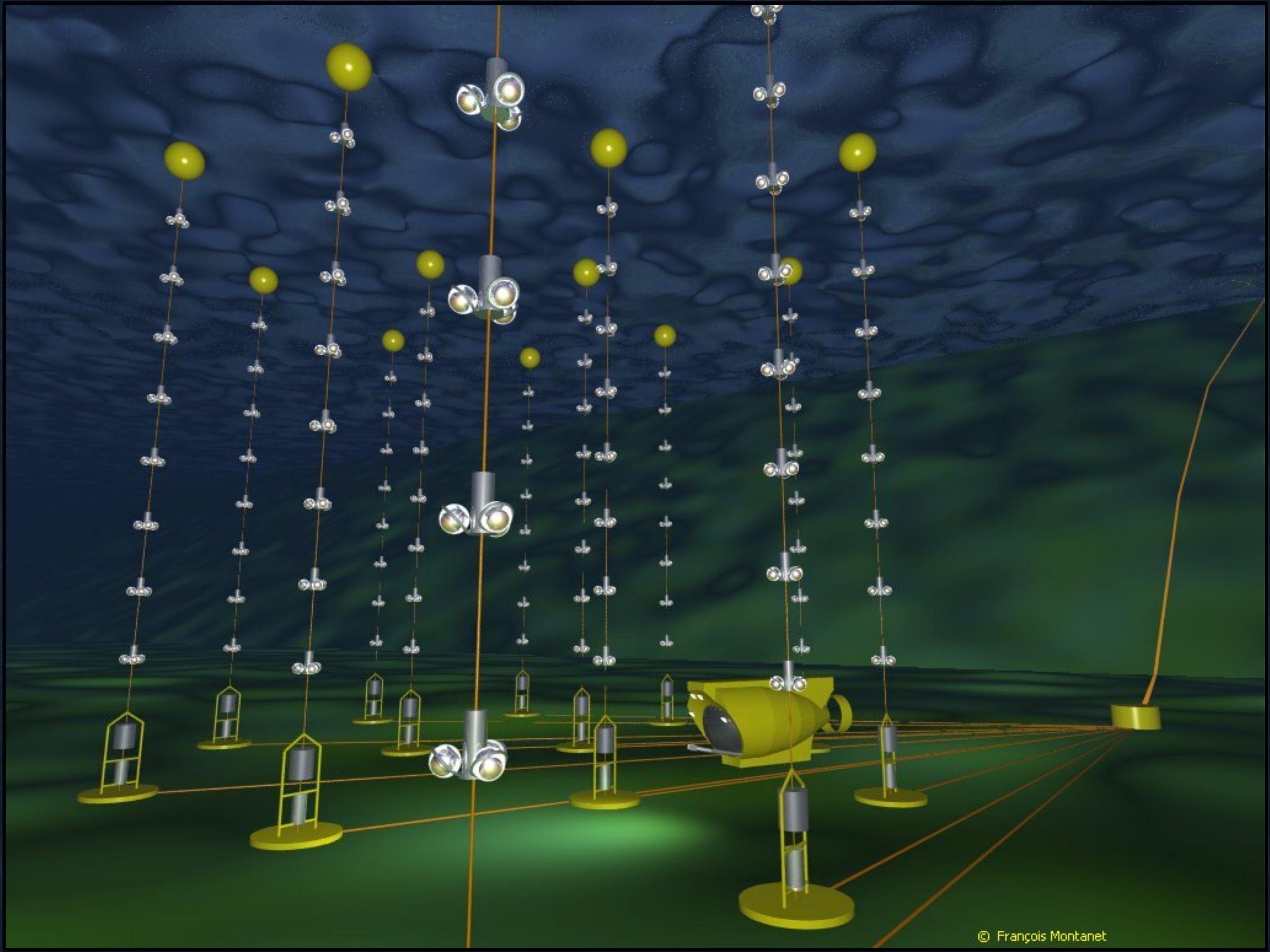
ANTARES Telescope

Installed off French coast, 2.5km under water



ANTARES Telescope

12 lines, 25 floors, each with 3 large PMT's



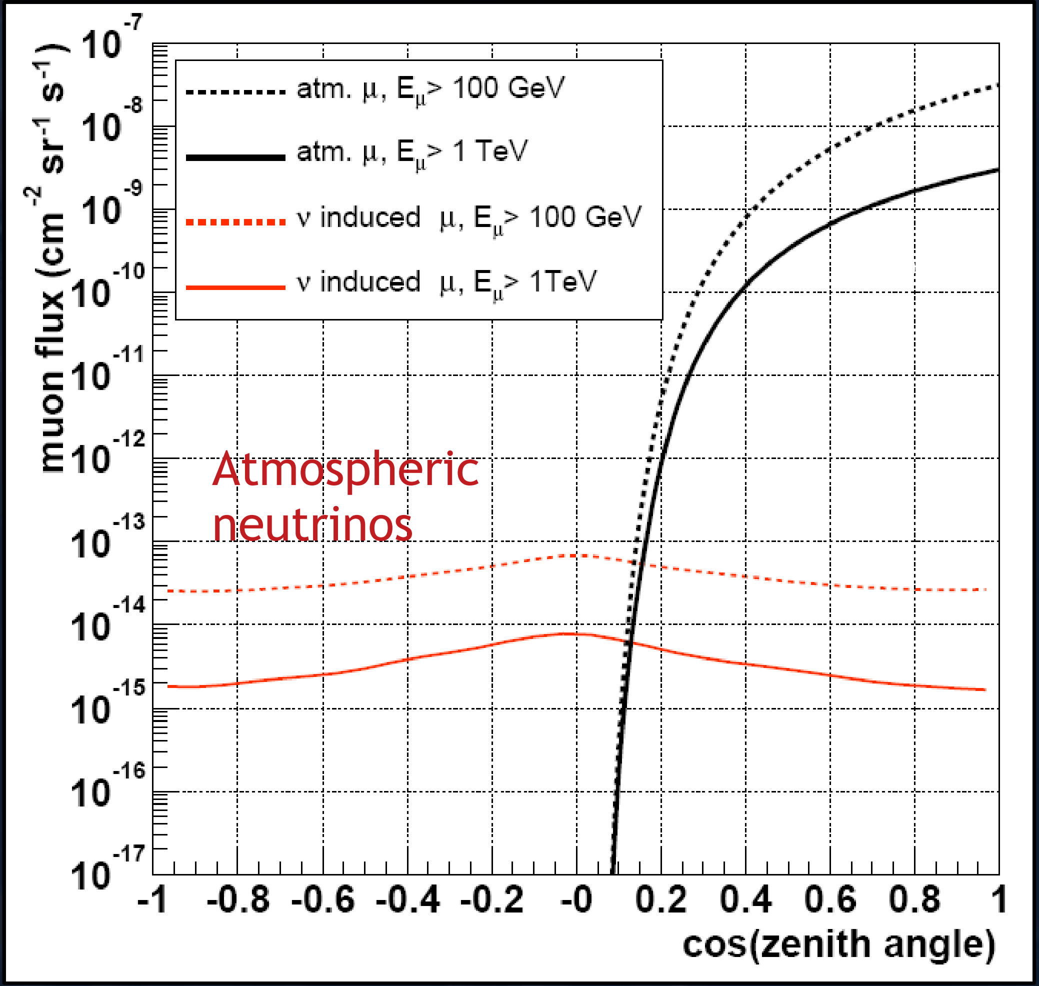
ANTARES Telescope

Completed in May, 2008!

Finding Neutrinos

Muons abound

- Vast majority of data
  - Down-going
- Use earth as filter
  - up-going $\Rightarrow \nu$



[From Aart Heijboer, PhD thesis]

Finding Neutrinos

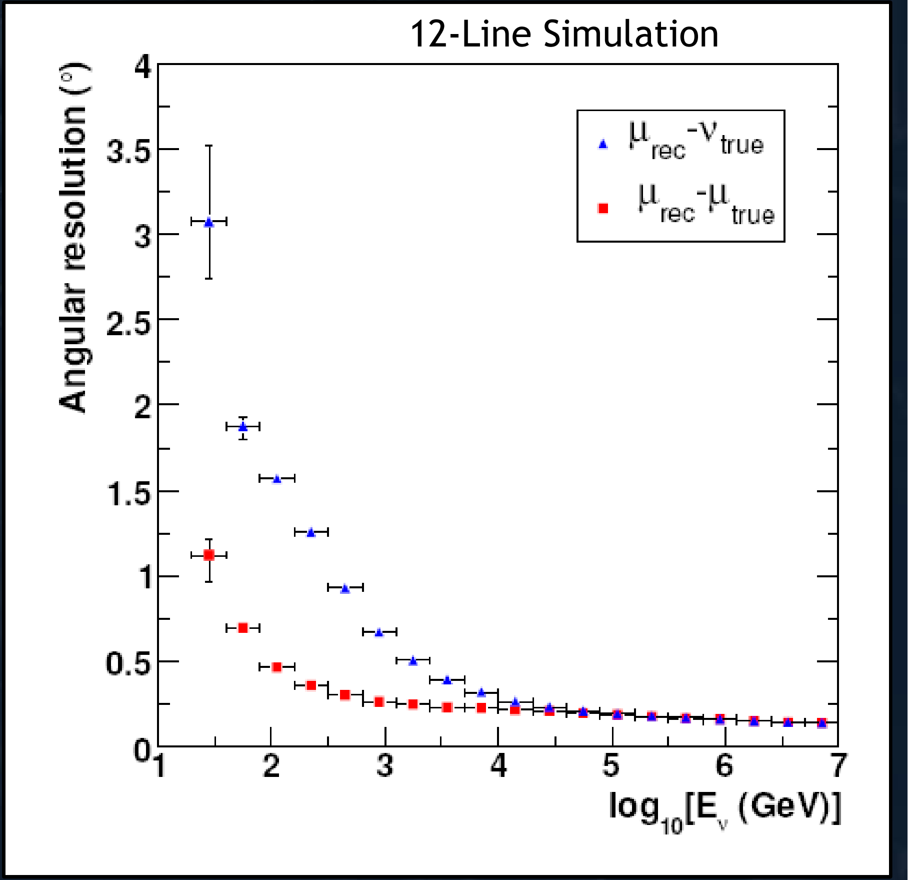
Reconstruct muon trajectory

- Different methods can be used
- Simple χ^2:
  - Minimize residuals assuming hits from Cherenkov photons
- More elaborate:
  - Maximize likelihood of residual distribution
  - Use PDF including Cherenkov and background photons

Finding Neutrinos

With elaborate tracking

- Expect very good resolution
  - Long scattering length of light in water!
- Full PDF fit
  - Account for both direct and background hits
- Bkgnd must be understood
  - Huge progress over last ~year
  - Results coming very soon



[From Aart Heijboer, PhD thesis]

Finding Neutrinos

With “simple” reconstruction on '07-'08 data

- Strict hit selection
  - Fit only direct Cherenkov photons
- Total active time of 341 days
- Various detector configurations
  - 5, 9, 10 and 12 lines

