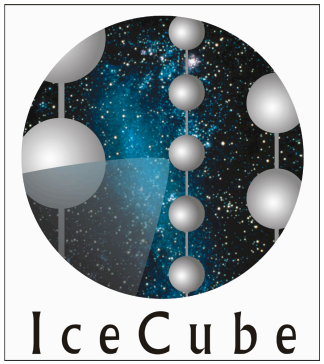
High-Energy Neutrino Astrophysics Experiments and the correlation with Gamma Ray Experiments

Stefan Schlenstedt

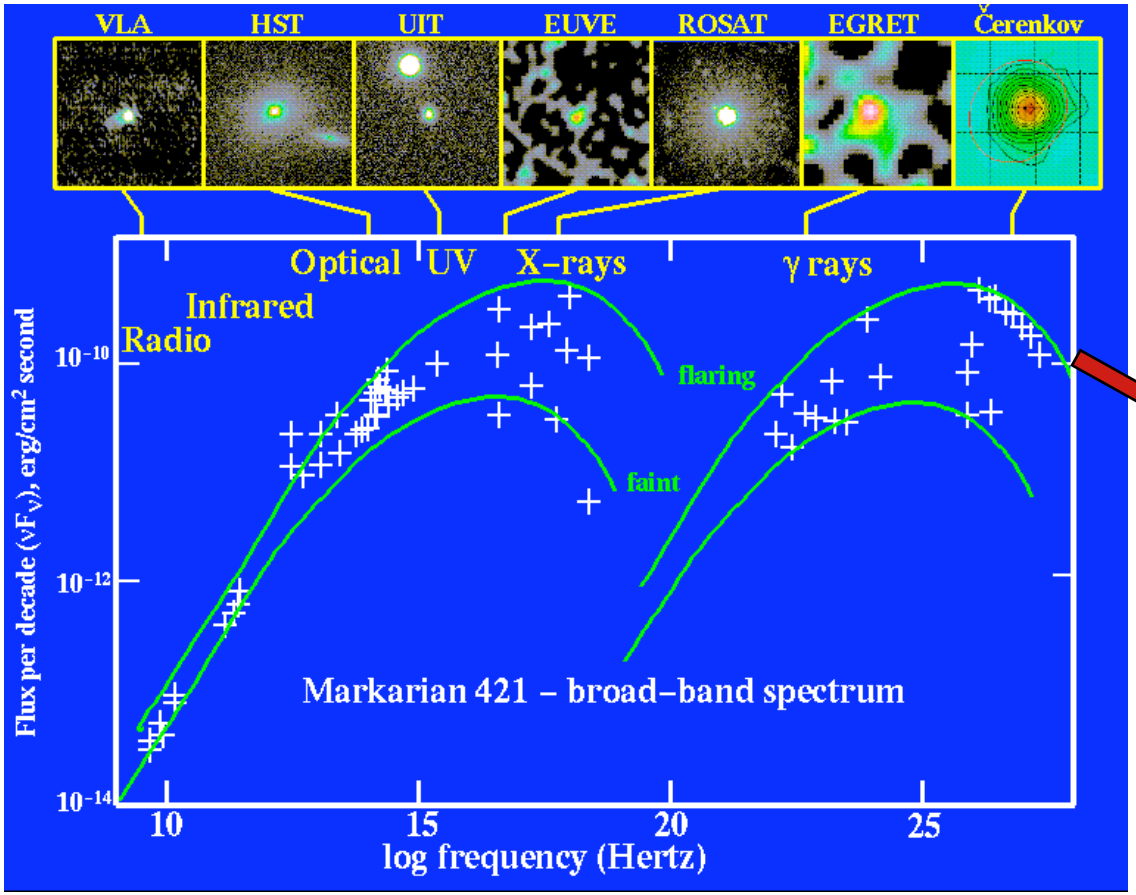
HELMHOLTZ ASSOCIATION

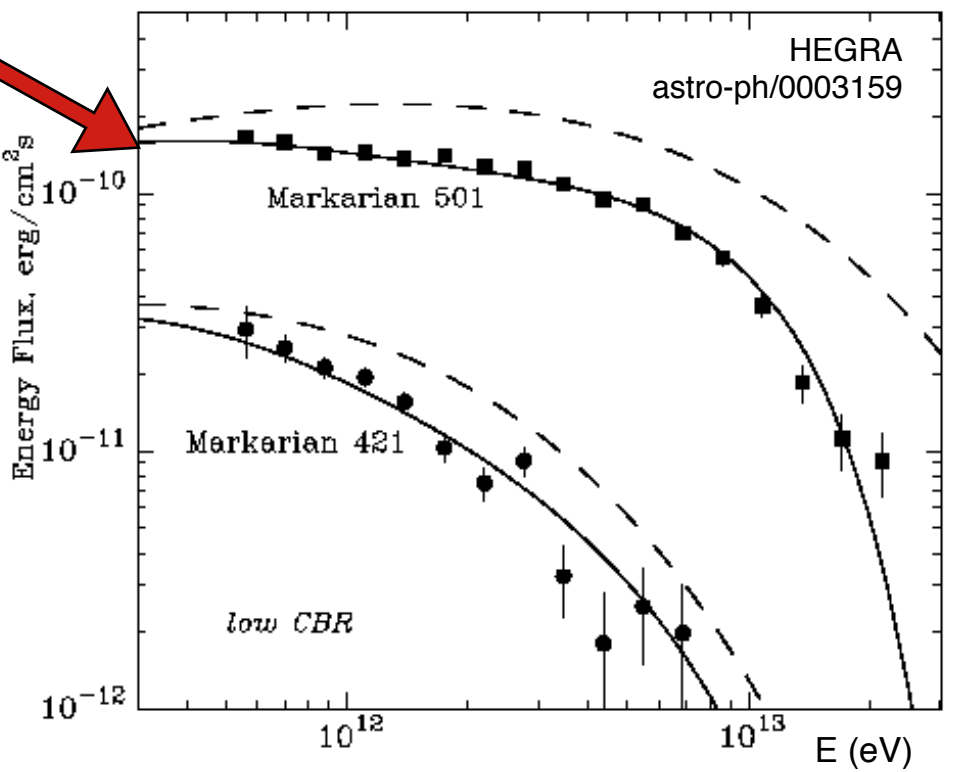
DESY



SciNeGHE07, Frascati, June 18-20, 2007

Cosmic Gamma-Rays





$$\sim \epsilon^{-\Gamma} e^{-(\epsilon/\epsilon_0)}, \Gamma \sim 2$$

electrons → gamma rays
(synchrotron, inverse Compton)

Neutrino Astro-Particle Physics

- Cosmic rays with energies TeV (and above)
- Photon sources with TeV energies

➡ Are there neutrino sources: blazars, quasars, Gamma Ray Bursts, supernovae ... is there a diffuse flux?

Neutrinos

are elementary particles
– light
– neutral
– interact only by weak force

⇛ good astrophysical probes:
– travel straight
– 'not' absorbed over cosmological distances and dense environment

Neutrino Astro-Particle Physics

- Cosmic rays with energies TeV (and above)
- Photon sources with TeV energies

➡ Are there neutrino sources: blazars, quasars, Gamma Ray Bursts, supernovae ... is there a diffuse flux?

Neutrinos

are elementary particles
– light
– neutral
– interact only by weak force

⇛ good astrophysical probes:
– travel straight
– 'not' absorbed over cosmological distances and dense environment

can help to understand
- the origin of cosmic rays
- cosmic cataclysms
- basic properties (σ, m_ν, ν_τ)
- dark matter (neutralino annihilation)
- new kinds of objects
  - tests of relativitiy, search for big bang relics, effects of ED etc ...

Neutrino Astro-Particle Physics

- Cosmic rays with energies TeV (and above)
- Photon sources with TeV energies

➡ Are there neutrino sources: blazars, quasars, Gamma Ray Bursts, supernovae ... is there a diffuse flux?

Neutrinos

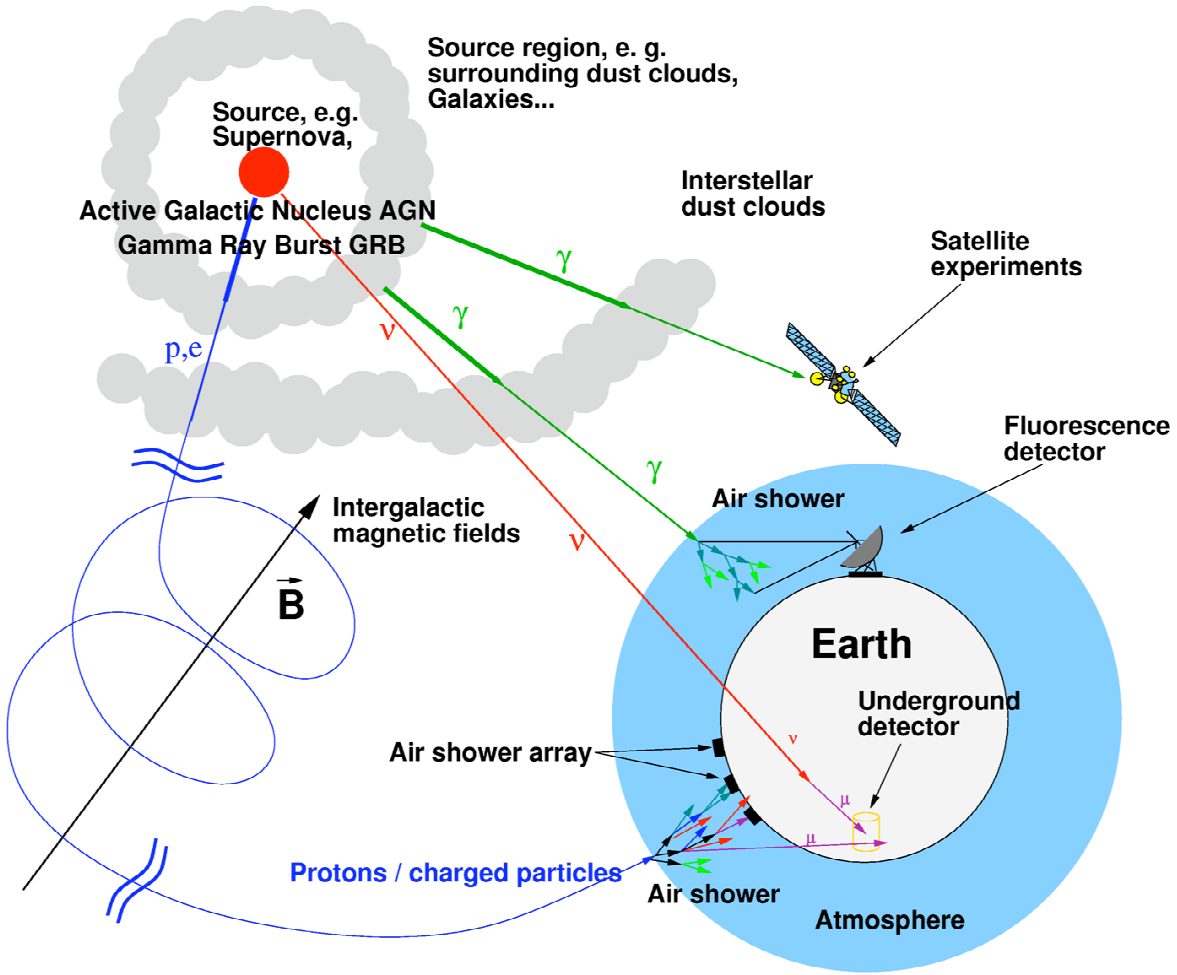
are elementary particles
– light
– neutral
– interact only by weak force

