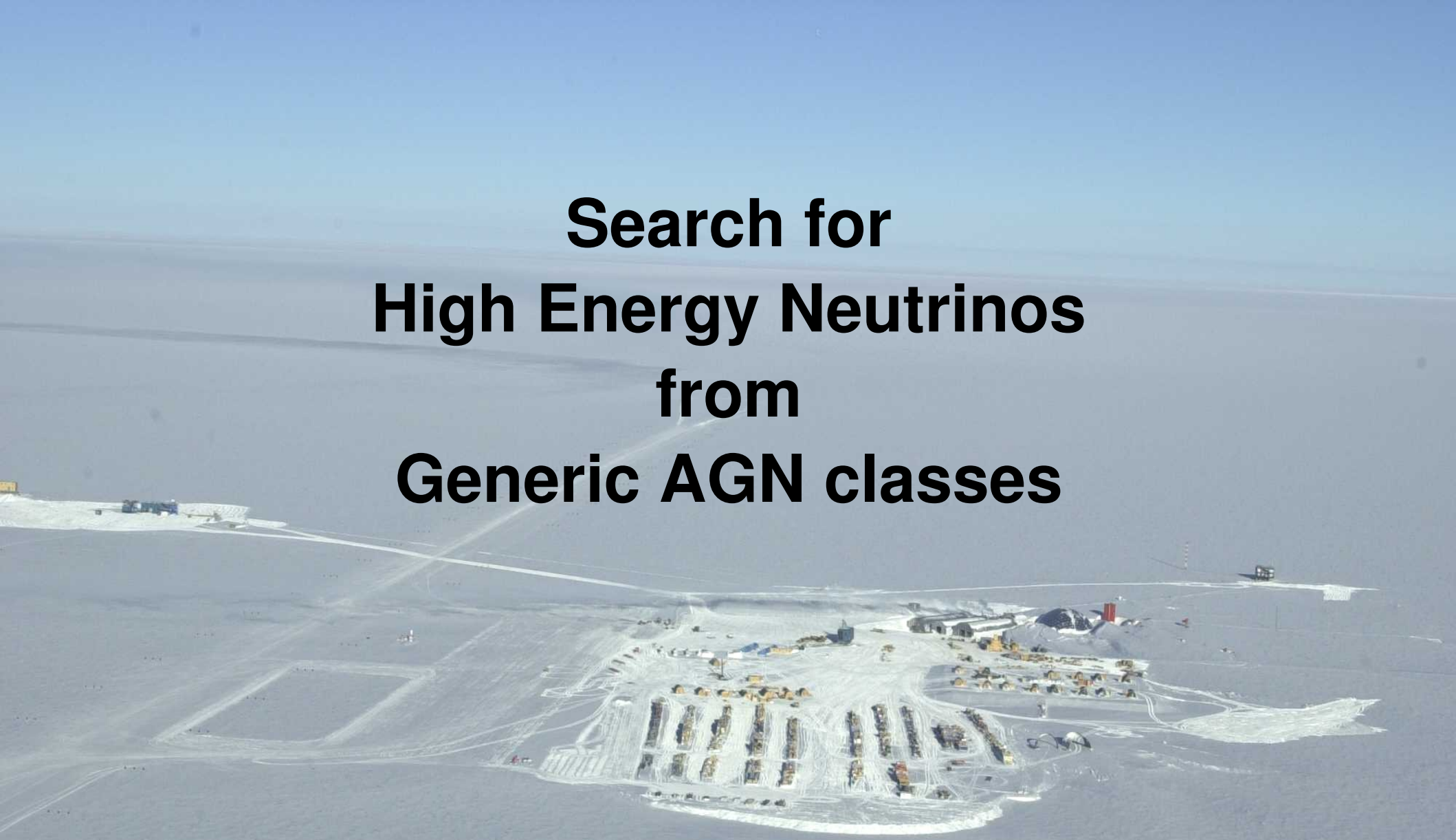
Search for High Energy Neutrinos from Generic AGN classes



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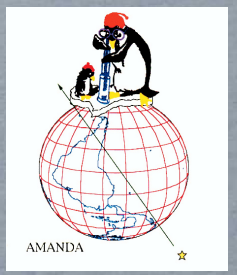


