Suche nach hochenergetischen Neutrinos im Baikalsee und im Südpoleis

Stefan Schlenstedt
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Astroteilchenphysik-Treffen Zeuthen, 5. Oktober

Themen

- Eigenschaften von Neutrino ☞ Vortrag M Lindner
- Hochenergetische Quellen von Neutrino ☞ Vortrag G Sigl

- Neutrino Teleskope - Prinzipien
- Die Detektoren Baikal, AMANDA und IceCube
- Eine Auswahl von Ergebnissen:
  - Messung der atmosphärischen Muon- und Neutrino-Flüsse
  - Suchen nach einem "diffusen" Überschuss von Neutrinos
  - Suche nach Punktquellen von Neutrinos
  - Suche nach Neutrinos von GRBs und AGNs
- Zusammenfassung

Neutrino astro-particle physics

- Cosmic rays with energies TeV (and above) observed
- 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:

- not deflected
- ‘not’ absorbed over cosmological distances and dense environment

can help to understand

- the origin of cosmic rays
- cosmic cataclysms
- own basic properties (xsec, 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

Observation of Neutrinos

Interaction cross section is small

$\sigma(\nu_\mu N) \approx 6.7\ 10^{-36}\ E\ [TeV]\ /cm^2/$ nucleon

$\Rightarrow$ interaction probability [H_2O, d=1km]:

$= N_A\ \sigma\ d\ \rho \approx 4\ 10^{-7}\ E\ [TeV]$

and sources are million to billion LYs away

- Requirement of a large neutrino interaction target →

Markov and Zheleznykh proposed the use of natural targets

Deep sea water and polar ice:

- huge (and inexpensive) targets for neutrino interaction
- good optical characteristics as Cherenkov radiators
- shielding from cosmic background

Expected astrophysical ν Rates

Diffuse sources

Guaranteed (GZK): few / year ?

Diffuse GRB: 20 / year

Waxman

Diffuse AGN (thin): few / year

Mannheim

(thick): >100 / year

Point sources

GRB: 1÷10 / burst

AGN: few / y

Waxman

Galactic SNR (Crab): few / year ?