⇛ good astrophysical probes:
– travel straight
– 'not' absorbed over cosmological distances and dense environment

can help to understand
- the origin of cosmic rays
- cosmic cataclysms
- basic properties (σ, m_ν, ν_τ)
- dark matter (neutralino annihilation)
- new kinds of objects
  - tests of relativitiy, search for big bang relics, effects of ED etc ...

connect astrophysics and particle physics

Particle Propagation through the Universe



Photons: absorbed by dust and radiation

Protons/nuclei: deflected by magnetic fields (up to very high energies)
reactions with radiation (CMB)

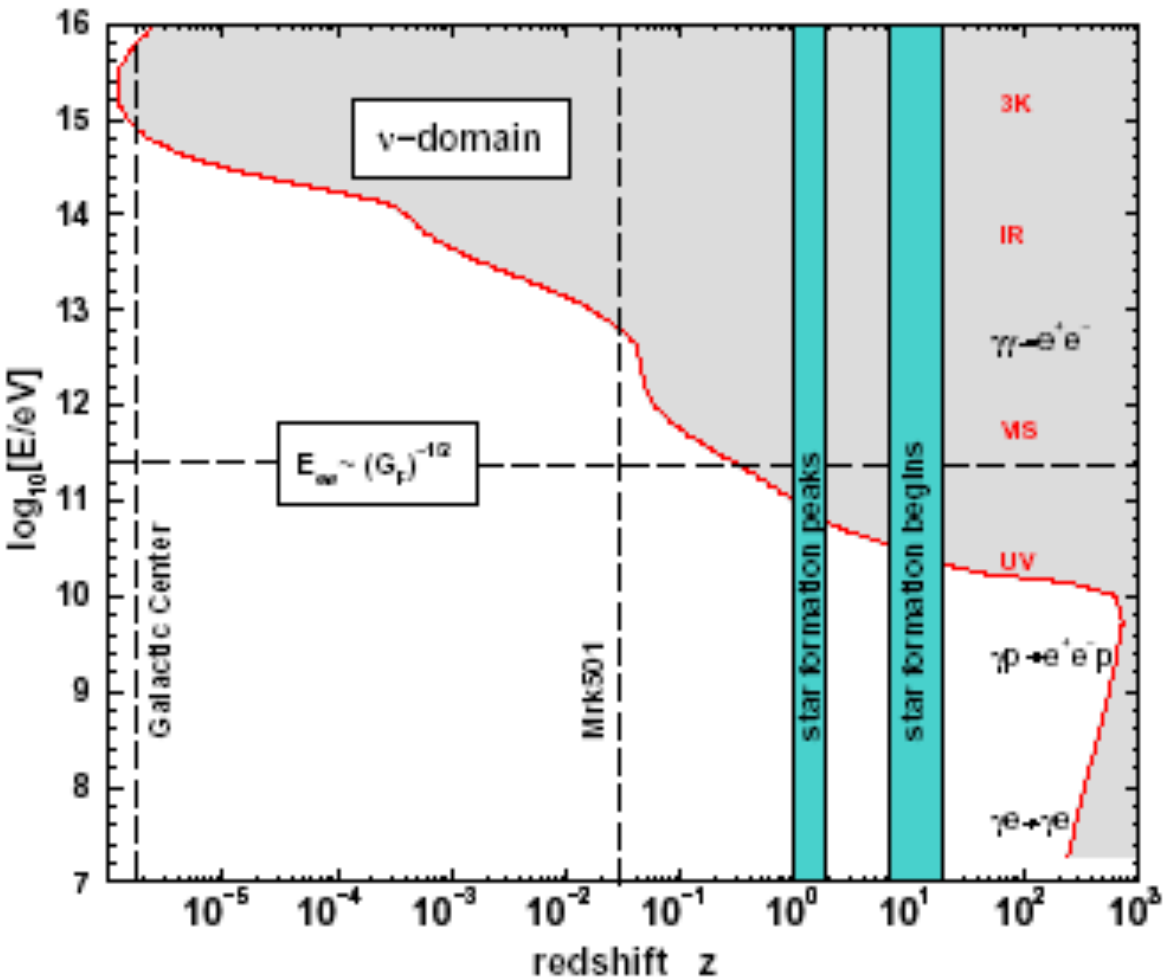
The Gamma Ray Horizon

photons interact electromagnetically
- in the interior of stars
- with starlight, inter-stellar matter and CMBR

$$\gamma\ e \rightarrow \gamma\ e$$

$$\gamma\ \gamma \rightarrow e^+\ e^-$$

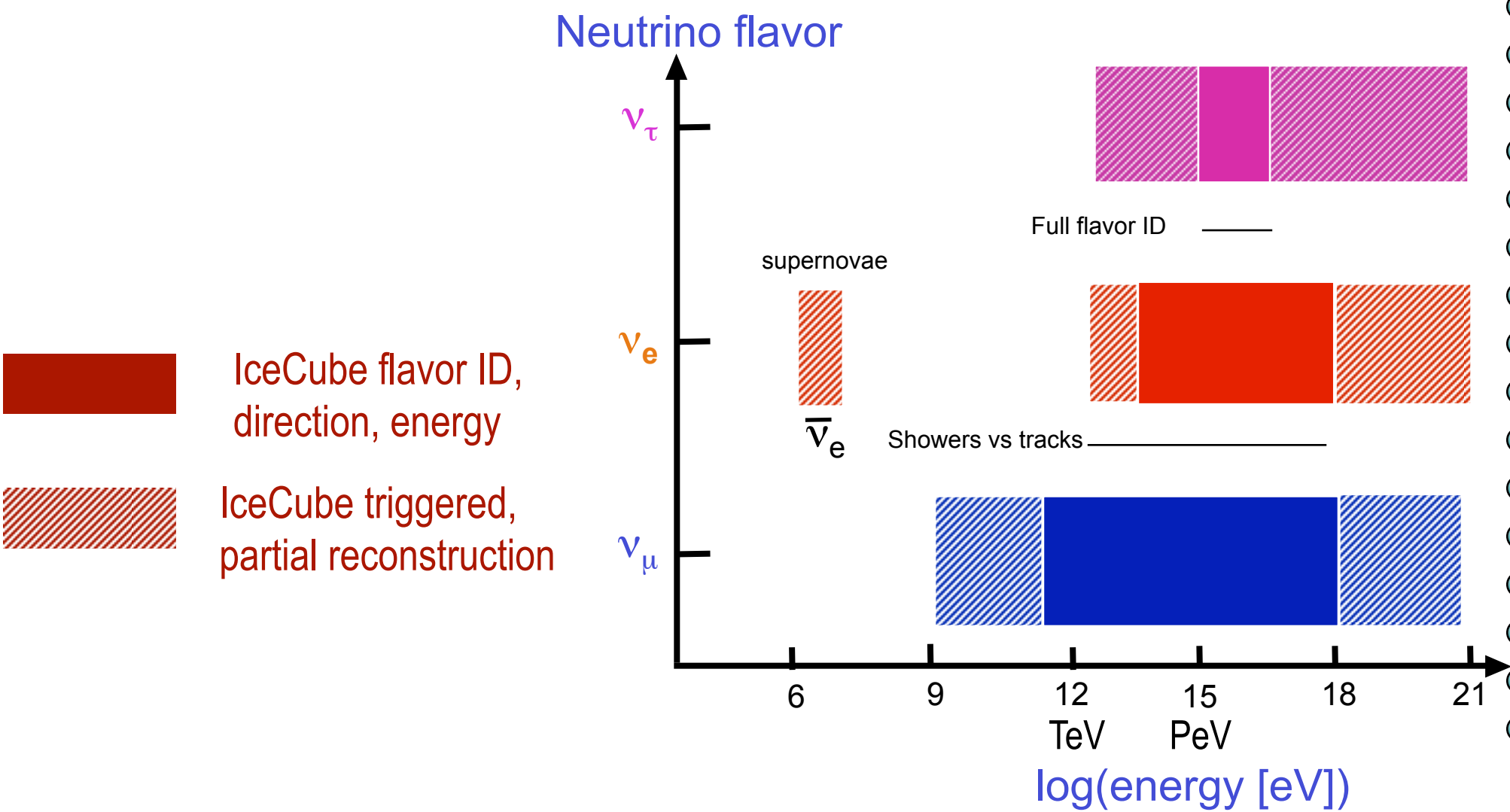
$$\gamma\ N \rightarrow N\ e^+\ e^-$$



➟ photons with energy of 10^{15} eV do not reach us from the edge of our galaxy

Large Energy Coverage

Tracks and Showers (cascades)



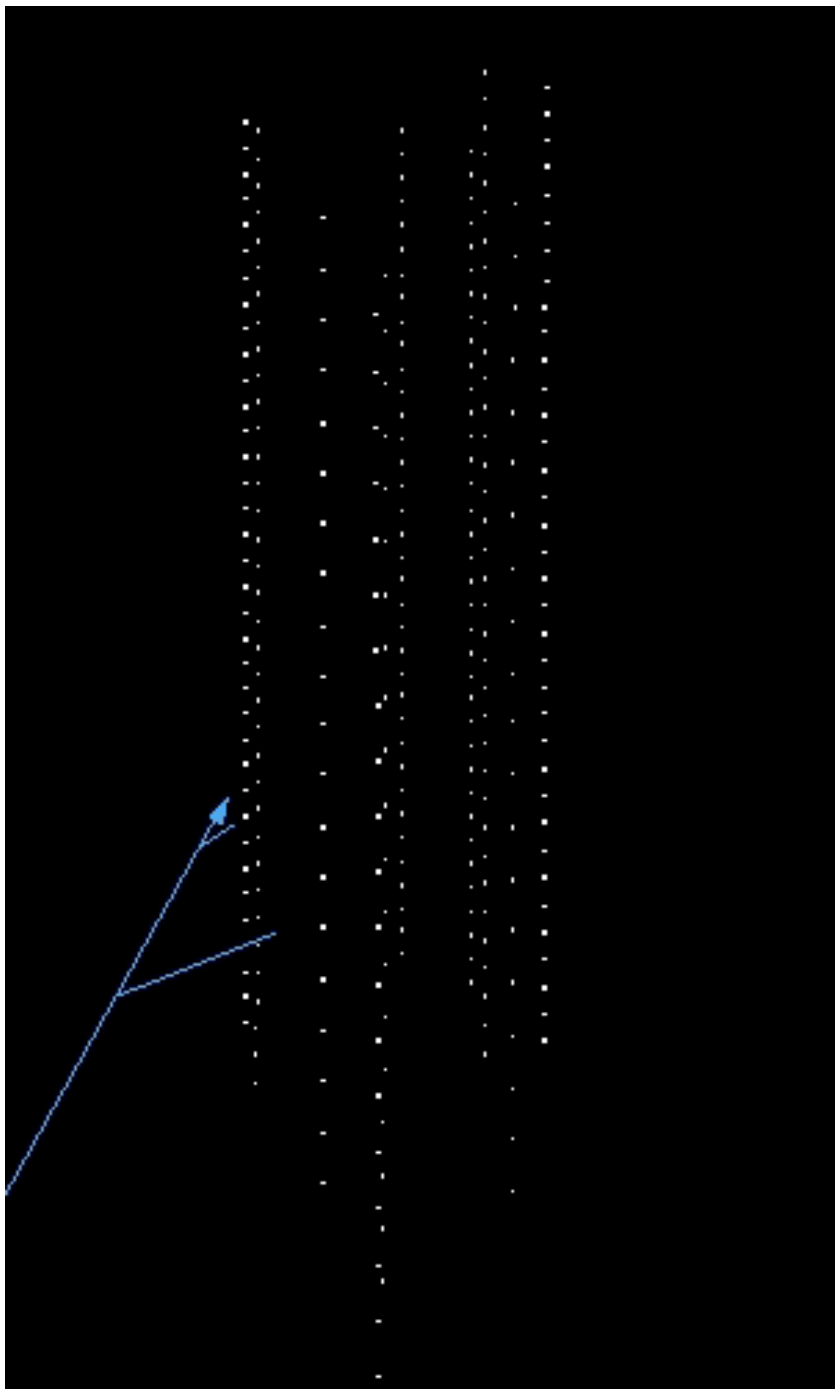
IceCube flavor ID, direction, energy

IceCube triggered, partial reconstruction

Use of Cherenkov Light

Cherenkov light is efficiently emitted by relativistic particles in transparent media at UV-blue wavelengths under the condition: $\beta n(\lambda) > 1$