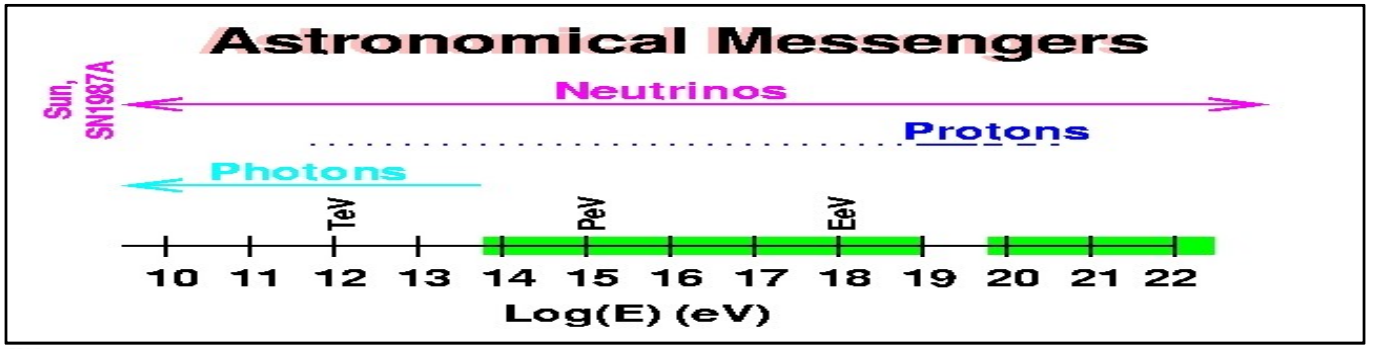
http://amanda.uci.edu

Cosmic Accelerators

How is it possible to accelerate particles to TeV-EeV?
Where is it possible?
Do we get ν?

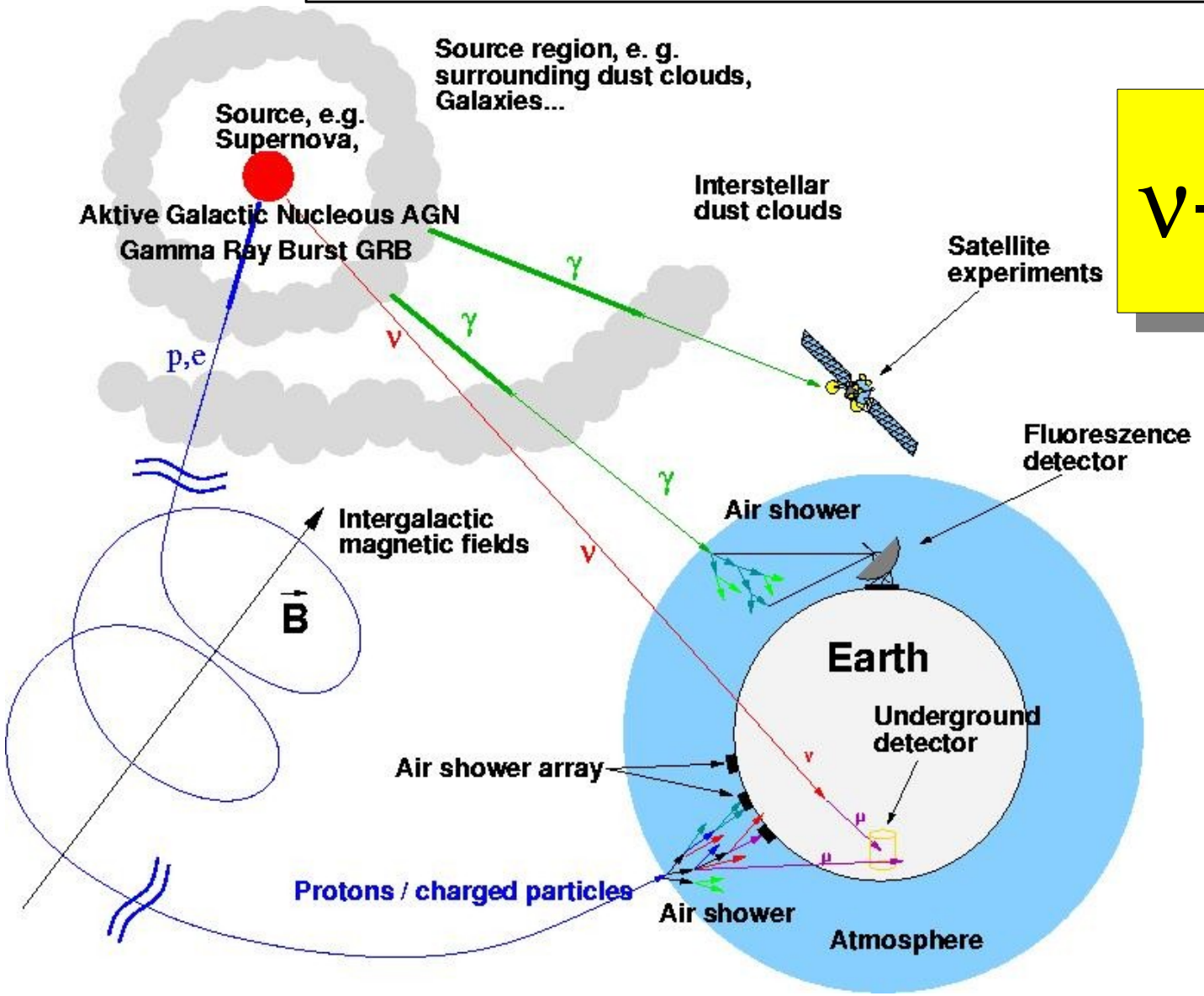
- Fermi-acceleration at shock waves ← Power law α~-2
- Pion-production by $p\gamma$ (or pp) reactions ← ν sources emit γ
- High energy needed → Grav. potential of black holes ← AGN, GRB, μQuasar, SNR

