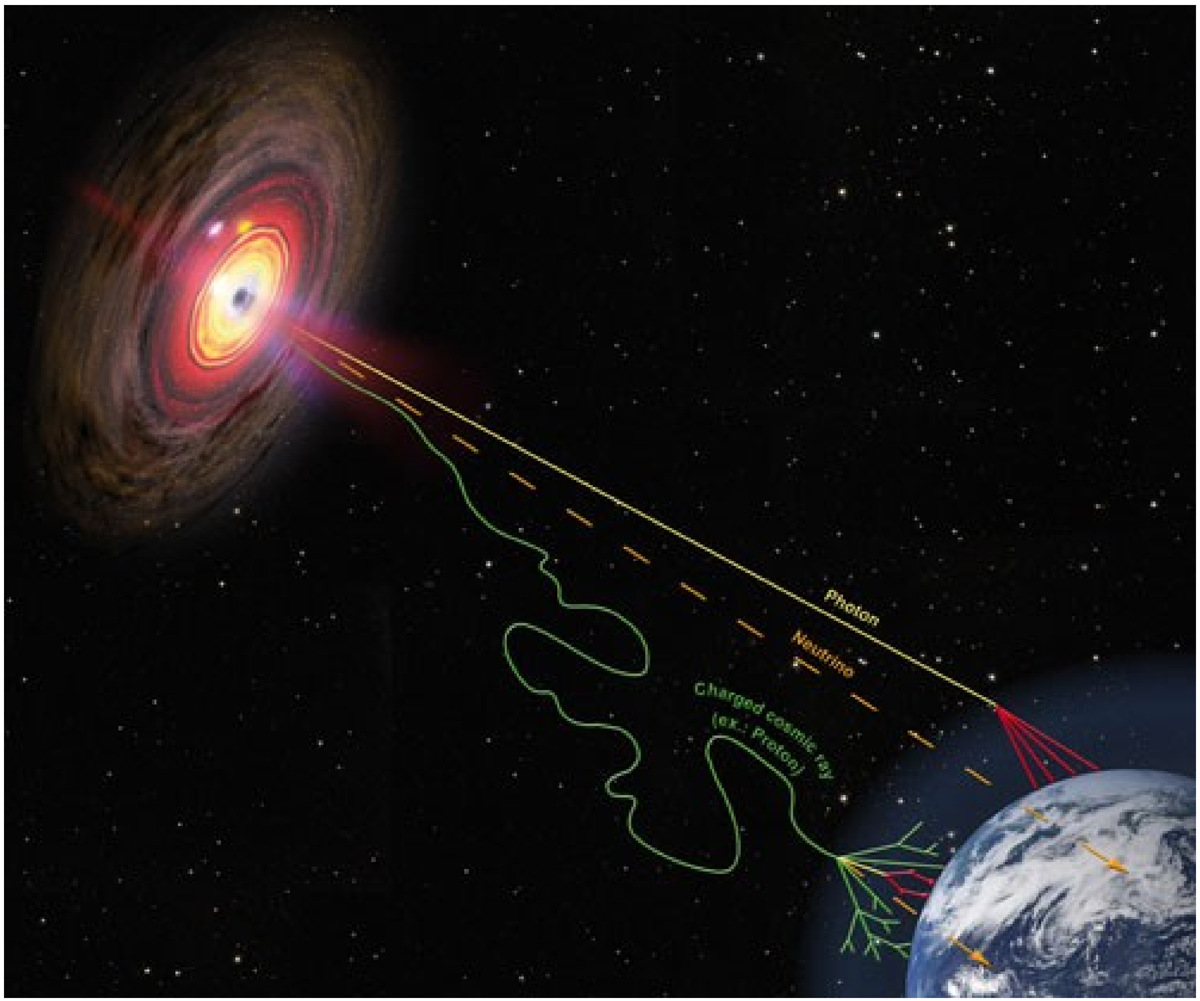
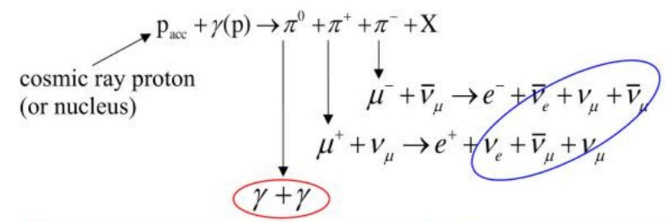
Potraga za mogućim astrofizičkim izvorima neutrina i visoko energetskih kosmičkih zraka

Jelena Petrovic – Astronomska Opservatorija Beograd - Mart 2019

Cosmic particle accelerators



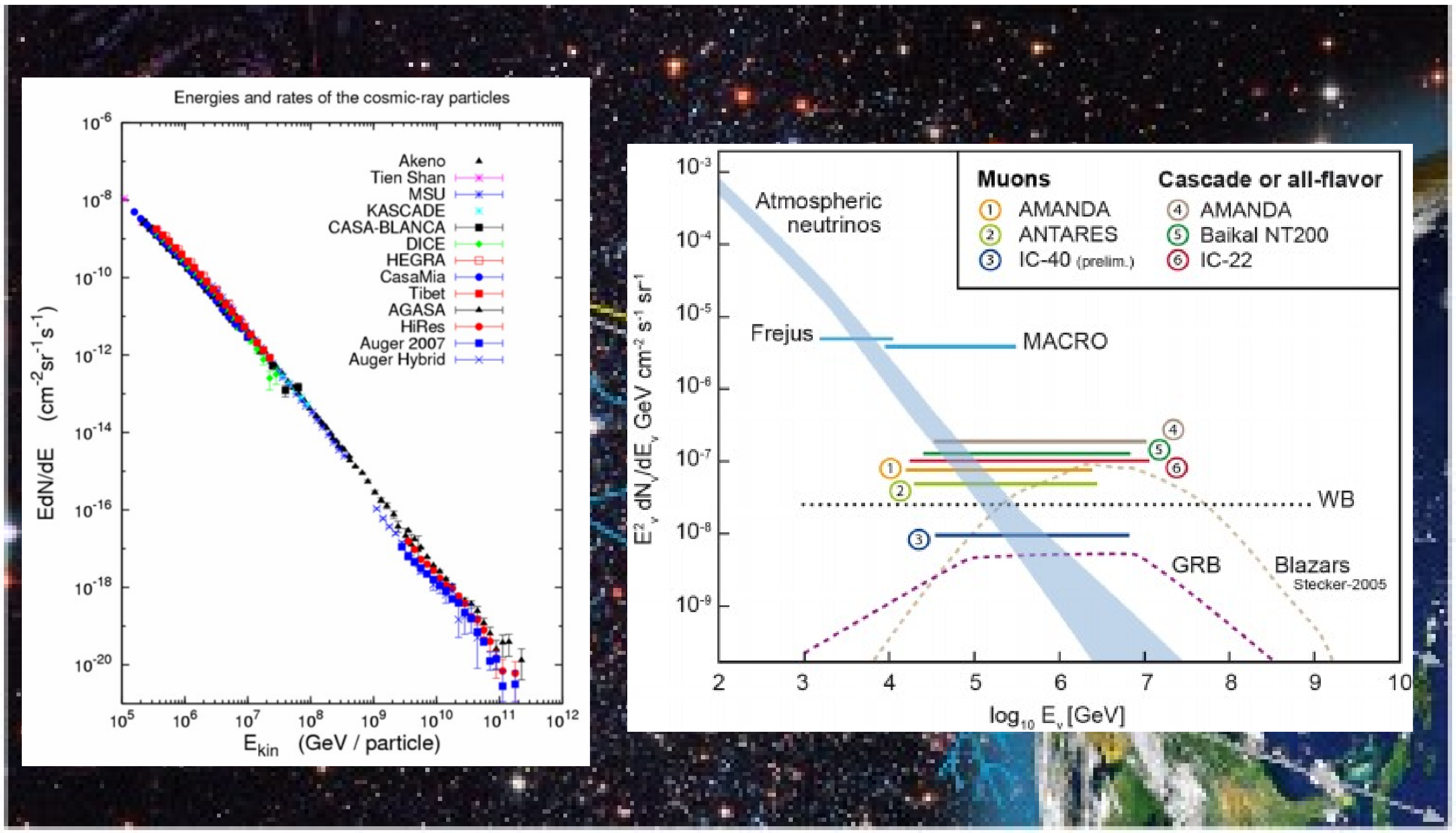


Photons
-straight propagation
-reprocessed to low E in (opaque) sources
-absorbed on extra-galactic photon background
-alternative production mechanism: electrons
-sources detected by H.E.S.S., MAGIC, Fermi