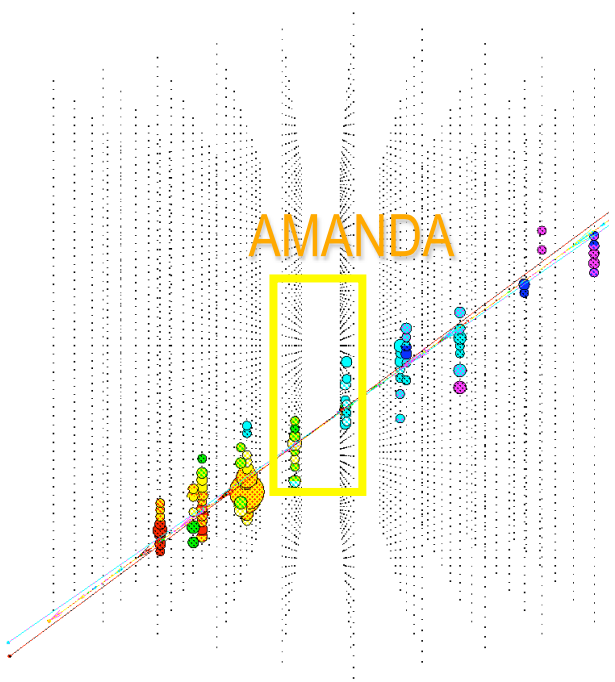
Cherenkov radiation: sonic boom of light



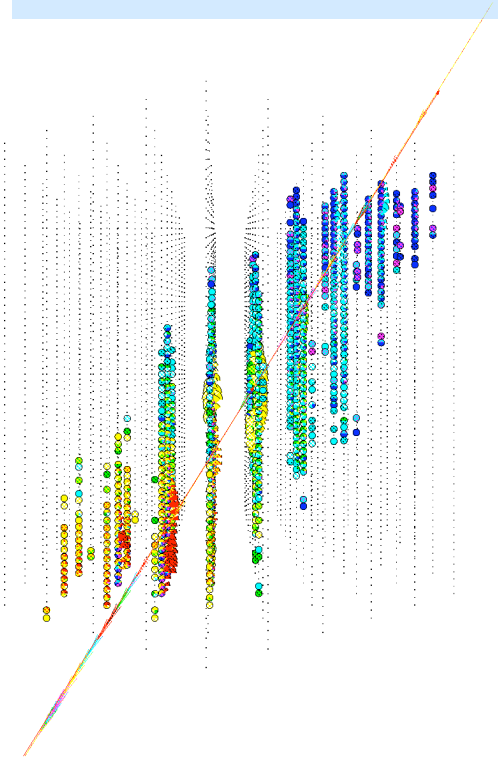
reconstruction uses causality relation $c\,(t_j - t_0) = l_j + d_j\,\cot\theta_c$

Event Signatures in IceCube

10^{13} eV (10 TeV)

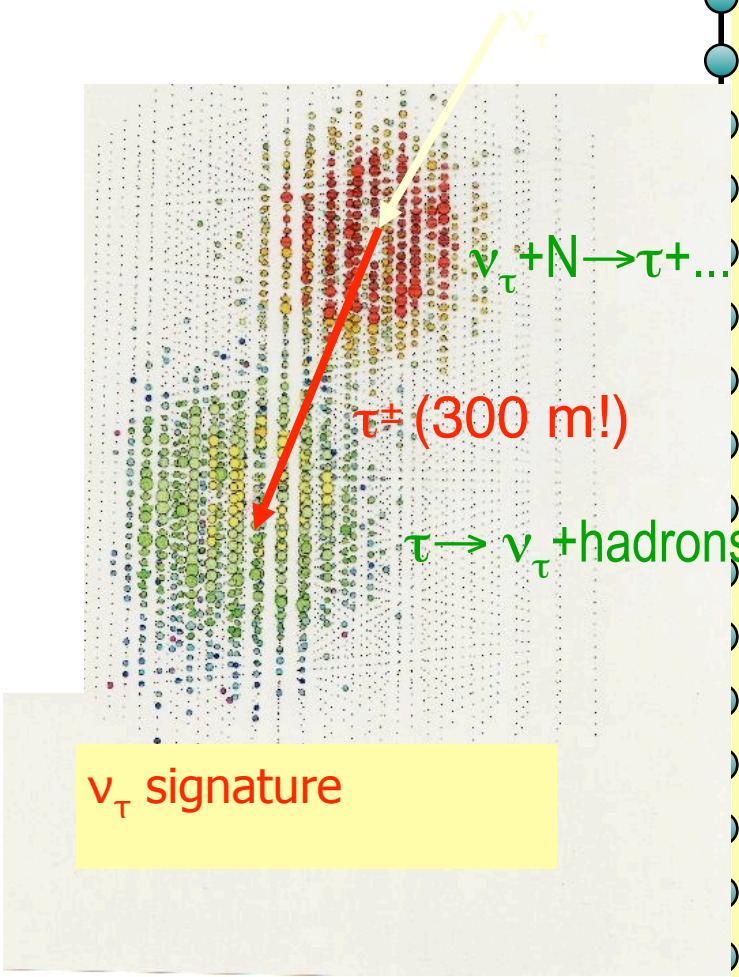


$6x10^{15}$ eV (6 PeV)



ν_μ signature

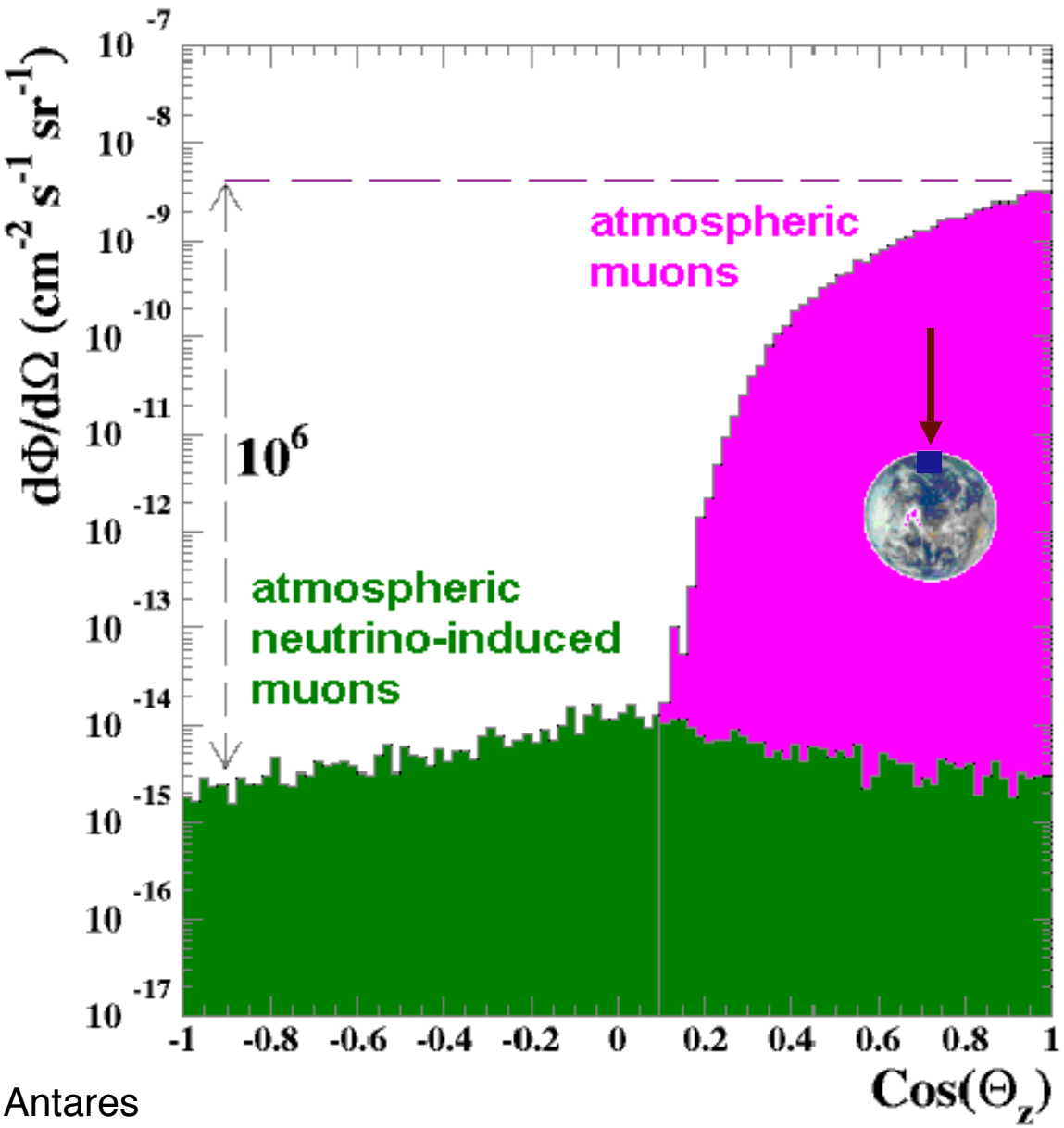
Multi-PeV



ν_τ signature

Atmospheric Muons and Neutrinos

Neutrino detectors must identify few astrophysical events on top of diffuse atmospheric backgrounds (μ and ν)



