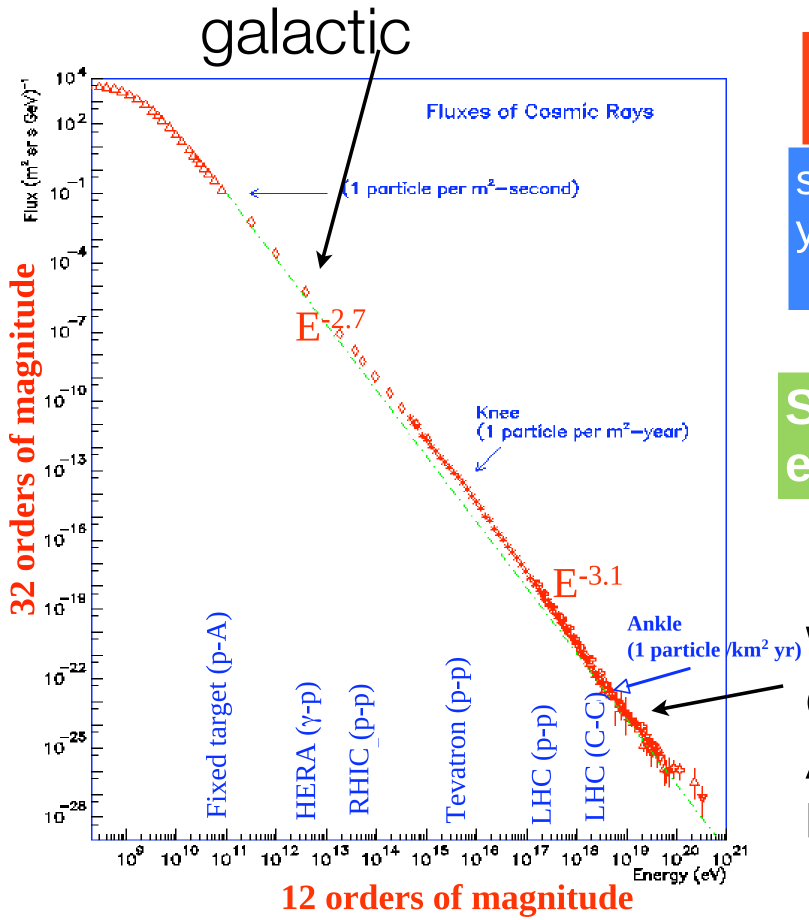
Lecture 2: properties of NT

- Extra-galactic CRs and Proton Astronomy
- Extra-galactic sources: AGNs and GRBs
- Experimental Upper limits for point-sources and diffuse fluxes
- Detection Technique
- Main Parameters of Detectors
- Performances of detectors

Cosmic Rays

1 TeV = 1.6 erg
1 EeV = 0.16 Joule



Below the knee (galactic CRs):

observed energy density of galactic CR: ~ 10^{-12} erg/cm^3

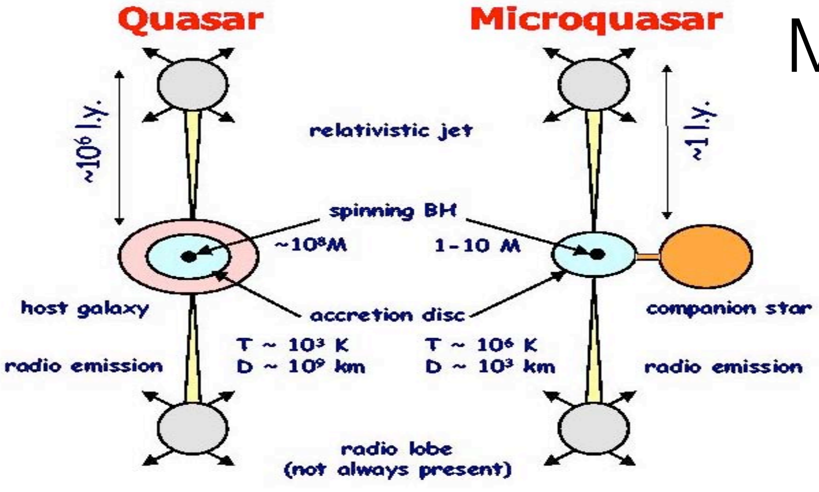
supernova remnants: 10^{50} ergs every 30 years ~10^{-12} erg/cm^3

SNRs provide the environment and energy to explain the galactic CRs!

Who are the sources of the highest energy CRs?

A 320 EeV CR has 50 J (energy of a tennis ball!)

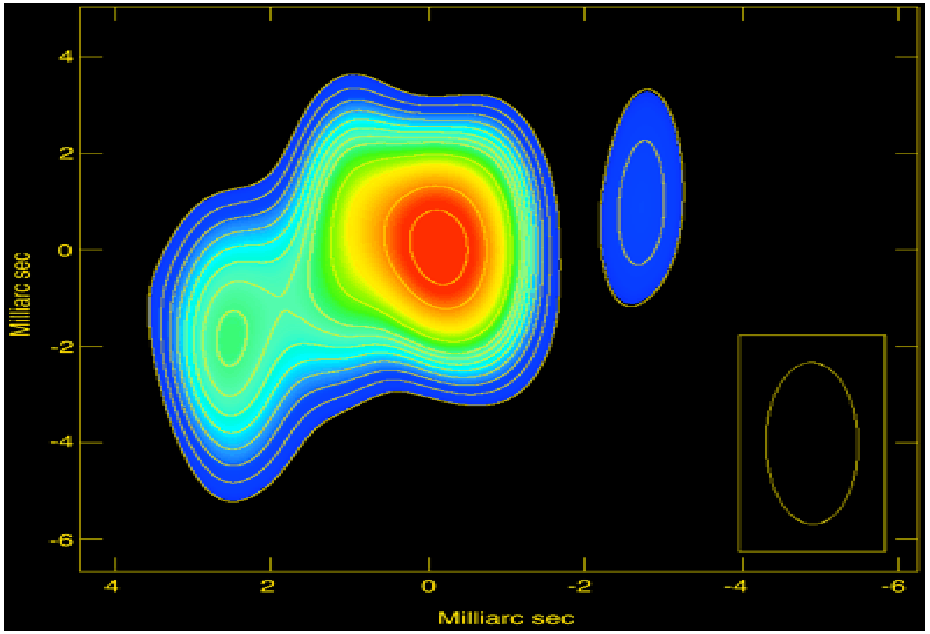
Micro-quasars



C.Distefano

Very Large Array

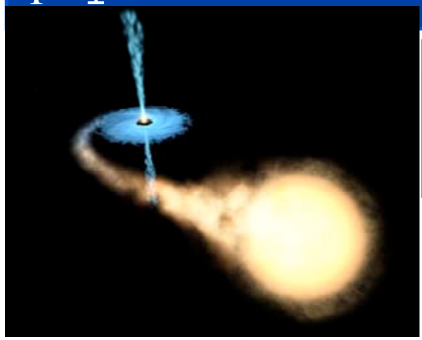
In μ-quasars particle acceleration can take place inside and along the jet



Paredes, Marti, Ribo, Massi, Science 288 (2000) 2340

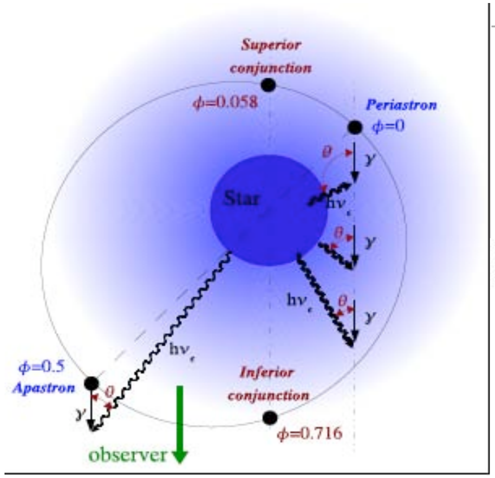
μ-quasars are galactic X-ray binaries that exhibit radio-jets

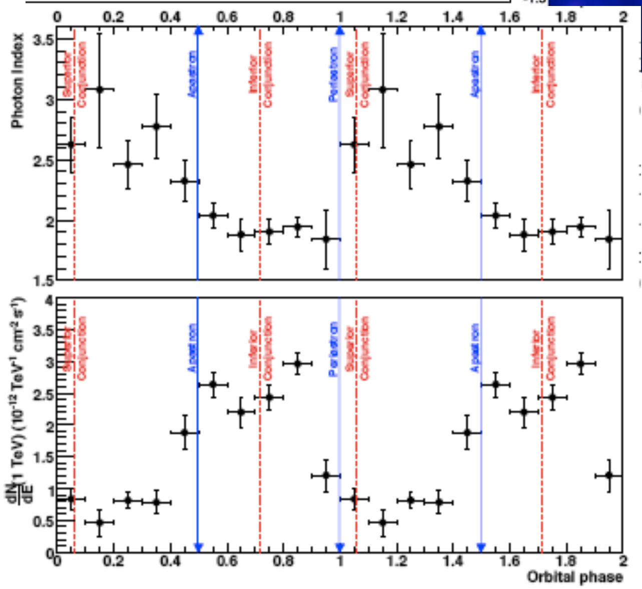
Γ ~1



BH with M ~10^6
companion star

Periodical TeV emissions from Micro-quasars

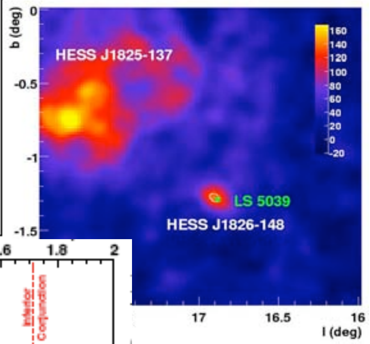




In ANTARES FoV: LS5039

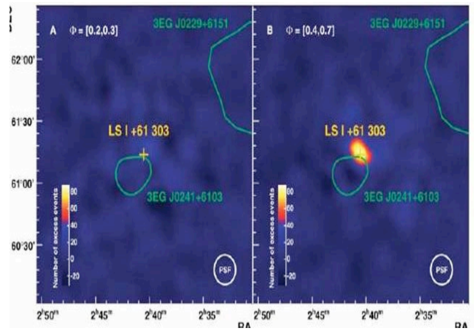
Science 309, 746 (2005)
astro-ph/0607192 (to appear in A&A)

HESS

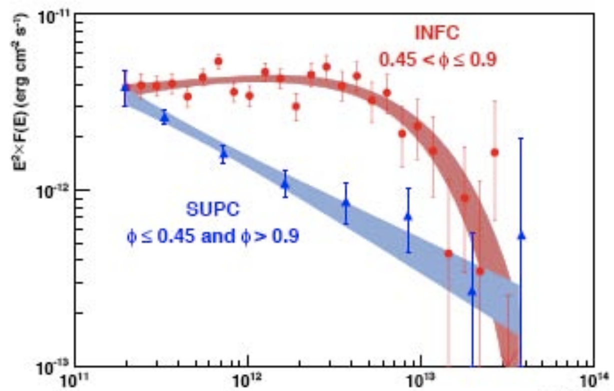


In IceCube FoV: LSI +61º303

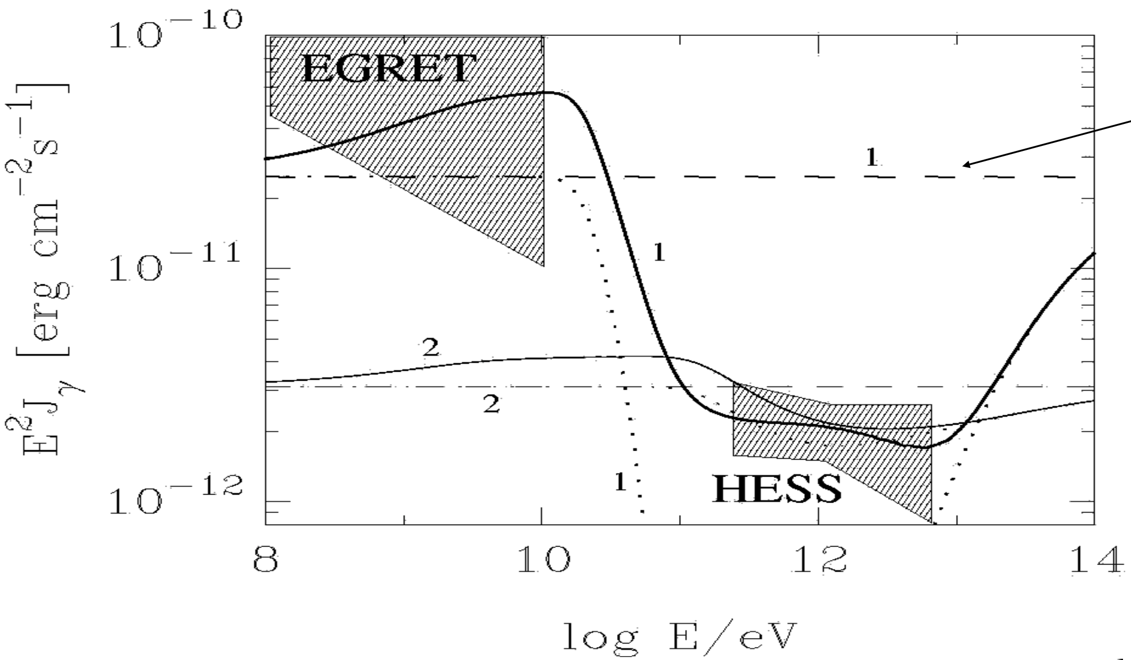
MAGIC: astro-ph/0605549
VERITAS
26.5 d period



Bulk of VHE at ϕ ~0.5-0.9 at inferior conjunction (compact object aligned). Evidence of absorption while IC would peak at periastron



An example of γ attenuation: LS5039 and LSI+61 303



Initial flux for numbers in table

Absorption by synchrotron ….

cascading __

E_{max} [TeV]	$\Gamma = 1.5$	$\Gamma = 2.0$	$\Gamma = 1.5$	$\Gamma = 2.0$
10	0.20	0.11	6.0	3.0
100	0.26	0.15	8.3	5.0

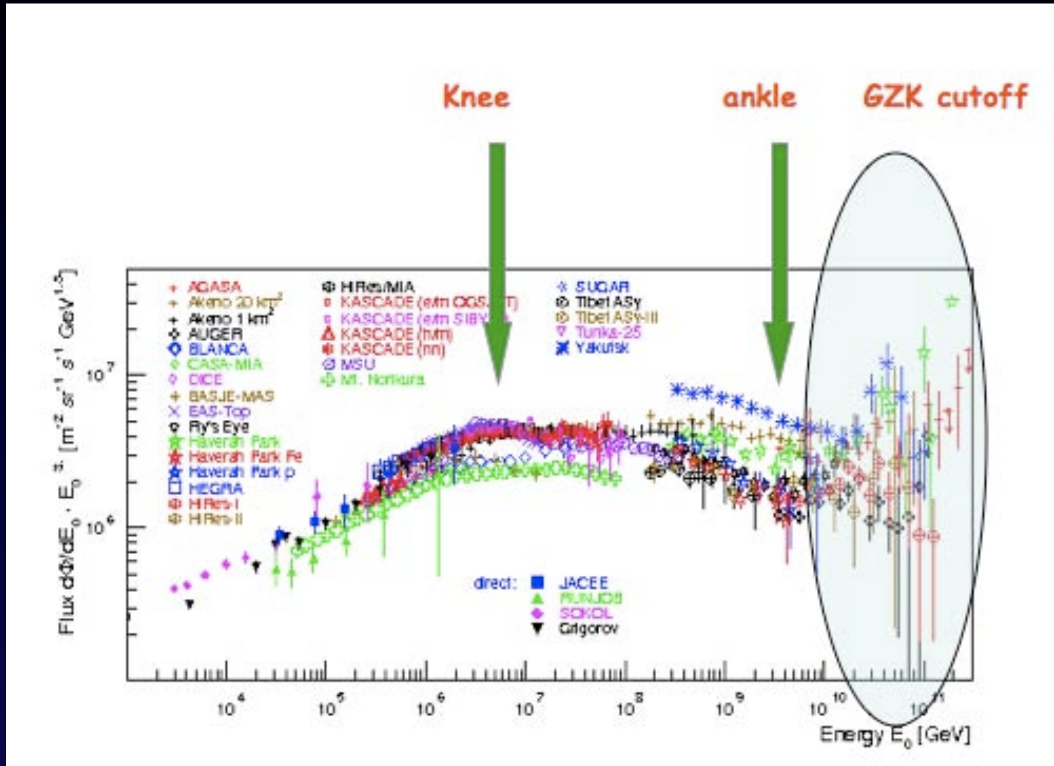
0.05 km^2 1 km^2

(1) Gamma ray production close to jet base (more absorption, larger flux at low energy)

(2) Gamma ray production far from jet base

Aharonian, Anchordoqui, Khangulyan, TM, astro-ph/0508658
Torres and Halzen, astro-ph/0607368: 4 events/5 backg for modulation (γs absorbed at periastron but not νs)

Extragalactic CRs



observed energy density of extragalactic CR:
~ 3 x 10^{-19} erg/cm^3

~ 6 x10^{44} erg/yr/Mpc^3 for 13.6 Gyrs

Gamma-Ray Bursts:
2 x 10^{51} erg x 300/yr/Gpc^3 = 6 x 10^{53} erg/yr/Gpc^3
~ 6 x10^{44} ergs/yr/Mpc^3

GRBs provide environment and energy to explain the extragalactic cosmic rays! P. Auger and HiReS observations provide hints toward AGNs

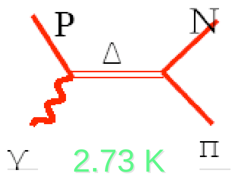
Greisen-Zatsepin-Kuzmin cutoff

- Interaction with CMB: above E ≈ 6 x 10^{19} eV via photoproduction. Energy loss ≈15%/ interaction. Interaction length ≈ 5-10 Mpc

$$\gamma + p \rightarrow \Delta^{+} \rightarrow p\pi^{0}$$

$$\gamma + p \rightarrow \Delta^{+} \rightarrow n\pi^{+}$$

{γ from π^0 , ν from π+}



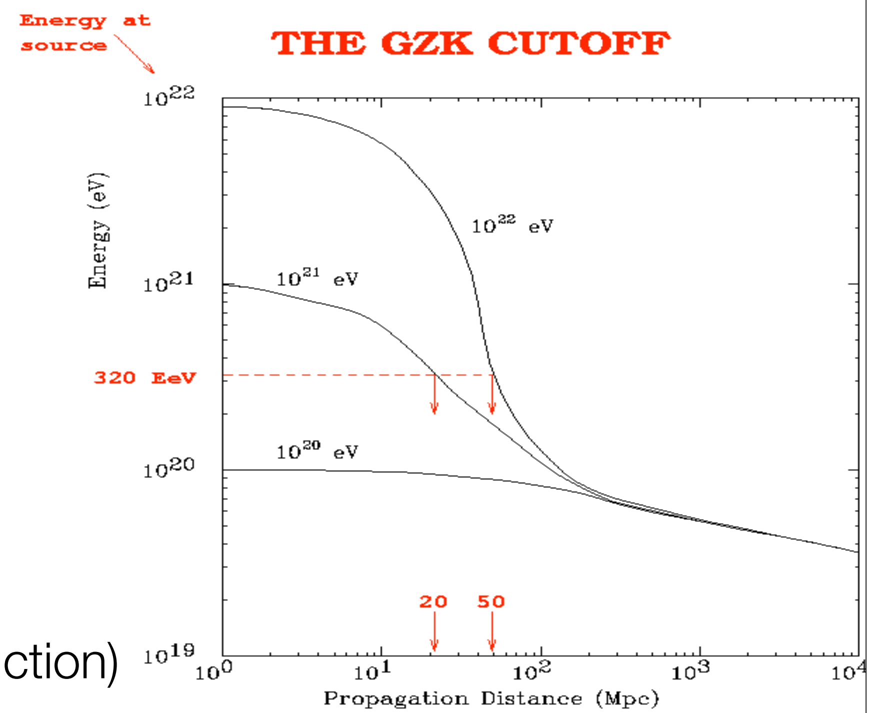
$$E_{k,p} = \frac{\left(\sum_f M_f\right)^2 - (m_t + m_p)^2}{2m_t} = \frac{(m_N + m_\pi)^2 - m_p^2}{2m_p}$$ ~150 MeV

Energy of CMB photons (Planck spectrum) = ϵ_γ = 3 k_B T = 3 x 2.73 x 8.62 x 10^{-5} eV in CM

Energy of gammas in Lab

$$E_\gamma = \gamma_p \varepsilon_\gamma = 150\text{MeV}$$ (threshold for Δ production)

$\gamma_p \rightarrow$ 2x10^{11}



$E_{p,thr} = \gamma_p m_p$ = 2 x 10^{20} eV

More precise calculations require accounting for Planck spectrum and lead to 6 x 10^{19} eV

Proton Astronomy: Pierre Auger

Fluorescence Detector (FD)

24 fluorescence telescopes in 4 buildings

Longitudinal development of the shower

Calorimetric measurement of the energy

Calibration of the energy scale

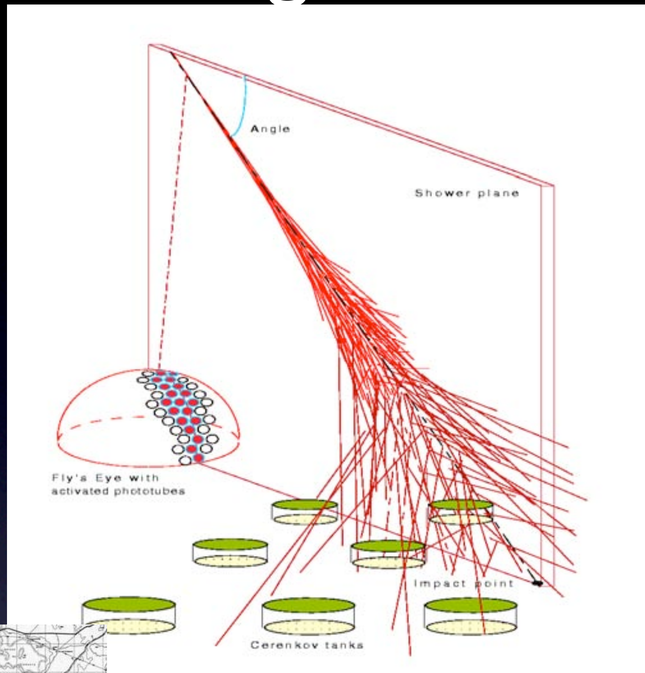
Only moonless nights: 12% duty cycle !