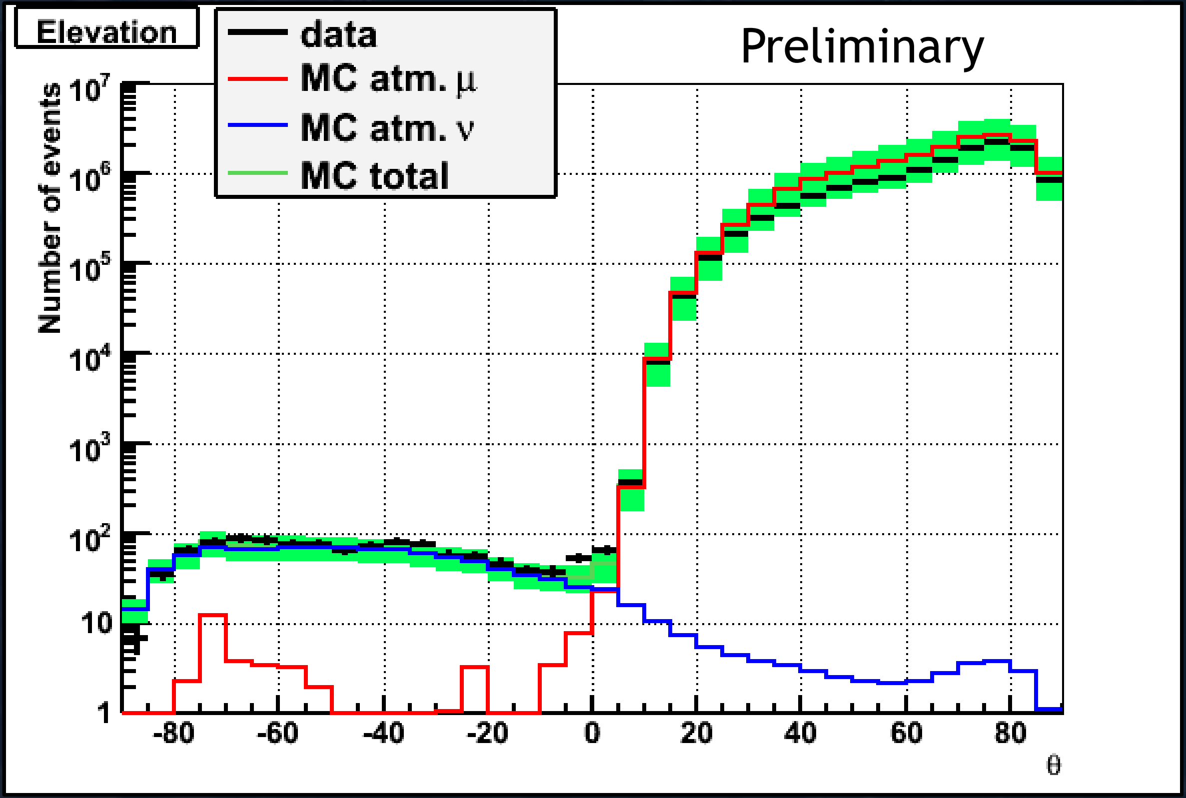
Finding Neutrinos

With “simple” reconstruction on '07-'08 data

Look at elevation of muon origin

341 days live time

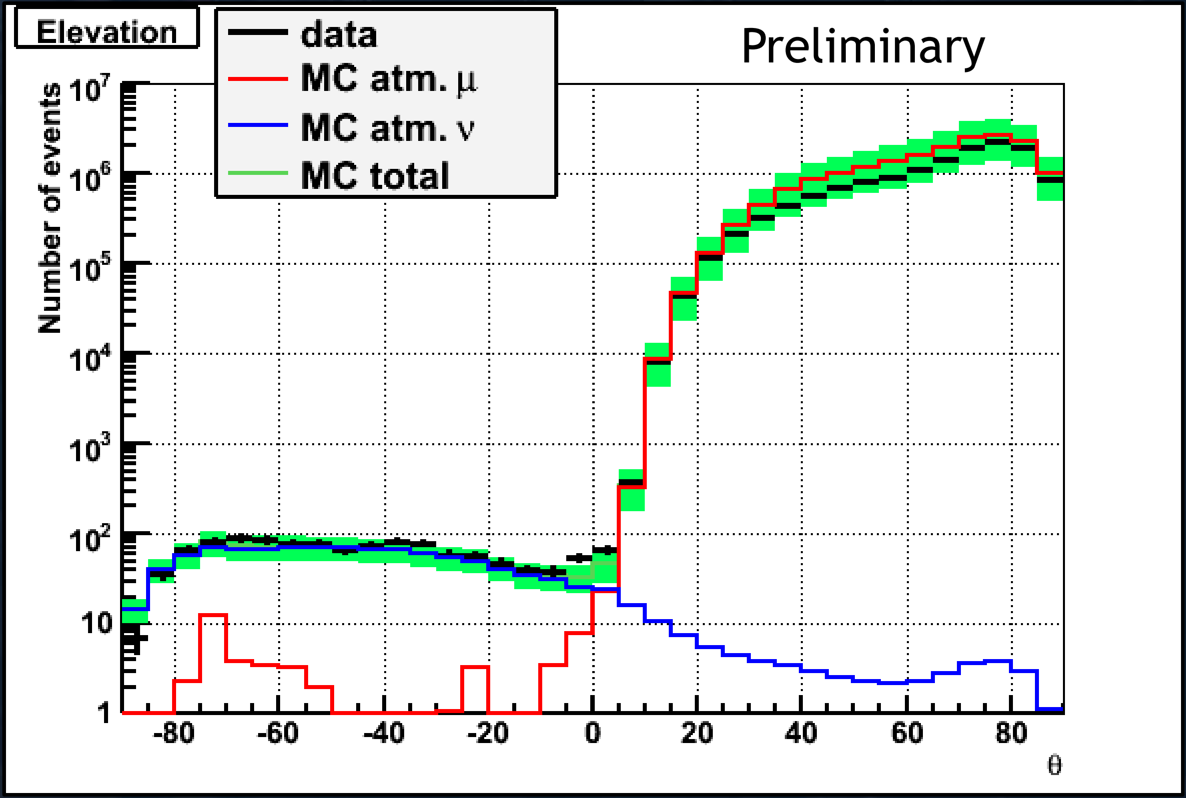
Only well reconstructed tracks shown



Finding Neutrinos

With “simple” reconstruction on '07-'08 data

- 341 days live time
- Simulation uncertainties
  - Theoretical
    - Flux
  - Detector
    - PMT efficiency
    - Background hits



Finding Neutrinos

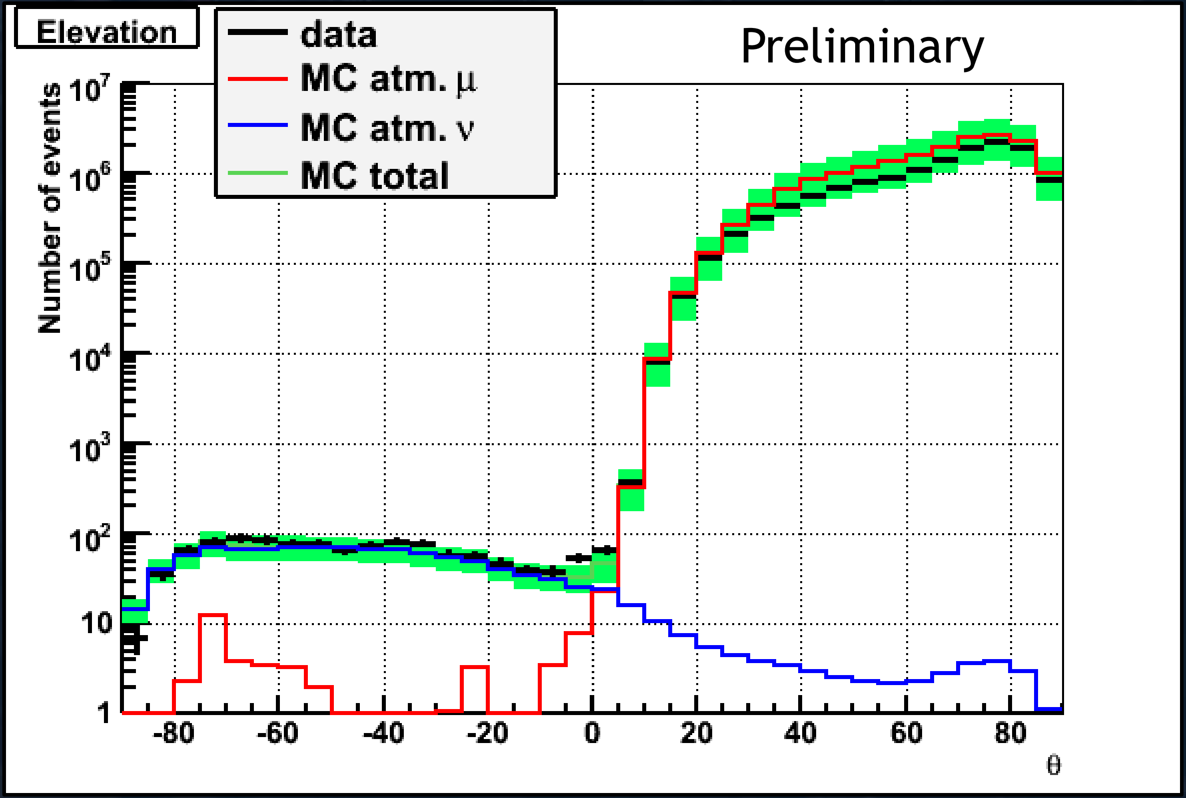
With “simple” reconstruction on '07-'08 data