Dermer

Protheroe

Galactic microquasars: 1 ÷ 100 / y

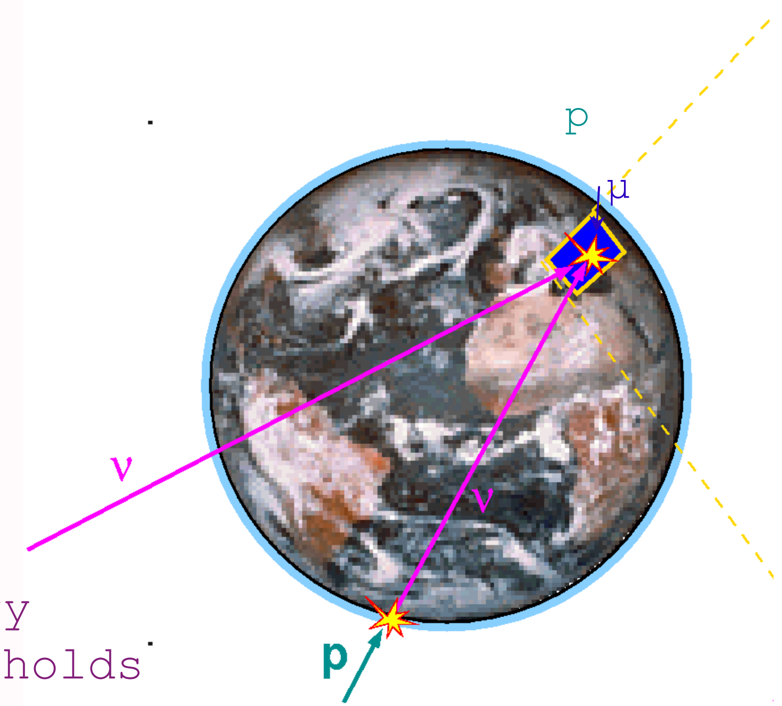
Distefano

per km^2

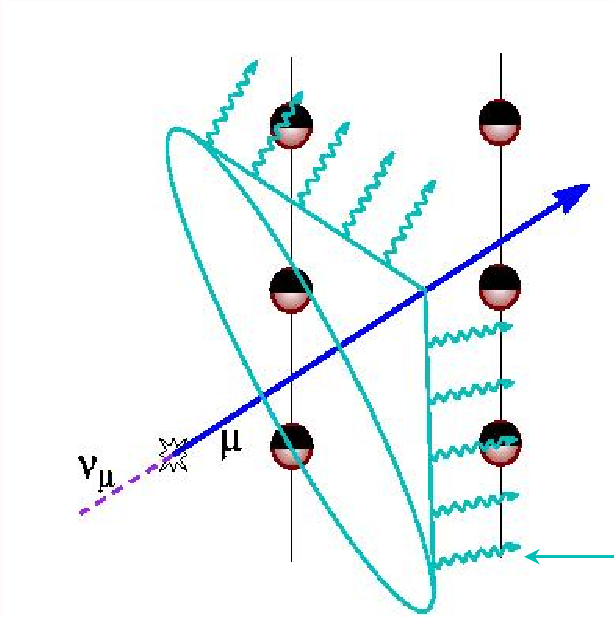
Rate of expected events from diffuse fluxes or point sources is small and has big uncertainties

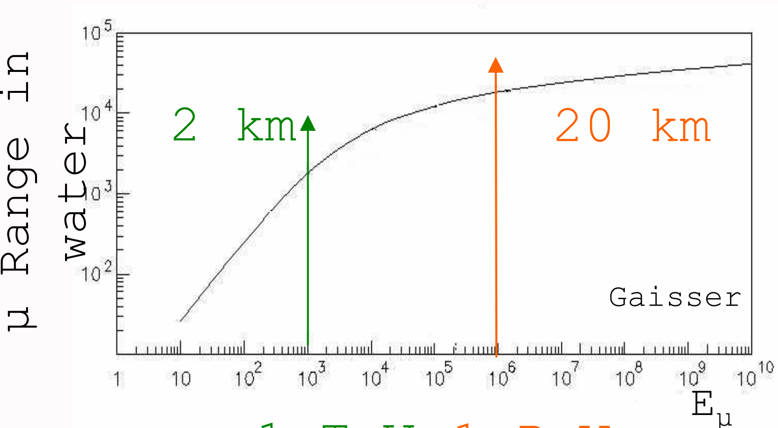
Principles of Neutrino Telescopes

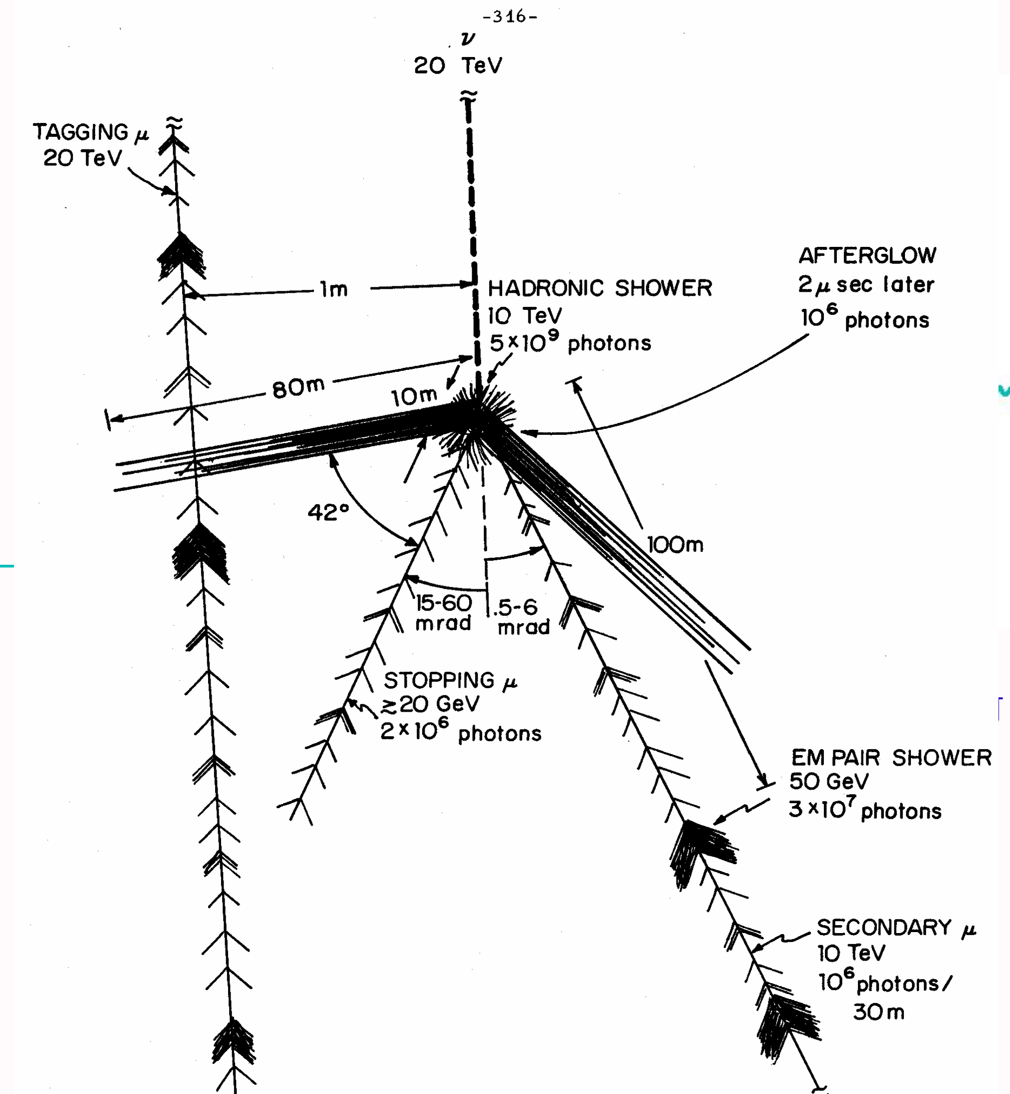
- Earth screens detectors against particles except neutrinos
- rare ν interactions ⇒ big natural volume
- atmosphere: cupios production of muons ⇒ go under'ground'