Surface Detector (SD)

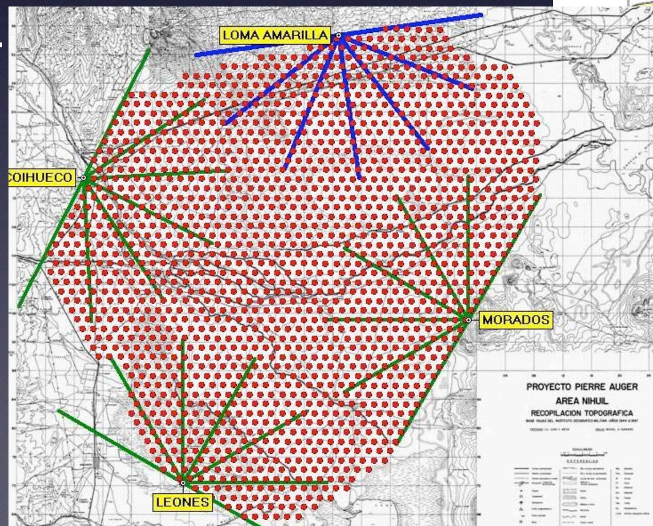
1600 water tanks with1.5 km spacing

Front of shower at ground

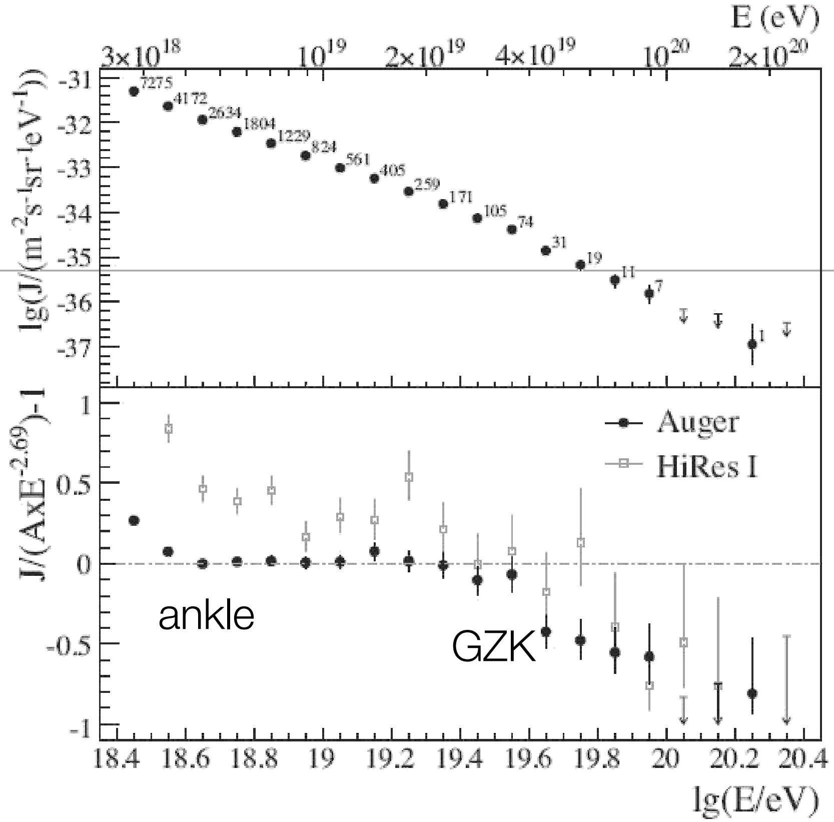
Direction and “energy” of the shower



Total area 300 km^2



Spectrum

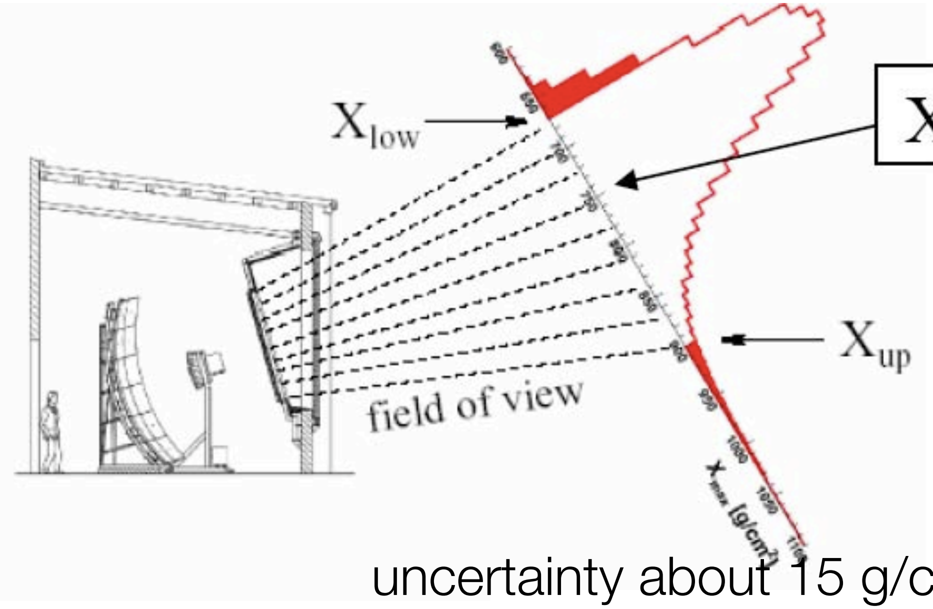


Use SD detector but calibrate energy on Hybrid events
20% systematic error at 10^{19} eV due to fluorescence yield and SD calibrations errors
10% difference can be due to E calibration (different values of fluorescence yields)

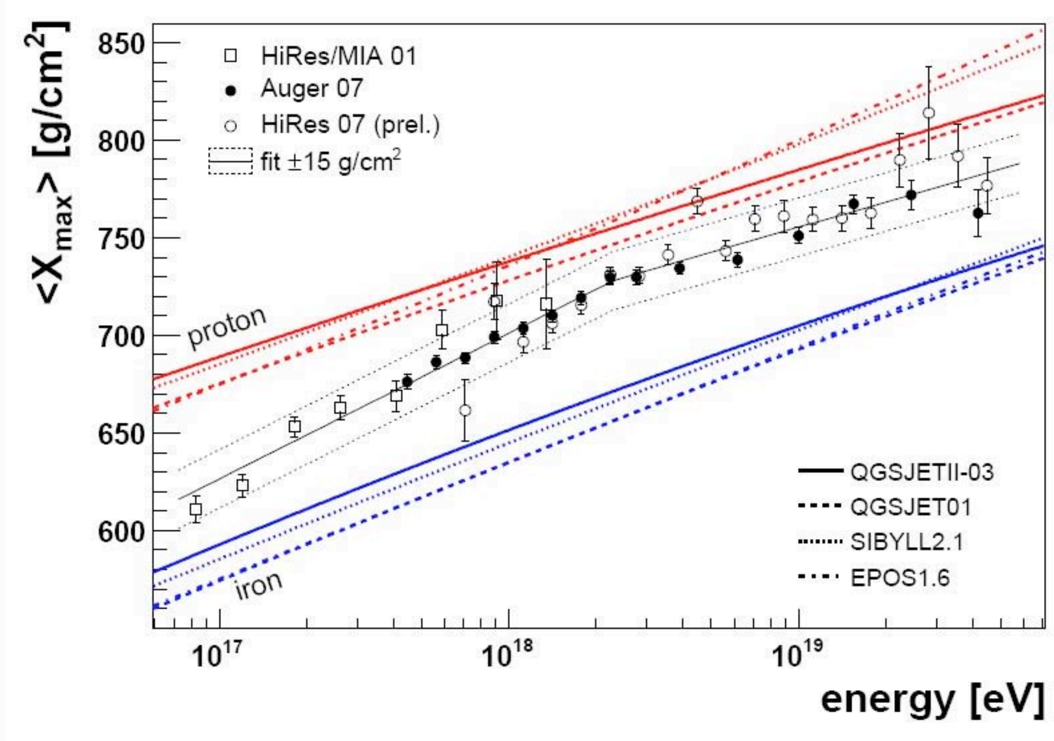
	Auger	HiRes
E_{ankle} (eV)	4.5×10^{18}	4.5×10^{18}
E_{GZK} (eV)	3.5×10^{19}	5.6×10^{19}
γ ($E < E_{ankle}$)	3.30 ± 0.06	
γ for ($E_{ankle} < E < E_{GZK}$)	2.62 ± 0.03	2.81 ± 0.03
γ for ($E > E_{GZK}$)	4.1 ± 0.4	5.1 ± 0.7

Composition

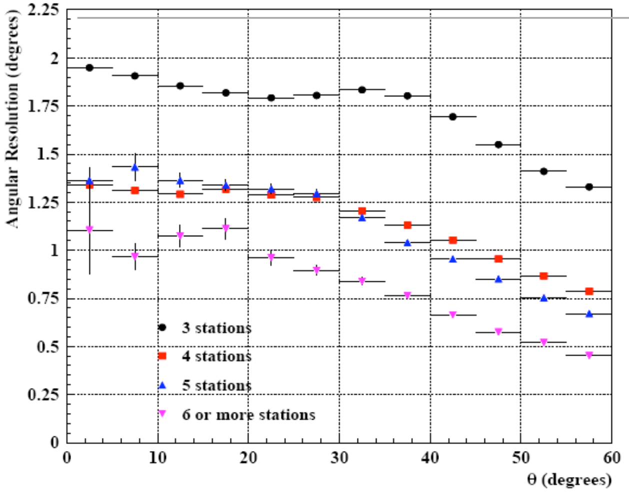
Depth of shower max correlated with composition: protons interact deeper in atmosphere than Fe

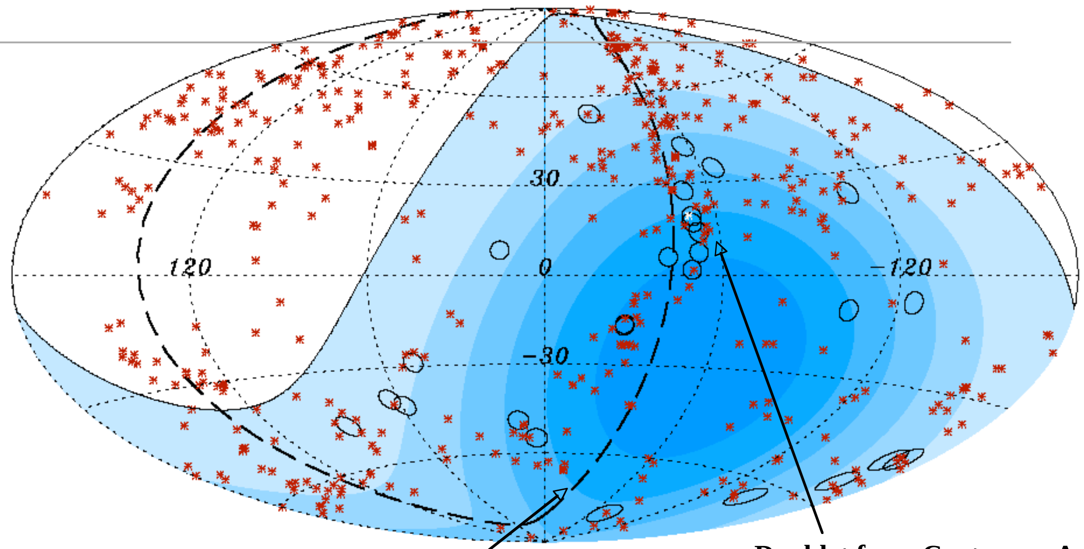


uncertainty about 15 g/cm^2



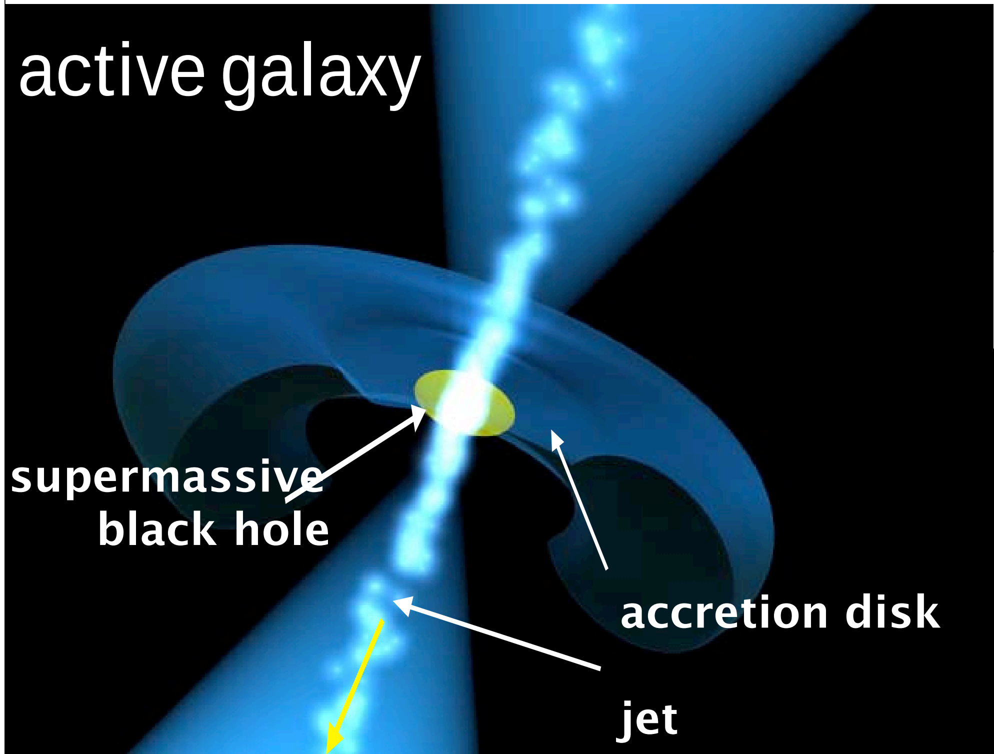
Proton astronomy



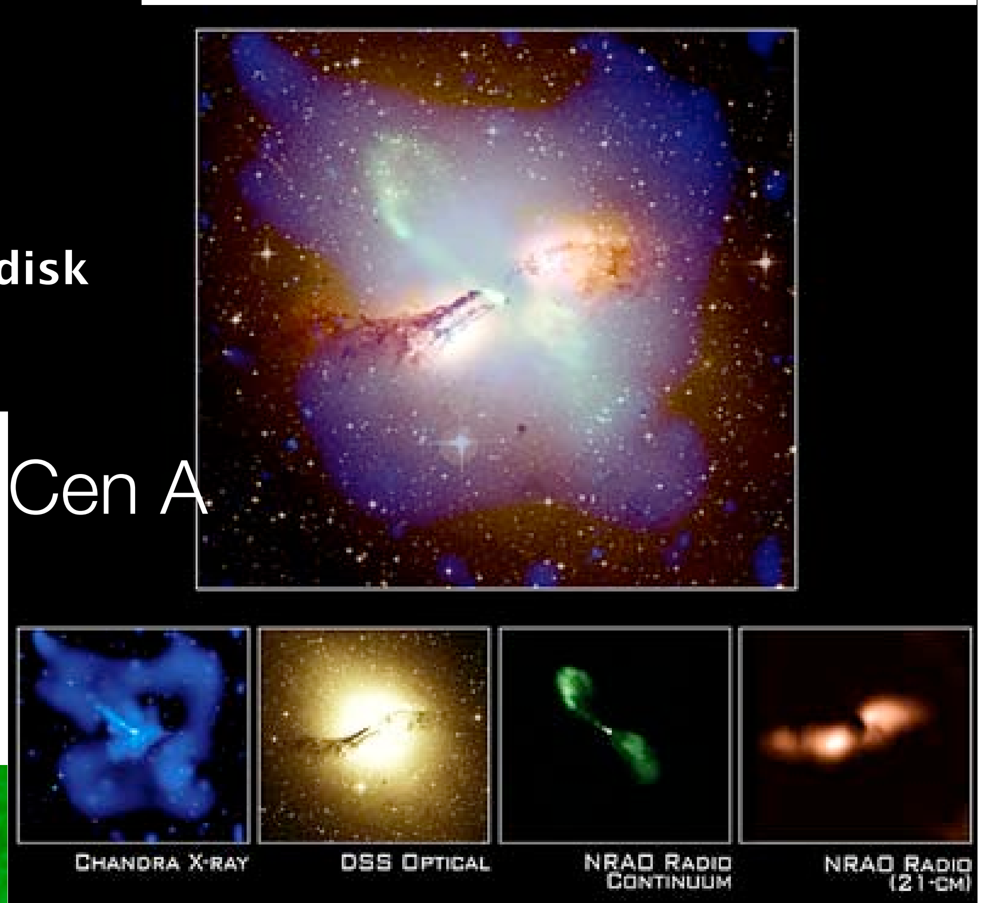


Vertical shower of energy 10^{19} eV activates
7-8 tanks

Auger does not confirm the 4.5σ excess seen by AGASA from the Galactic Centre for 1-2.5 eV
20 of 27 with E>57 EeV correlate with an incomplete catalogue of 292 AGN (< 75 Mpc) within 3.2°.
Isotropy of this observed configuration has probability of 10^{-5}