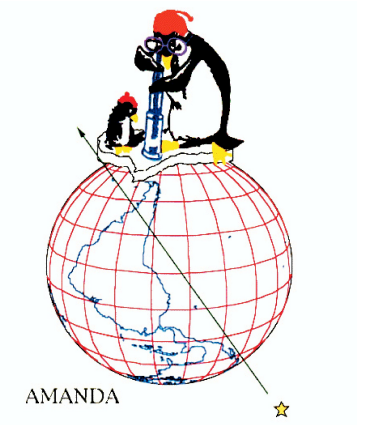
Or top-down scenario:
decay of new heavy particles


Astronomical Messengers
Sun, SN1987A
Neutrinos
Protons
Photons
TeV
PeV
EeV
10 11 12 13 14 15 16 17 18 19 20 21 22
Log(E) (eV)

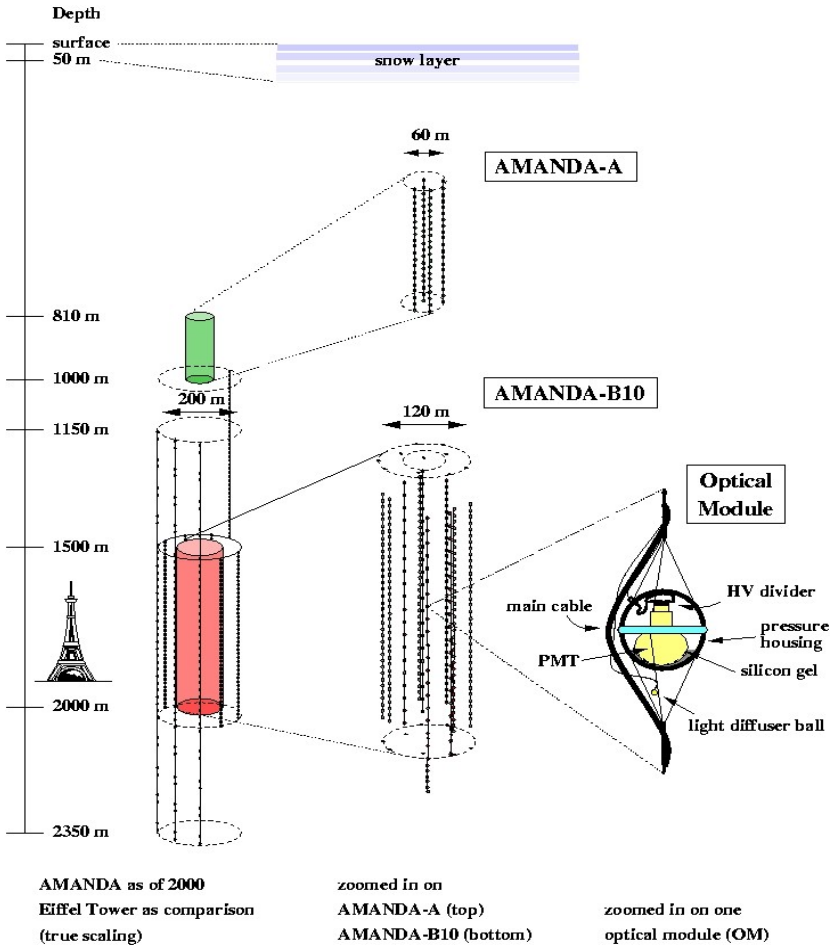

IceCube

ν-Astronomy

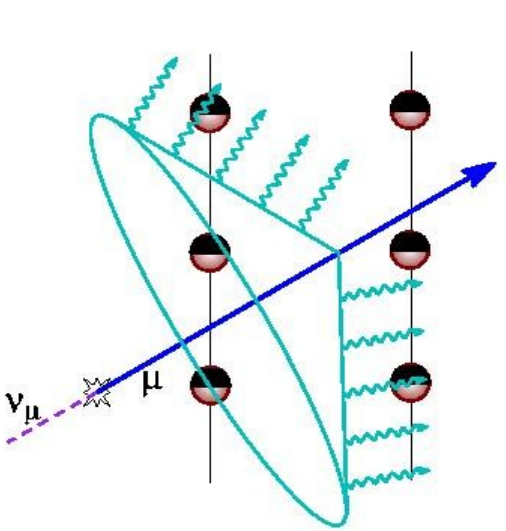

Source region, e. g. surrounding dust clouds, Galaxies...
Source, e.g. Supernova,
Aktive Galactic Nucleous AGN
Gamma Ray Burst GRB
Interstellar dust clouds
Satellite experiments
γ
γ
ν
p,e
Fluoreszence detector
Air shower
Intergalactic magnetic fields
B
ν
Earth
Underground detector
Air shower array
ν
μ
μ
Protons / charged particles
Air shower
Atmosphere

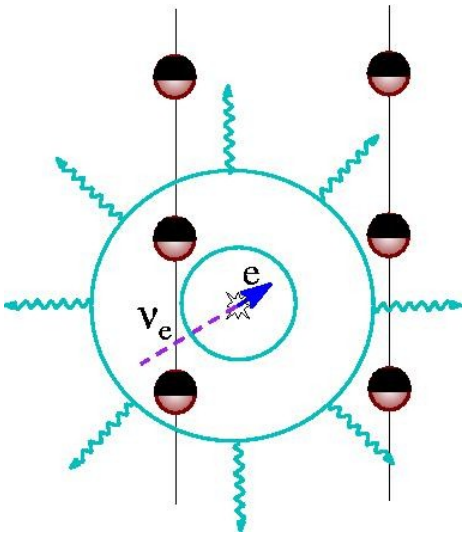

AMANDA

The AMANDA II ν–telescope



- Geographic South Pole (Amundsen Scott Station)
- 677 PMT on 19 strings
- Detection of Čerenkov light (muon tracks + cascades) in ice