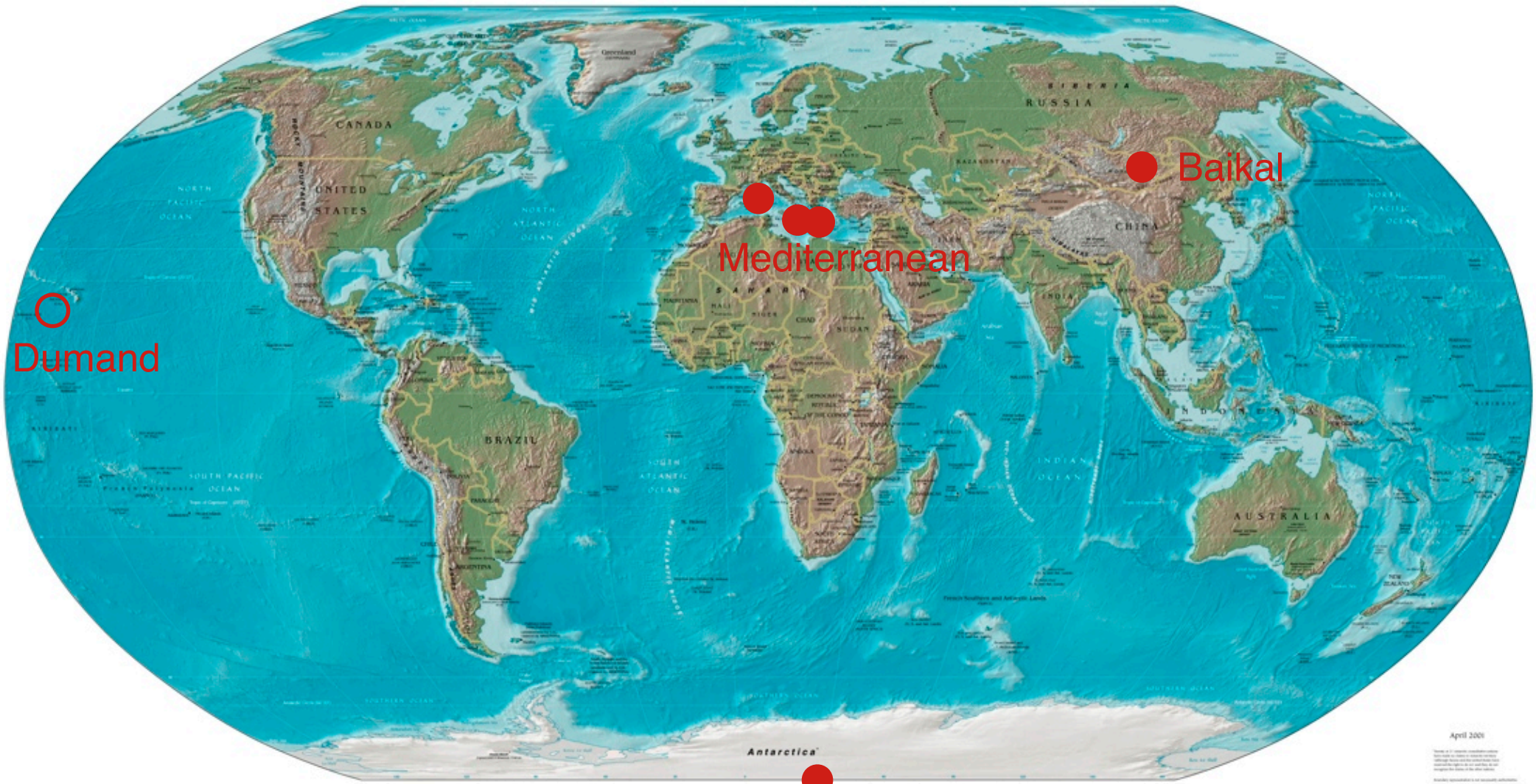
Record every year (e.g. AMANDA)
≈ 1.3 billion cosmic μ
≈ 1000 neutrinos

Trigger efficiency:
≈ 70 % Gamma-Ray Bursts
≈ 25 % point sources
≈ 15 % atmospheric ν

Atmospheric muons: down-going events background is due to mis-reconstructed (fake) tracks

Atmospheric neutrinos:
- upward tracks are good neutrino candidates
- lower energy

Where are the Neutrino Telescopes



Northern Hemisphere Detectors

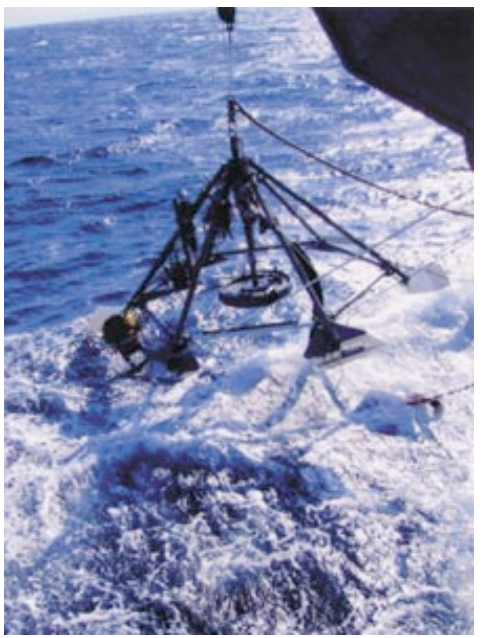
Baikal NT-200

data taking since 1998
1100 m deep
new: 3 distant strings

Antares

5 lines in
2400 m deep
12 lines in 2007

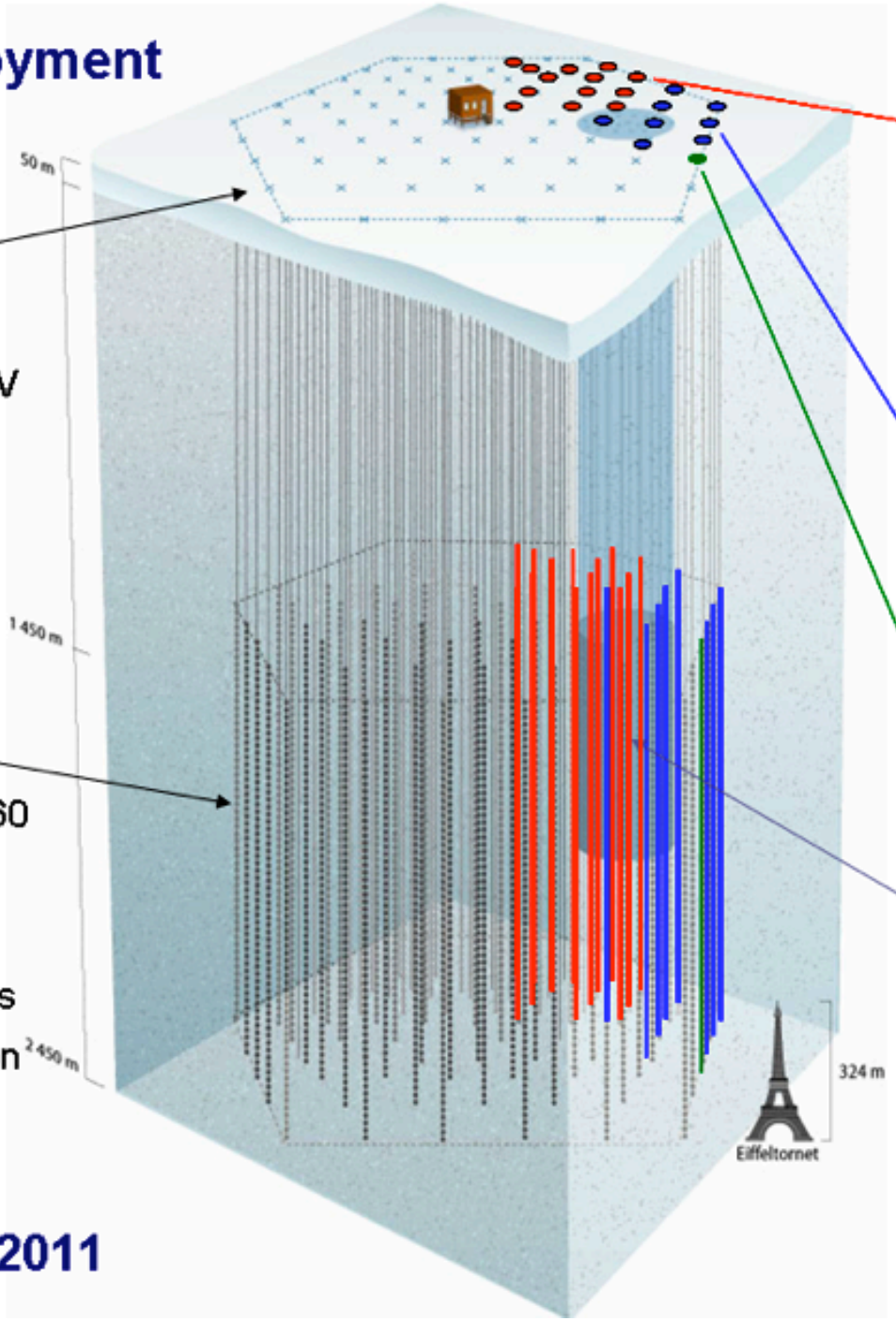
Nestor



had 1 of 12 floors down
4000 m deep
completion: 2007?