341 days live time

ANTARES has seen neutrinos

1062 candidates

956 expected from simulation



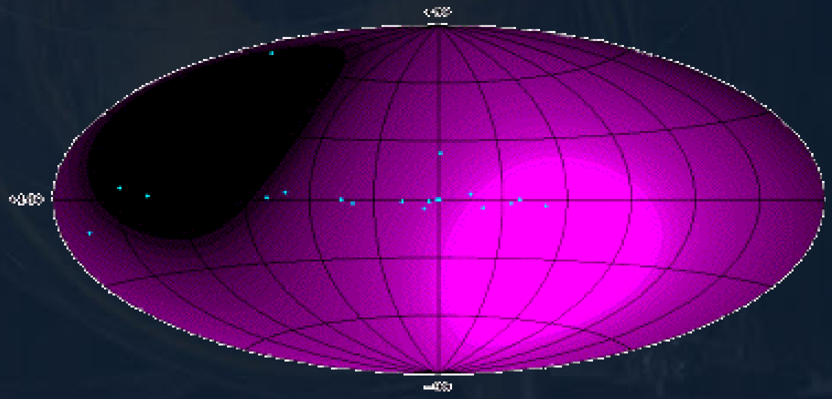
Cosmic Neutrino Search

Most neutrinos seen are "atmospheric"

- Cosmic ray interacts in atmosphere, produces ν
- Want cosmic ν's

ANTARES sees much of the sky

- Complements IceCube



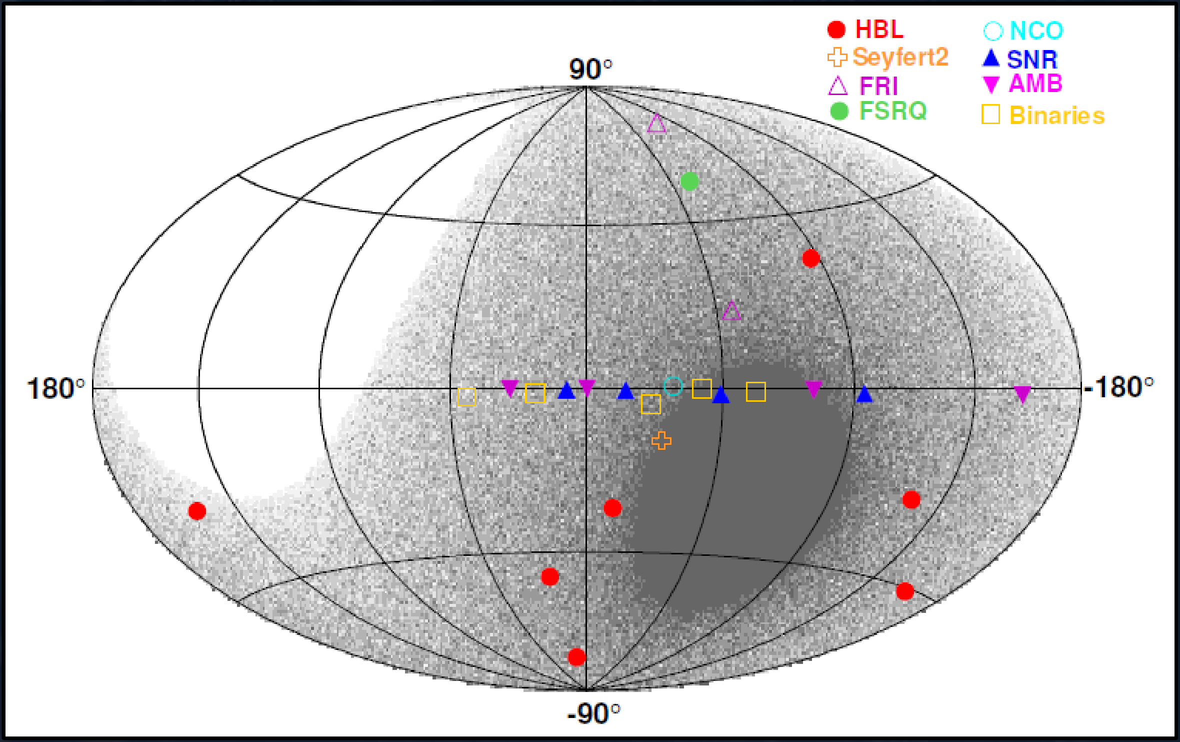
Cosmic Neutrino Search

ANTARES sees much of the sky

Do we see neutrinos from space?

Choose some interesting sources

Look for (excess of) neutrinos in source regions



Cosmic Neutrino Search

Very first look at early data...

- 2007, 5-line data (140 days live-time)
- Use "simple" reconstruction
  - Remove background hits
- Require well fit track
  - And poorly fit shower
- Require up-going

→ 276 neutrino candidates

Cosmic Neutrino Search

How to tell if they're cosmic ν's?