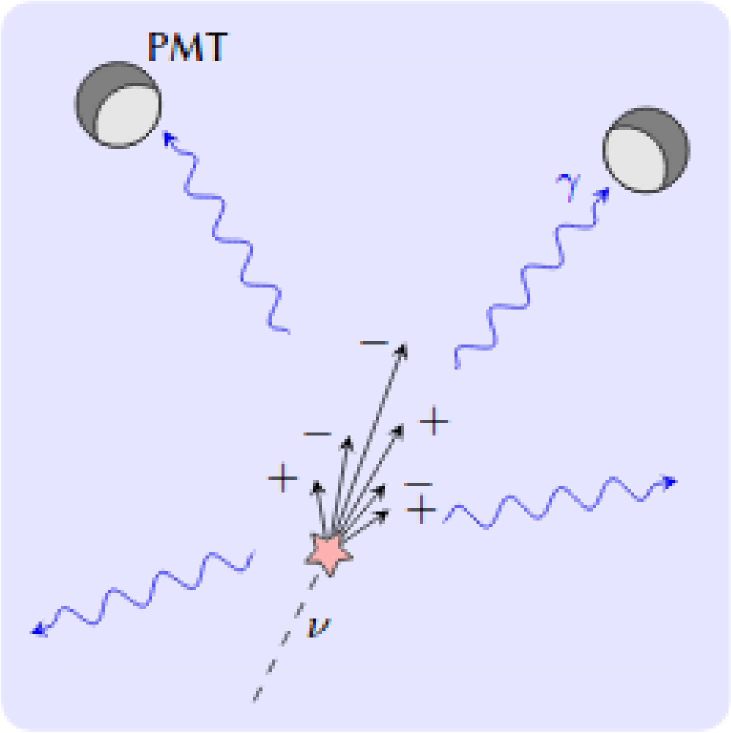
Neutrinos
-straight propagation
-no absorption while propagating
-produced in hadronic interactions
-hard to detect
-no sources detected yet

Cosmic rays
-deflected in magnetic fields

Cosmic particle accelerators



Neutrino detection in water or ice



-small interaction cross section →
large detectors are needed

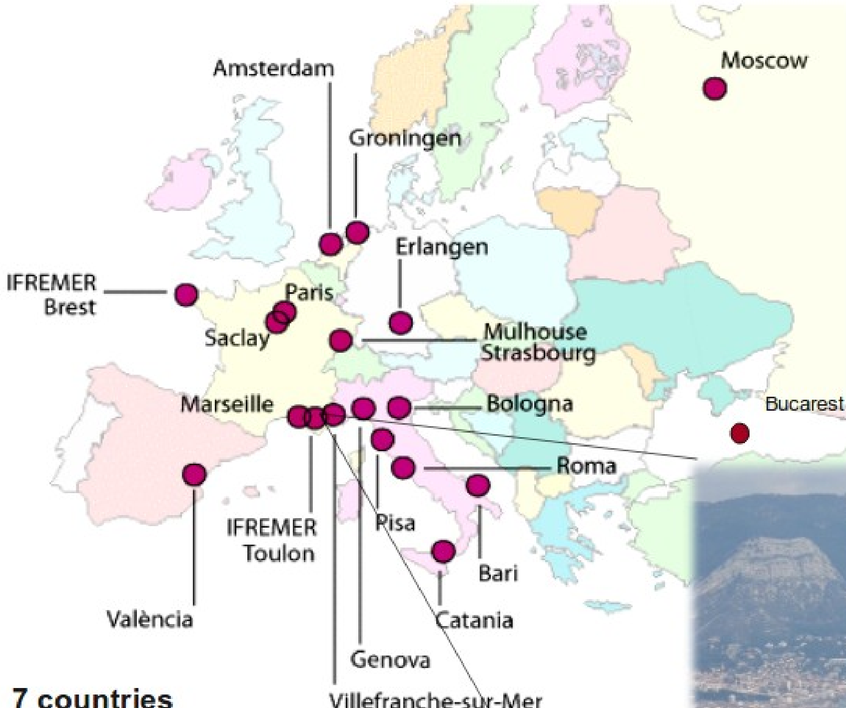
-upgoing neutrino can interact under sea bottom or
in water/ice creating charged particles in this process

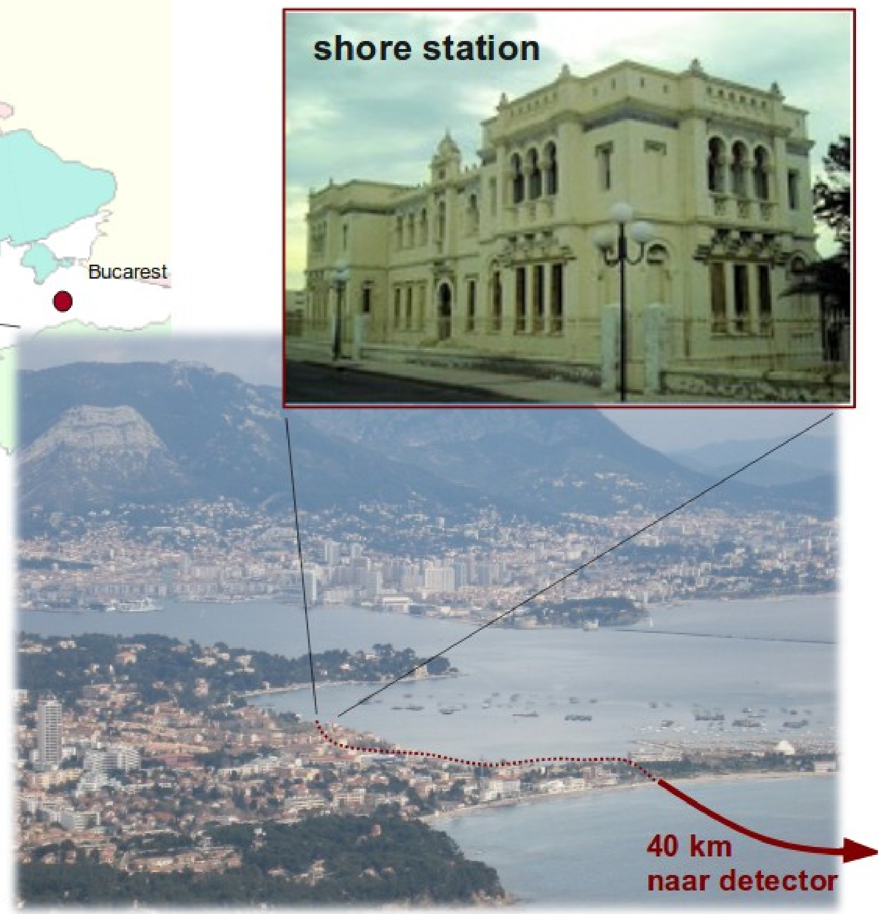
-Cherenkov radiation is produced

-light gets picked up by 3D array of optical modules with
photomultiplier tubes

Antares neutrino telescope (water)
IceCube neutrino telescope (ice)