⇒ Nemo
operating prototypes at 2000 m

IceCube under Construction – around AMANDA

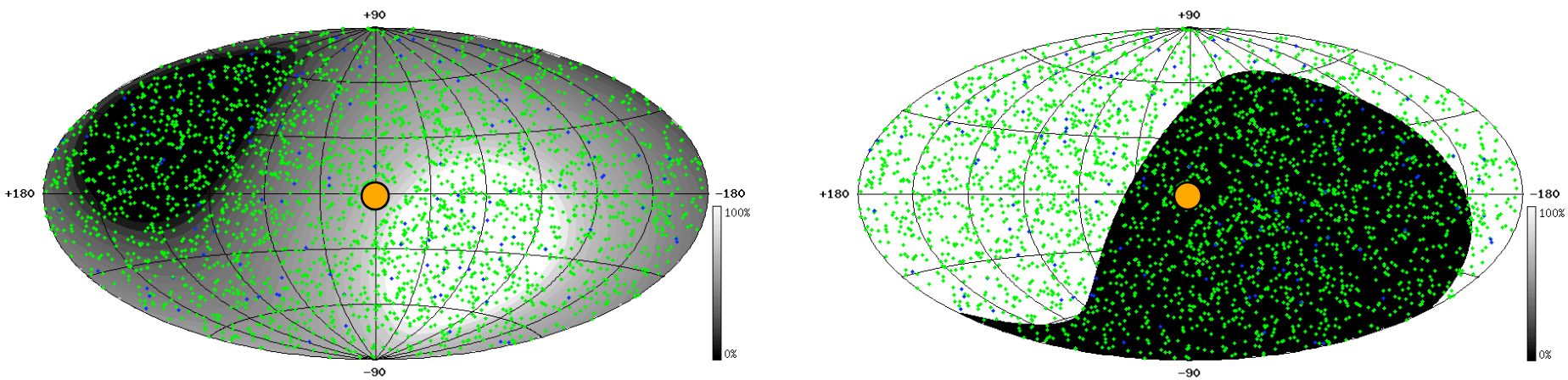


The Case for more than one Telescope

Complete sky coverage

Mediterranean (water)
Antares, Nestor, NEMO
1 km^3 ... and Baikal

South Pole (ice)
AMANDA, IceCube

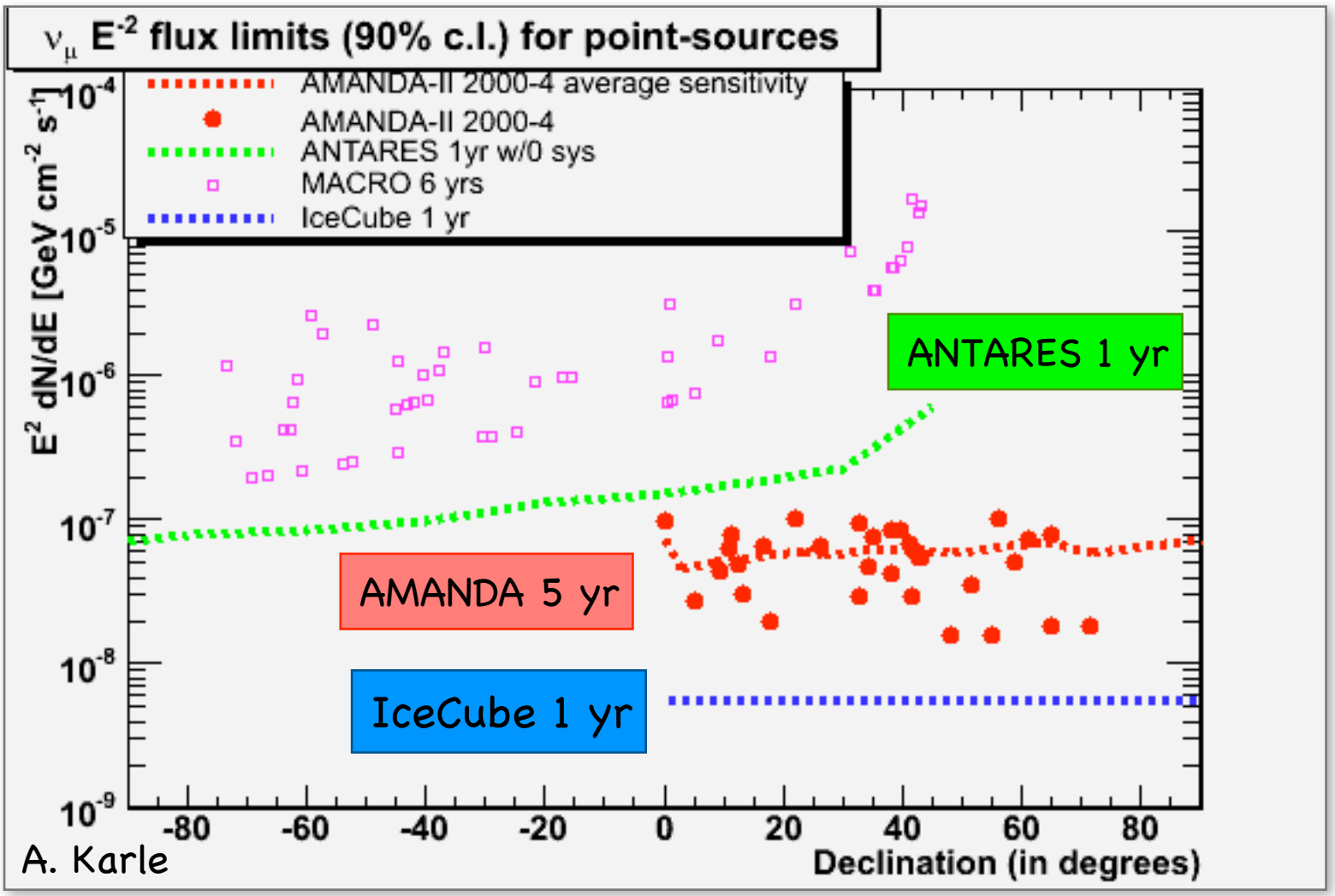


galactic center

0.5 π sr instantaneous common view
1.5 π sr common view per day

...complementary ν telescopes necessary in both hemispheres

Point Source Sensitivity



Expected Signals in km^3 Neutrino-Telescopes

Many calculations and predictions on neutrinos from diffuse and point-sources from Dermer, DiStefano, Mannheim, Protheroe, Stecker, Waxman (and...)

ν-Flux predictions for 5 year KM3Net operation (from γ-ray measurements)

A. Kappes et al., astro-ph 0607286

	Type	$E_\nu > 1$ TeV Src	Bkg
Vela X	PWN	9 – 23	23
RX J1713.7–3946	SNR	7 – 14	41
HESS J1825–137	PWN	5 – 10	9
Crab Nebula	PWN	4 – 8	5
HESS J1303–631	NCP	0.8 – 2.3	11
LS 5039* (INFC)	Binary	0.3 – 0.7	2.5

higher threshold
lower signal but
better S/N

NCP: No counterpart at other wavelengths *no γ-ray absorption

Expected Signals in km^3 Neutrino-Telescopes

Many calculations and predictions on neutrinos from diffuse and point-sources from Dermer, DiStefano, Mannheim, Protheroe, Stecker, Waxman (and...)

ν-Flux predictions for 5 year KM3Net operation (from γ-ray measurements)

A. Kappes et al., astro-ph 0607286

	Type	$E_\nu > 1$ TeV Src	Bkg
Vela X	PWN	9 – 23	23
RX J1713.7–3946	SNR	7 – 14	41
HESS J1825–137	PWN	5 – 10	9
Crab Nebula	PWN	4 – 8	5
HESS J1303–631	NCP	0.8 – 2.3	11
LS 5039* (INFC)	Binary	0.3 – 0.7	2.5

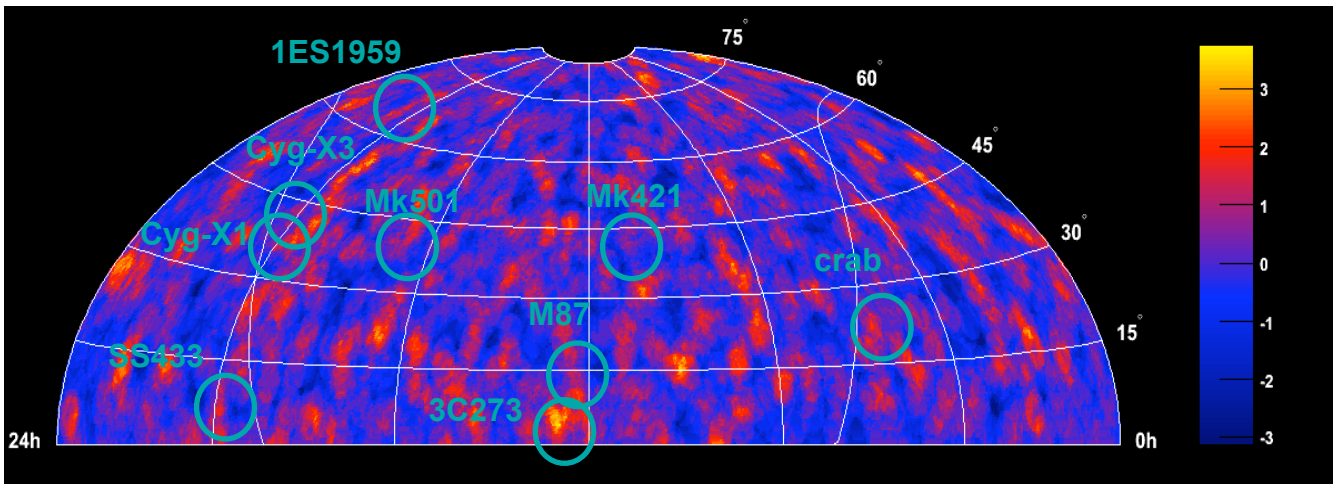
higher threshold
lower signal but
better S/N

NCP: No counterpart at other wavelengths *no γ-ray absorption

☑ neutrino astronomy is a low-statistics field

enhanced signals/sensitivity for
- transient sources
- opaque sources
- sources at higher energies ("PeVatrons")

Search for Neutrinos from specific Sources

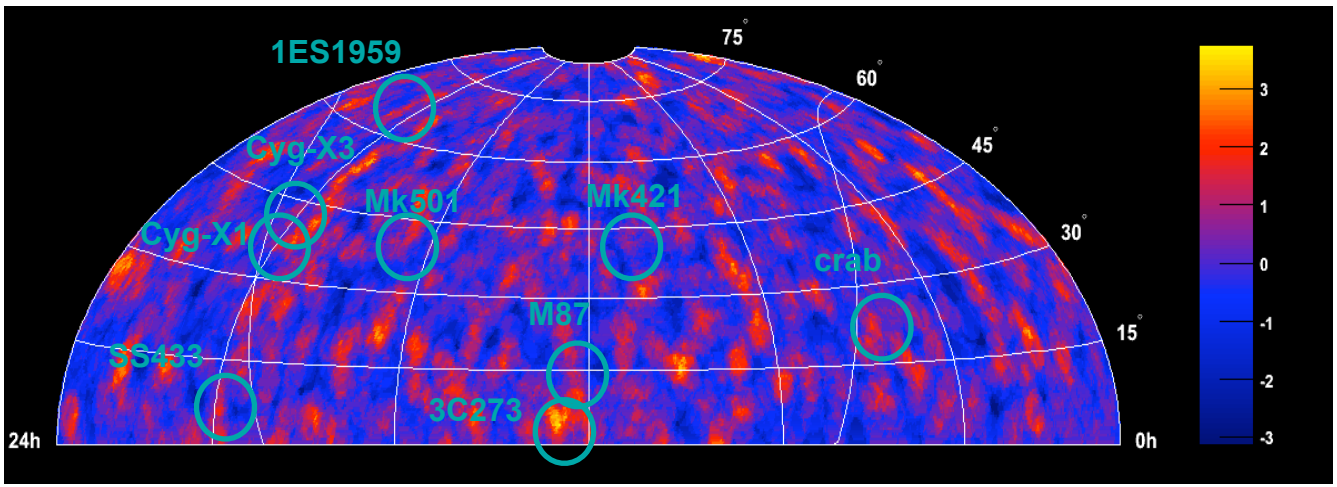


some examples (out of 32 sources) of a a five year data analysis

source	nr. of ν events	expected background	E^{-2} flux upper limit (90% c.l.) [10^{-11} TeV^{-1} cm^{-2} s^{-1}]
Markarian 421	6	7.4	7.4
M87	6	6.1	8.7
1ES 1959+650	5	4.8	13.5
SS433	4	6.1	4.8
Cygnus X-3	7	6.5	11.8
Cygnus X-1	8	7.0	13.2
Crab Nebula	10	6.7	17.8
3C 273	8	4.72	18.0