Calculate a statistic given data

(Likelihood ratio)

Ask:

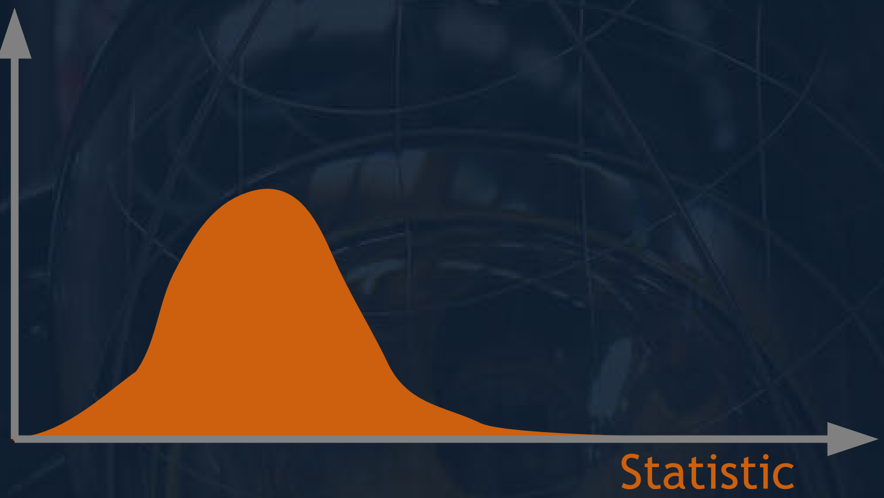
What are the odds to get this value (or better) if all data has no cosmic neutrinos?

i.e. all atmospheric ν's

Cosmic Neutrino Search

In other words:

If atmospheric ν's look like this:

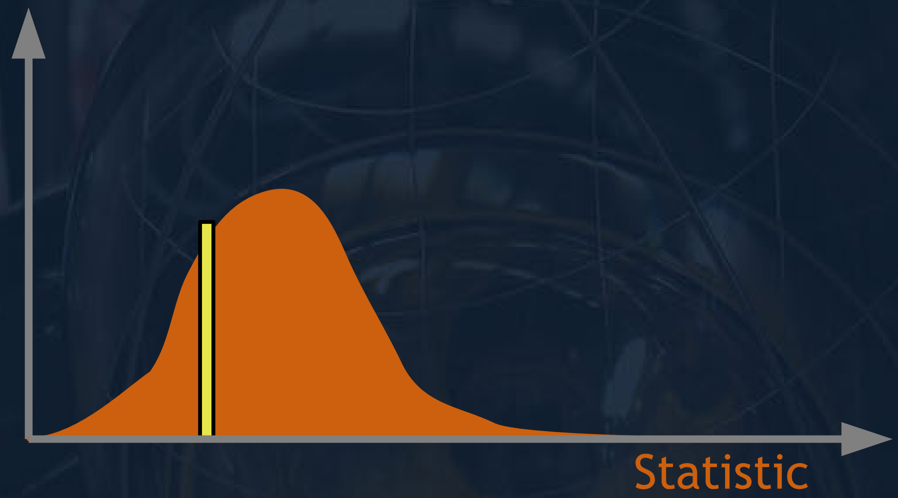


Cosmic Neutrino Search

In other words:

If atmospheric ν's look like this:

And data is here:



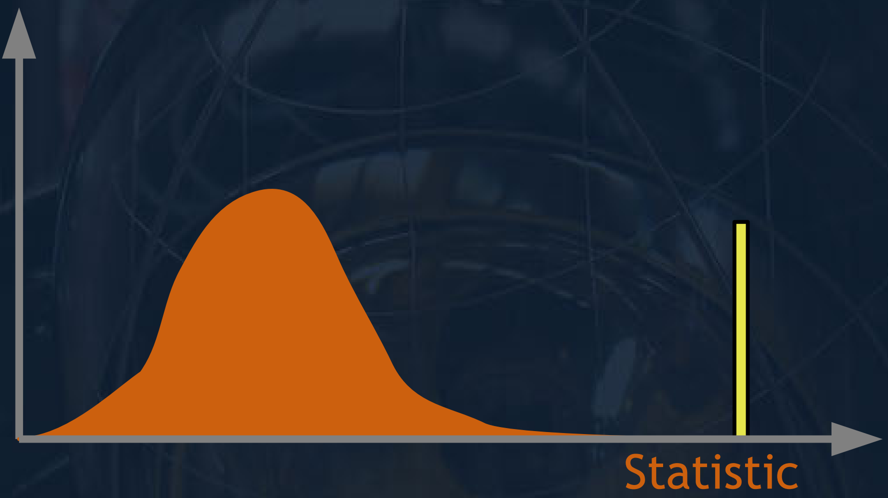
Then probably data is only atmospheric neutrinos

Cosmic Neutrino Search

In other words:

If atmospheric ν's look like this:

But if data is here:



Then probably data has some cosmic neutrinos!

Cosmic Neutrino Search

Of course, need a good statistic

Discriminating:

Small when neutrinos are far apart

Big when neutrinos cluster

Cosmic Neutrino Search

Find statistic distribution for background

Estimate background from real data

(Atmospheric neutrinos)