Event Types







Proc. Dumand Summer Workshop 1976

Dominant backgrounds:
- mis-identified atmospheric muons (down/up ~ million)
- after clean-up: atmospheric neutrinos (flux uncertainty)

Cherenkov Track Reconstruction

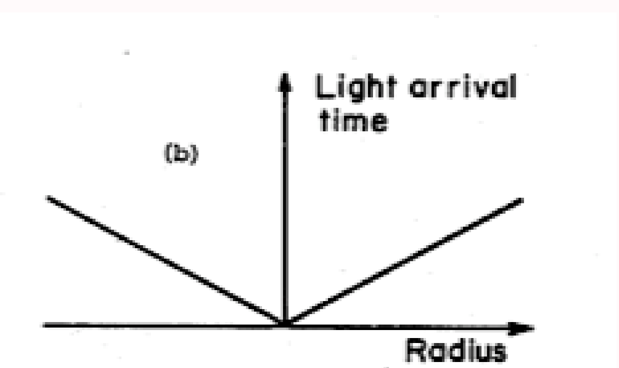
The challenge:

reconstruct energy and direction of particle tracks using
- light intensity
- arrival time

Cherenkov photons emitted by the muon track are correlated by the space-time causality relation:

$$c(t_j - t_0) = l_j + d_j \cot(\theta_c)$$

of the PMT signals (hits)