⇒

Search for Neutrinos from specific Sources

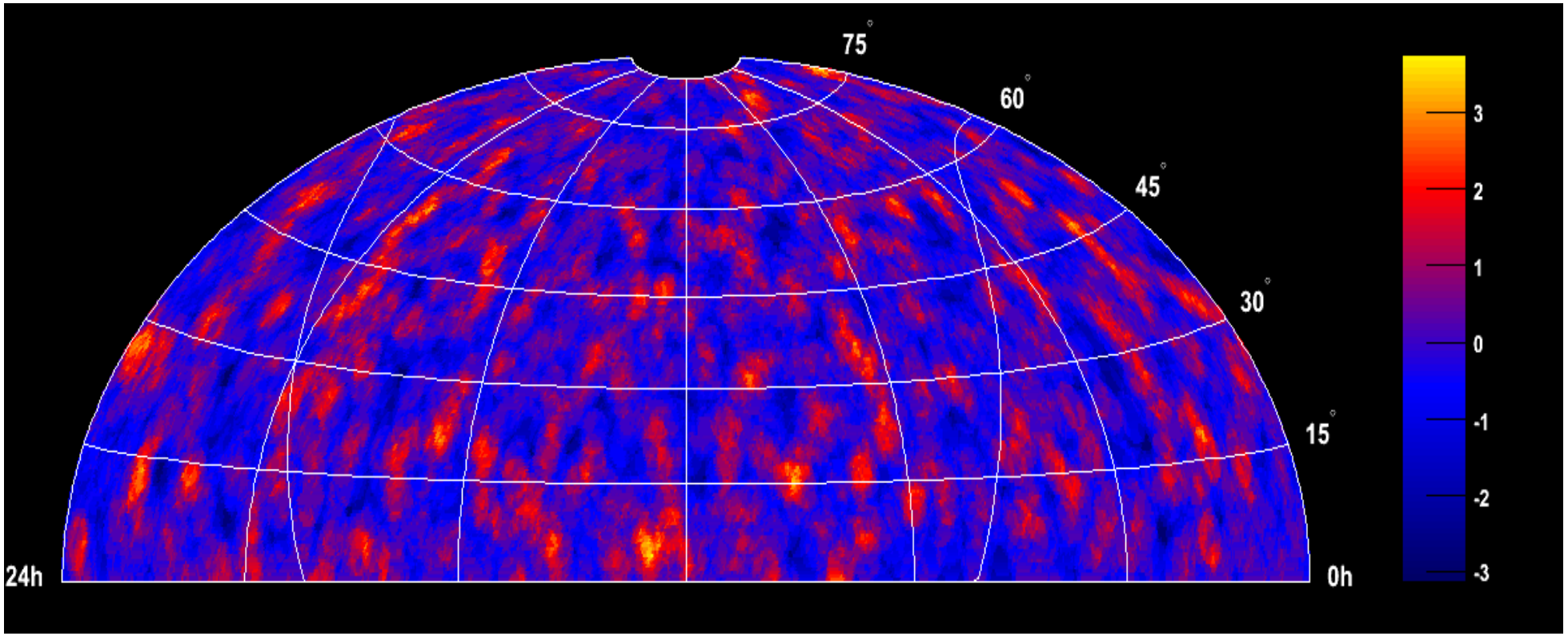


some examples (out of 32 sources) of a a five year data analysis

source	nr. of ν events	expected background	E^{-2} flux upper limit (90% c.l.) [10^{-11} TeV^{-1} cm^{-2} s^{-1}]
Markarian 421	6	7.4	7.4
M87	6	6.1	8.7
1ES 1959+650	5	4.8	13.5
SS433	4	6.1	4.8
Cygnus X-3	7	6.5	11.8
Cygnus X-1	8	7.0	13.2
Crab Nebula	10	6.7	17.8
3C 273	8	4.72	18.0

⇒ No significant excess observed

Point Source Search with AMANDA



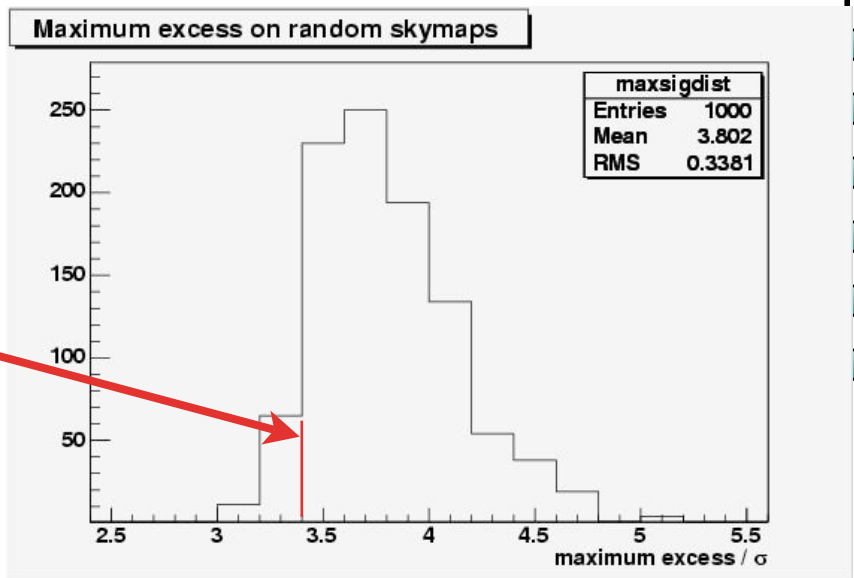
2000-04 (1001 live days) 4282 ν

→ no significant excess found

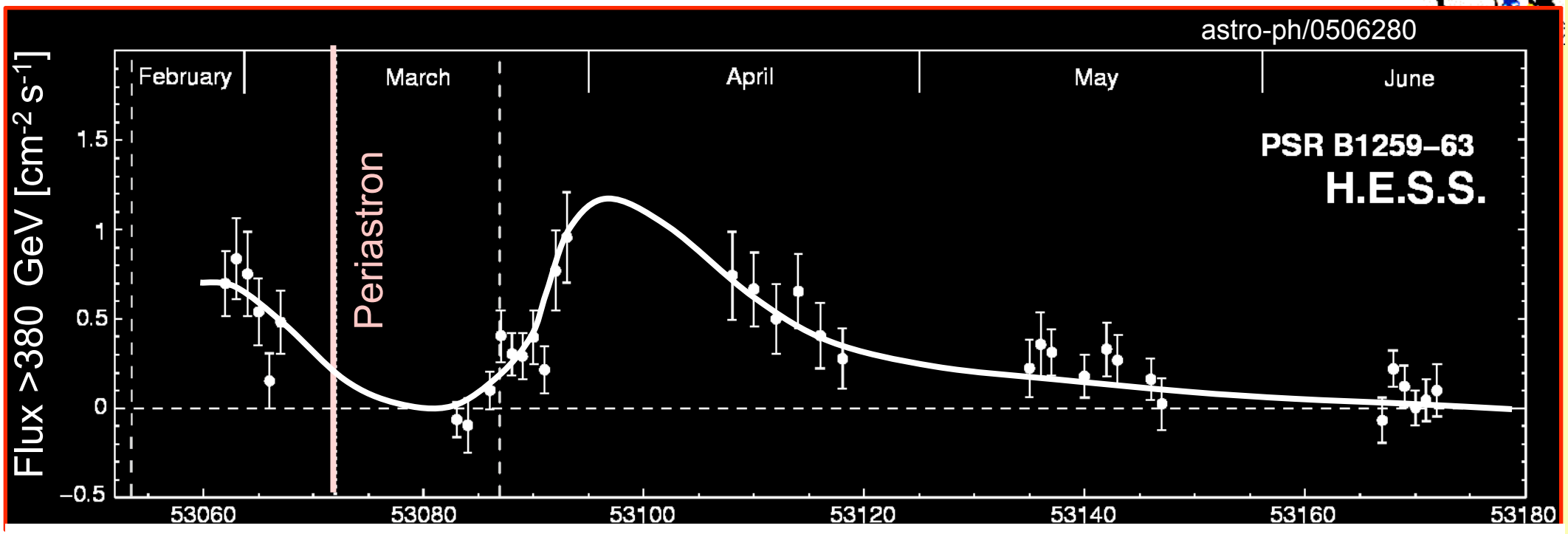
calculate significance of local fluctuations from expectation of atmospheric neutrinos

– un-binned statistical analysis

– maximum of 3.4 σ - compatible with background fluctuation



Search for Neutrino Flares

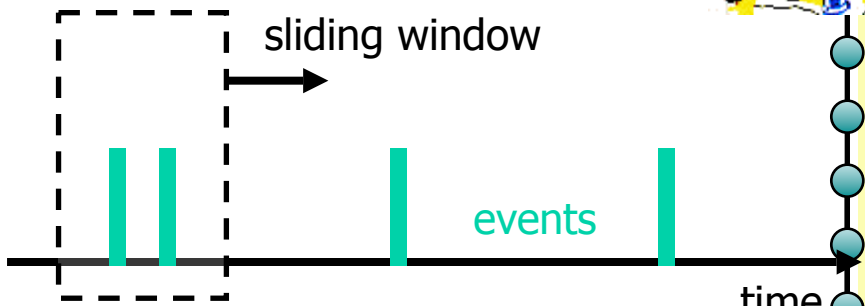


Search for Neutrino Flares

Excess in time-sliding windows?

= 2.25°-3.75°

= 40/20 days for extra-galactic/ galactic objects

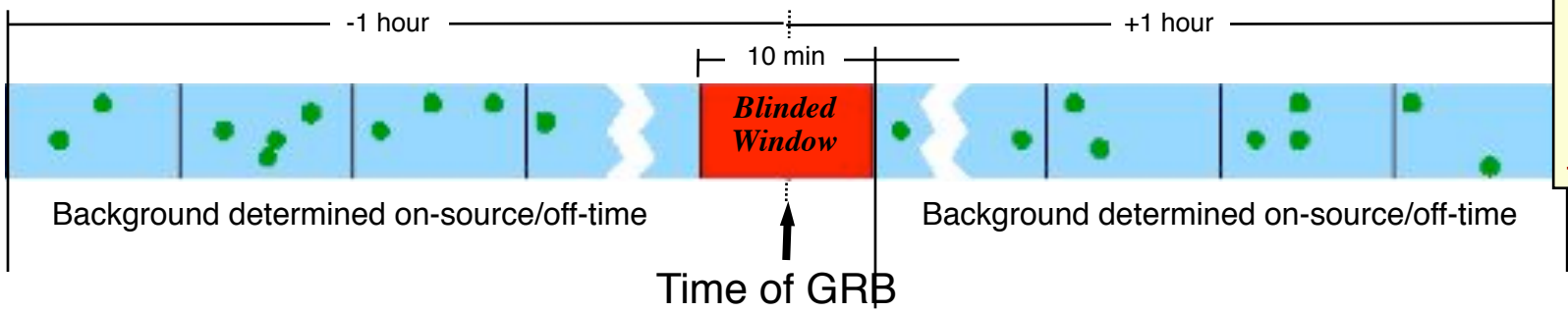


Source	Nr. of ν events (4 years)	Expected backgr. (4 years)	Period duration	Nr. of doublets	Probability for highest multiplicity
Markarian 421	6	5.58	40 days	0	Close to 1
1ES1959+650	5	3.71	40 days	1	0.34
3EG J1227+4302	6	4.37	40 days	1	0.43
QSO 0235+164	6	5.04	40 days	1	0.52
Cygnus X-3	6	5.04	20 days	0	Close to 1
GRS 1915+105	6	4.76	20 days	1	0.32
GRO J0422+32	5	5.12	20 days	0	Close to 1

Preliminary

… out of 12 sources: No statistical significant effect observed

GRB Neutrino search



Low background analysis due to space and time coincidence!