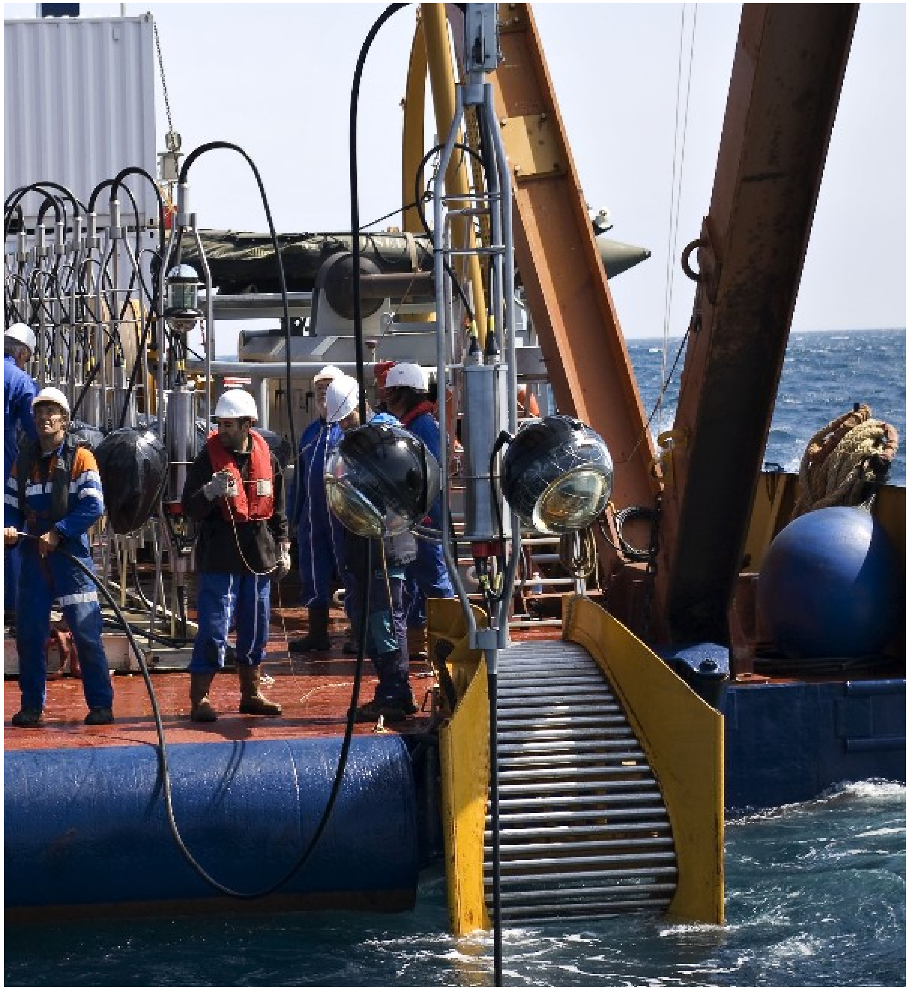
Antares neutrino telescope

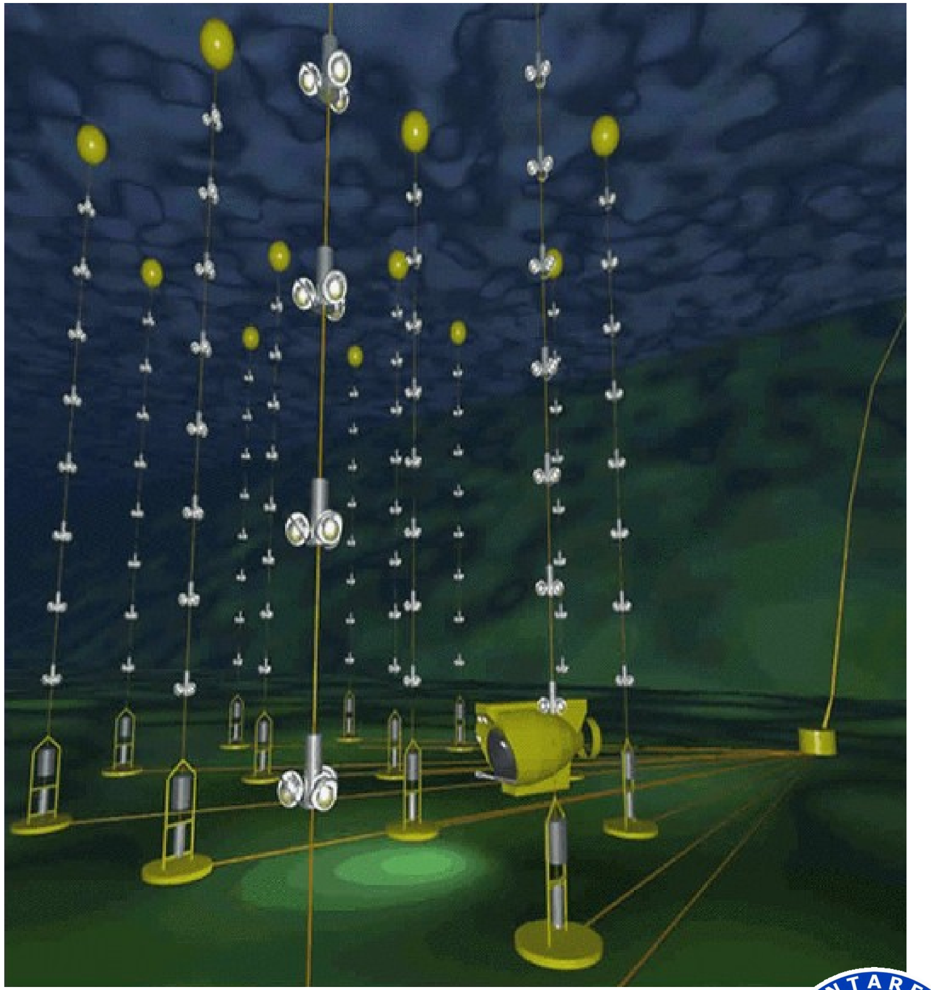




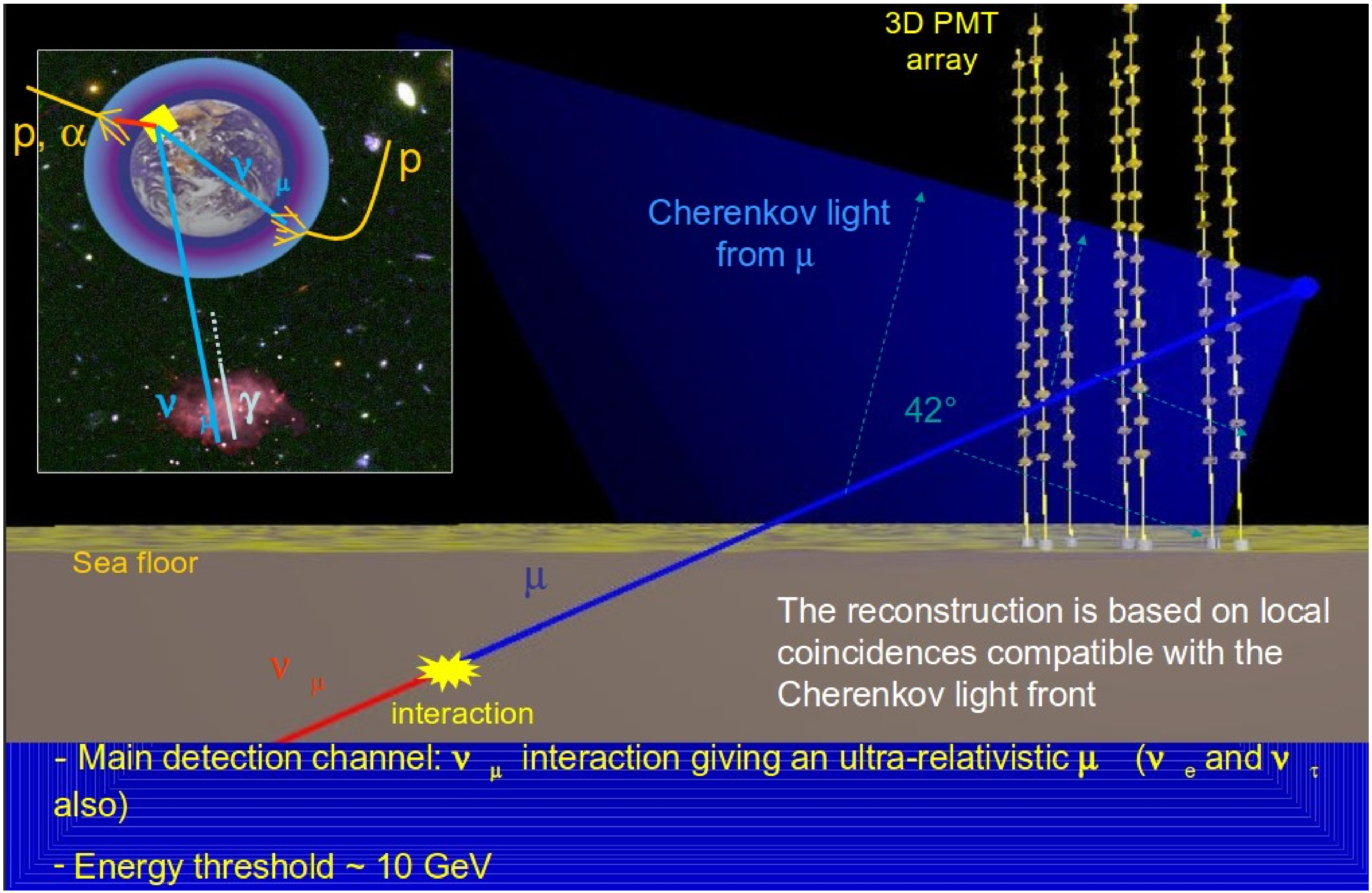
7 countries
29 institutes
~150 scientists+enginers