Parametrize: # background tracks vs declination

Cosmic Neutrino Search

Find statistic distribution for background

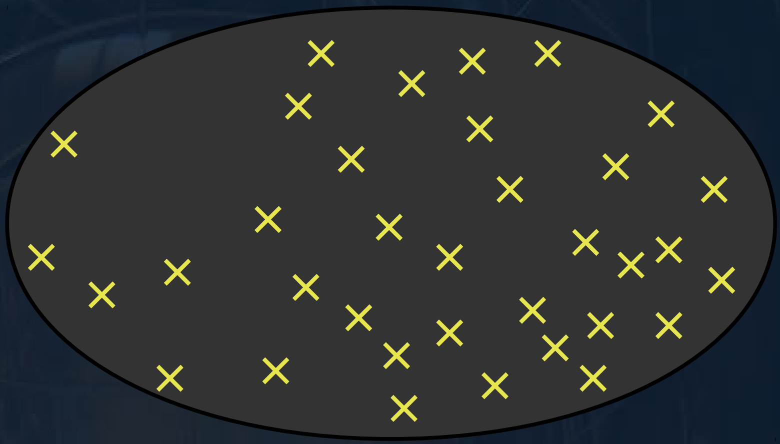
1) Sample background parametrization

Cosmic Neutrino Search

Find statistic distribution for background

1) Sample background parametrization

Enough times to simulate live-time of data



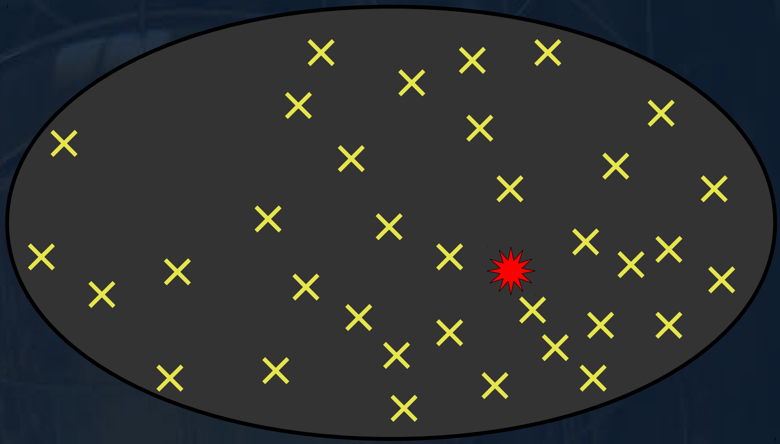
Cosmic Neutrino Search

Find statistic distribution for background

1) Sample background parametrization

Enough times to simulate live-time of data

2) Pick a source



Cosmic Neutrino Search

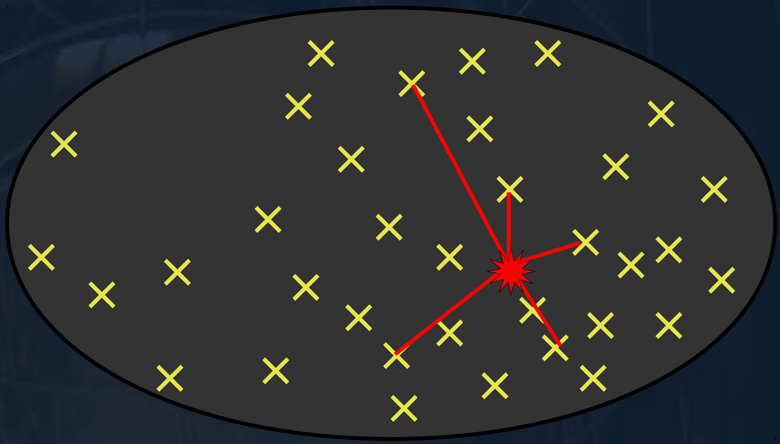
Find statistic distribution for background

1) Sample background parametrization

   Enough times to simulate live-time of data

2) Pick a source

3) Find statistic using background & this source



Cosmic Neutrino Search

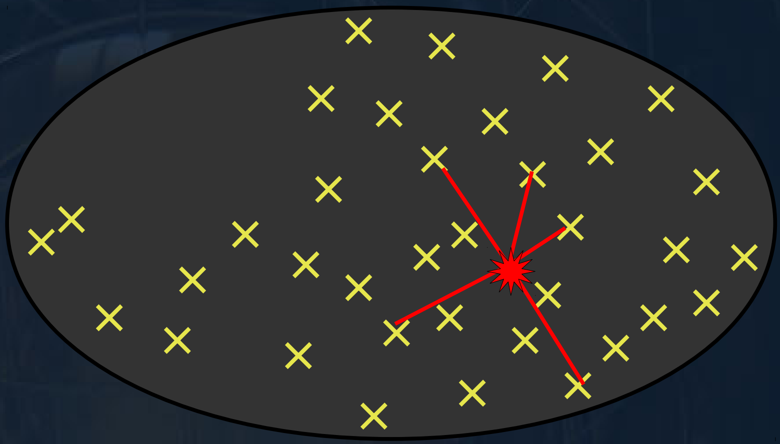
Find statistic distribution for background