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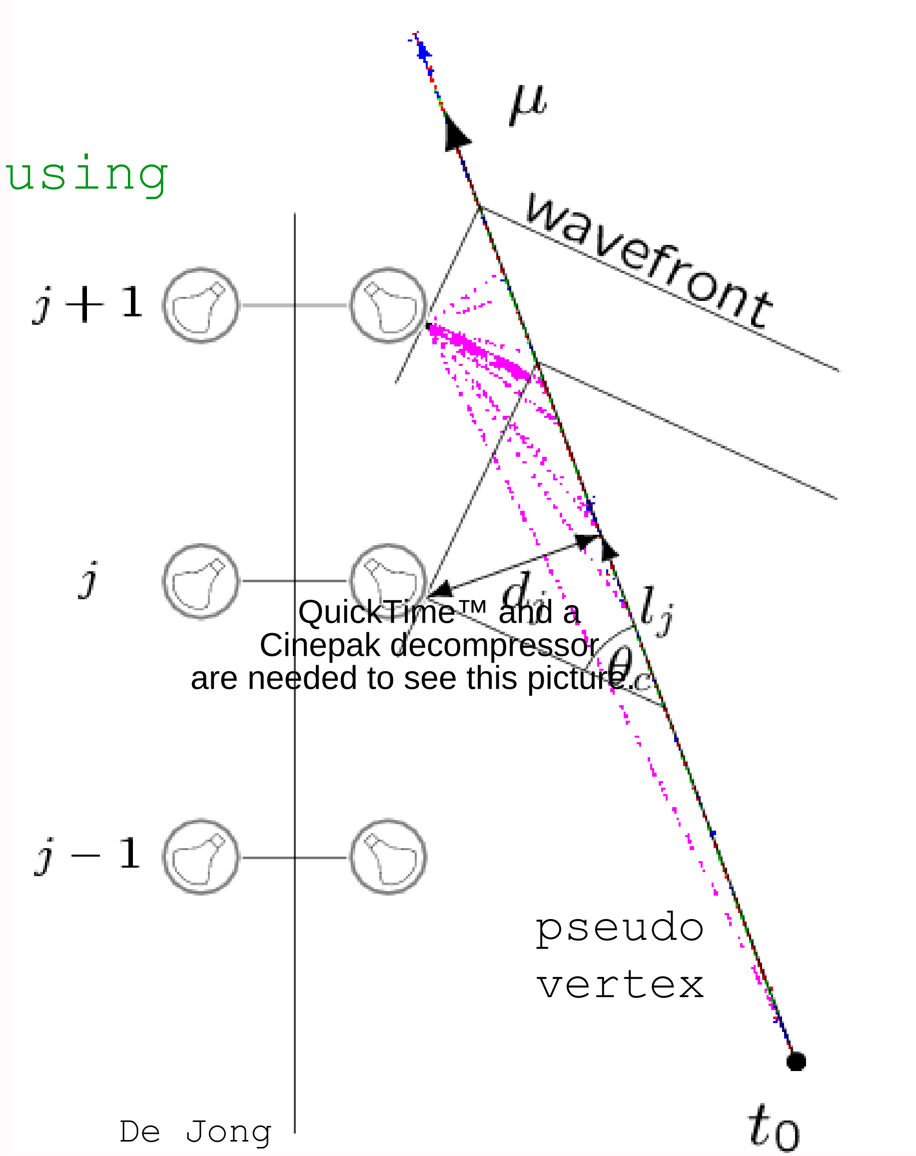
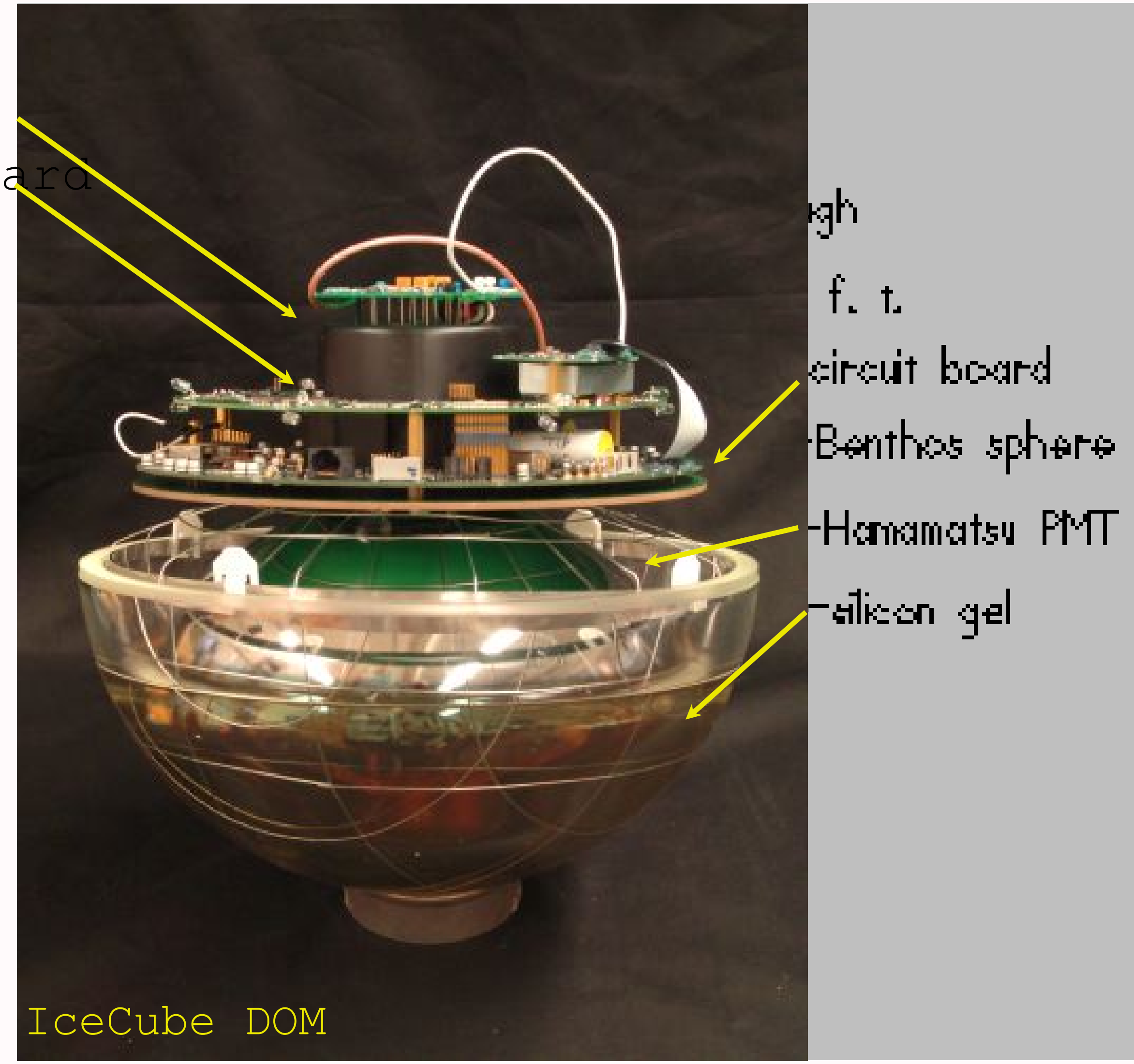