Antares neutrino telescope

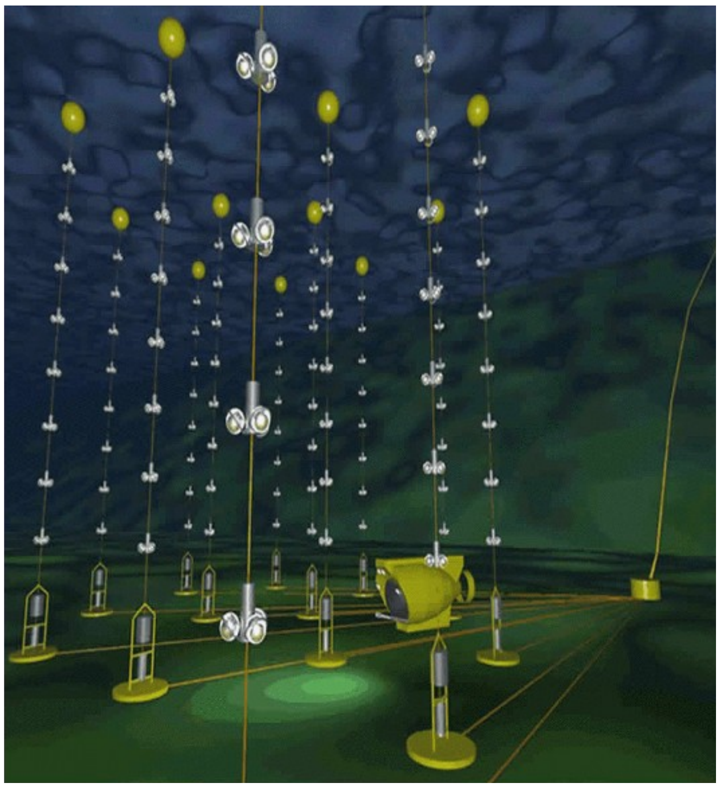


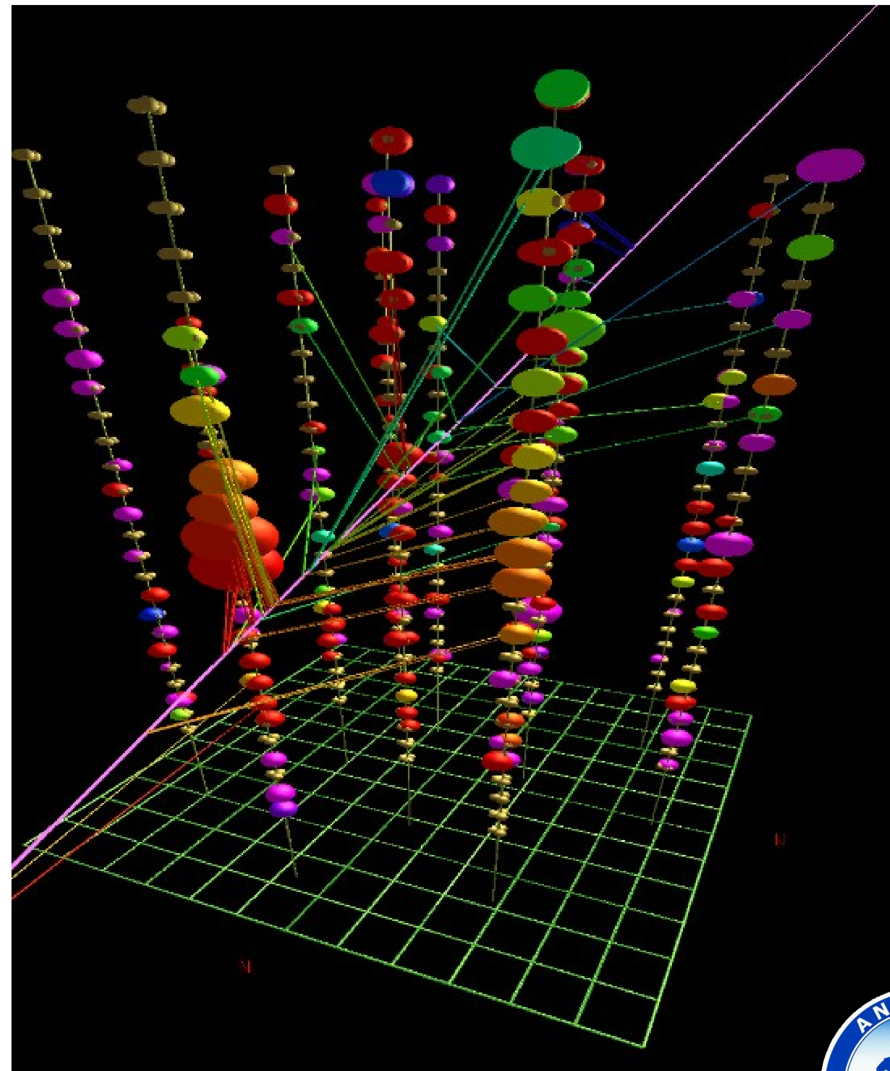


Detection of neutrinos

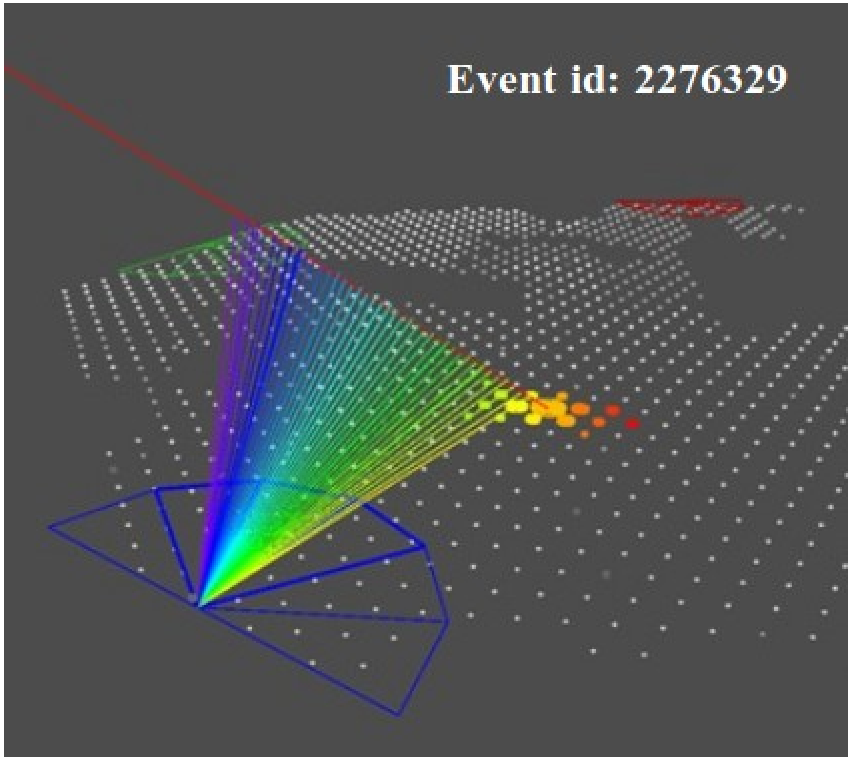


Event seen by neutrino telescope





Auger: hybrid detector

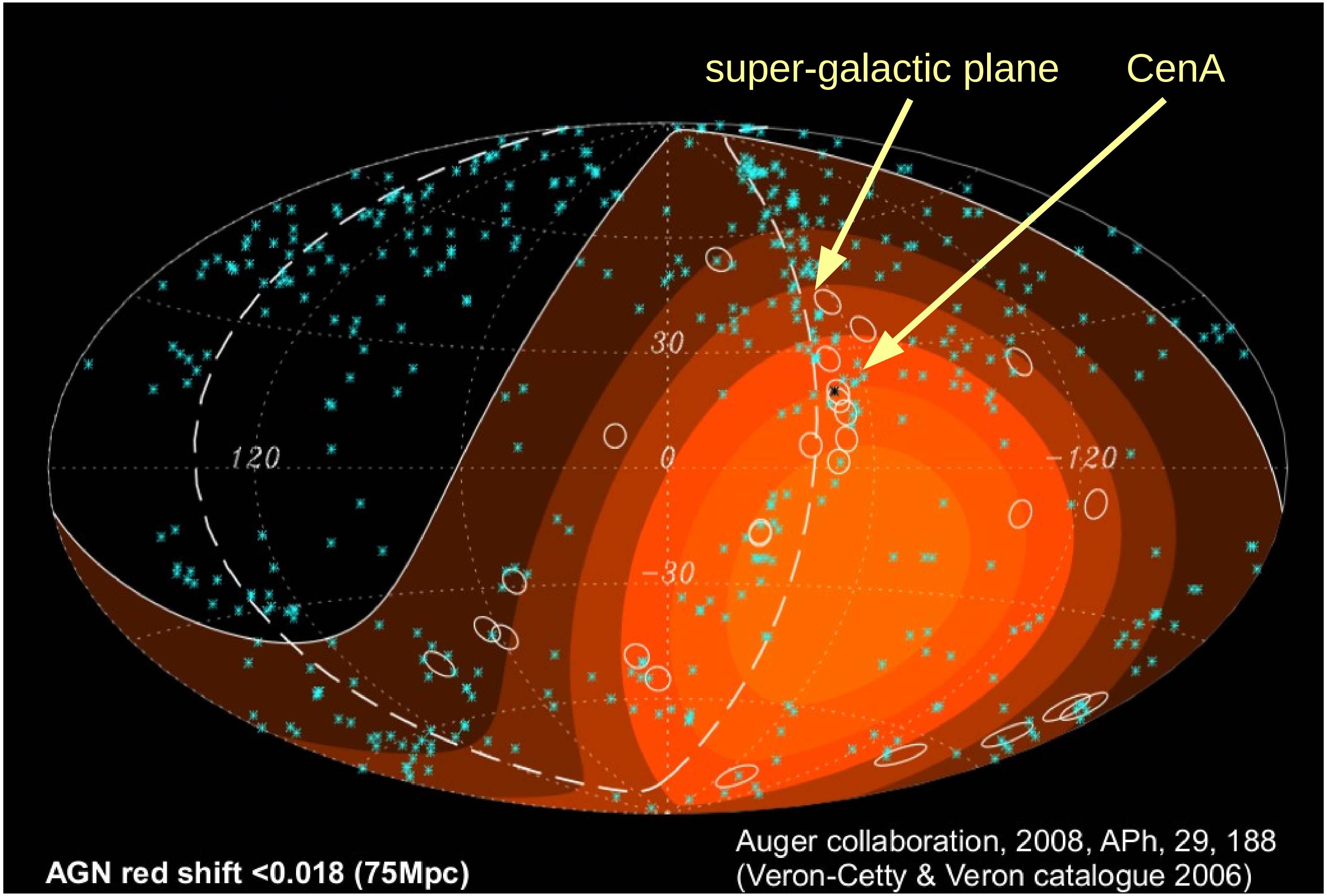


Two types of detectors
-surface detectors/water tanks with photomultiplier Tubes (~1700): for Cherenkov radiation
-fluorescent detectors (4)
for trail of UV radiation from reactions of cosmic rays with nitrogen in the atmosphere