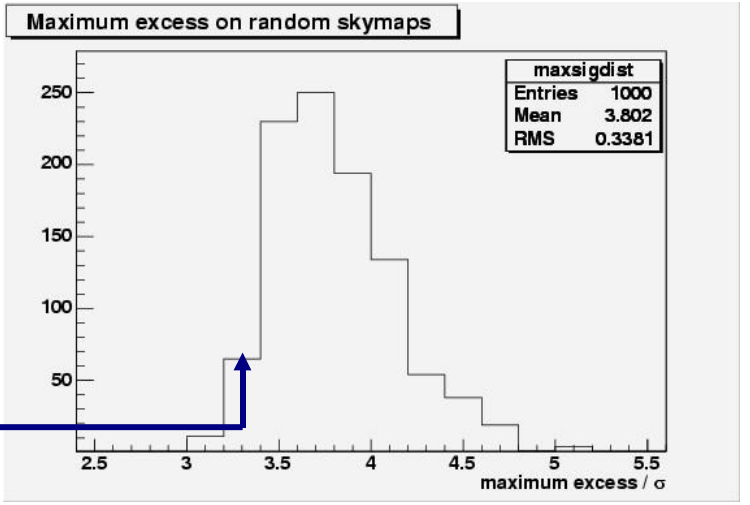


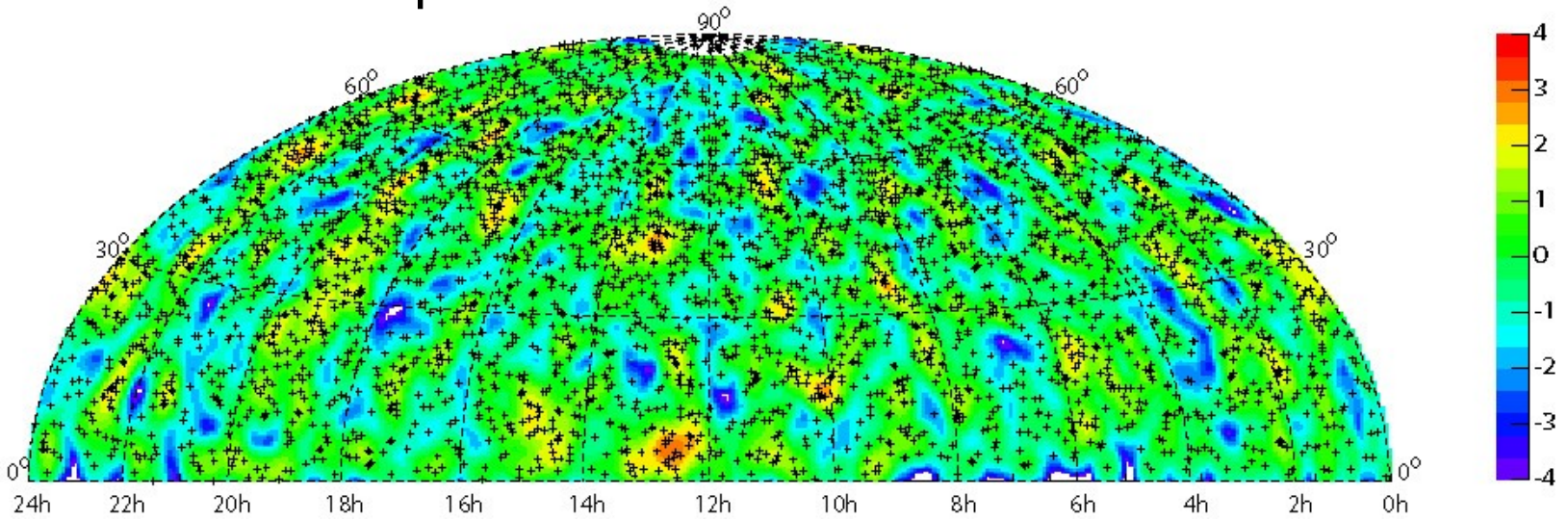


Upgoing events: Earth shields all particles except ν

Point Source Analysis: No evidence for point sources

- All (northern) sky search for clustering (3329 vents)
- Highest significance: 3.35 σ before correction for trial factor
- Random skymaps show: Chance probability 92 %
- No evidence for a point source