Optical Module

HV supply
flasher board

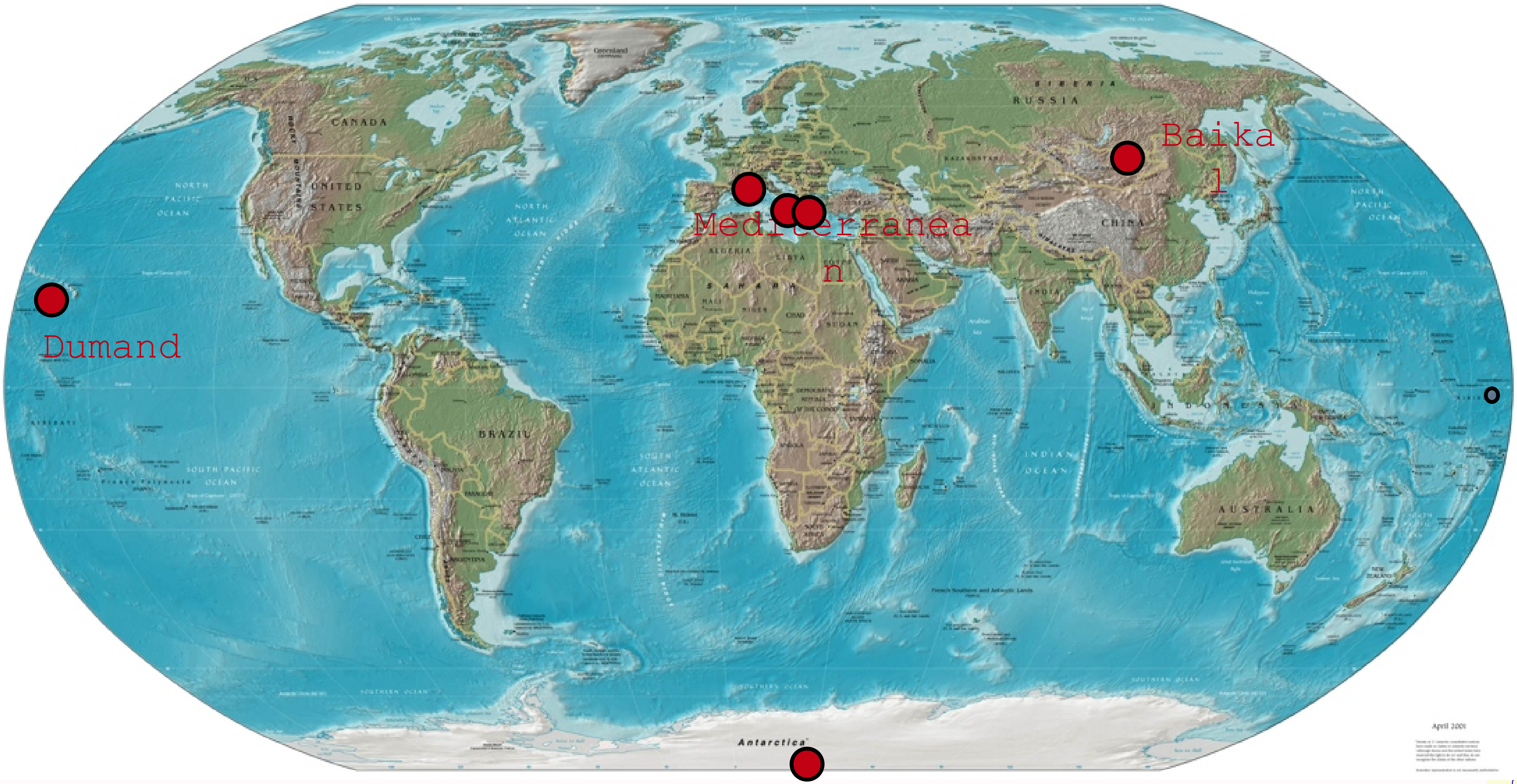
photomultipler housing:
precursor for
Amanda,
Antares...