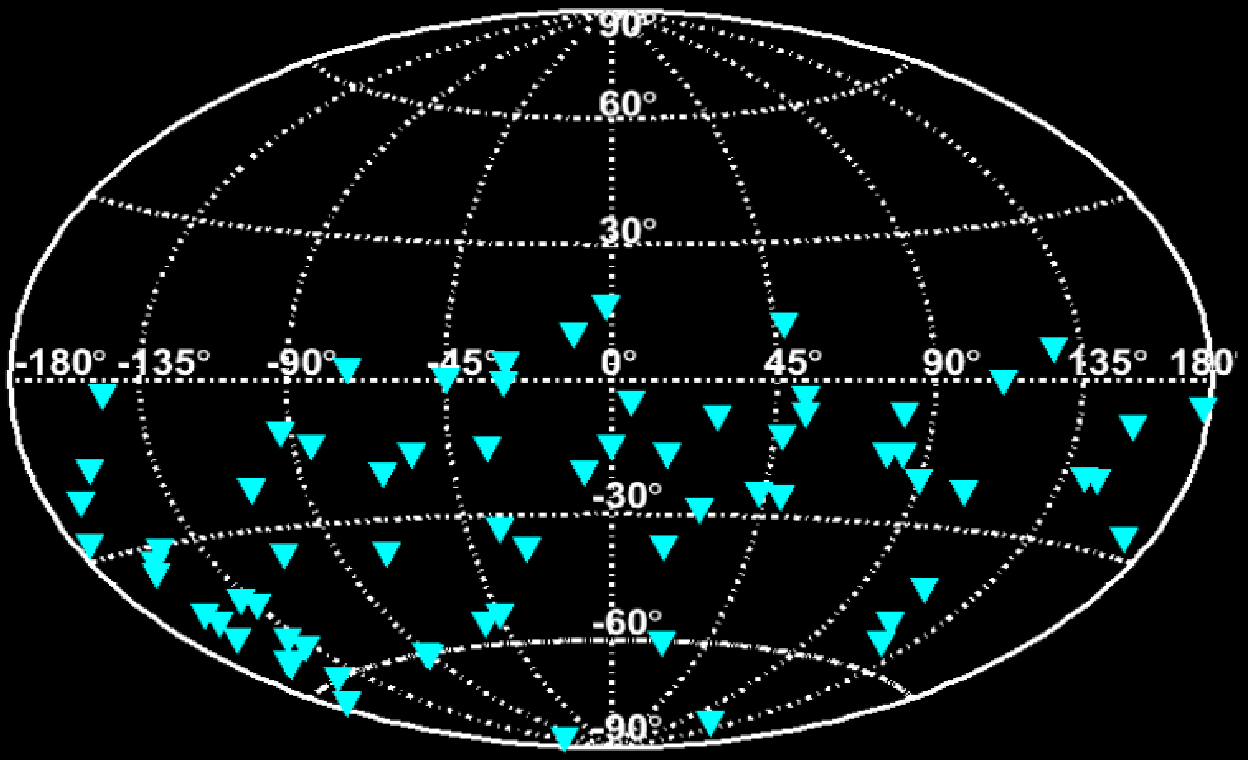
-amount of Cherenkov light in water tanks → energy of incoming primary particle
-slight difference in detection times in water tanks → trajectory of incoming particle

This can be compared with estimate of total shower energy and direction seen by fluorescent detectors

Pierre Auger: correlation of UHECRs with AGNs 2008 (27 events)

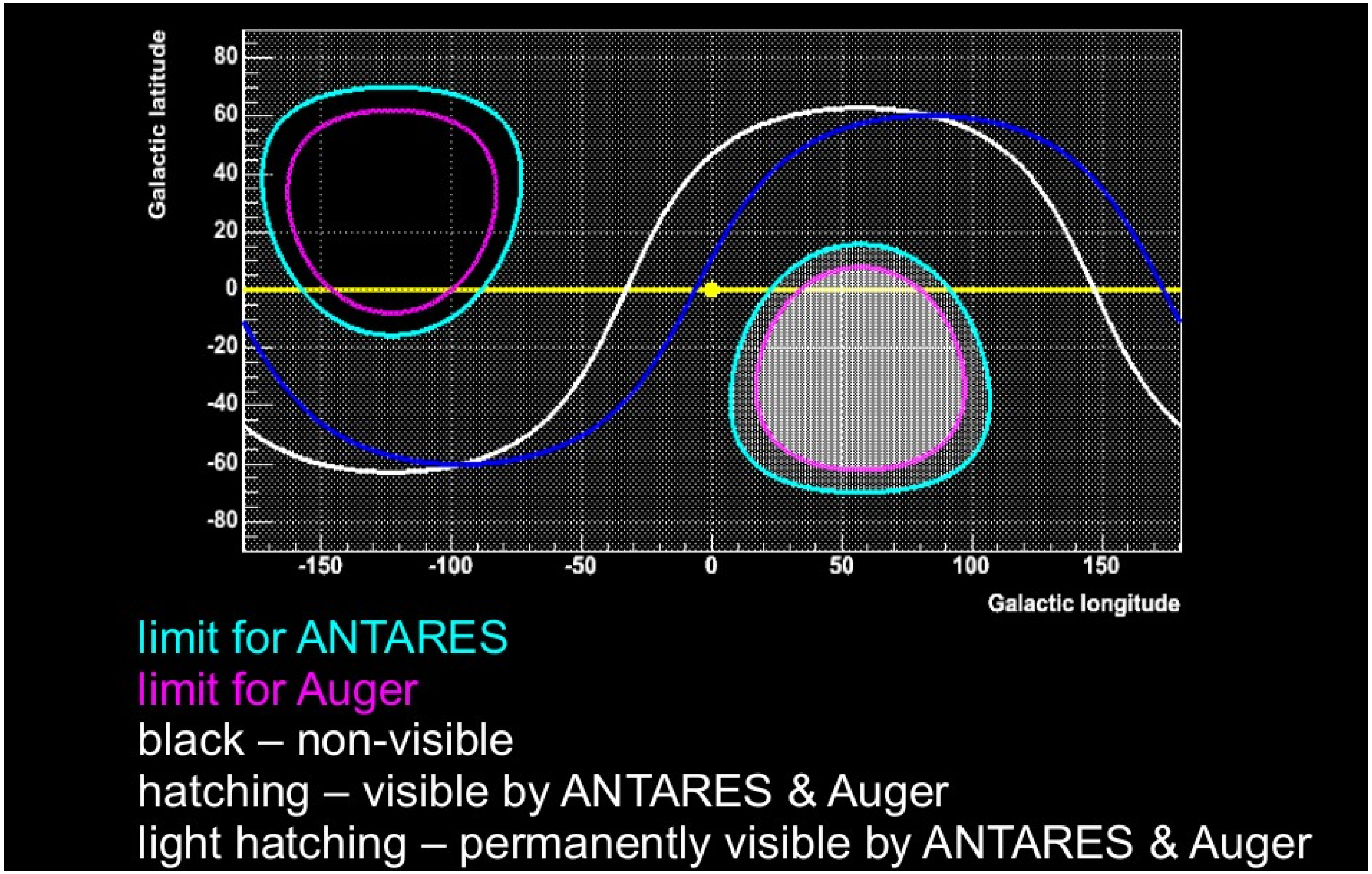


Pierre Auger: correlation of UHECRs with AGNs 2010 (69 events)



Astroparticle Physics, 2010
-energy > 57EeV
-for AGN correlation, an angular separation of ~3 degrees is considered
-mass composition of the observed UHECR events is not yet established
-all 69 UHECR events are in the Antares sky field view