How to increase sensitivity?

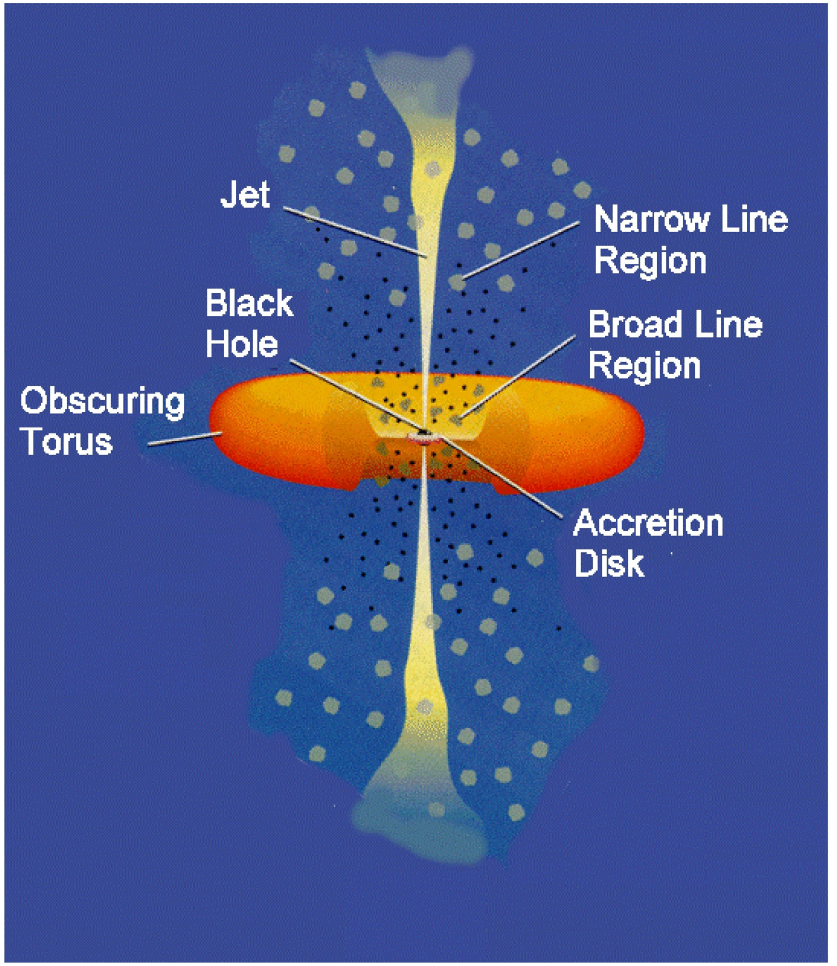
- Increase observation time?
  - 4 years of data already included, so double sensitivity requires 16 years of data (too long for PhD thesis)
- Build larger telescope?
  - Will be done, but also takes a lot of time
- Add signal from several sources of the same type?
  - Requires definition of generic source classes: Presented here