GRB catalogs:
BATSE (non-)triggered,
IPN3 & GUSBAD

	Year	#GRB	bkg	observed
muon	97-00	312	1.30	0
muon	01-03	51	0.24	0
cascades	2000	73	0.005	0

AMANDA

Cascade channel:
bad pointing but 4π

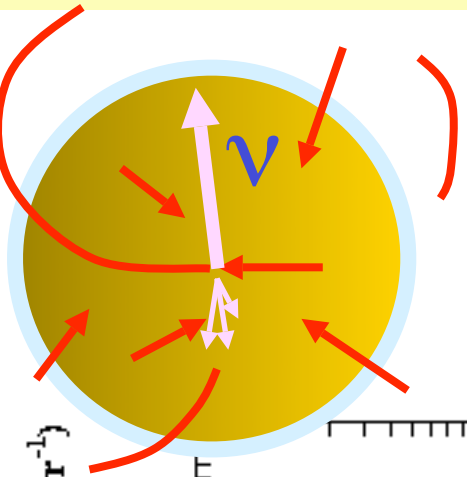
No coincident events observed

☛ limit assuming WB spectrum: $E_\nu^2\Phi_\nu < 3 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} (μ)

$< 9.5\times10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} (cascades)

Baikal analysed 1998-99 data with same technique in cascade channel leading to a slightly worse limit

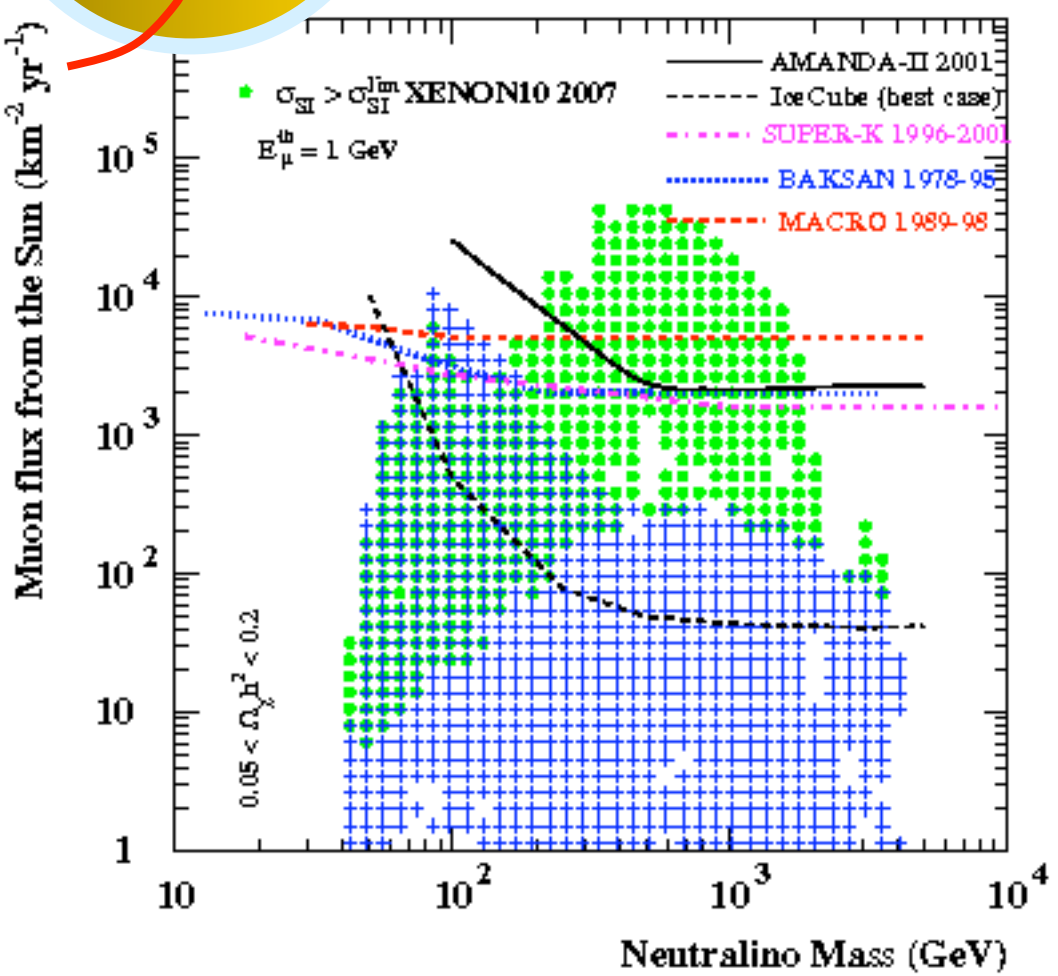
Neutralino Search with Baikal and AMANDA



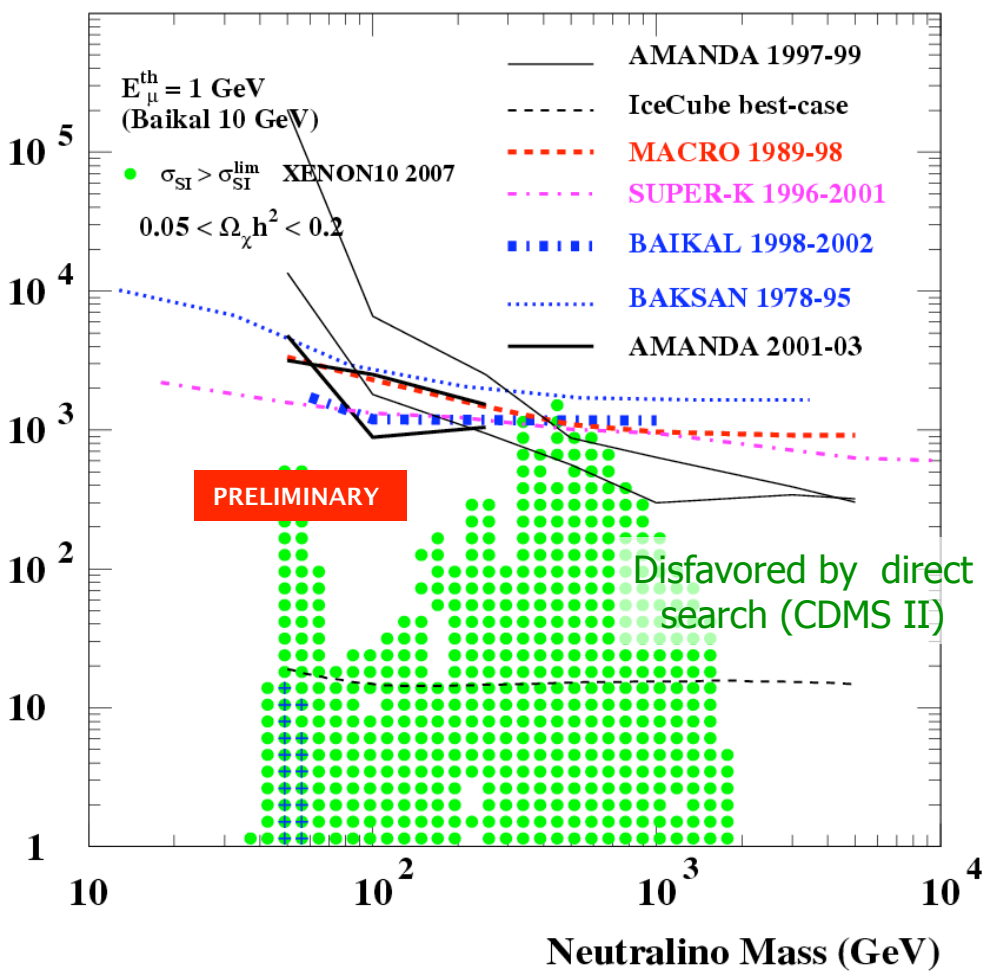
$$\text{e.g.soft channel } \chi + \bar{\chi} \rightarrow \mathrm{b} + \bar{\mathrm{b}}, \mathrm{b} \rightarrow \mathrm{c}\ \mu\ \nu$$
$$\text{hard channel through W}$$

S Schlenstedt

Muon flux from Sun

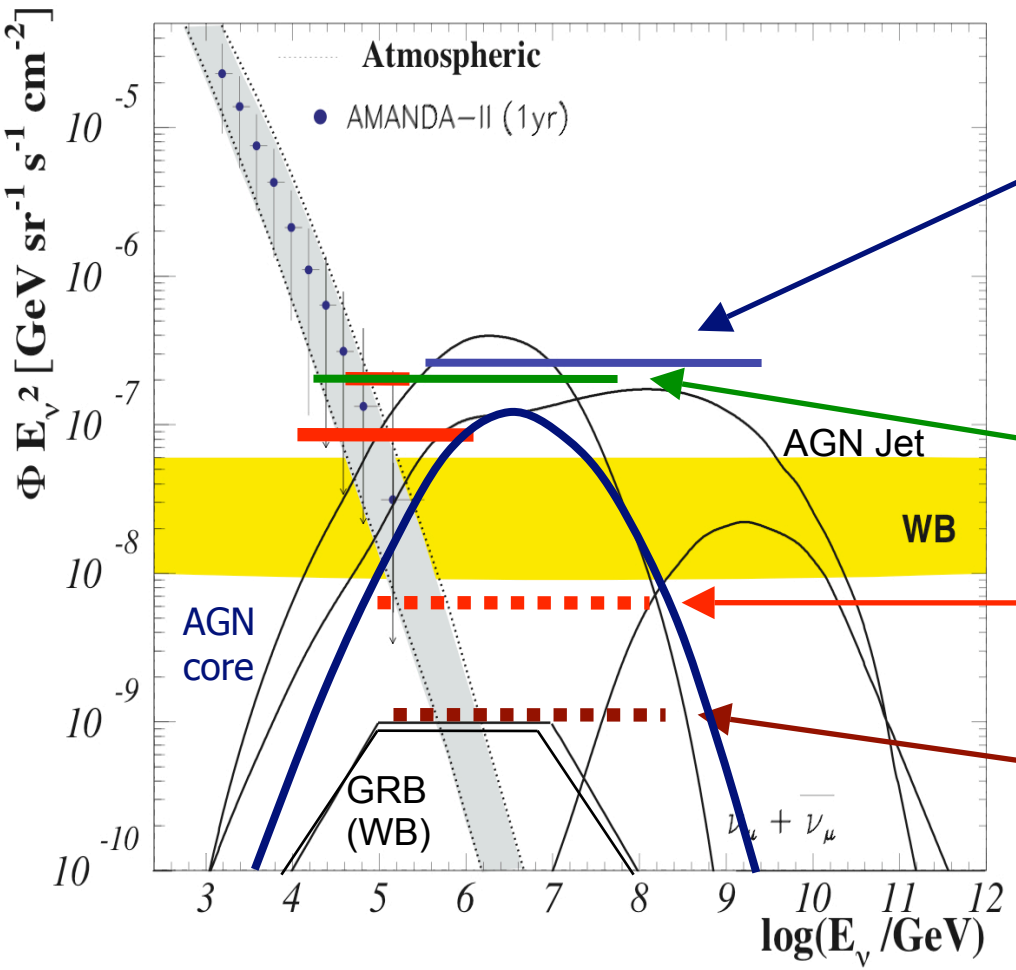


Limits on muon flux from Earth center



Nuclear Recoil and indirect searches are complementary and not equivalent

Measurements of the Diffuse extraterrestrial Flux



AMANDA HE analysis

Baikal

IceCube muons,
1 year

Icecube,
muons & cascades
4 years

Several models of AGN neutrino emission are ruled out by current measurements

→ precise flux measurement needs km^3-size detector

Physics Summary

AMANDA and Baikal are unique and complementary

(Northern/ Southern sky, ice/ water, different analyses techniques)

Both experiments have a rich physics program

Other results not shown like the moon shadow, search for fast and slow monopoles, prompt muons from charm decays, neutrino oscillation, Lorentz invariance...

Physics Summary

AMANDA and Baikal are unique and complementary

(Northern/ Southern sky, ice/ water, different analyses techniques)

Both experiments have a rich physics program

- Understanding of atmospheric μ's as calibration "beam"
- Measurement of the atmospheric neutrino spectrum
- Limits on diffuse extraterrestrial neutrino flux for TeV-EeV ν's
- Point source search in data between 1997 and 2004
- Search for neutrinos coincident with Gamma Ray Bursts
- The supernova–IceCube connection
- Search for trapped neutralinos

Other results not shown like the moon shadow, search for fast and slow monopoles, prompt muons from charm decays, neutrino oscillation, Lorentz invariance...