Extragalactic sources

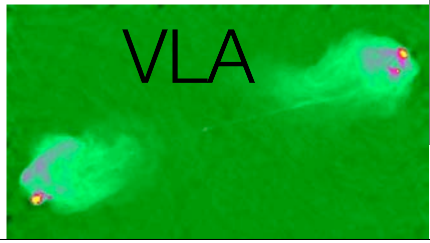


Active Galactic Nuclei

$\Gamma \sim 10$

$E_{max} \sim 10^{21}$ eV

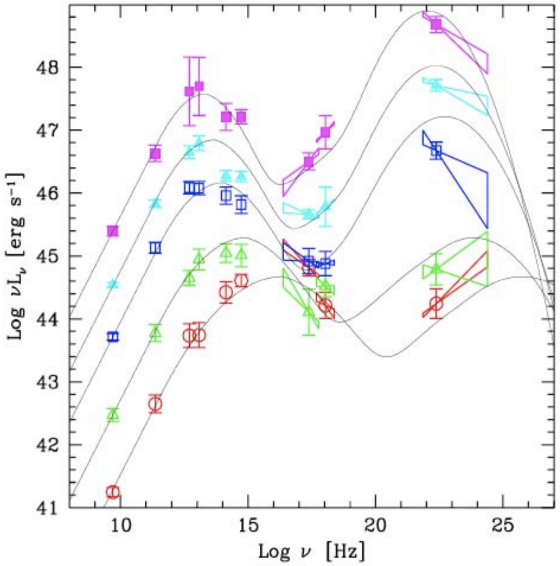
$L \sim 10^{46}$ erg/s



AGN classification

BL Lac are divided in HBL (high energy cutoff blazars) and LBL (low energy cutoff)

Average SED of BL Lacs



1ES1959+650, MWL

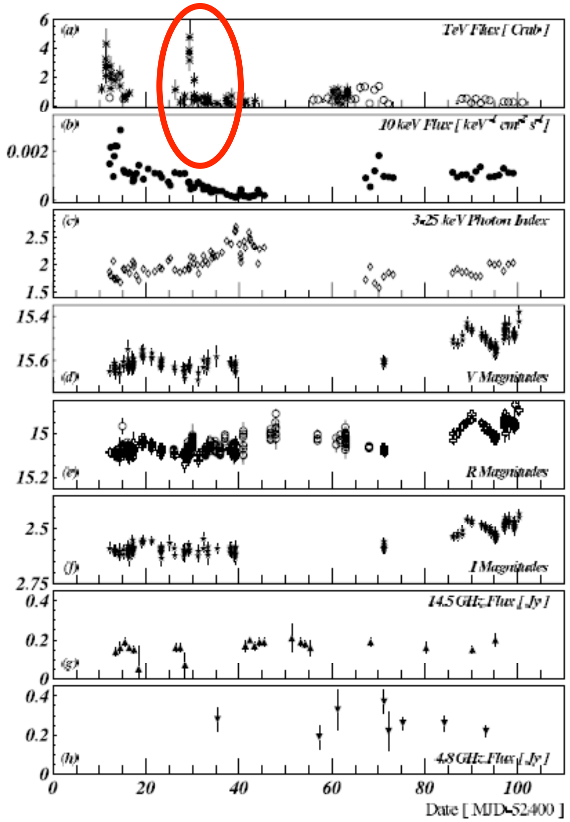


FIG. 2.—Results from the 1ES 1959+650 multiwavelength campaign (2002 May 16–August 14). (*a*) Whipple (*stars*) and HEGRA (*circles*) integral TeV γ-ray fluxes in Crab units above 600 GeV and 2 TeV, respectively; the Whipple data are binned in 20 minute bins and the HEGRA data in diurnal bins. (*b*) *RXTE* X-ray flux at 10 keV. (*c*) *RXTE* 3–25 keV X-ray photon index. (*d*) Absolute *V* magnitudes (Boltwood). (*e*) Absolute *R* magnitudes (*crosses*: Boltwood; *circles*: Abastumani). (*f*) Relative *I* magnitudes (Boltwood); (*g*) The 14.5 GHz flux density (UMRAO). (*h*) The 4.8 GHz flux density (UMRAO).

Neutrinos from GZK cosmic-rays

$$\mathcal{F}(E_\nu) = \frac{c}{4\pi}\int_{z_{\min}}^{z_{\max}}\int_{0}^{E_{\max}} J(E,z)\times Y(E_p,E_\nu,z)\times\zeta(z)\times dE_p\,dz$$

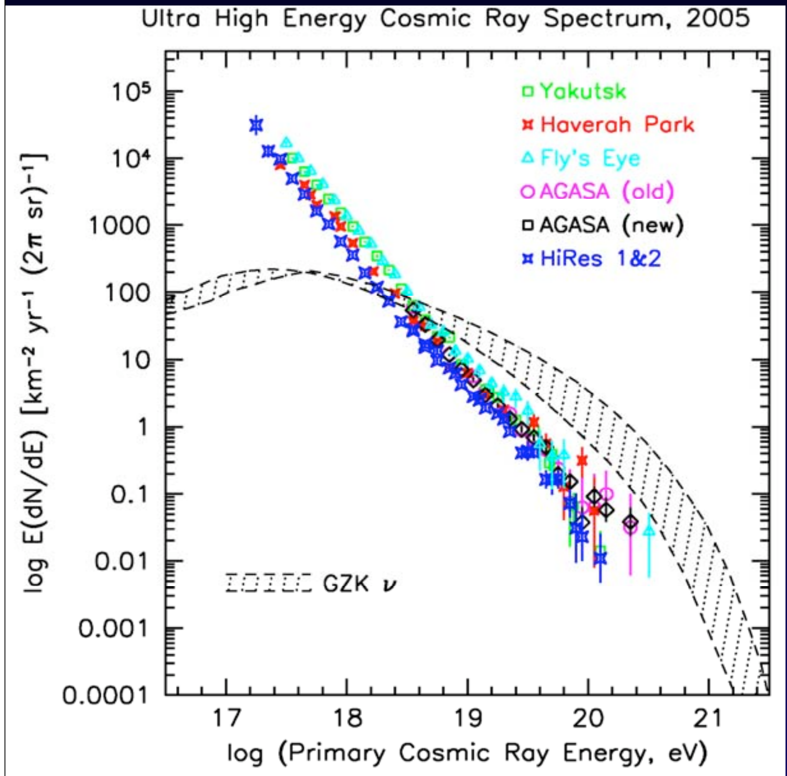
Neutrino flux

UHECR Flux

Neutrino Yield

Source Evolution

UHECR sources increase with z



cosmic rays interact with the microwave background

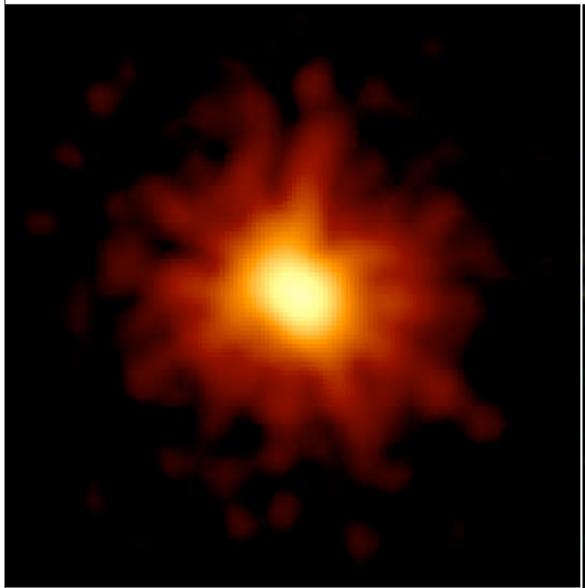
$$p+\gamma \rightarrow n+\pi^{+}$$

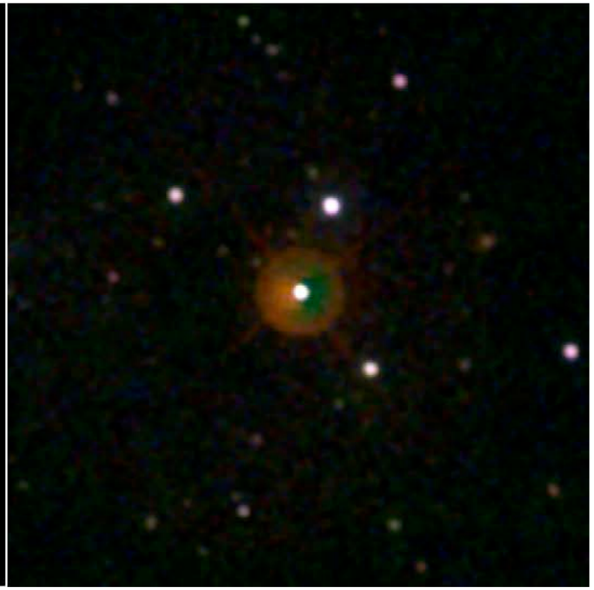
cosmic rays disappear, neutrinos appear

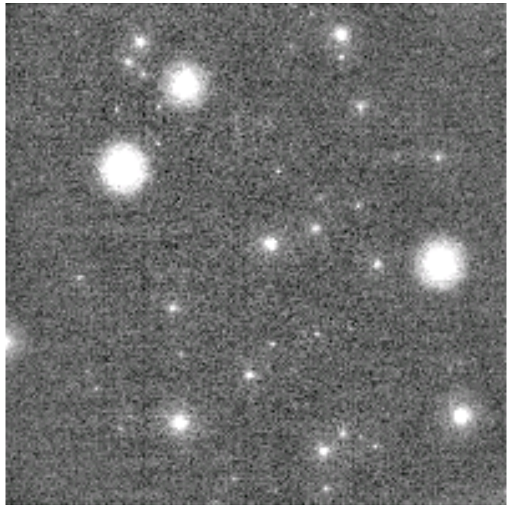
$$\pi \rightarrow \mu+\upsilon_{\mu} \rightarrow \{e+\upsilon_{\mu}+\upsilon_{e}\}+\upsilon_{\mu}$$

~ 1 event per km^2/yr

GRB080319B with SWIFT







http://grb.fuw.edu.pl/pi/index.html

XRT (X-ray)

UVOT (ultra violet)

Gamma Ray Bursts

$100 < \Gamma < 1000$

$E_{max} \sim 10^{21}$ eV

$L \sim 10^{51}$ erg/s

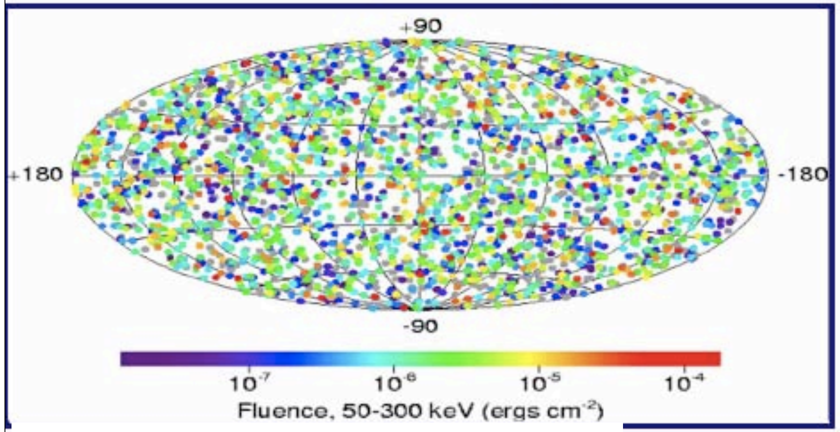
~10 sec duration

Visible to the naked eye for ~10 s !!!

1969: discovery with military Vela satellites

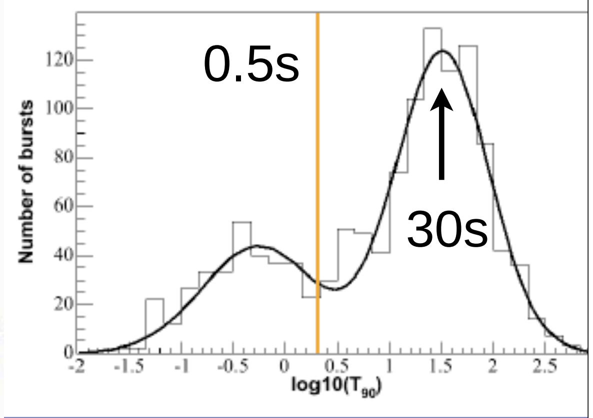
Gamma-Ray Bursts

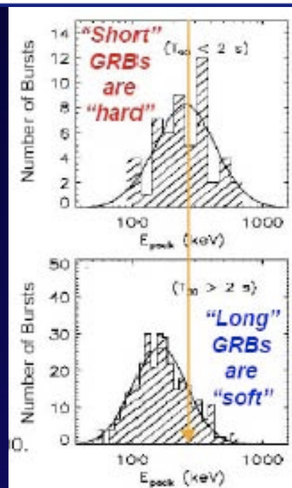
- The Burst And Transient Source Experiment
  - 9 year mission aboard CGRO (1991-2000)
  - With 1/2 sky coverage, detected ~1 GRB/day (2704)

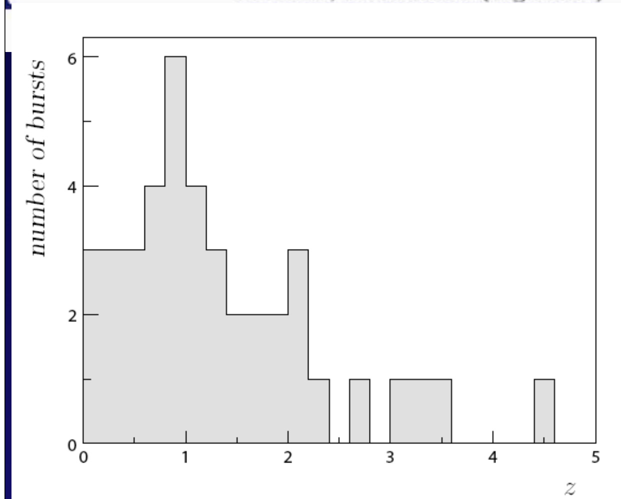


Isotropic distribution implies extragalactic origins

2 classes: long GRBs (associated to type Ic SN) are softer than short

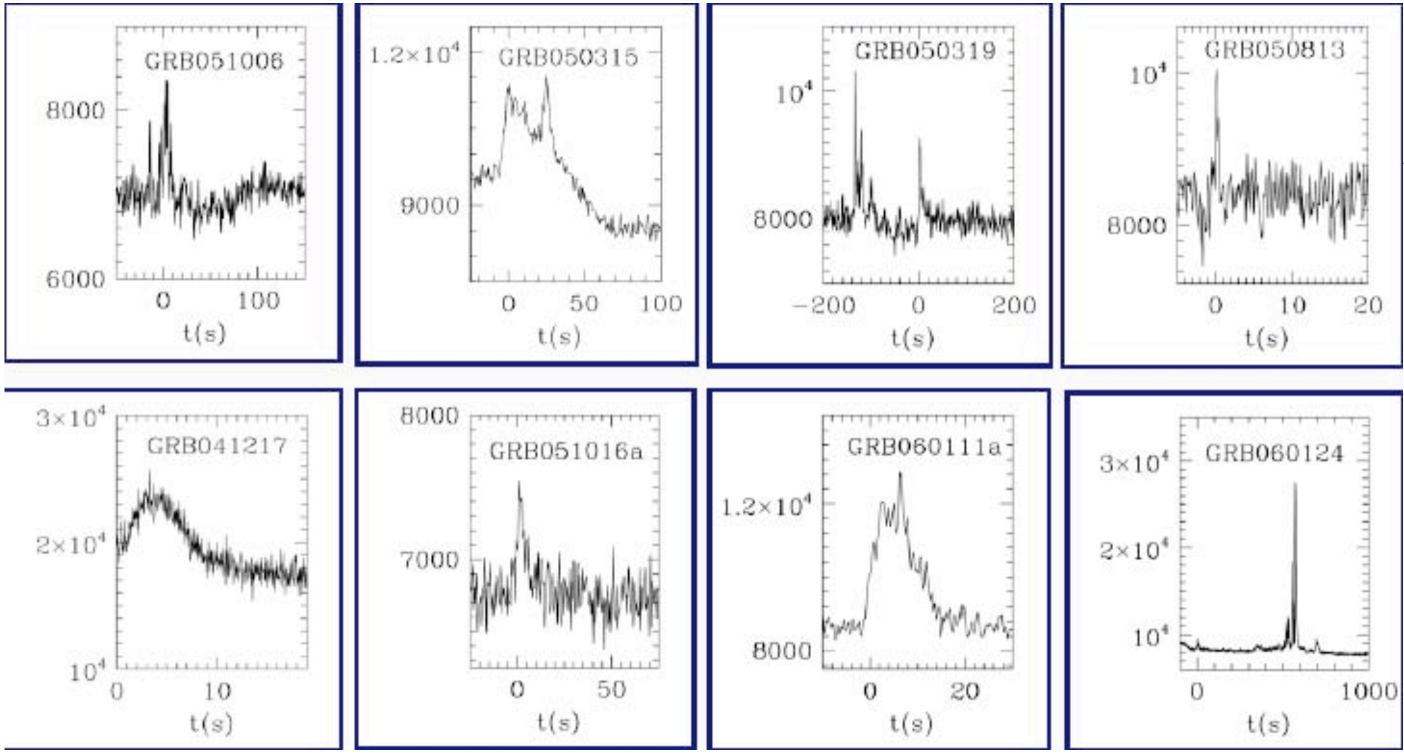






Cosmological origin proved by BeppoSAX when optical counterparts where found. Measurement of afterglows allowed to measure z.

Time Variability and compactness



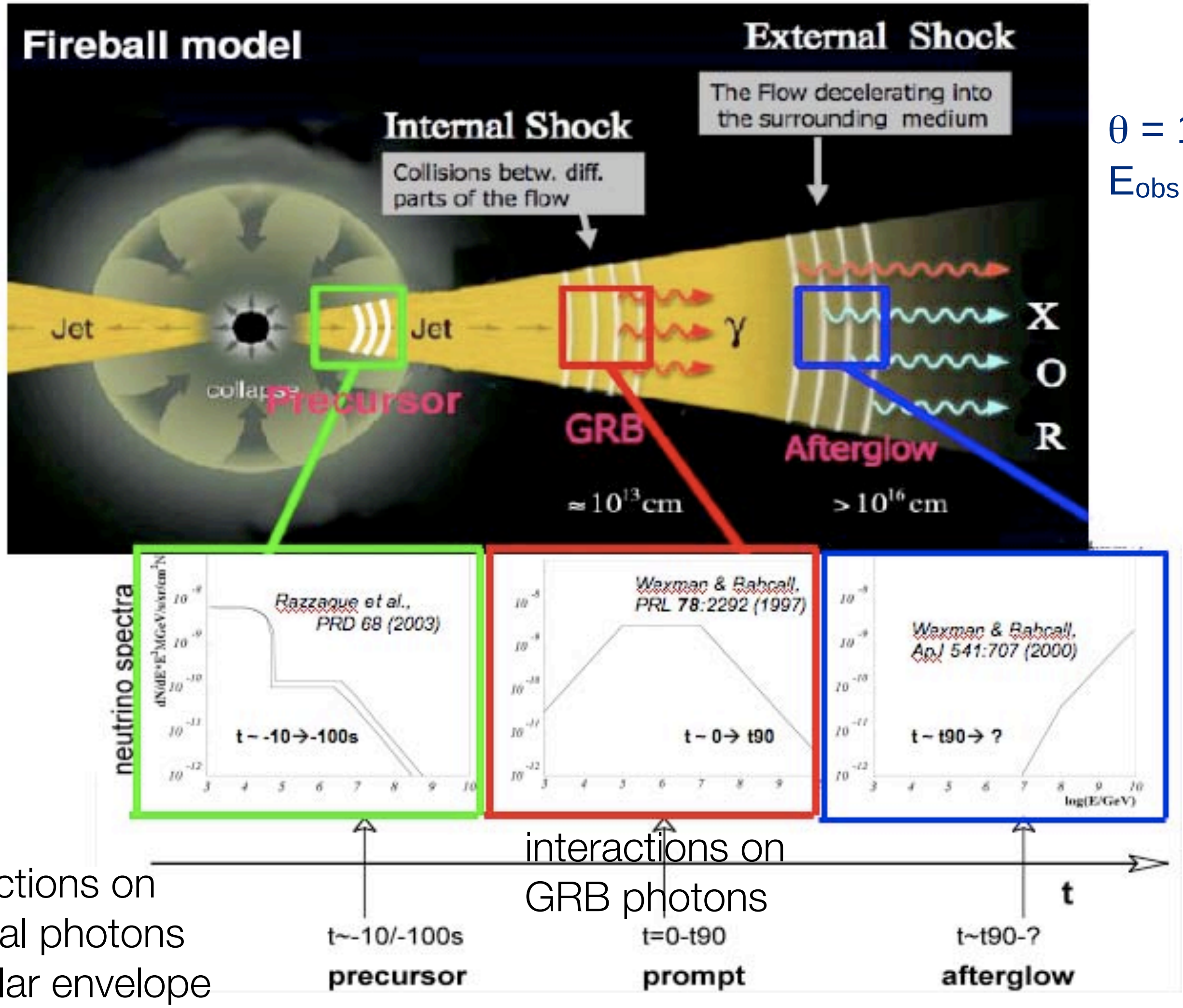
Energies ~10^{53}-10^{54} erg released in ~ 10 s in the collapse of a massive star into a BH (long bursts) and formation of 2 jets, or compact binary stars merge forming a BH (short bursts).