Source stacking

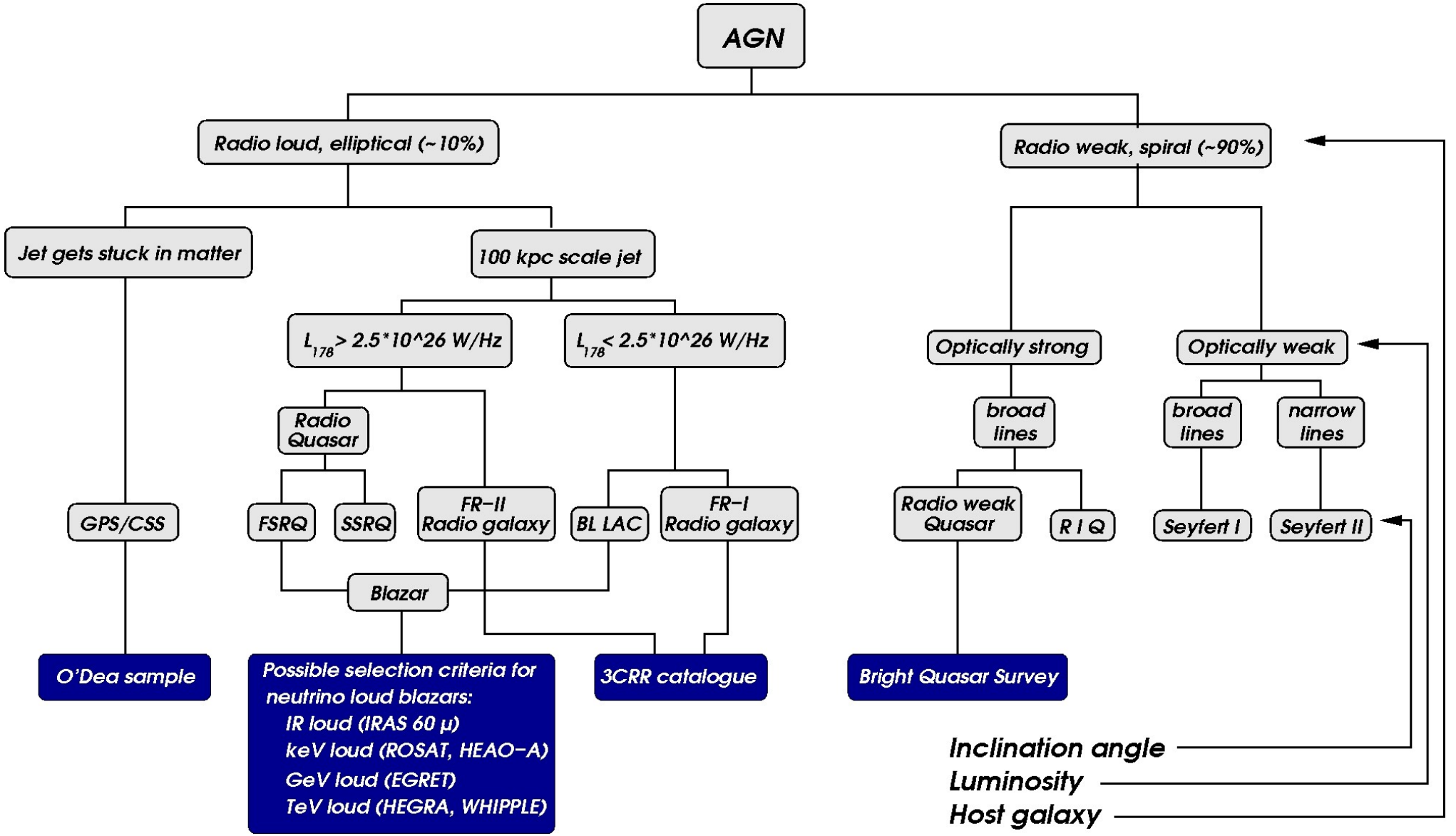
- Standard method in optical astronomy and in Gamma astronomy
- Add signal and background for various sources of the same type
- Aim: Detection of generic sources, if individual sources slightly below sensitivity
- Systematic source selection required

AGN basics

- Center: super-massive black hole
- High accretion rate: 0.1-100 solar masses/year
- Candidate sources for UHE cosmic rays
- Photon spectra cover 20 orders of magnitude in energy
- Axisymmetric sources: different appearance as a function of inclination angle (+ intrinsic differences)