Sky field view for Antares and PAO



UHECR deflection in Galactic magnetic field depending on energy

Takami&Sato 2009

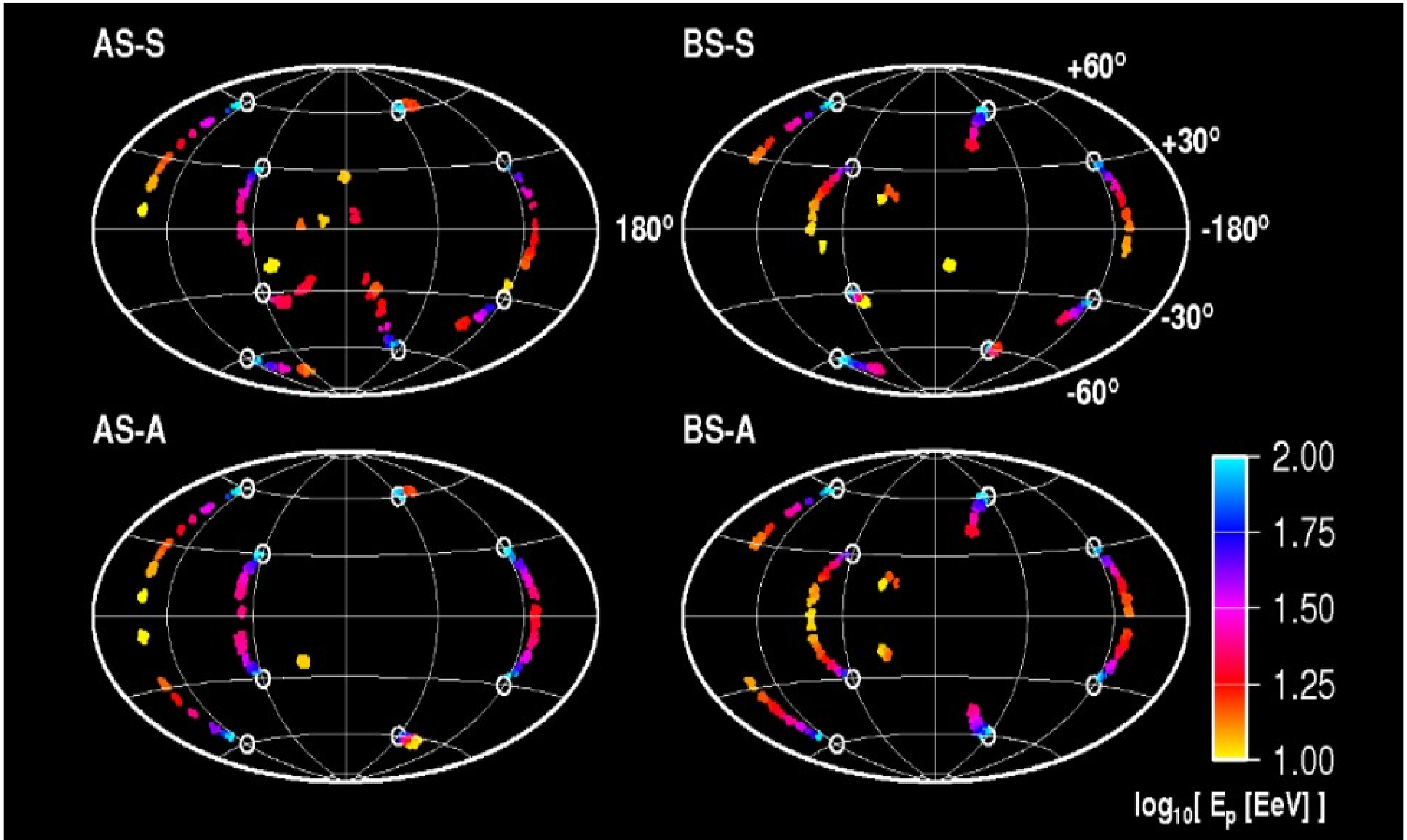
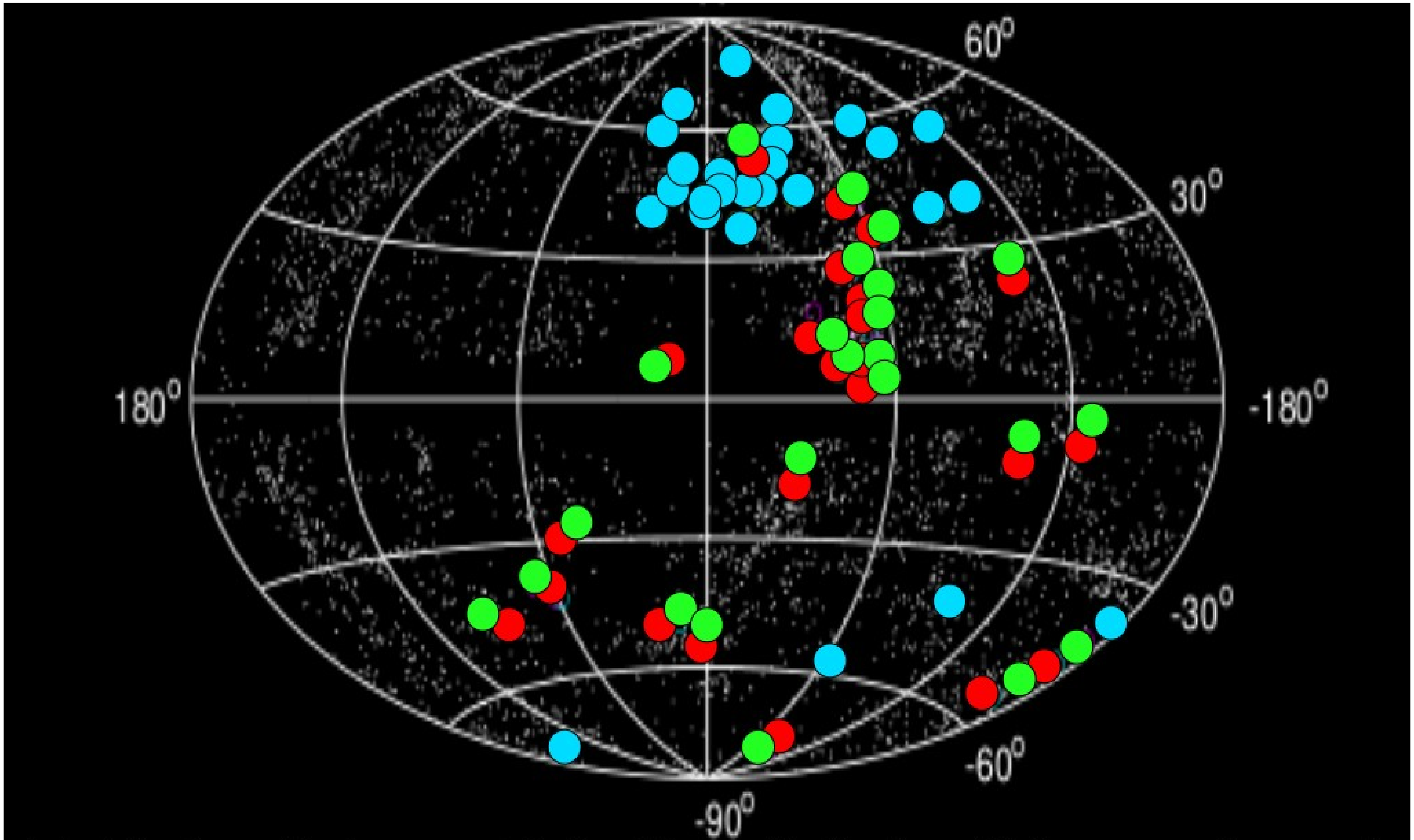


FIG. 2.— Arrival directions of HEPs with energies above 10^{19} eV emitted from sources located at 50 Mpc from the Earth (*black circles*) in Galactic coordinates. The energies of HEPs are represented in color. The 4 different GMF models are taken into account.

UHECR deflection in Galactic magnetic field depending on composition

Takami&Sato 2009



Arrival directions of the Auger events (*red*) and the possible directions of their sources on the assumption that all events are protons (*green*) and irons(*blue*). Example: BS-S model

Correlation analysis

Adrian-Martinez S, Petrovic. J et al, ApJ 2013

Statistical analysis for correlation of arrival directions of neutrinos and UHECRS was developed:

-Monte Carlo simulations of neutrino background

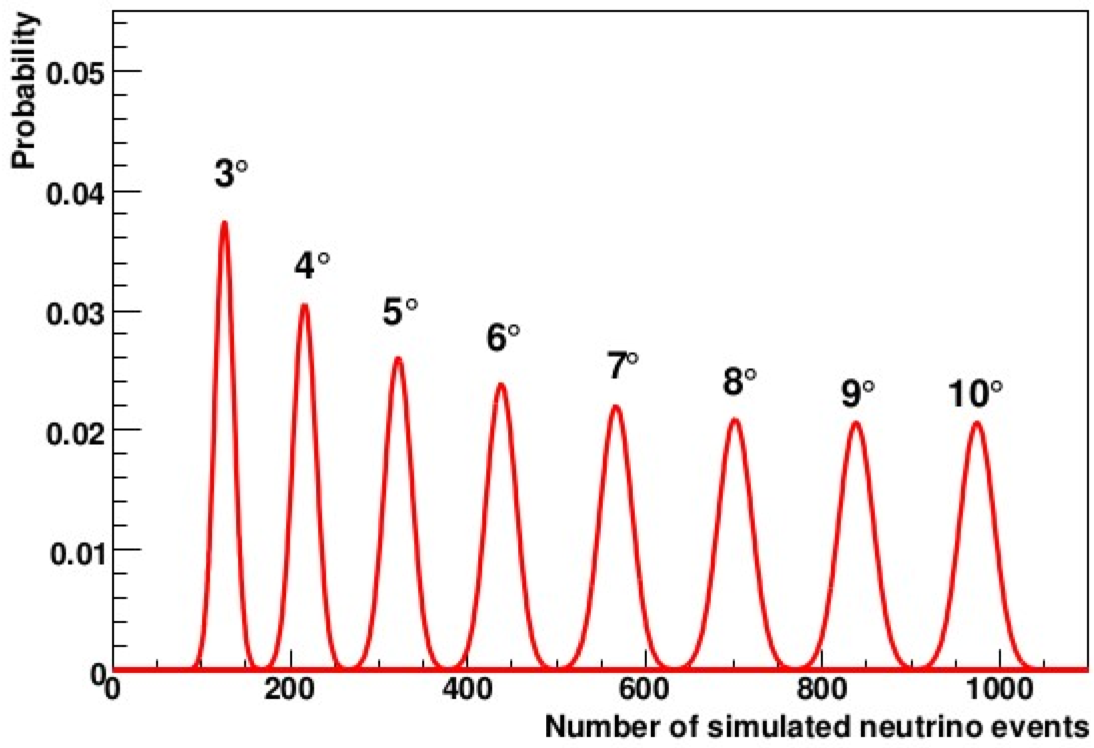
-Sensitivity and bin optimization

-Monte Carlo simulations of neutrino signal

-Discovery potential determination

-Unblinding of the neutrino data set and analysis results

Background simulation



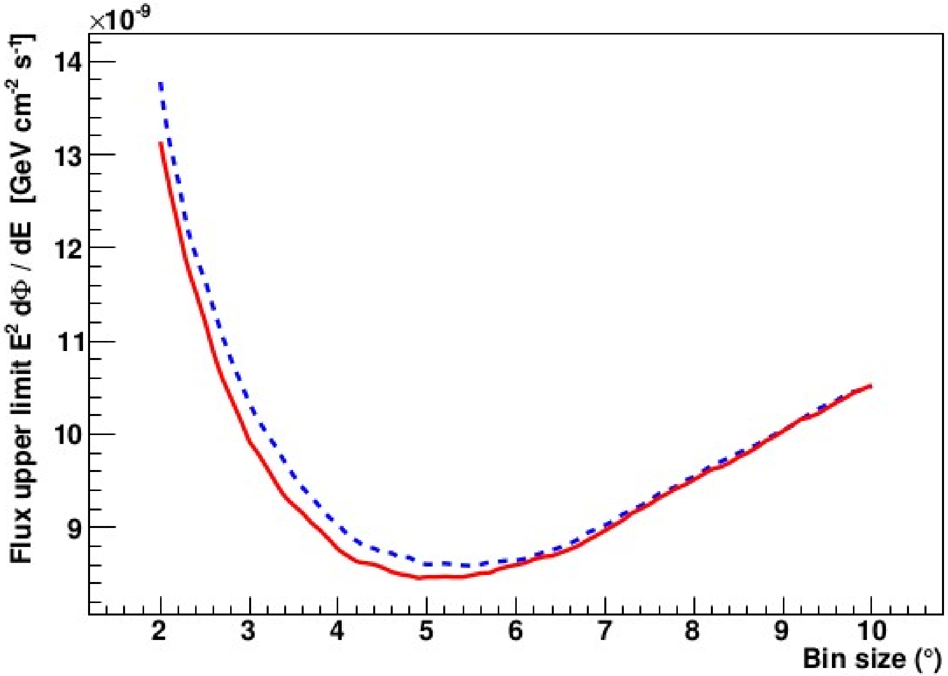
-**Weak signals: blinded analysis**

-10^6 Monte Carlo skies are produced with neutrino candidate events (2190) scrambled in right ascension

-neutrinos within bins of 1-10 degrees centered on 69 UHECR events are counted and probability density function fitted with Gaussian distributions

-after optimizing the bin for analysis, significance of observed neutrino events within 69 bins can be calculated by comparison with the distributions for pure Monte Carlo samples

Search bin optimization: sensitivity



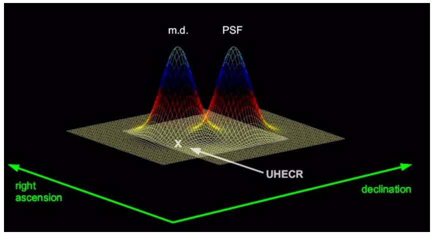
Monte Carlo sets are used to calculate the mean upper limit, or Feldman-Cousins sensitivity (Feldman & Cousins 1998; Hill & Rawlins 2003) that would be observed over the set of MC skies with expected background n_b and no true signal.

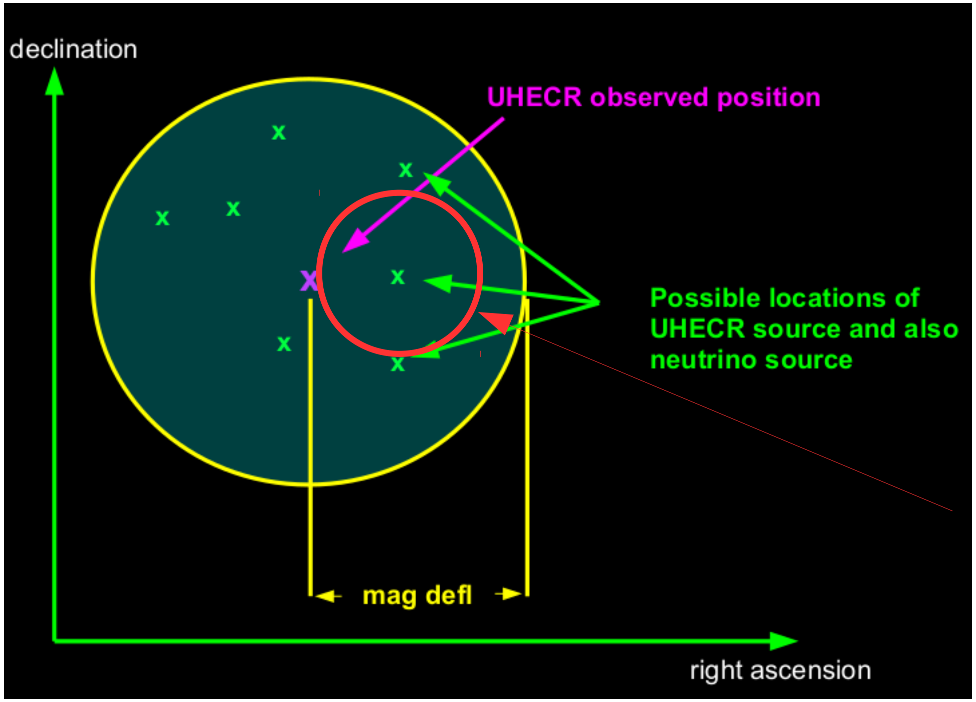
Over an ensemble of experiments with no true signal, the background n_b will fluctuate to different values: the mean upper limit is the sum of expected upper limits, weighted by their Poisson probability of occurrence.

Over an ensemble of identical experiments, the strongest constraint on the expected signal flux corresponds to a set of cuts that minimizes the model rejection factor (at the same time minimizes the mean flux upper limit that would be obtained over MC sets)

The angular search bin that minimizes the flux upper limit is **4.9º**

Signal simulation



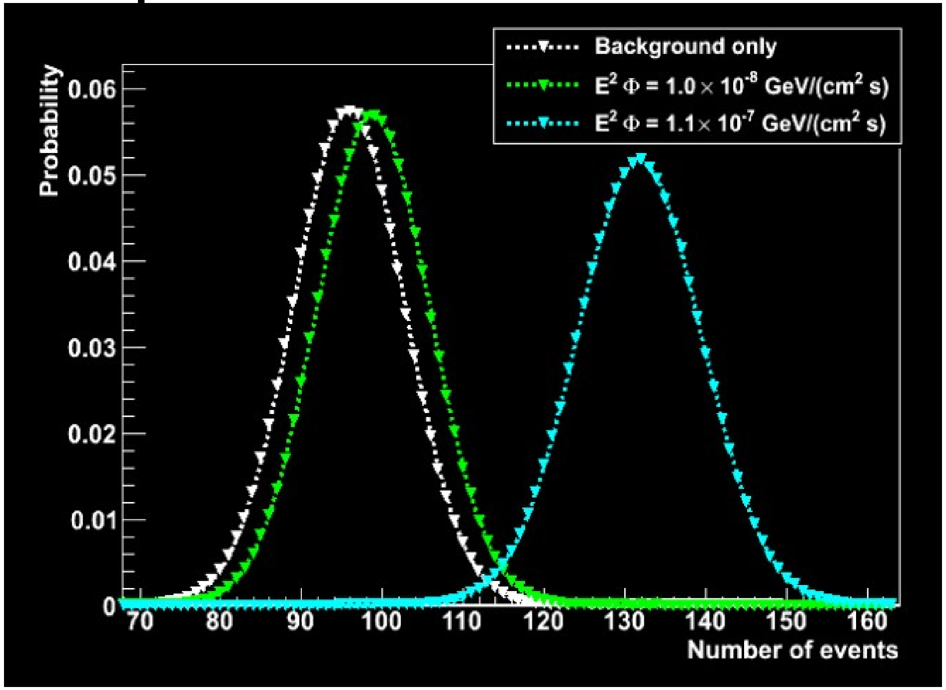


Possible location of
UHECR source due to magnetic
deflection: signal position is obtained
based on magnetic deflection Gaussian

Final signal position is obtained from
a convolution of magnetic deflection Gaussian
and Antares points spread function (resolution)
Gaussian

Signal simulation

Example



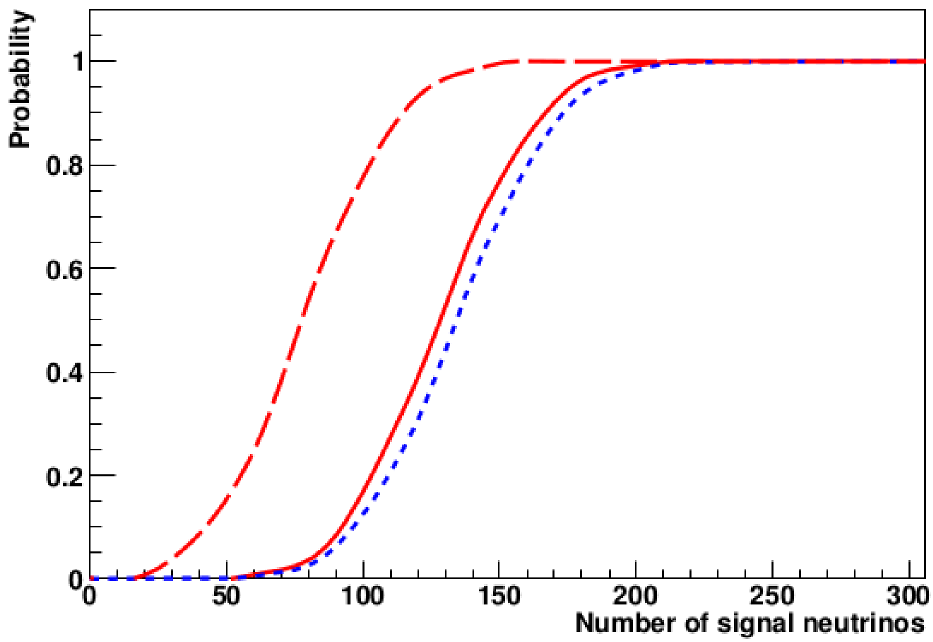
The signal events are simulated assuming a neutrino energy spectrum proportional to E^{-2} and equal flux strength from each of UHECR directions.