Compactness problem: variability of Δt~10ms imply a source dimension of the order of cΔt~3000km and optical depth for pair production of ~10^{13} cm (only thermal spectra possible). But photons of energies ~1MeV are emitted in non thermal spectra.

The solution to these problem is assuming a beam of Lorentz Γ~100-1000 since then sources are larger by a factor Γ^2.

Neutrino emissions in Fireball Model

Relativistically expanding fireball of e±, γ initially optically thick until Γ high enough and $\tau_{\gamma\gamma} < 1$
Kinetic energy dissipated via shocks: internal shocks between shells with varying Γ and external shocks on ISM. The dissipated energy can be used to accelerate particles or create B-fields and accout for rapid variabilities, external shocks can account for afterglows.



$\theta = 1/\Gamma$

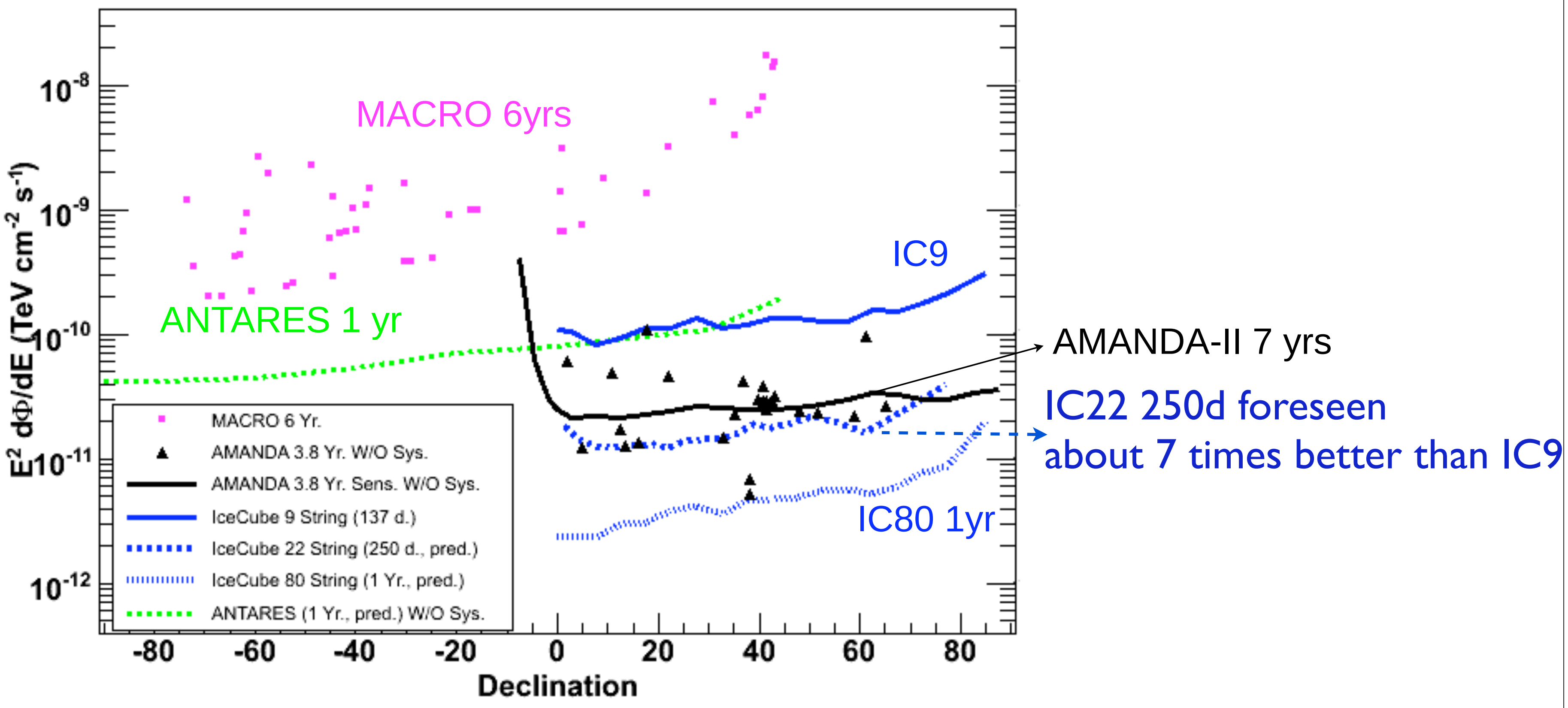
$E_{obs} = \Gamma E_{emitted}$

interactions on thermal photons in stellar envelope

interactions on GRB photons

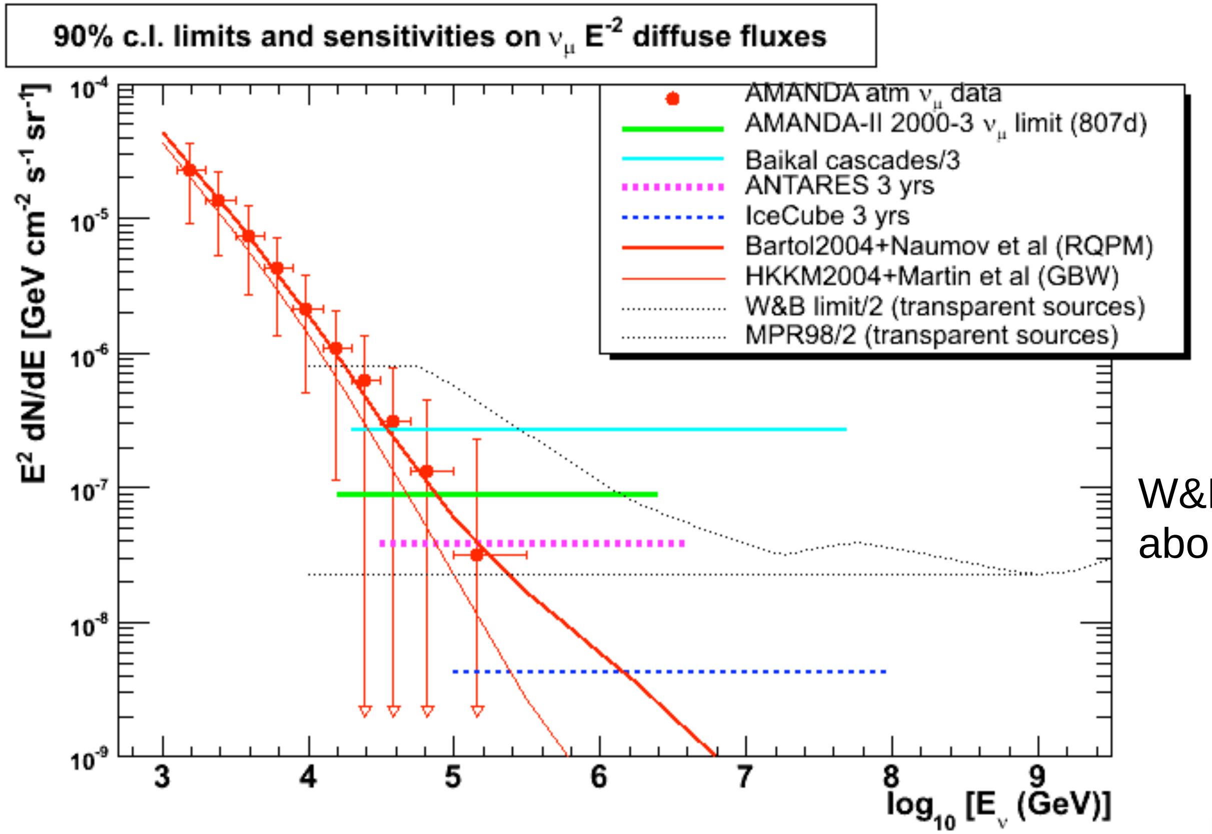
interactions on afterglow photons

Point-source Limits



Interesting fluxes are between 10^{-11} and 10^{-12} TeV cm^{-2} s^{-1}

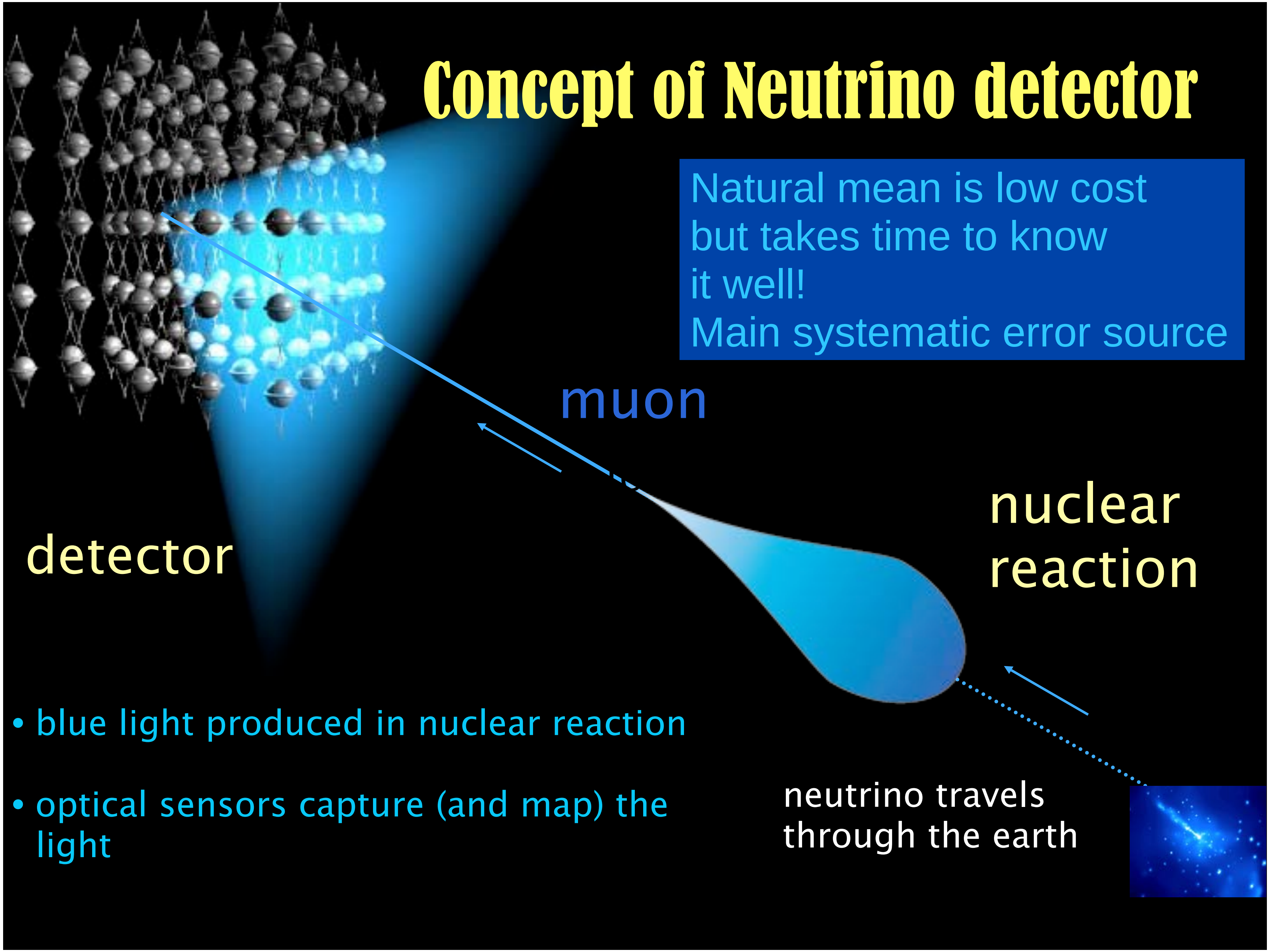
Diffuse limits



W&B corresponds to about 50 ev/yr/km^2

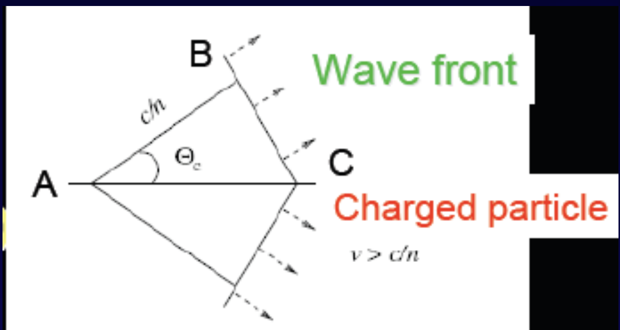
IceCube can test in Auger sources (with evolution ~6 x 10^{-9} E^{-2} GeV^{-1} cm^{-2} s^{-1} sr^{-1}).

Julia's talk and Halzen & O'Murchadha, 2008


Concept of Neutrino detector
Natural mean is low cost
but takes time to know
it well!
Main systematic error source
muon
nuclear
reaction
detector
• blue light produced in nuclear reaction
• optical sensors capture (and map) the
light
neutrino travels
through the earth

Cherenkov light

Radiation emitted by a charged particle traveling in a dielectric medium with velocity v > c/n. Emission due to asymmetric polarization of medium in front and at rear of particle giving rise to an oscillating electric dipole. Some of the particle energy is converted in light and a coherent wave front movig at velocity v and at an angle given by



$$\cos\theta_c = \frac{AB}{AC} = \frac{\frac{c}{n}t}{\beta c t} = \frac{1}{\beta n}$$

Cherenkov Radiation in a Research Reactor

In water and ice and for ultrarelativistic muons β = 1, about 41-42 deg

Energy Loss in Cherenkov

$$\frac{d^2N}{dxd\lambda} = \frac{4\pi^2 z^2 e^2}{hc\lambda^2}\left(1-\frac{1}{n^2\beta^2}\right) = \frac{2\pi z^2}{\lambda^2}\alpha \sin^2\Theta_C$$

$$\alpha = \frac{2\pi e^2}{hc} = 1/137$$

Number of photons/L and radiation length depends on charge and velocity of particle

Using light detectors (photomultipliers) sensitive in 400-700 nm for an ideally 100% efficient detector in the visible

$$\frac{dN_\gamma}{dx} = \int_{\lambda_1}^{\lambda_2} d\lambda \frac{d^2N_\gamma}{dxd\lambda} = 2\pi z^2 \alpha \sin^2\Theta_C \int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda^2} = 2\pi z^2 \alpha \sin^2\Theta_C \left(\frac{1}{\lambda_1^2} - \frac{1}{\lambda_2^2}\right) = 490\, z^2 \sin\Theta_c \quad photons/cm$$

$$\frac{d^2N}{dxdE} = \frac{d^2N}{dxd\lambda}\frac{d\lambda}{dE} = \frac{\lambda^2}{2\pi\hbar c}\frac{d^2N}{dxd\lambda}$$

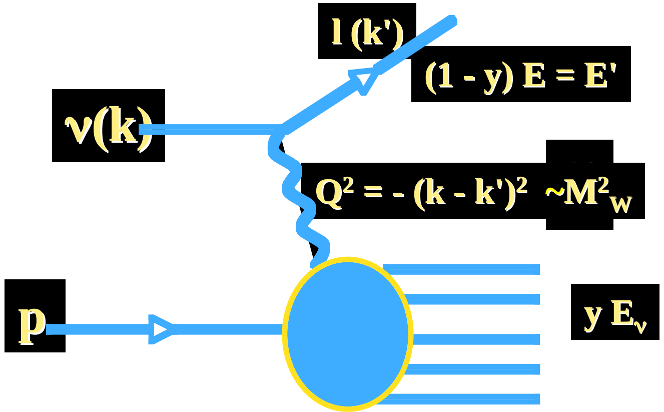
$$E = h\nu = \frac{hc}{\lambda} = \frac{2\pi\hbar c}{\lambda}$$

$$\frac{d^2N}{dEdx} = \frac{\alpha z^2}{\hbar c}\sin^2\theta_c = \frac{\alpha^2 z^2}{r_e\, m_e c^2}\left(1 - \frac{1}{\beta^2 n^2(E)}\right)$$

$$\approx 370 \sin^2\theta_c(E)\ \mathrm{eV^{-1}cm^{-1}} \qquad (z=1)\ ,$$

Energy loss is about 10^4 less than 2 MeV/cm in water from ionization but directional effect

Detector large target mass



$$\frac{d^2\sigma}{dxdy} = \frac{2G_F^2 M E_\nu}{\pi}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2\left[xq(x,Q^2)+x\overline{q}(x,Q^2)(1-y)^2\right]$$

$$Q^2 = 2ME_\nu xy \qquad y = \nu/E_\nu \qquad \nu = E_\nu - E_\mu$$

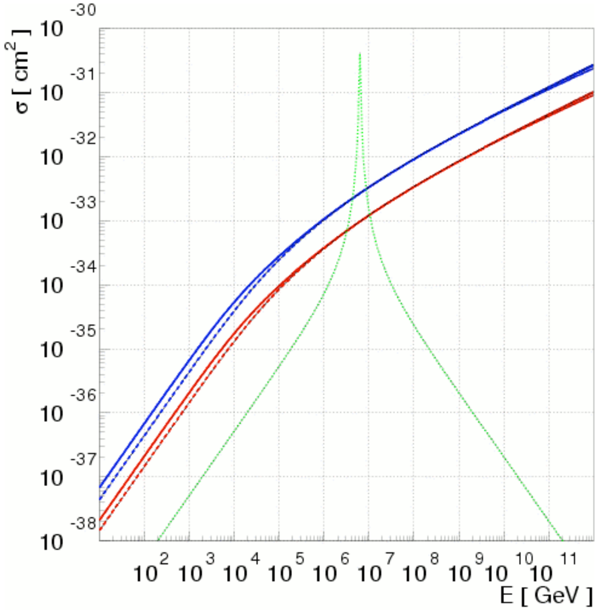


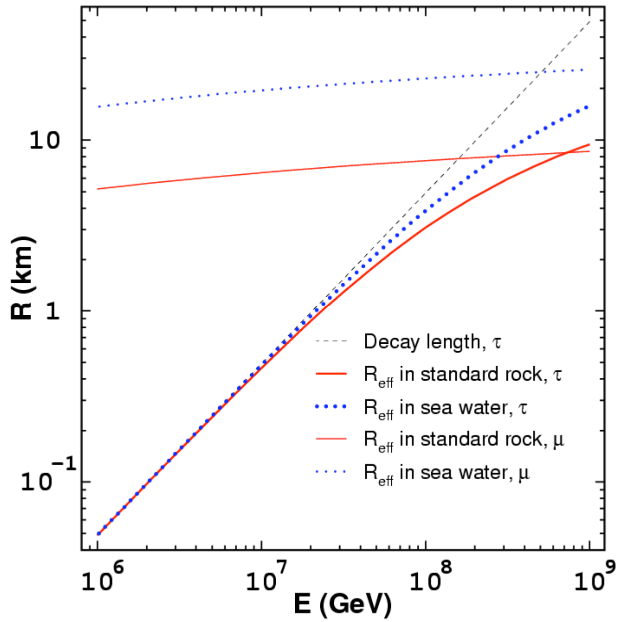
Figure 33: Simulated neutrino cross sections: higher blue curves are CC, lower red curves are NC; solid are ν, dashed are $\bar{\nu}$; green dotted is $\bar{\nu}_e e^- \to W^-$

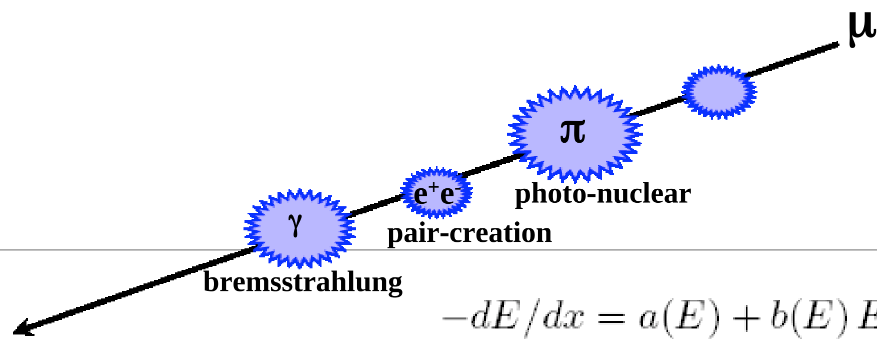
$$\overset{(-)}{\nu}_\mu + N \rightarrow \mu^\pm + X$$

External events => greater target mass!