AGN classification scheme



Selection of sources
Ordering principle

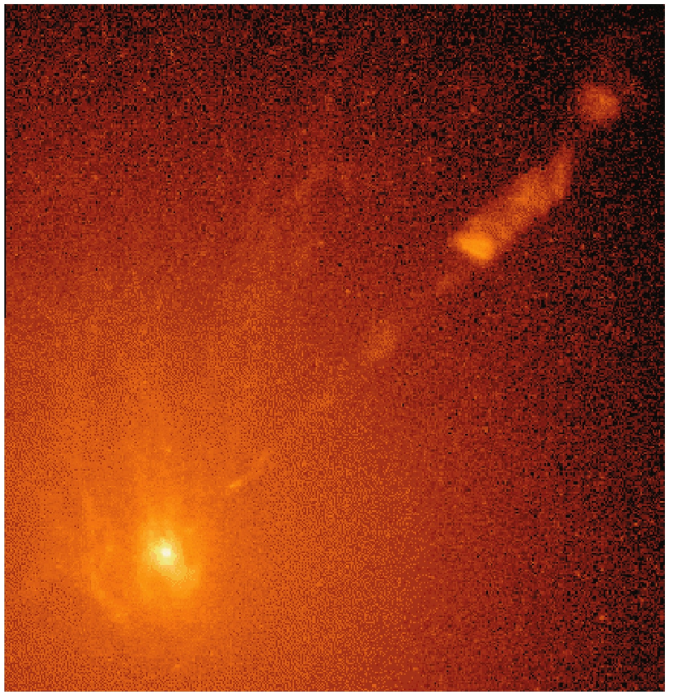
- ν–production in decay of charged pions, γ–production in decay of neutral pions ➡ correlation
- Energy of photons may be redistributed in synchrotron-pair cascades to low energy photons
- Optical depth for γ unknown, for ν negligible
- Thus: correlate γ flux to ν flux, but vary the photon energy (also lower than AMANDA threshold for ν)
- Sort sources according to γ flux in various samples, each with a certain selection energy

The final samples

- Optimize number of sources to be stacked by the assumption of linear correlation between γ and ν
- Signal normalization: Consider only values, for which the strongest source alone is no significant point source
- Result: Optimum source number ~10 for most samples, optimum search bin size ~2.5° (56% signal efficiency)

Exceptions: FR-I and FR-II radio galaxies

- FR-I/-II radio galaxies:
  No optimum stacking sample found:
  - FR-I: dominated by local source M87
  - FR-II: There are many sources with similar fluxes, optimization: include all!



Strategy: analyze best possible stacking samples additionally:

- FR-I galaxies with M87 excluded
- FR-II galaxies with a cut-off at 17 sources (saddle point)

Results from source stacking

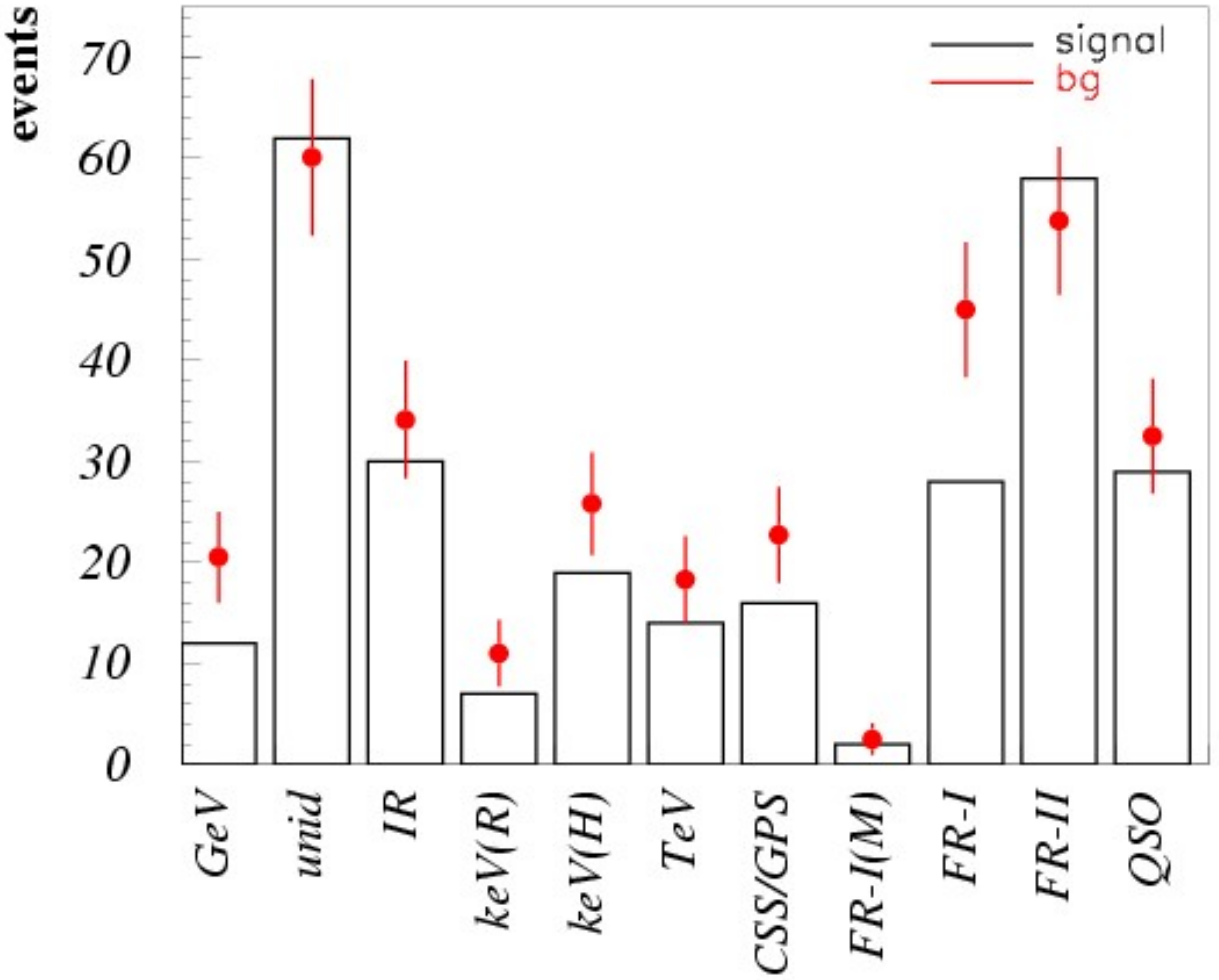
Sensitivities are given for the integral flux above 10 GeV in units of $10^{-8}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