Physics Summary

AMANDA and Baikal are unique and complementary

(Northern/ Southern sky, ice/ water, different analyses techniques)

Both experiments have a rich physics program

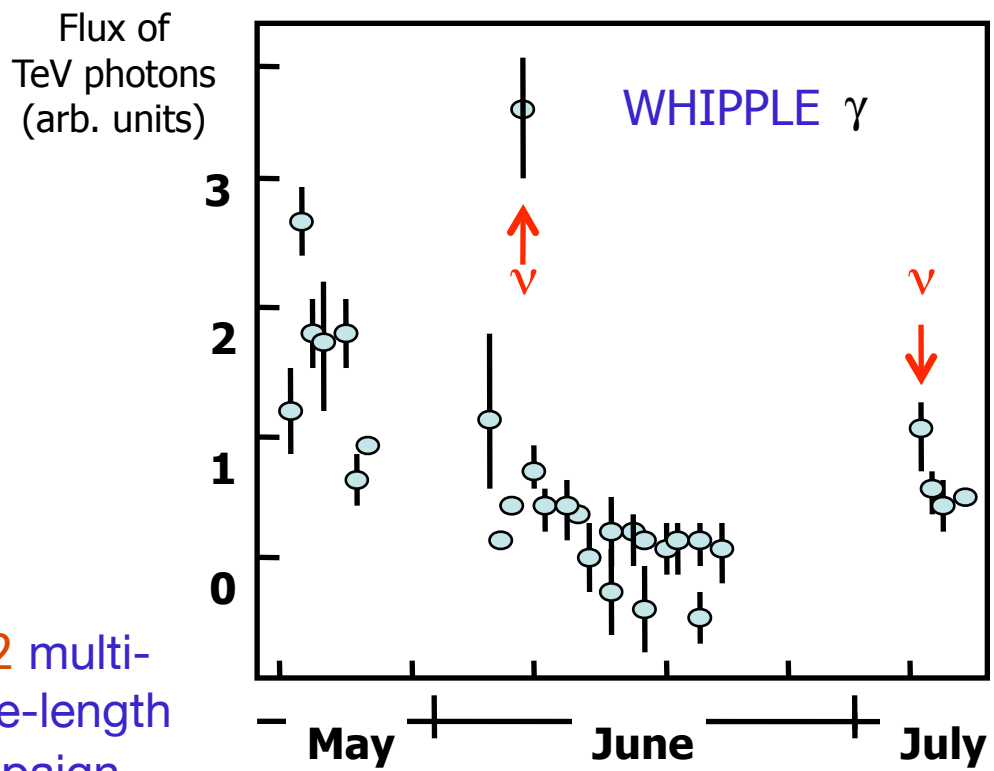
- Understanding of atmospheric μ's as calibration "beam"
- Measurement of the atmospheric neutrino spectrum
- Limits on diffuse extraterrestrial neutrino flux for TeV-EeV ν's
- Point source search in data between 1997 and 2004
- Search for neutrinos coincident with Gamma Ray Bursts
- The supernova–IceCube connection
- Search for trapped neutralinos

No extraterrestrial ν signal observed… yet

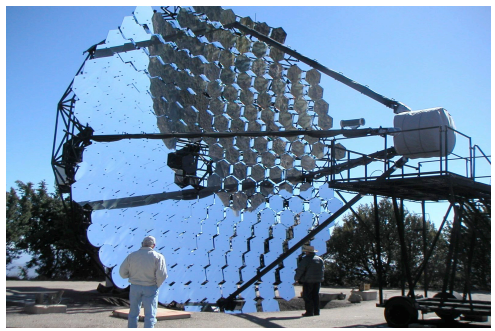
Other results not shown like the moon shadow, search for fast and slow monopoles, prompt muons from charm decays, neutrino oscillation, Lorentz invariance...

Neutrinos and 1ES1959

A posteriori search: three neutrinos in a 66 day period of major outburst – "the orphan flare" (TeV– but no X-ray signal)



2002 multi-wave-length campaign



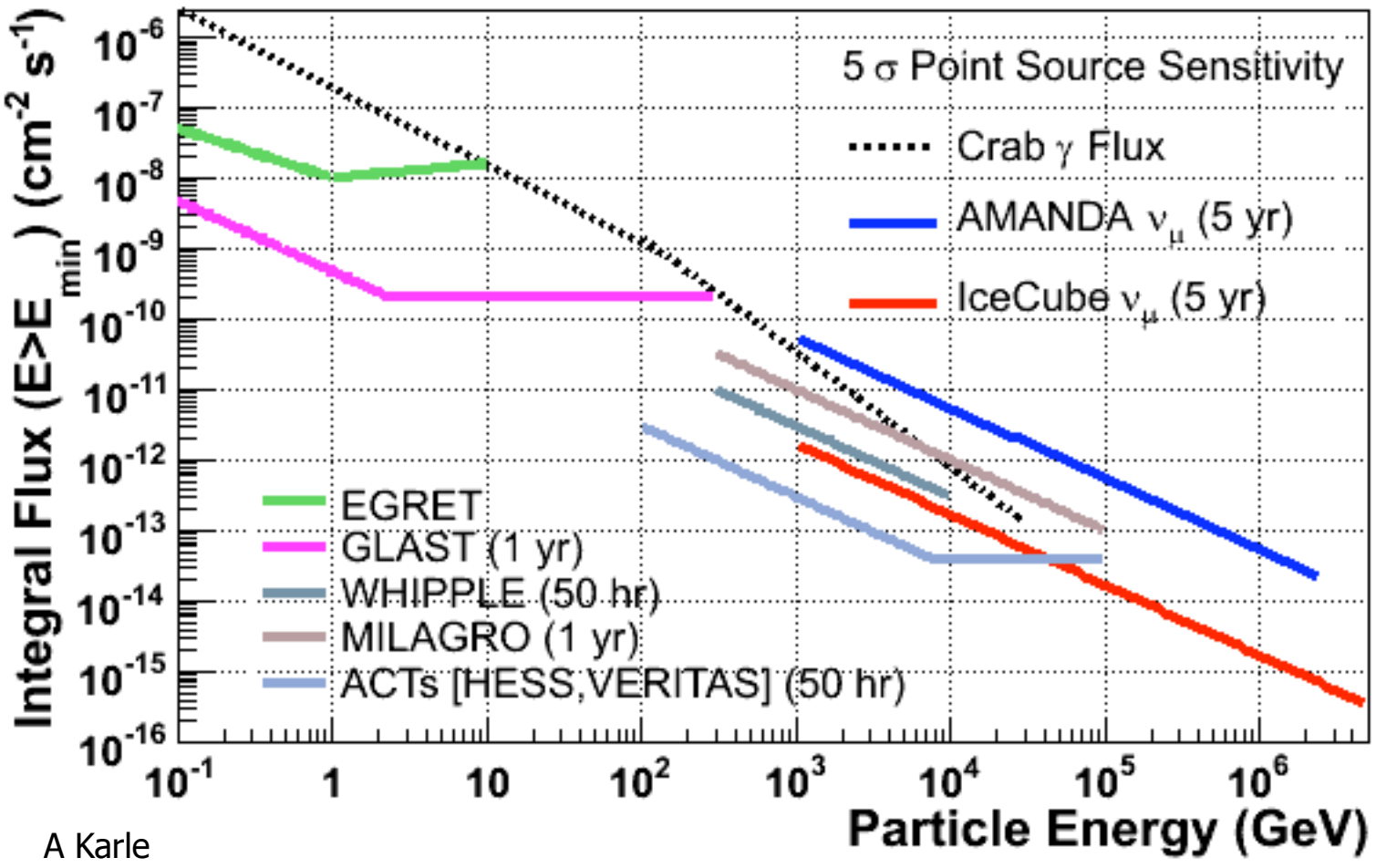
– one event is within a few hours of the orphan flare

– a blazar with γ-ray flare without X-ray counterpart: some interpret this as hadronic acivity in the blazar jet

not statistically significant – but interesting observation

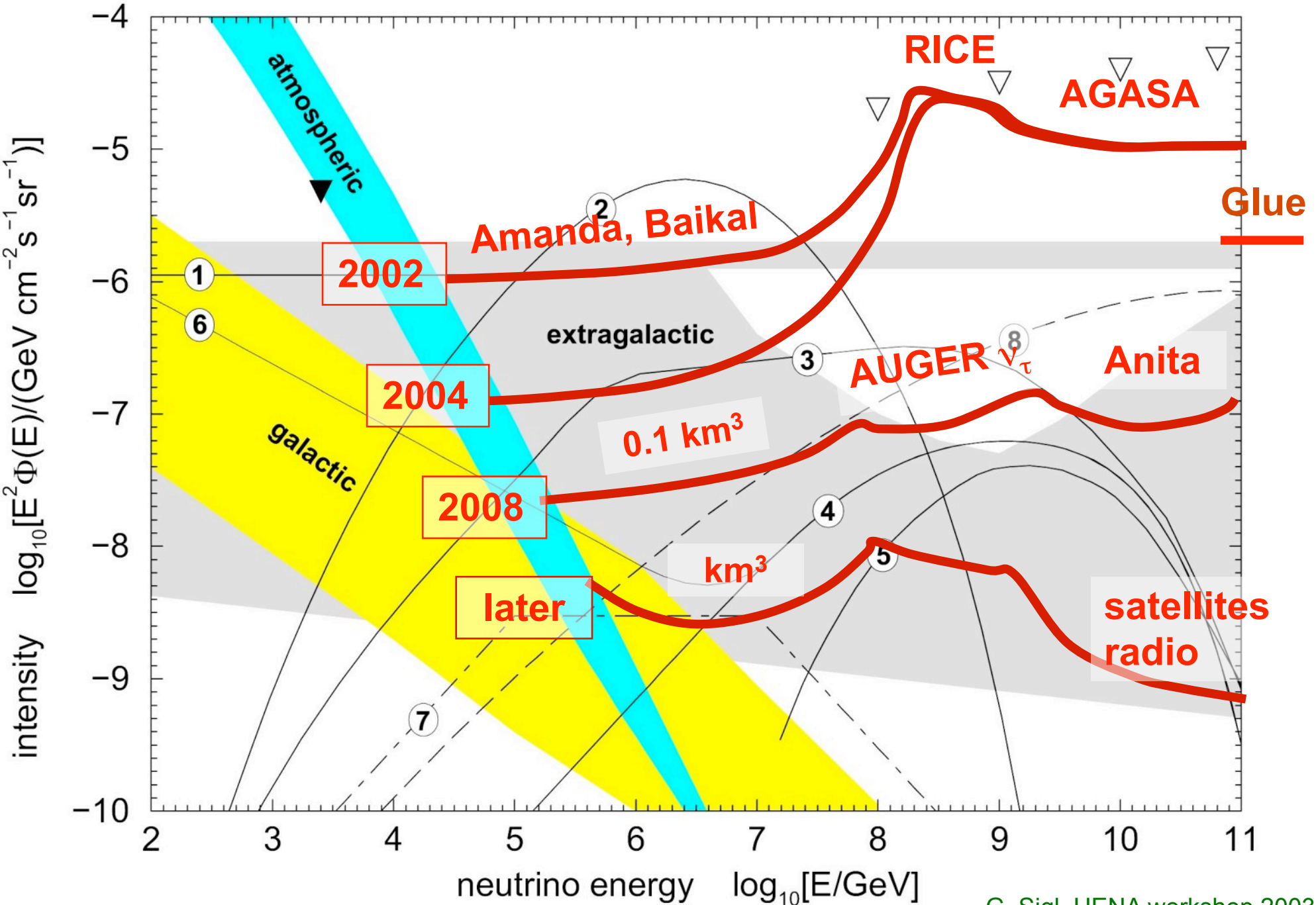
⇛ lead to a modified search strategy and a close collaboration with the γ-ray community (two month test run between AMANDA and MAGIC)

Sensitivities for Point Sources



A Karle

Diffuse Searches now and in the Future



G. Sigl, HENA workshop 2003