1) Sample background parametrization

    Enough times to simulate live-time of data

2) Pick a source

3) Find statistic using background & this source



Repeat many (many) times to get distribution

Cosmic Neutrino Search

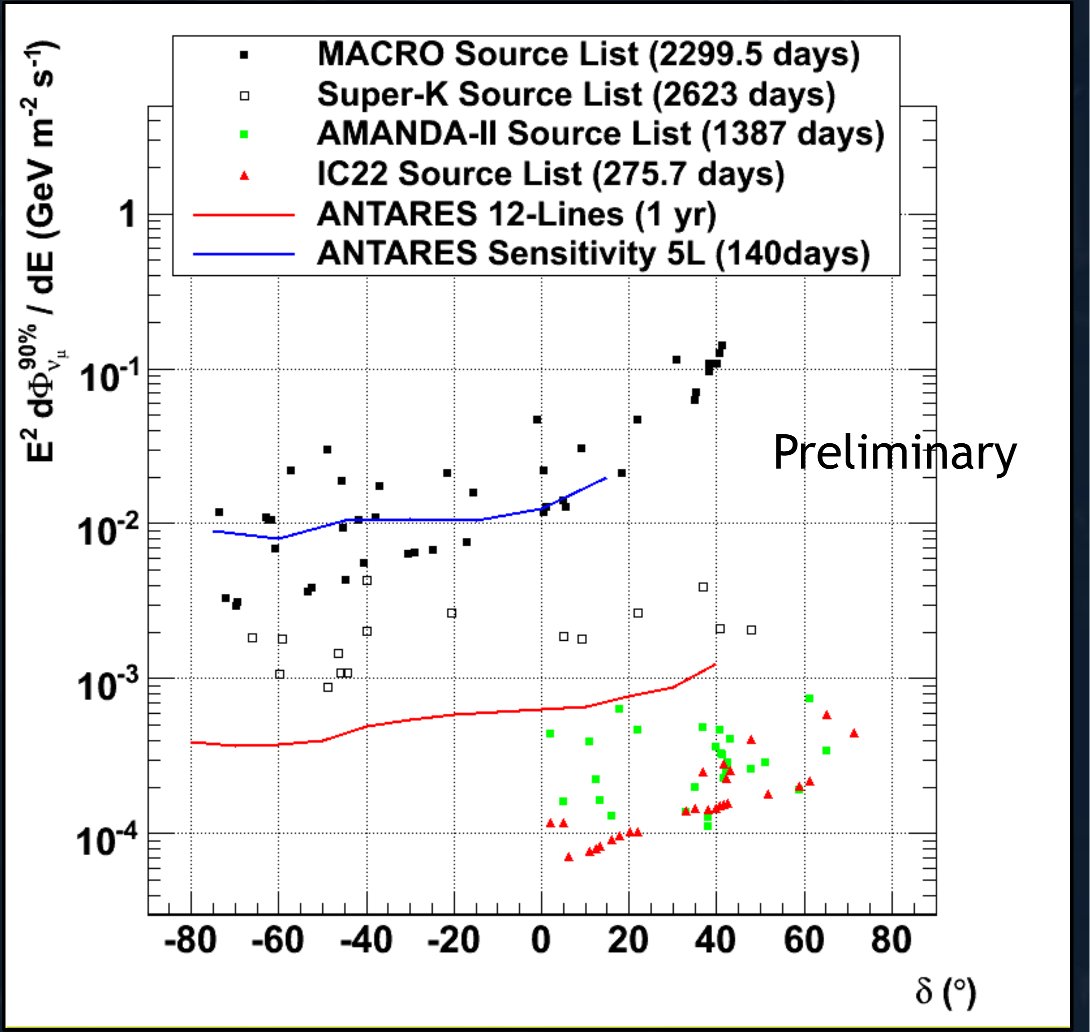
Search in progress

But sensitivity is encouraging

- Low resolution
- Low live-time

Results coming soon!

- Also with more data, better reconstruction

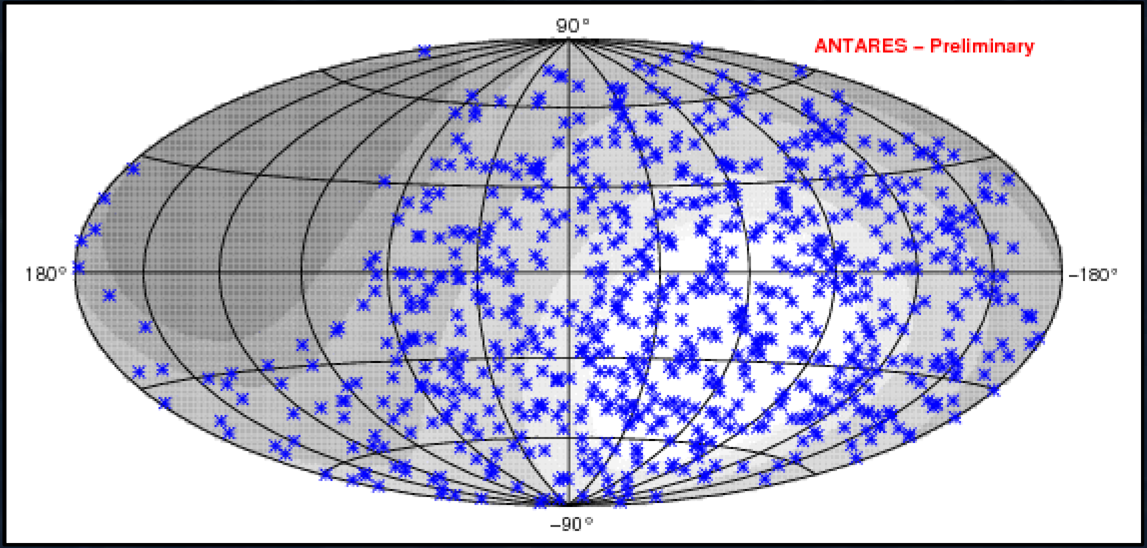


Cosmic Neutrino Search

We have collected a lot of data!

Multiple groups doing searches in parallel

2007-2008, 5-12 line detector (341 days live)
Scrambled positions! (still blinded)



Cosmic Neutrino Search

How much signal do we need?

Ask question:

"Consider my tests where I had $<N_s>$ signal tracks. In how many of them did I find the source?"

In other words..

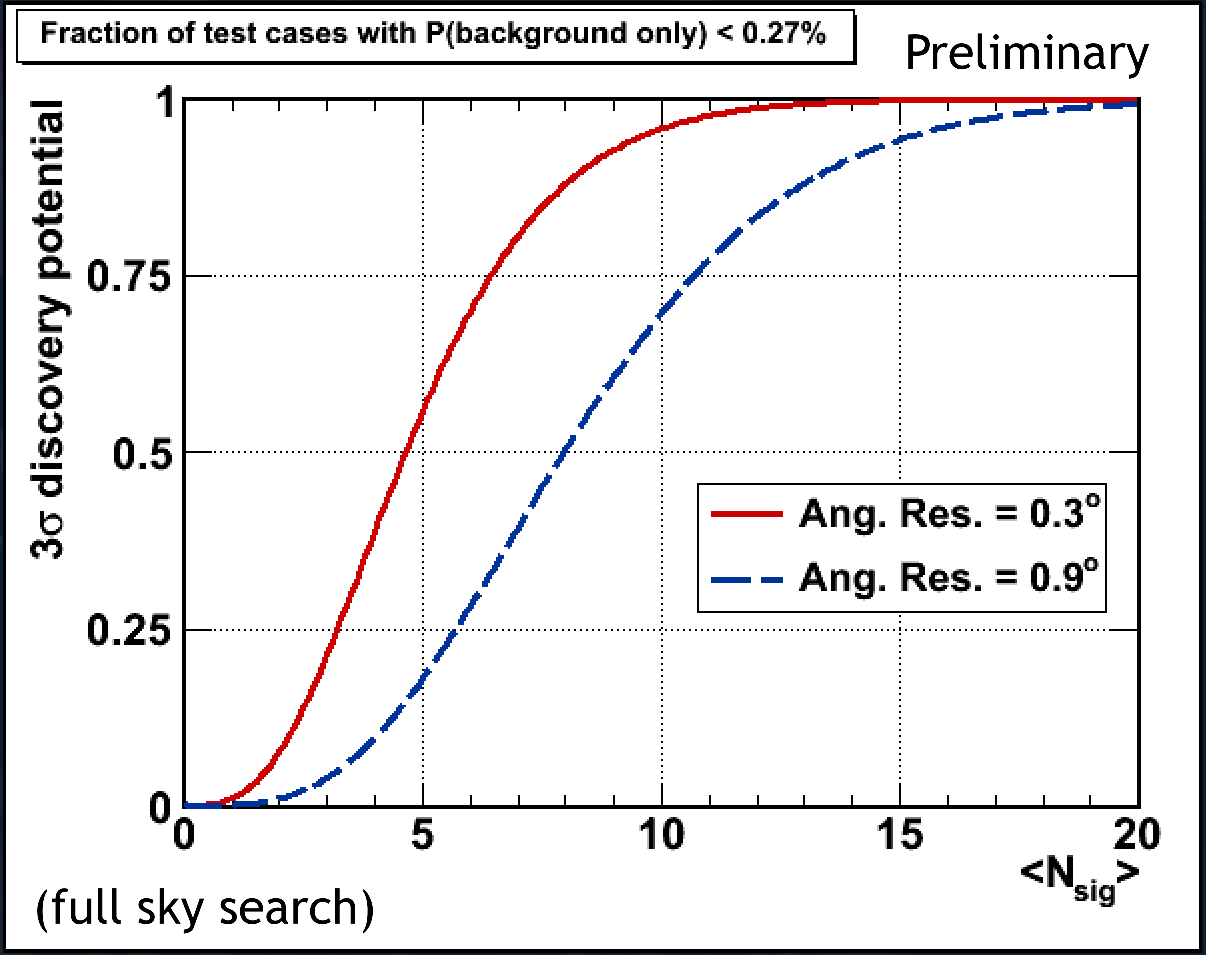
"In what fraction of my test cases did my statistic have very little chance of coming from background only?"