M = ρ R_{muon} S (E_{muon} = 1 TeV : R_{muon} = 2.5 km)

Muon Energy loss





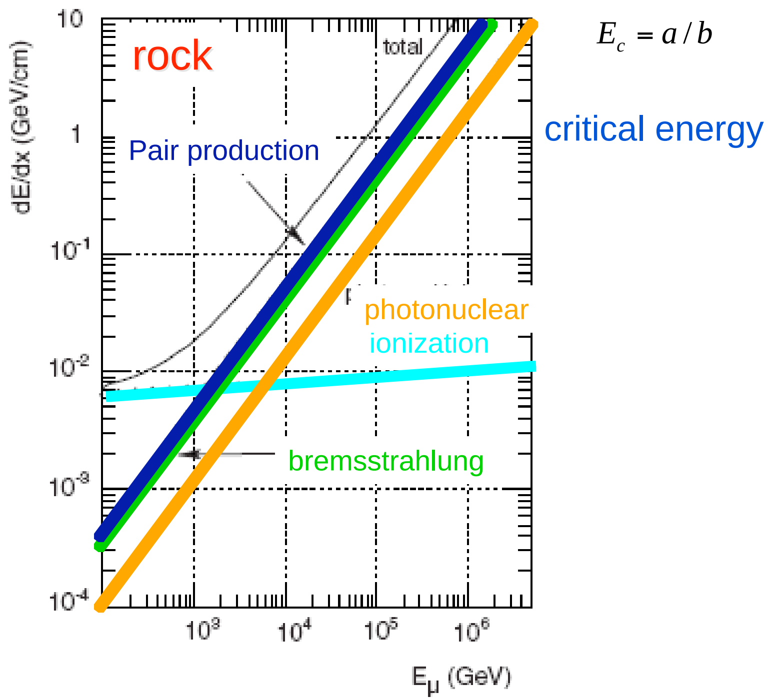
$$-dE/dx = a(E) + b(E)\,E$$

Ionization ~2 MeV/g/cm^2

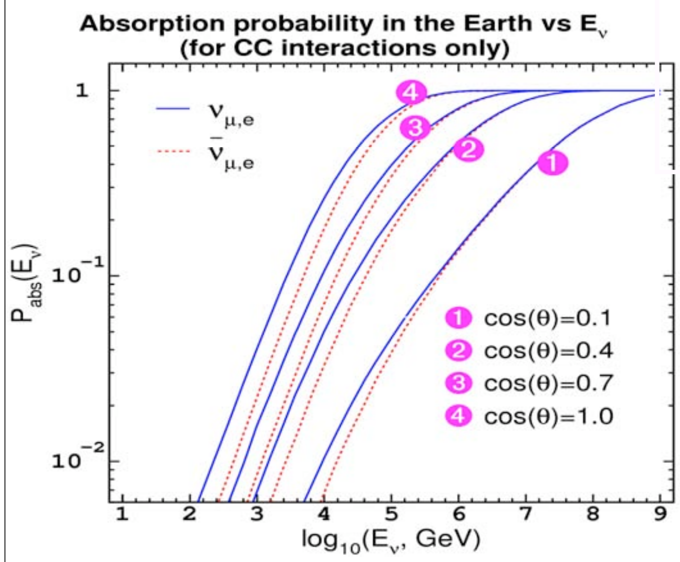
Stochastic losses (dominate > 1TeV)

$$R_\mu = \int_0^E \frac{dx}{dE}\,dE \approx \int_0^E \frac{1}{a+bE}\,dE = \frac{1}{b}\log(1+E/E_c)$$

$$E_c = a/b$$

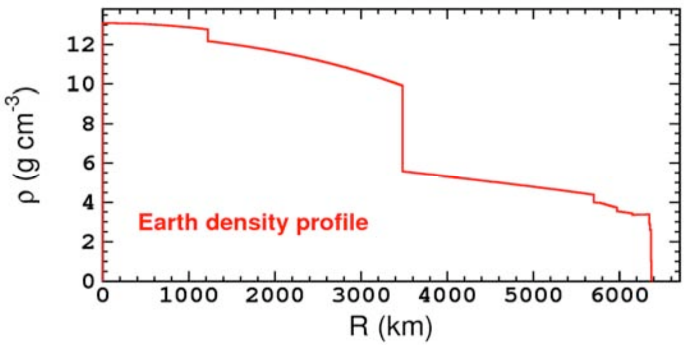


Absorption in the Earth

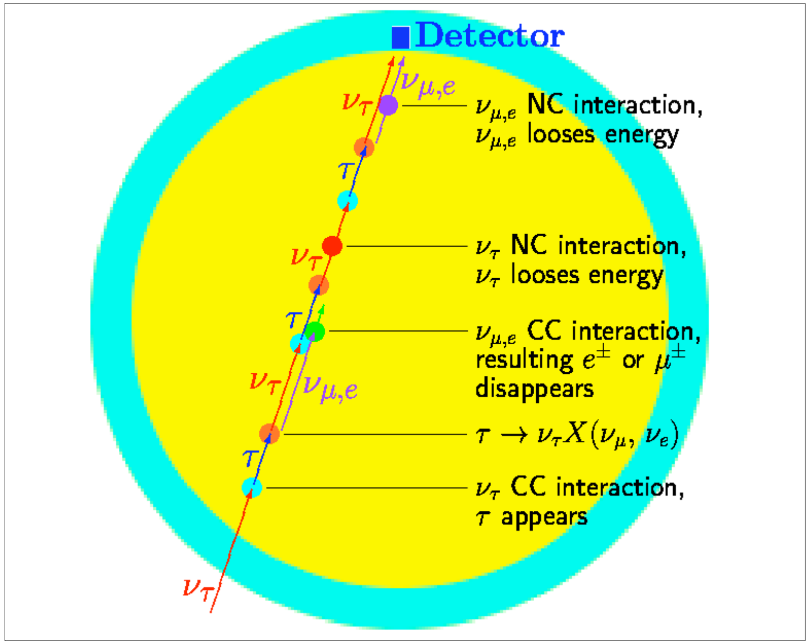


$P_{survival} = \exp -(l/\lambda_\nu)$
$\lambda_\nu = 1/(\rho\, N_A\, \sigma_\nu\, (E_\nu))$

Tau neutrinos never absorbed but loose energy



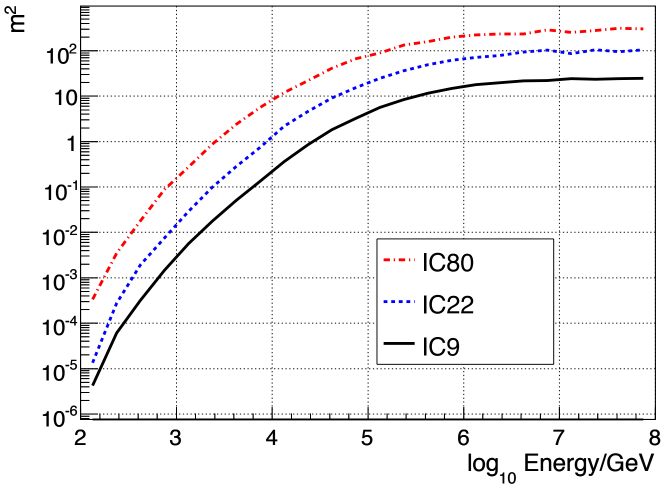
L'Abbate, TM, Sokalski, Astropart.Phys.23:57-63,2005



Bugaev, TM, Shlepin, Sokalski, Astropart.Phys. 21:491-509,2004

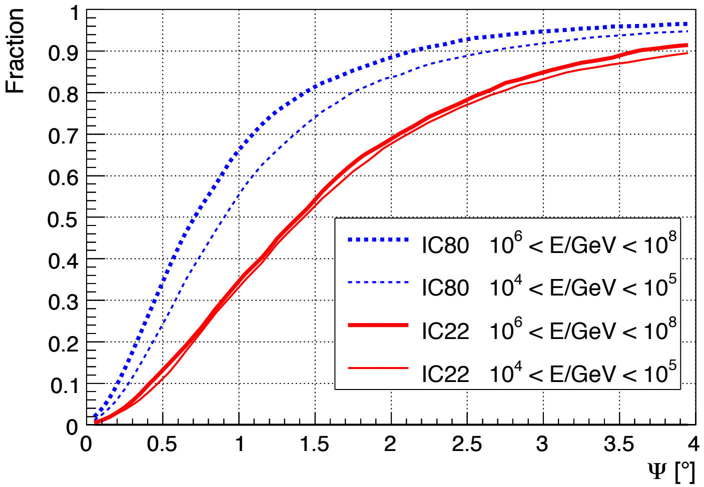
Detectors optimal at high energies

Effective area for neutrinos (E,θ,Φ)



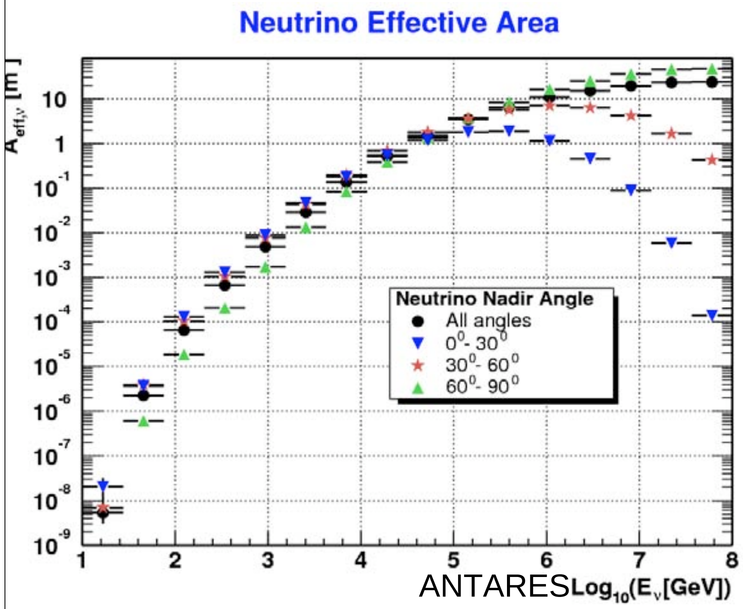
Point Spread function

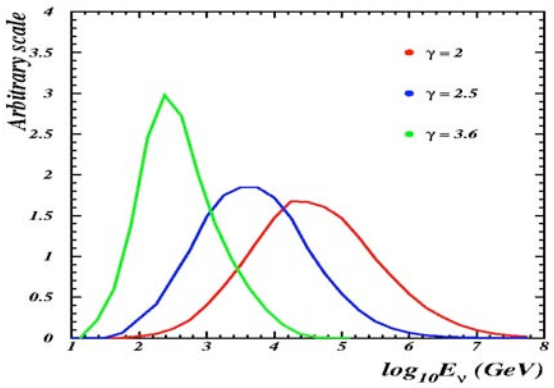
PSF: angle betwen nu and reco mu

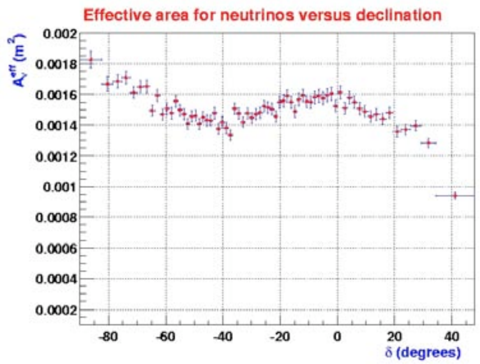


IC22, IC80 analysis not optimized yet (reconstruction and cuts optimized for IC9)
IC9 measured: 233 in 137d, expected 227
Atmospheric neutrinos expected rates per yr:
IC22 2/d
IC40 20/d
IC80 200/d

Effective area







Neutrino-nucleon cross-section

Neutrinos flux model

$$N_\mu = \int V_{eff}(E_\nu,\theta_\nu,\phi_\nu)\ (\rho\ N_A)\ \sigma(E_\nu)\ \frac{d\Phi_\nu}{dE_\nu d\Omega_\nu}\ dE_\nu\ d\Omega_\nu$$

Target nucleon density

Shadowing effect

$$A^\nu_{eff} = V_{gen} \times \frac{N_{xxx}(E_\nu,\theta_\nu,\phi_\nu)}{N_{gen}(E_\nu,\theta_\nu,\phi_\nu)} \times (\rho\ N_A)\ \sigma(E_\nu) \times P_{earth}(E_\nu,\theta_\nu)$$

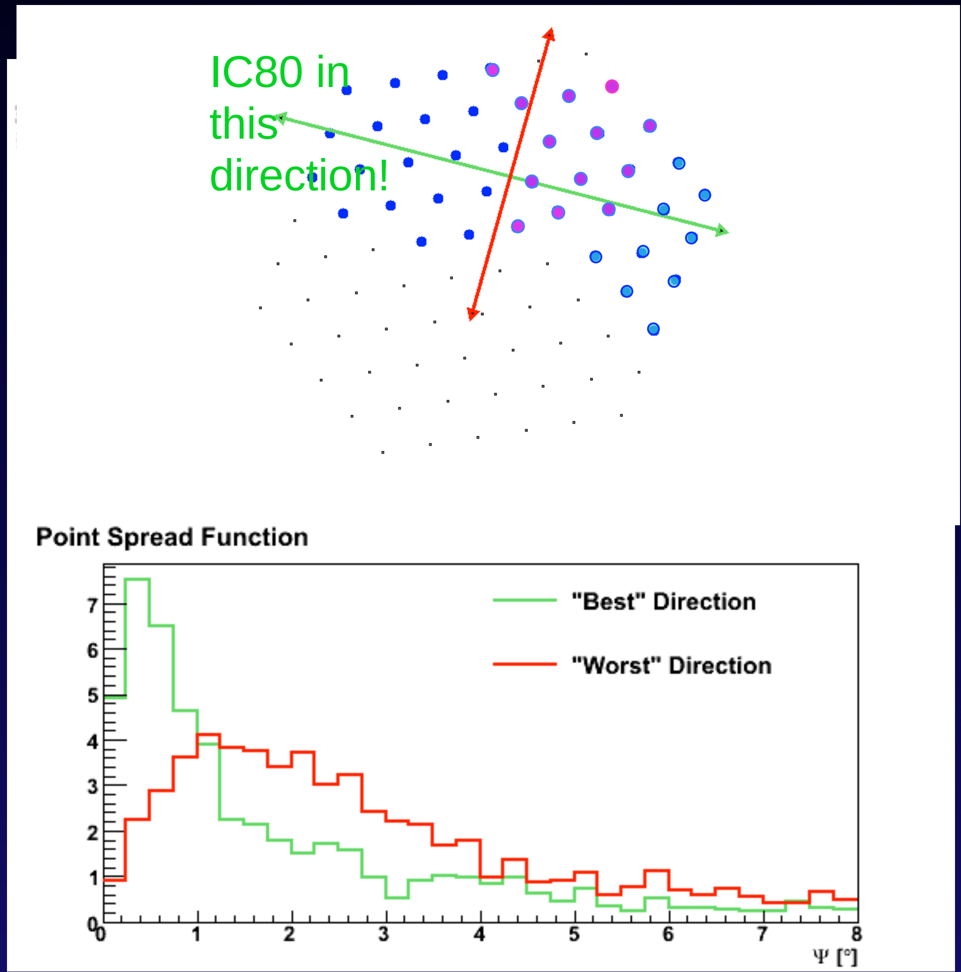
$$P_{earth}(E_\nu,\theta_\nu) = e^{-N_A\ \sigma(E_\nu)\int \rho\ dl}$$

Event rate

$$N_\mu = \int A^\nu_{eff}(E_\nu,\theta_\nu,\phi_\nu)\ \frac{d\Phi_\nu}{dE_\nu d\Omega_\nu}\ dE_\nu\ d\Omega_\nu$$

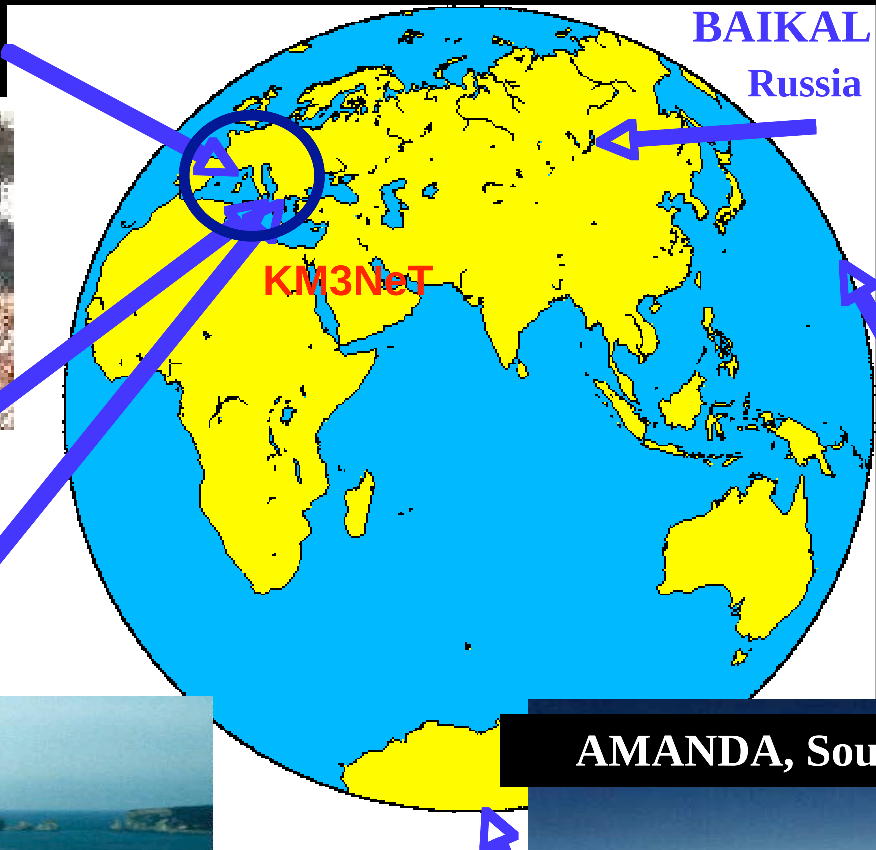
Detectors properties

Current configuration IC40



Cherenkov
Neutrino Telescope Projects

ANTARES
La-Seyne-sur-Mer, France



BAIKAL
Russia

NEMO
Catania, Italy

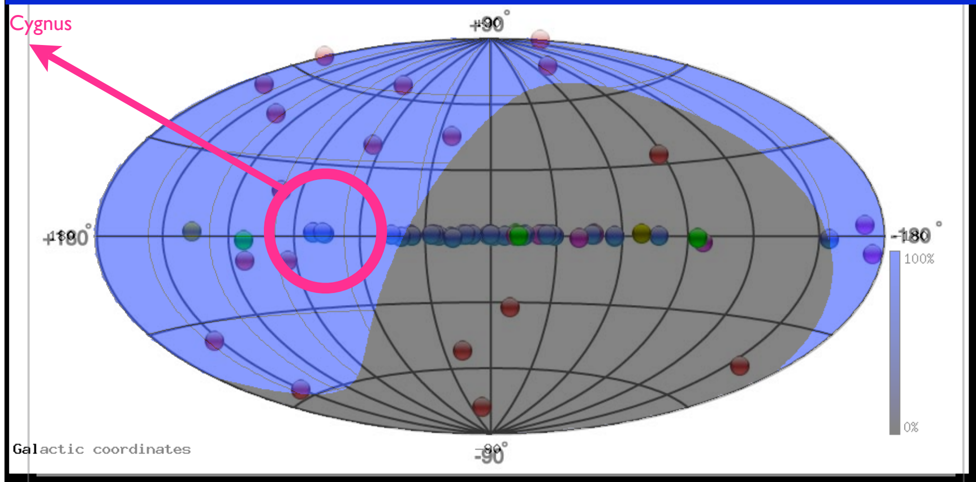
NESTOR
Pylos, Greece

DUMAND
Hawaii
(cancelled 1995)