AGN category	N_{src}	N_ν^{obs}	N_ν^{bg}	f_{sens}	f_{sens}/N_{src}
GeV blazars	8	12	20.5	1.5	0.19
unid. GeV sources	22	62	60.1	2.6	0.12
IR blazars	11	30	34.1	2.0	0.18
keV blazars (HEAO-A)	3	7	11.0	1.4	0.47
keV blazars (ROSAT)	8	19	25.8	1.8	0.23
TeV blazars	5	14	18.3	1.5	0.3
GPS and CSS	8	16	22.7	1.7	0.21
FR-I galaxies	1	2	2.5	0.7	0.7
FR-I without M87	17	28	45.0	2.4	0.14
FR-II galaxies	17	58	53.8	2.6	0.15
radio-weak quasars	11	29	32.5	2.1	0.19

Compare: Sensitivity of standard point source analysis: 0.6 in that units

Limits will be set when investigations of systematics are finished

Signal/background for the samples

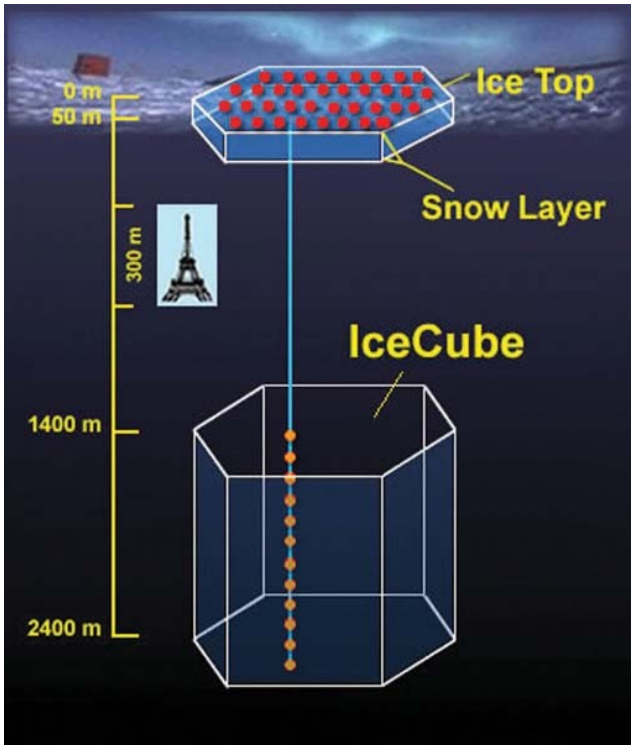


Summary

- Sensitivity to generic point sources was improved by stacking
- No significant excess has been found for any source class
- Limits on the cumulative flux will be set when systematic investigations finished
- No detection of a ν Point Source with AMANDA yet, sensitivity improvement by longer on-time limited, but ...

The (near) future: IceCube

- 2-3 orders of magnitude improvement in sensitivity
- 80 strings, 4800 optical modules (OMs)
- Surface array IceTop for Air Showers



First string deployed, all modules work, first muons observed