Cosmic Neutrino Search

How much signal do we need?

Angular resolution is important for source discovery!

Results with better reconstruction on the way



Summary

ANTARES has been taking data since 2006

- Has seen thousands of (atmospheric) neutrinos

Multiple groups searching for point sources

- Publications expected very soon
  - 2007, 5 lines, low resolution
    - Imminent
  - 2007-2008, 10-12 lines, high resolution
    - Around end of summer

Open Questions

Obvious: Are there high energy neutrino sources?

When we have some...

- What are the (brightest) neutrino sources?
- If neutrinos are seen from source type X (i.e. SNR), will they always be seen from type X sources?
- What are the ratios of neutrino flavors?
  - At Earth & at the source?
- Are there hidden neutrino sources?

Backup Slides

Cosmic Neutrino Search

Future telescope in the works

- KM3NeT – large telescope in the Mediterranean
- Finding sources gets easier
  - Many more events in a year
  - Measure higher energy neutrinos
  - Angular resolution improved

Neutrino Astronomy

High energy photon sources have been found

- Produced how?
  - Leptonic?
    - Synchrotron from electrons
    - Inverse Compton scattering

Neutrino Astronomy

High energy photon sources have been found

Produced how?

Hadronic?

$$p\,\gamma \rightarrow \pi^0\;p$$
$$\pi^0 \rightarrow \gamma\;\gamma$$

Neutrino Astronomy

High energy photon sources have been found

Produced how?

Hadronic?

$$p\,\gamma \rightarrow \pi^{+}\;n$$
$$\pi^{+} \rightarrow \mu^{+}\;\nu_{\mu}$$
$$\mu^{+} \rightarrow \nu_{\mu}\;\nu_{e}\;e^{+}$$

Candidate Sources

Table 4: *Golden*-list for the 5-line data analysis

Name	Class	Equatorial coordinates RA	Equatorial coordinates δ	Galactic coordinates l	Galactic coordinates b	Vis.
Galactic Sources						
HESS J0632+057	AMB	$6^h\ 32^m\ 58^s$	$5°\ 48'\ 20''$	205.66	-1.44	0.46
RX J0852.0-4622	SNR	$8^h\ 52^m\ 00^s$	$-46°\ 22'\ 00''$	266.28	-1.24	0.91
HESS J1023-575	AMB	$10^h\ 23^m\ 18^s$	$-57°\ 45'\ 50''$	284.19	-0.39	1
PSR B1259-63	Binary Pulsar	$13^h\ 02^m\ 49^s$	$-63°\ 50'\ 02''$	304.19	-0.99	1
RCW 86	SNR	$14^h\ 42^m\ 43^s$	$-62°\ 29'\ 00''$	315.79	-1.46	1
Cir X-1	XRB	$15^h\ 20^m\ 41^s$	$-57°\ 10'\ 00.26''$	322.12	0.04	1
HESS J1614-518	NCO	$16^h\ 14^m\ 19^s$	$-51°\ 49'\ 12''$	331.52	0.58	1
GX 339	XRB	$17^h\ 02^m\ 49^s$	$-48°\ 47'\ 23''$	338.94	-4.33	0.99
RX J1713.7-3946	SNR	$17^h\ 13^m\ 00^s$	$-39°\ 45'\ 00''$	347.28	-0.38	0.75
Galactic Center	AMB	$17^h\ 45^m\ 41^s$	$-29°\ 00'\ 22''$	359.95	-0.05	0.66
W28	SNR	$18^h\ 01^m\ 42^s$	$-23°\ 20'\ 06''$	6.66	-0.27	0.62
LS 5039	XRB	$18^h\ 26^m\ 15^s$	$-14°\ 49'\ 30''$	16.90	-1.28	0.57
HESS J1837-069	AMB	$18^h\ 37^m\ 38^s$	$-6°\ 57'\ 00''$	25.18	-0.12	0.52
SS 433	XRB	$19^h\ 11^m\ 50^s$	$4°\ 58'\ 58''$	39.69	-2.24	0.48
extra-Galactic Sources						
RGB J0152+017	HBL	$1^h\ 52^m\ 40^s$	$1°\ 47'\ 19''$	152.38	-26.61	0.49
1ES 0347-121	HBL	$3^h\ 49^m\ 23^s$	$-11°\ 59'\ 27''$	201.93	-45.71	0.55
PKS 0548-322	HBL	$5^h\ 50^m\ 40.6^s$	$-32°\ 16'\ 16.4''$	237.56	-26.14	0.69
1ES 1101-232	HBL	$11^h\ 03^m\ 38^s$	$-23°\ 29'\ 31''$	273.19	33.08	0.62
3C 279	FSRQ	$12^h\ 56^m\ 11^s$	$-5°\ 47'\ 21''$	305.10	57.06	0.51
Centaurus A	FRI	$13^h\ 25^m\ 27.6^s$	$-43°\ 01'\ 08.8''$	309.52	19.46	0.81
ESO 139-G12	Sy2	$17^h\ 37^m\ 39.5^s$	$-59°\ 56'\ 29''$	334.04	-13.77	1
PKS 2005-489	HBL	$20^h\ 09^m\ 29^s$	$-48°\ 49'\ 19''$	350.39	-32.61	1
PKS 2155-304	HBL	$21^h\ 58^m\ 53^s$	$-30°\ 13'\ 18''$	17.74	-52.25	0.67
H 2356-309	HBL	$23^h\ 59^m\ 08^s$	$-30°\ 37'\ 39''$	12.84	-78.04	0.67