AMANDA, South Pole, Antarctica

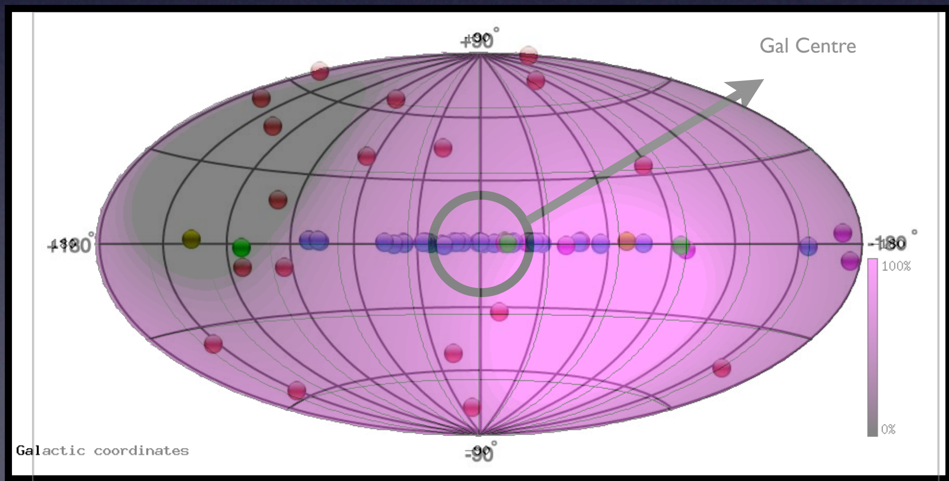
Full Sky Coverage with upgoing neutrinos

To cover better galactic sources we need Med detectors



ANTARES 43° N
Galactic Centre 2/3 of day

IceCube/AMANDA
at South Pole



TeV sources from tevcat.uchicago.edu > 70 TeV sources

IceCube

http://icecube.wisc.edu

United states

- Univ Alaska, Anchorage
- UC Berkeley
- UC Irvine
- Clark-Atlanta University
- U Delaware / Bartol Research Inst
- University of Kansas
- Lawrence Berkeley National Lab
- University of Maryland
- Pennsylvania State University
- University of Wisconsin-Madison
- University of Wisconsin-RiverFalls
- Southern University, Baton Rouge

Europe

University Utrecht

- Uppsala University
- Stockholm University

- University of Oxford

- Universität Mainz
- Humboldt Univ., Berlin
- DESY, Zeuthen
- Universität Dortmund
- Universität Wuppertal
- MPI Heidelberg
- RWTH Aachen

- Universite Libre de Bruxelles
- Vrije Universiteit Brussel
- Université de Mons-Hainaut
- Universiteit Gent

Japan

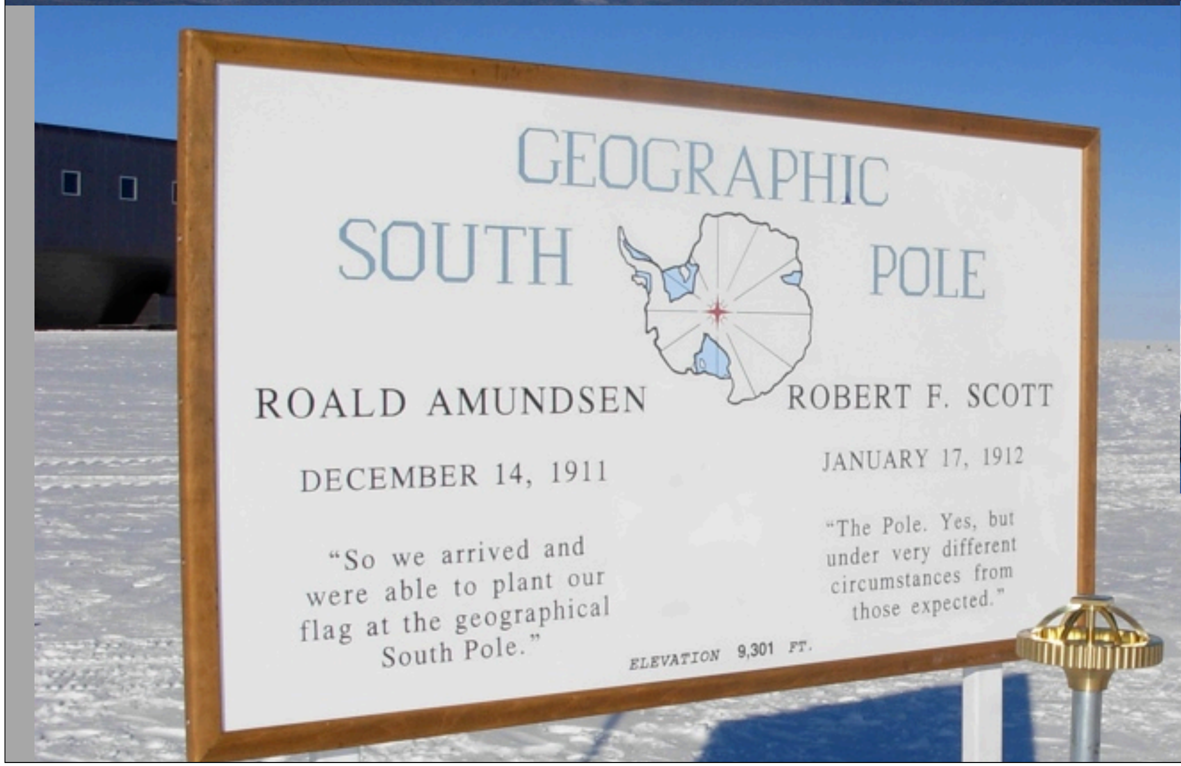
Chiba University

New Zealand

Univ. of Canterbury, Christchurch


The dome, the old station

new South Pole station



IceCube Neutrino Observatory

IceCube

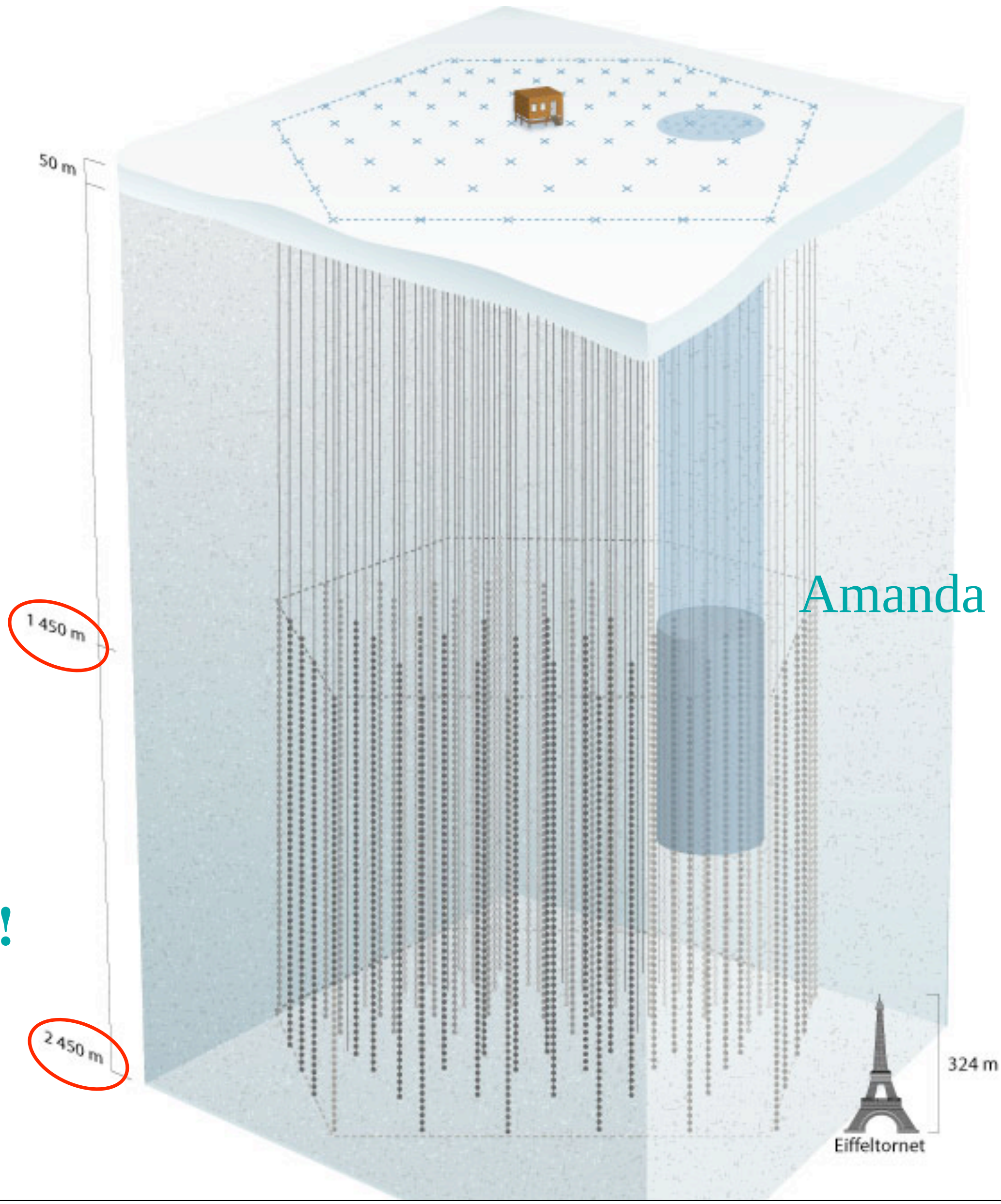
up to 80 strings with 60 Digital Optical Modules
4800 DOMs
17 meters between them
125 meters between strings
1 Giga Ton Detector
No single point failure in a string!
DOM failure rate about 1%

Now: 2400 DOMs on 40 strings!

IceTop Air shower array

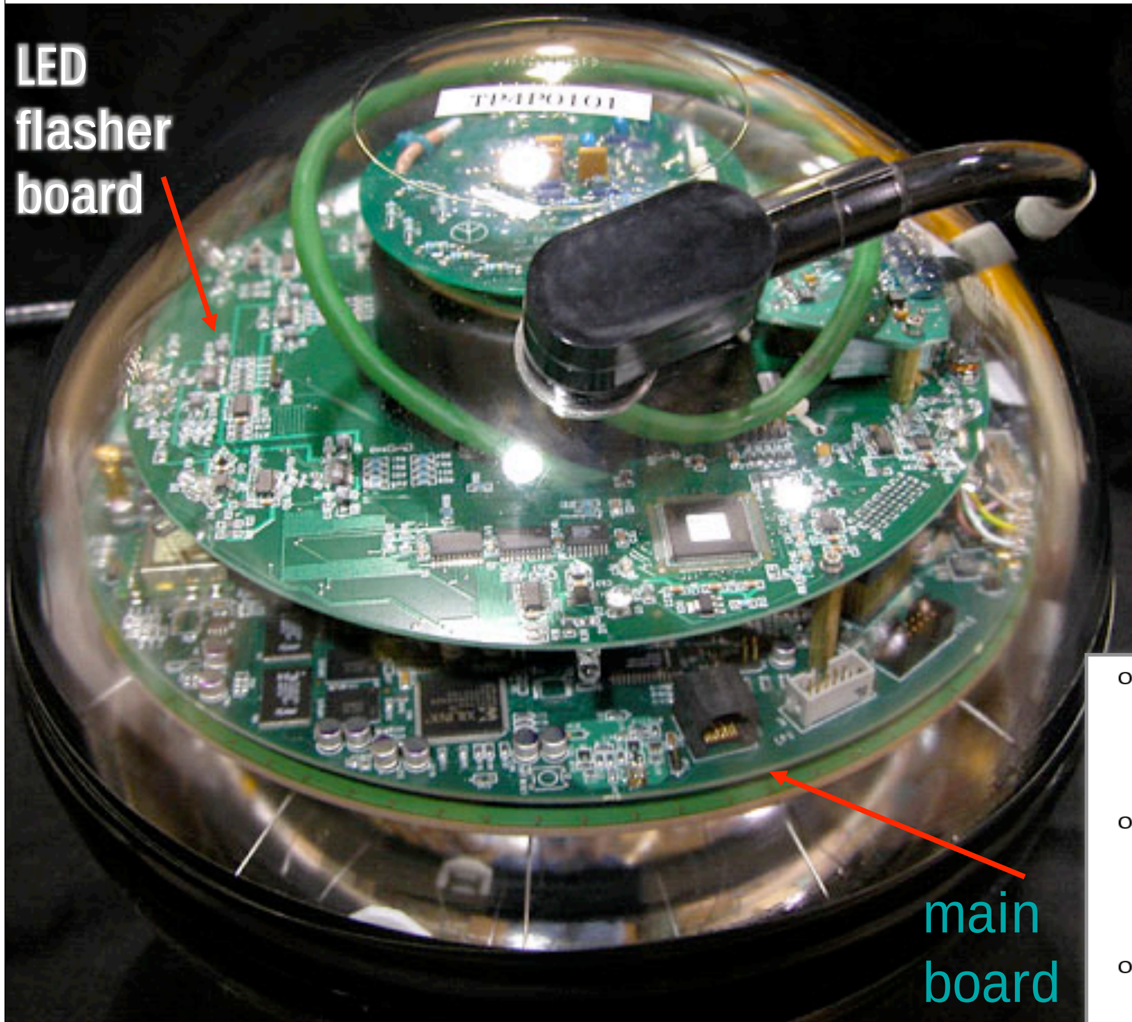
80 Pairs of Ice Cherenkov Tanks 10 m apart each with 2 DOMs

Now: 80 tanks => 160 DOMs!




The Site
ICL
Drilling Tower
IceCube
AMANDA
1500 m
road to work
South Pole
Dome
Summer camp
Skiway
http://icecube.wisc.edu

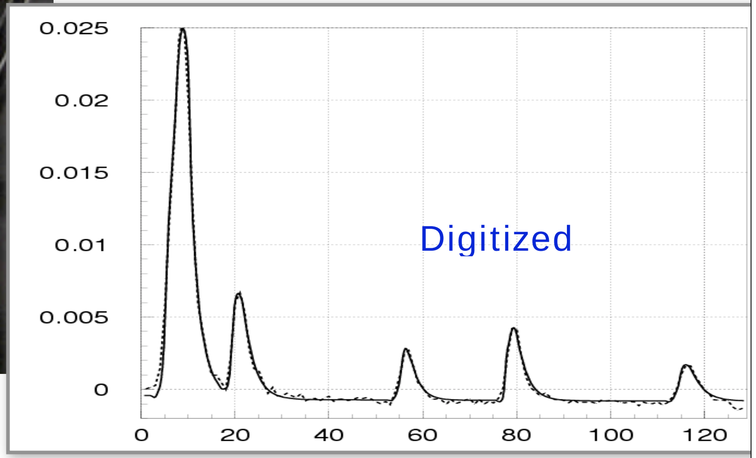
Digital Optical Module (DOM)



PMT: 10 inch Hamamatsu
Power consumption: 3 W
Digitize at 300 MHz for 400 ns with custom chip
40 MHz for 6.4 μs with fast ADC
Dynamic range 200pe/15 nsec

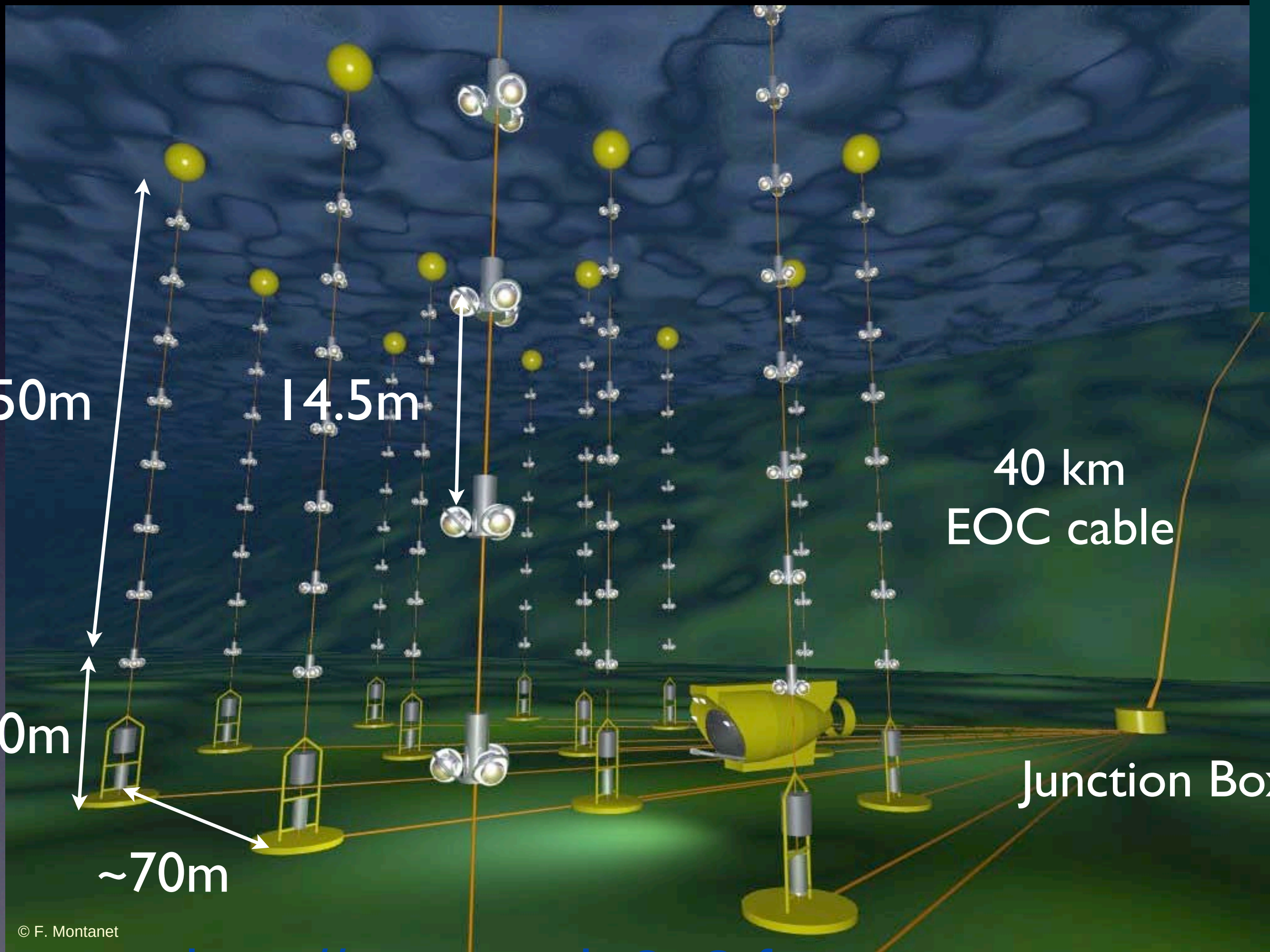
Send all data to surface over copper
2 sensors/twisted pair.
Flasherboard with 12 LEDs
Local HV

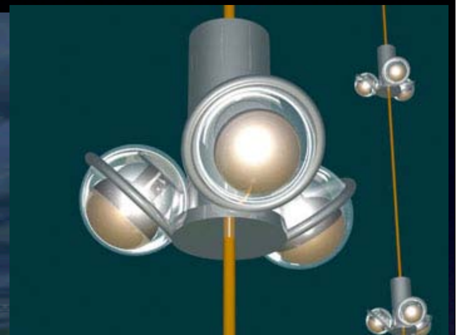
Clock stability: $10^{-10} \approx 0.1$ nsec / sec
Synchronized to GPS time every ≈ 10 sec
Time calibration resolution = 2 nsec



ANTARES

- The largest underwater NT in the Northern Hemisphere and the first undersea NT, an invaluable step towards KM3 in the Mediterranean Sea