The flux is converted into signal event rate per source using the effective area for 5-12 lines and the corresponding live time.

Signal neutrinos are randomly generated according to a Gaussian which is a result of a convolution of the magnetic field tolerance window of 3^o and the angular resolution of the ANTARES telescope.

The same amount of background neutrinos is removed from a declination band of 10^o centered on each UHECR to ensure that every random sky has the same number of events and to keep the neutrino declination distribution profile close to the observed profile.

Discovery potential



The discovery potential at 3 σ (red long-dashed line) and 5 σ (red solid line) 90% C.L. as a function of the number of neutrino signal events from 69 sources on the whole sky. The discovery potential for two times lower angular resolution is shown with the blue dashed line.

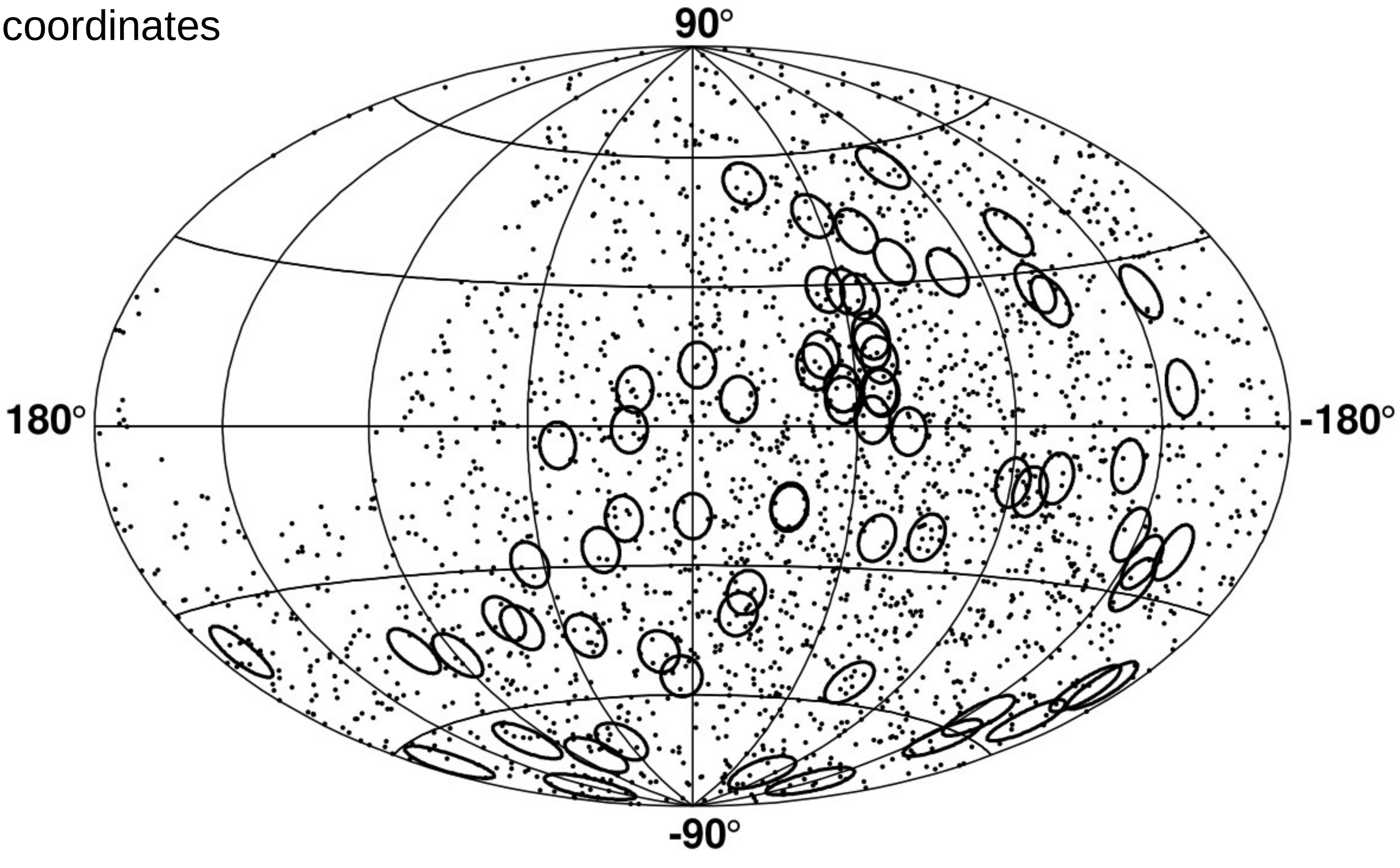
With the angular search bin size optimized and fixed, it is possible to estimate the probability of making a 3σ or a 5σ

The neutrino count necessary for a chosen σ level is determined from the background MC samples. The number of pseudo-experiments with signal, that have more neutrinos in 69 optimized bins than the chosen σ level from background only → measure of the discovery potential

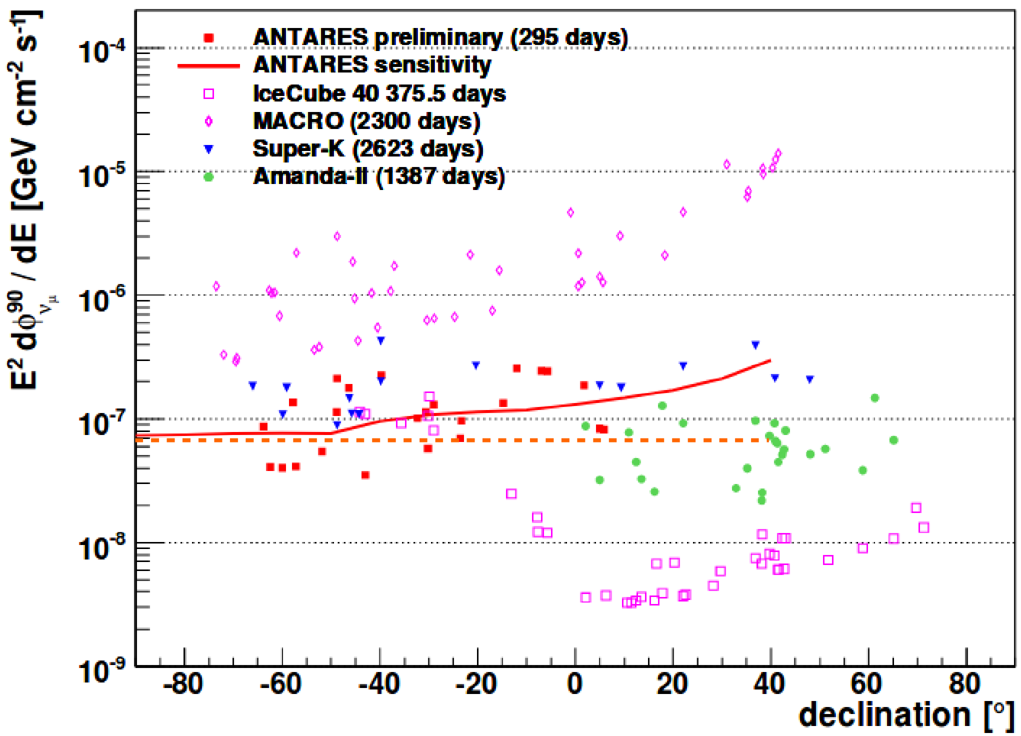
Around 126 (75) signal events correlated to the 69 UHECRs directions are needed for a 5σ (3σ) discovery in 50% of trials

Results: unblinded data

Galactic coordinates



Results



The significance of observed correlation is determined with the help of randomized background samples, using the optimized bin of 4.9 degrees.

The most probable count for this optimized bin, is **310.5** events (in all 69 bins), with the standard deviation of 15.2 events.

After unblinding 2190 ANTARES neutrino events, a count of **290** events within 69 bins is obtained which is slightly lower than expected.

This count is compatible with a fluctuation of the background, with a significance of **1.4 σ**

The upper limit on the neutrino flux from each observed UHECR direction (assuming an equal flux from all of them and for E^{-2} energy spectrum) is 4.9×10^{-8} GeVcm^{-2}s^{-1}

Outlook

- Further attempts to correlate neutrinos and UHECRs are done both by the Antares and IceCube collaborations (for example Albert et al, 2017; Christov et al, 2016; Aartsen et al, 2016)
- Larger data sets will provide higher sensitivity of this method
- Pierre Auger Observatory is working on determination of composition of the observed UHECR, which will give more insight in their deflection in magnetic fields
- Research to determine magnetic deflection in Galactic and extragalactic magnetic fields more accurately