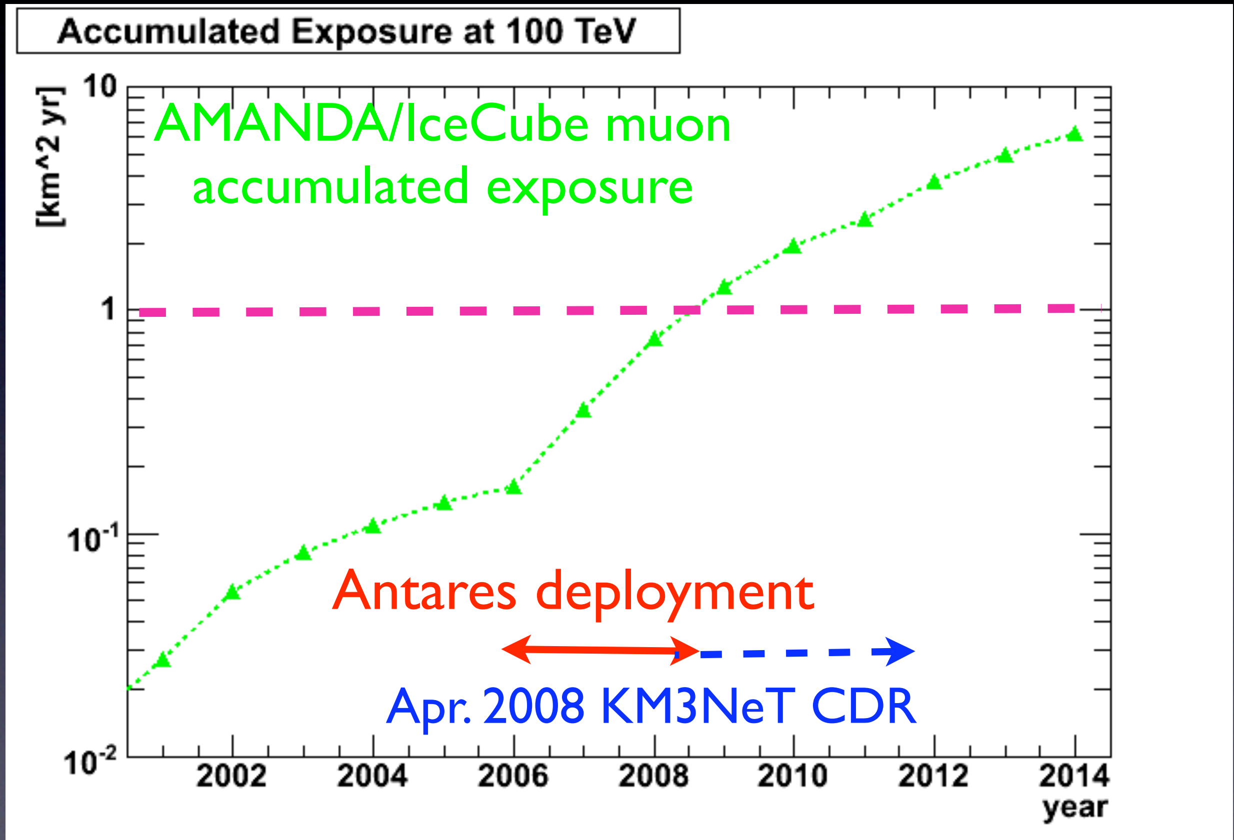


Storey: 10 inch PMT
Front end electronics:
pulse shape discrimination,
time stamp and
digitization above a threshold

http://antares.in2p3.fr

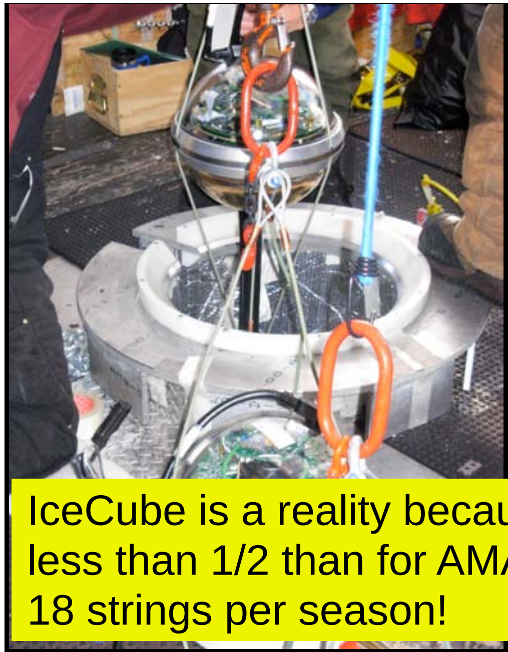
- Consortium of 40 Institutions from 10 European countries in European Strategy Forum on Reasearch Infrustructures roadmap
- Propose a facility for Deep Sea Science
- CDR ready
- Site decision still open

Entering the km^3 era



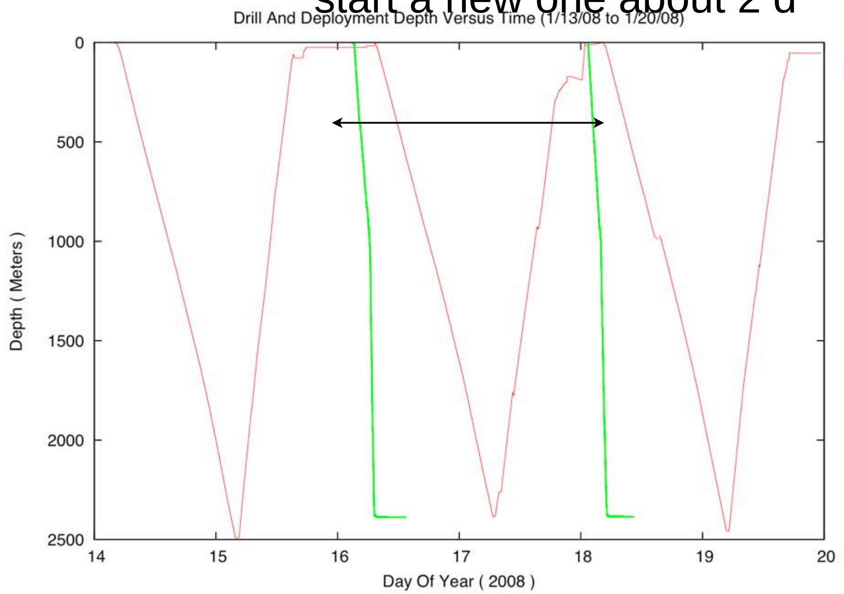
this yr IceCube/ AMANDA integrated exposure about 1 km^2 yr at 100 TeV

Technological challenges



IceCube is a reality because installation time less than 1/2 than for AMANDA. We can deploy 18 strings per season!

Time for a full hole and start a new one about 2 d



5MW x 30 hrs = 0.56 TJ!

ANTARES

Properties of ice/sea water radiators

Dark and transparent environment for Cherenkov light detection

Sea water: λ_{att} ~ 50 m λ_{abs} ~ 50-60 m λ_{scatt} > 200 m (Blue 450 nm)

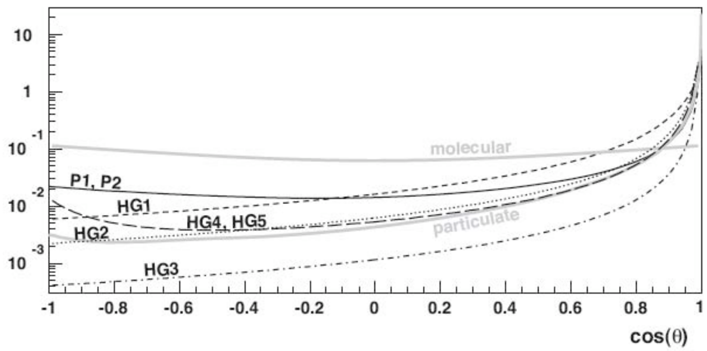
Polar ice: λ_{abs} ~ 100-200 m λ_{scat} ~ 25 m

$$I = I_0 \frac{A}{4\pi R^2} e^{-R/\lambda_{att}^{eff}} \qquad \frac{1}{\lambda_{att}} = \frac{1}{\lambda_{abs}} + \frac{1}{\lambda_{scatt}}$$

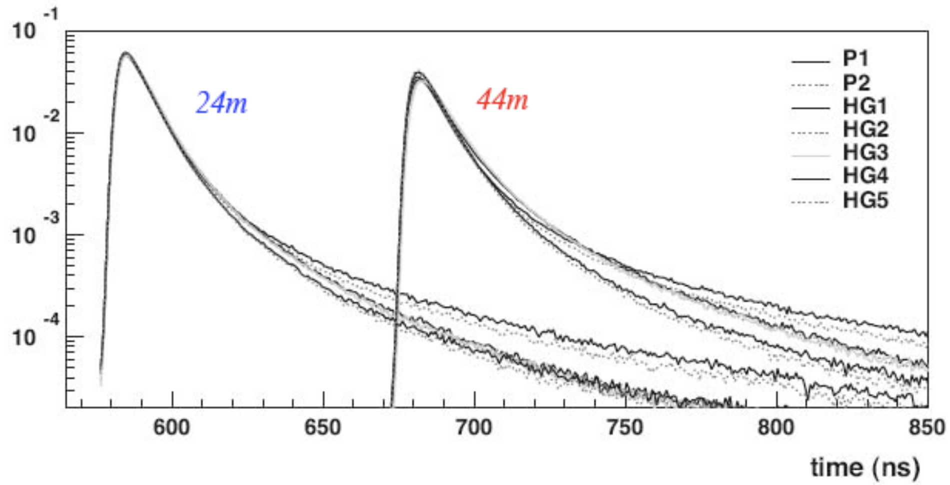
Ned to account for angular distrubution of scattered photons

$$\lambda_{sct}^{eff} \simeq \frac{\lambda_{sct}}{1 - \langle \cos\theta \rangle} \qquad \langle \cos\theta \rangle \simeq 1$$

Scattering affects the angular resolution.

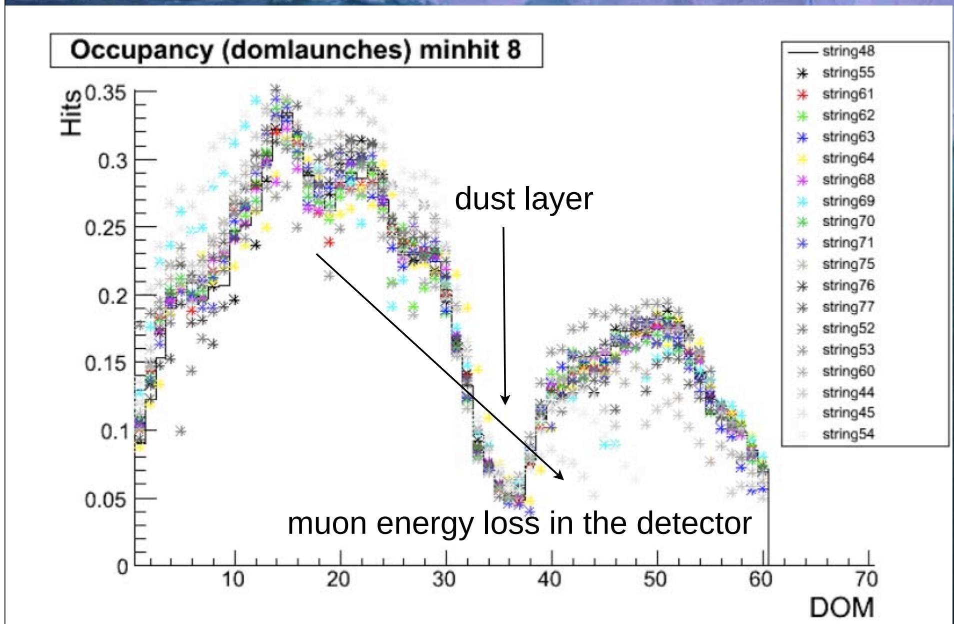


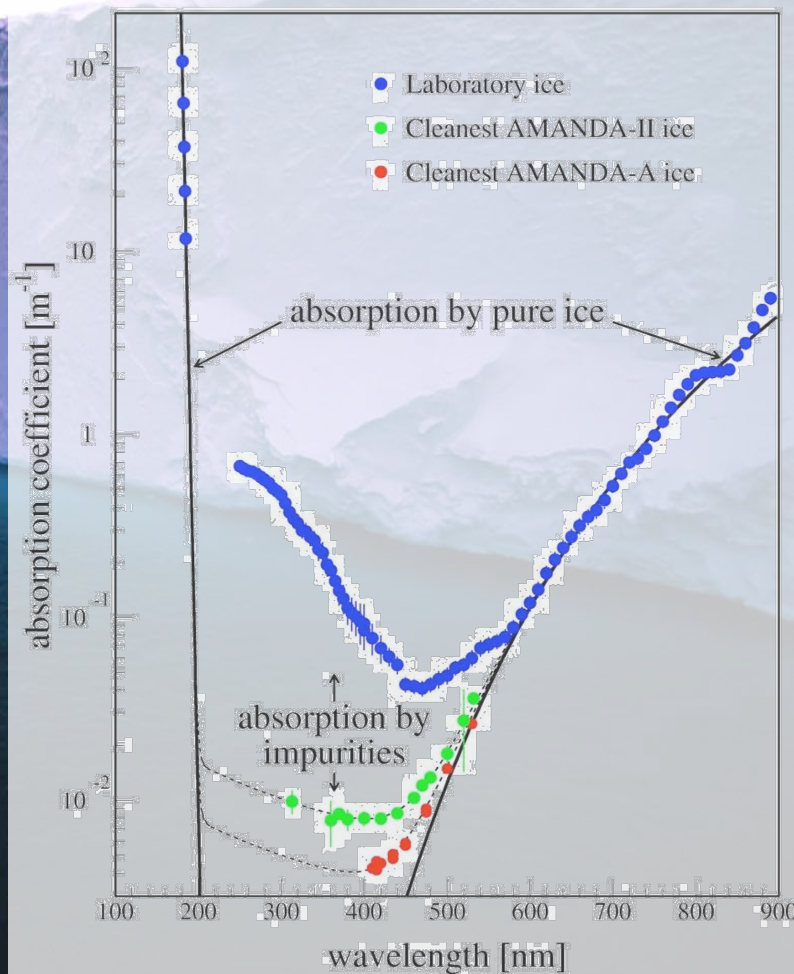
Photon delays in sea water for
LED source - detector distance = 24m, 44m



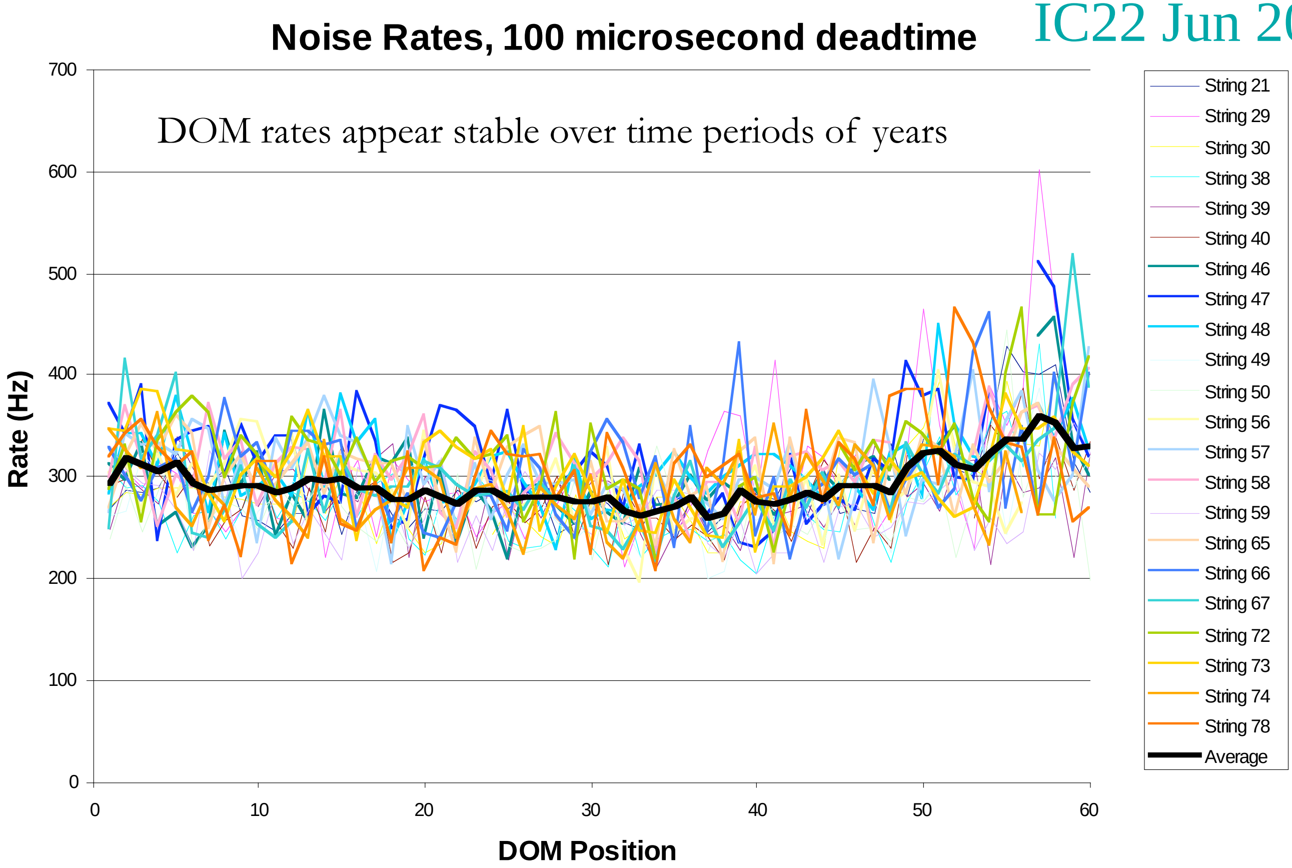
Scattering in Ice

IceCube new strings compared to string 48 (line)





IC22 Jun 2007 data

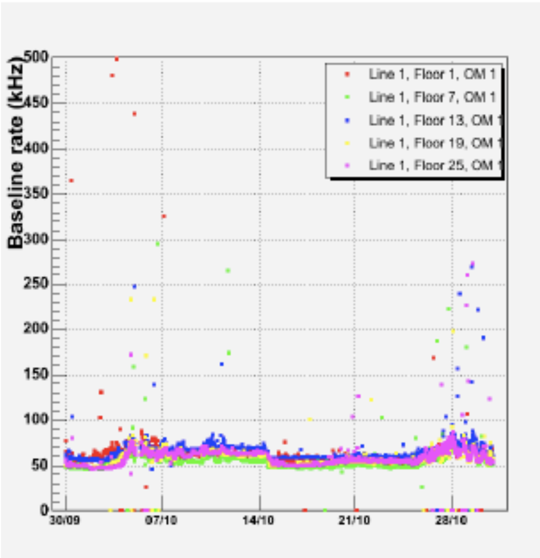


IC22 2007: muon rates 670 Hz, IC40 about 1.4 kHz

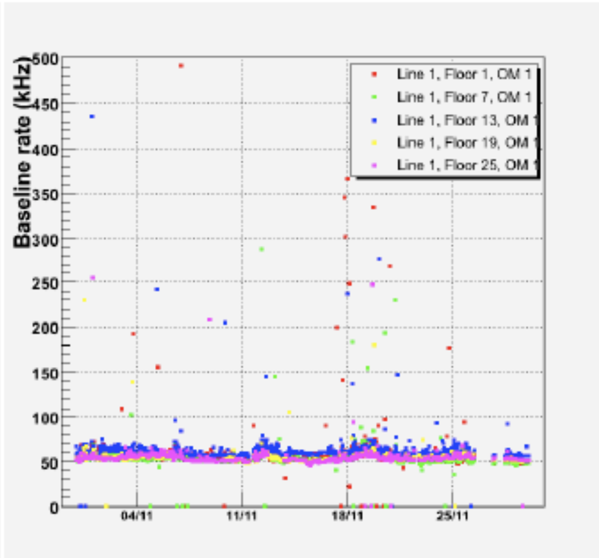
Target rate on satellite bandwidth : 30-40 Gb/d

Bio-luminescence
(rates in ANTARES)

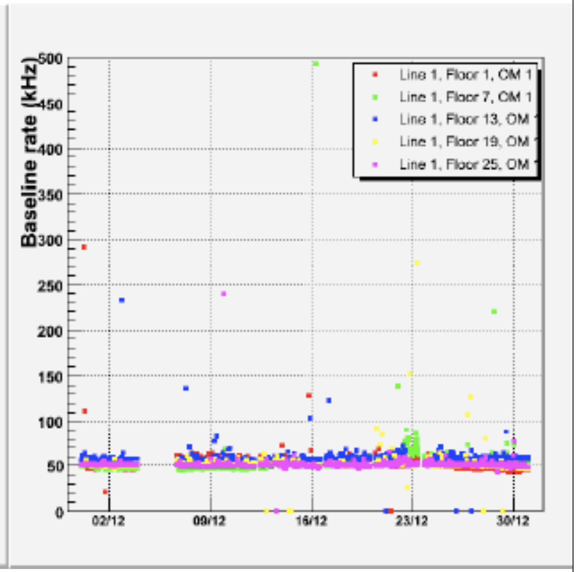
oct



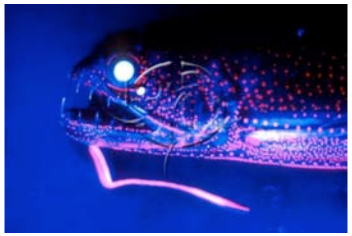
nov

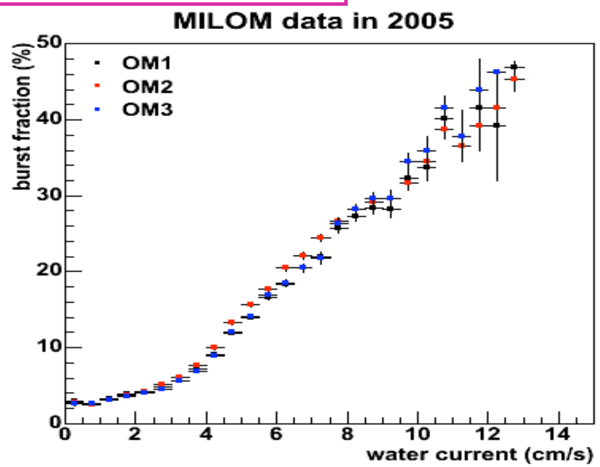


dec

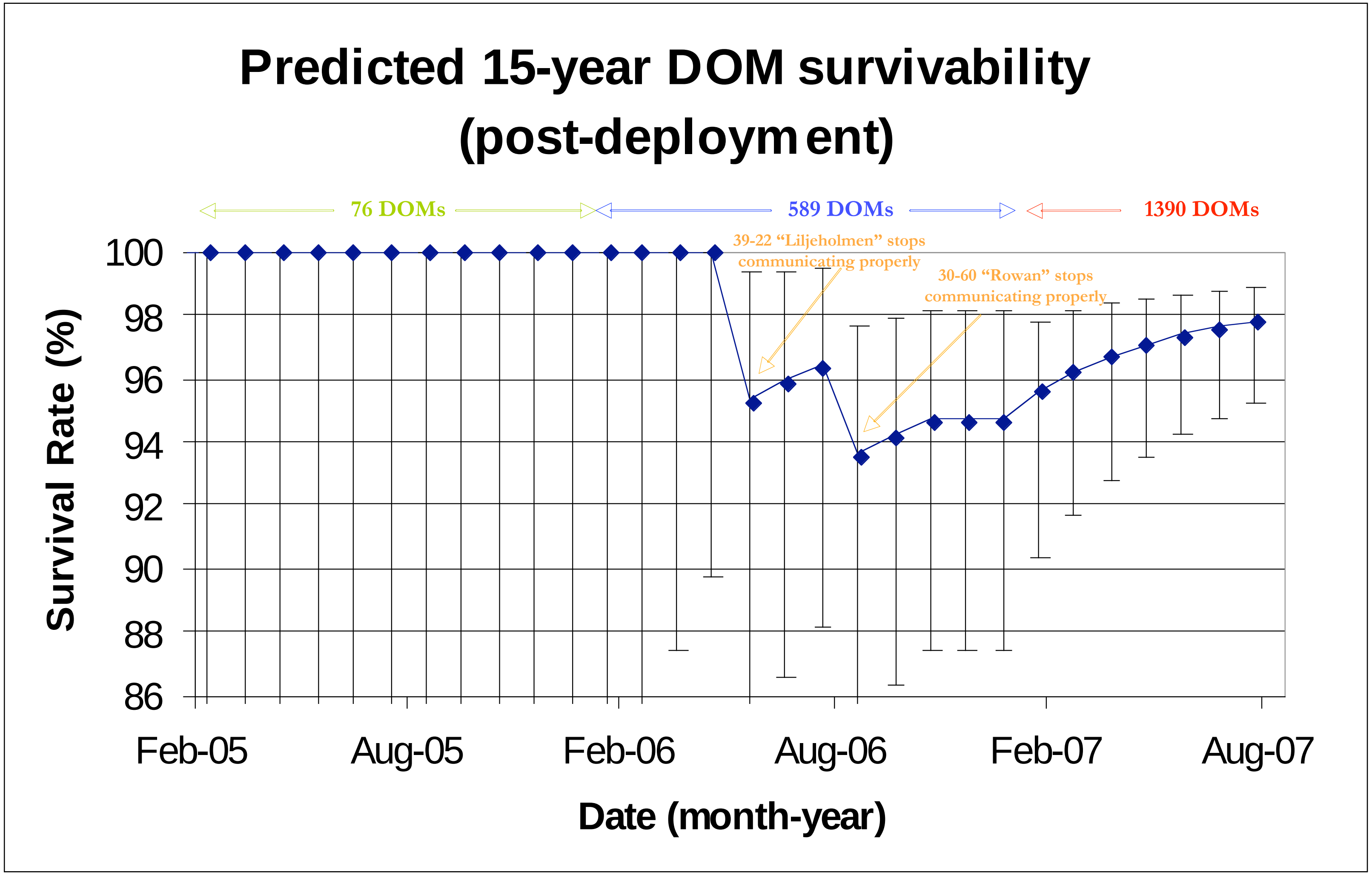


main contributions: ^{40}K decays + bioluminescence





Detector reliability

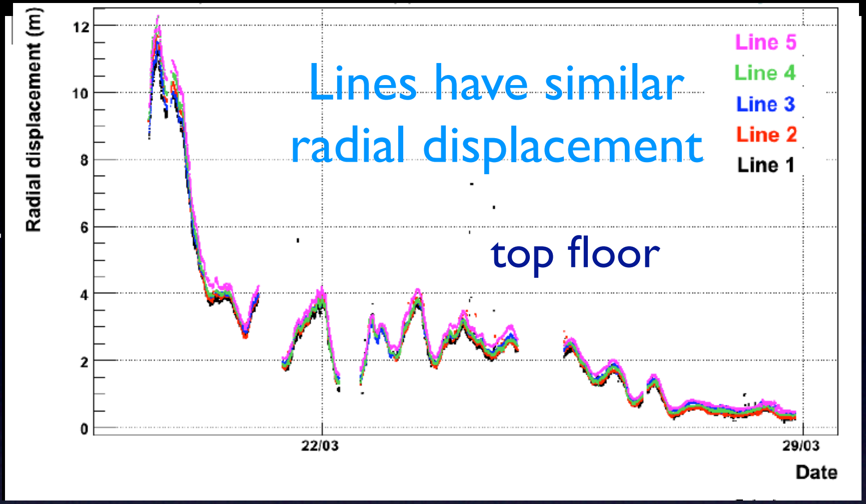


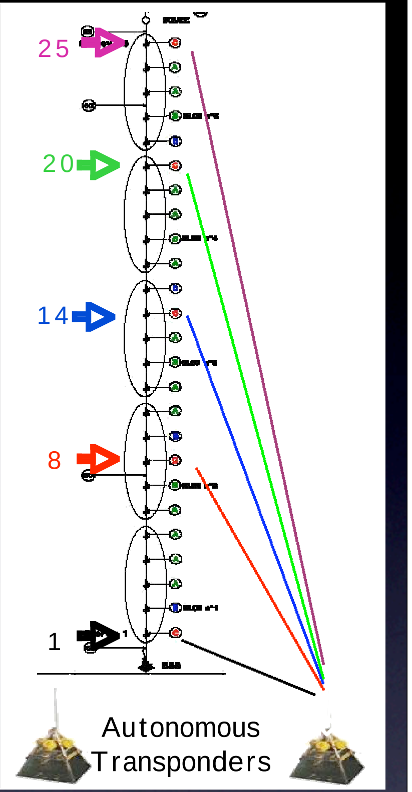
- Est. survival rate after 15 years: 97.5%
  - Estimate based on the assumption of a constant failure rate.

ANTARES 12% PMT not working

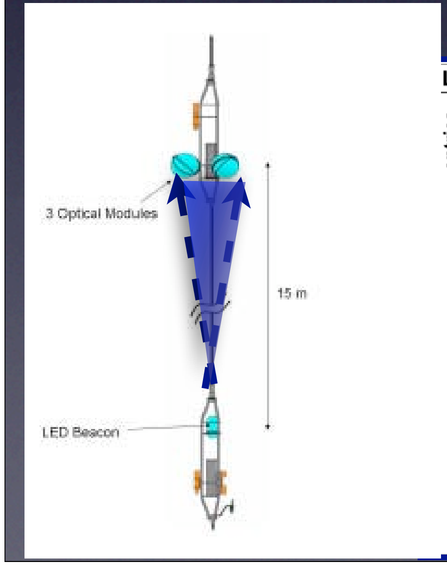
Calibrations in sea water

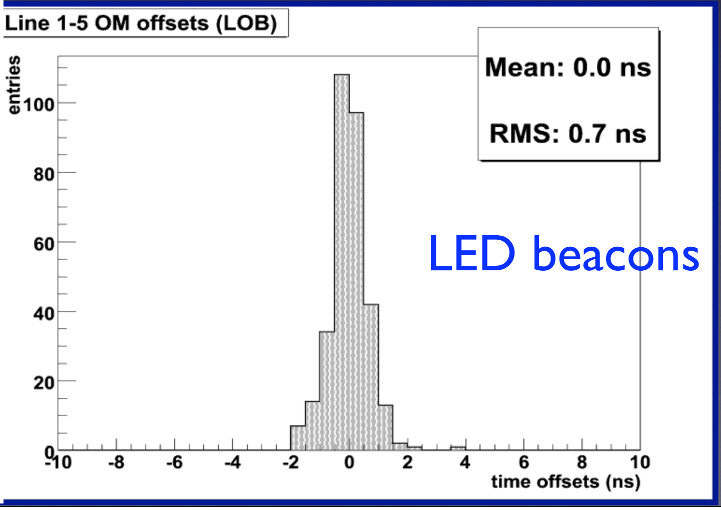
Lines move:
acoustic triangulation and tiltmiter-compasses reconstruct line shape





Measured position resolution < 10 cm





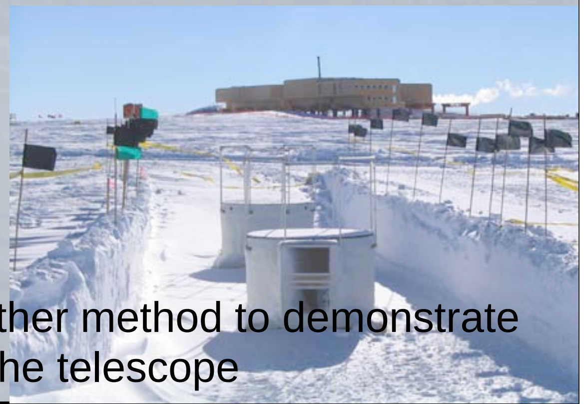
Electronics+calibration σ~0.5ns

TTS PMTs σ~1.3ns

Light scattering+chromatic dispersion σ~2ns

Angular resolution limitation ~ 0.2°-0.3°

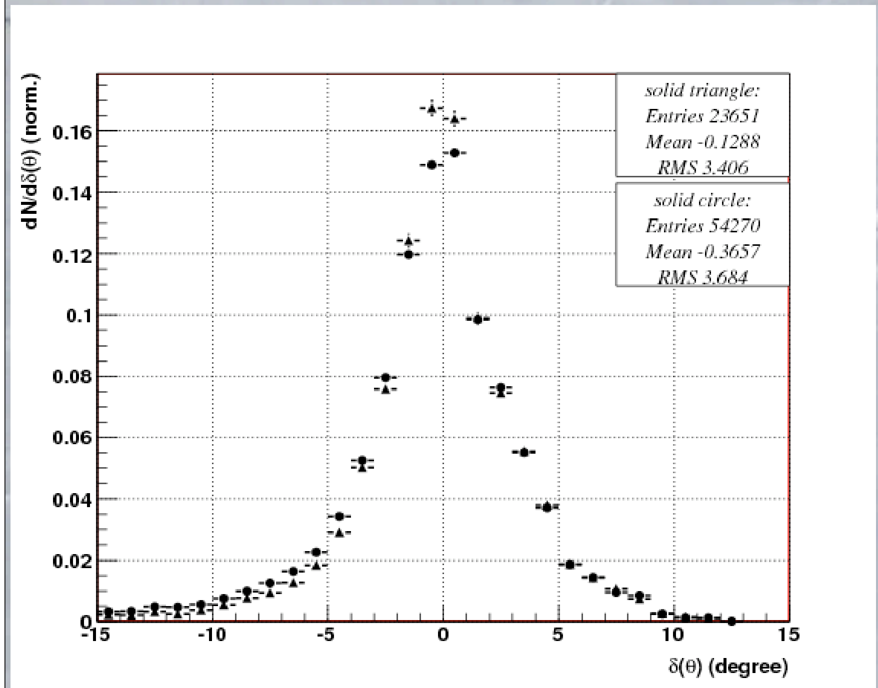
IceCube - IceTop coincident events



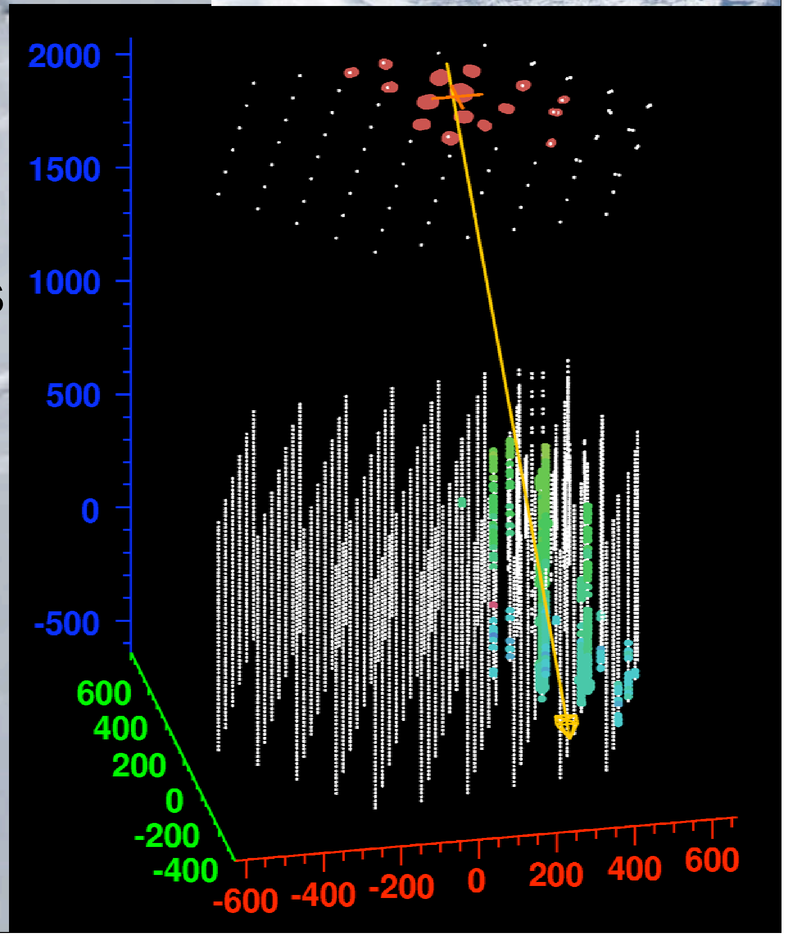
26 stations (52 tanks)

- Muon direction given by position of station and Center Of Gravity of InIce Signals.
- Comparison of InIce reconstruct-ion to “known” muon direction.

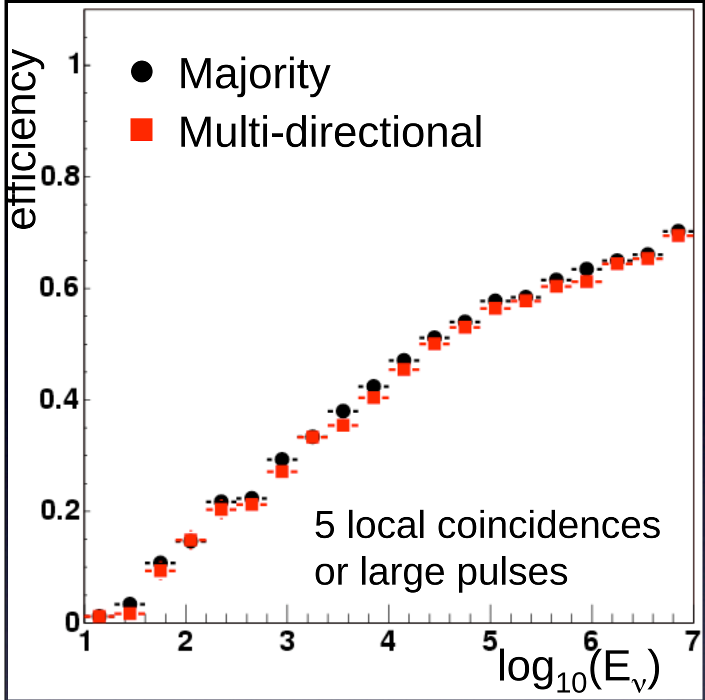
Moon shadow is another method to demonstrate absolute pointing of the telescope



6 μs



Trigger/hit filtering in sea water



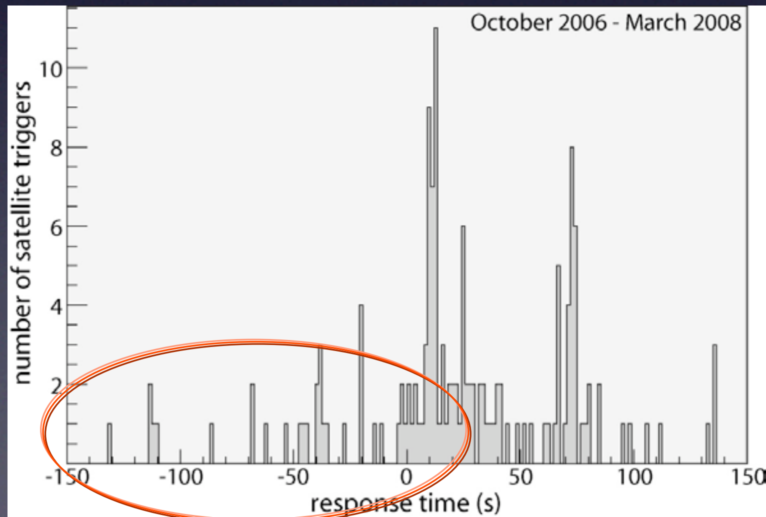
- L0: PMT hit above 1/3 p.e.
- L1: local coincidence (2 L0 in the OM triplet in Δt<20 ns) or a large pulse (> 3 p.e.)

TRIGGER:
- ≥ 5 L1
- causal connection between L1:

Trigger rate: ~1 Hz (5 lines)
~2-3 Hz (10 lines)

GRB trigger
data can be buffered

delay time of start of observation respect to astronomical event time



Out of 198 GCN triggers 176 have been handled by Antares DAQ

What science with these fluxes?

Astrophysics

- Extragalactic sources: AGN & GRBs
- Galactic sources: SNRs, pulsar wind nebulae, magnetars, micro-quasars, unidentified sources, galactic plane
- GZK neutrinos (CRs interacting with CMWB)
- SN collapse
- Large scale anisotropies with muons

Physics beyond the SM and Dark Matter

- Dark Matter: WIMPs, Monopoles
- cross sections at EeV energy
- test of Lorentz invariance and equivalence principle, cross sections at UHE

Standard particle physics and Hadronic interactions

- pion, K and charm physics at TeV energies in the Lab
- Neutrino oscillations
- Climatology with muons