without Benthos
spheres,
similar for IMB,
Kamioka
and Super-K



Proc. Dumand Summer Workshop 1976

From DUMAND to the Future



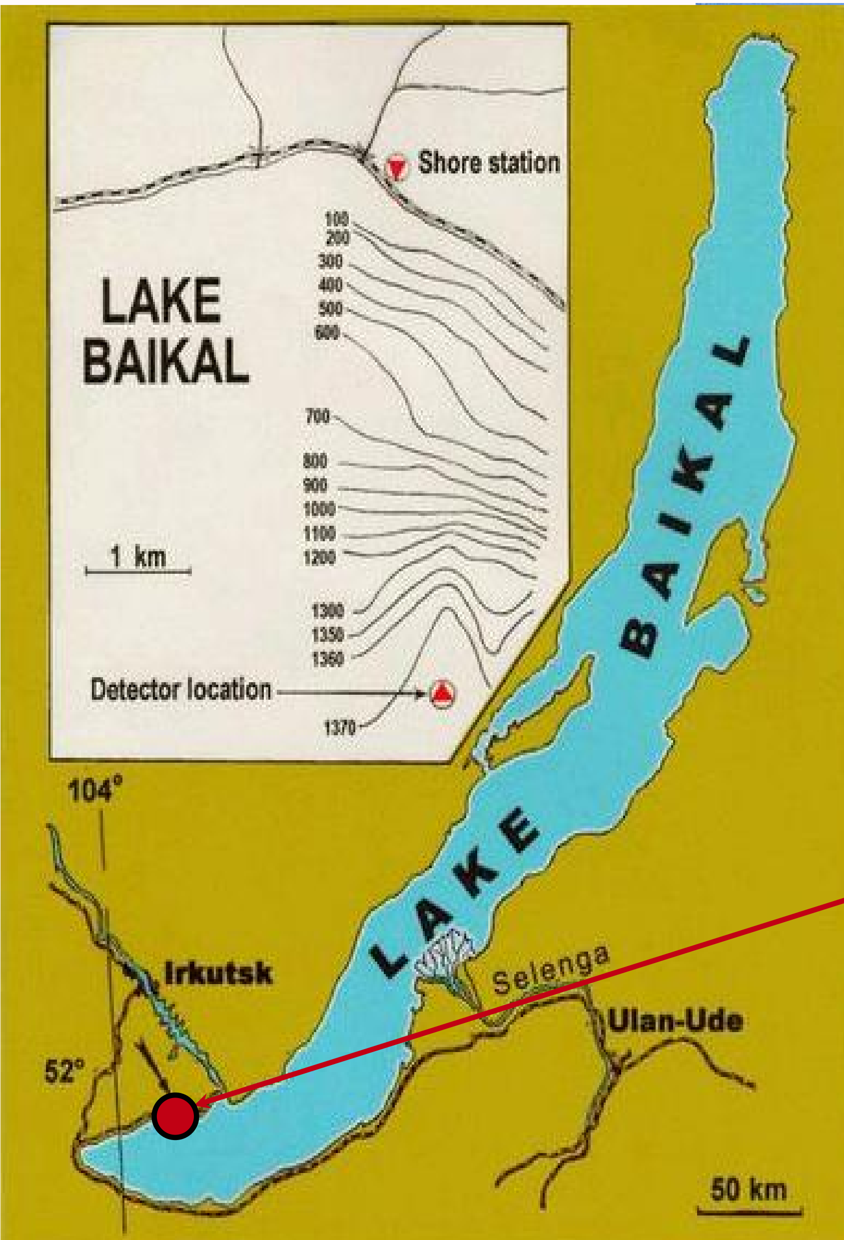
The Case for more than one Telescope

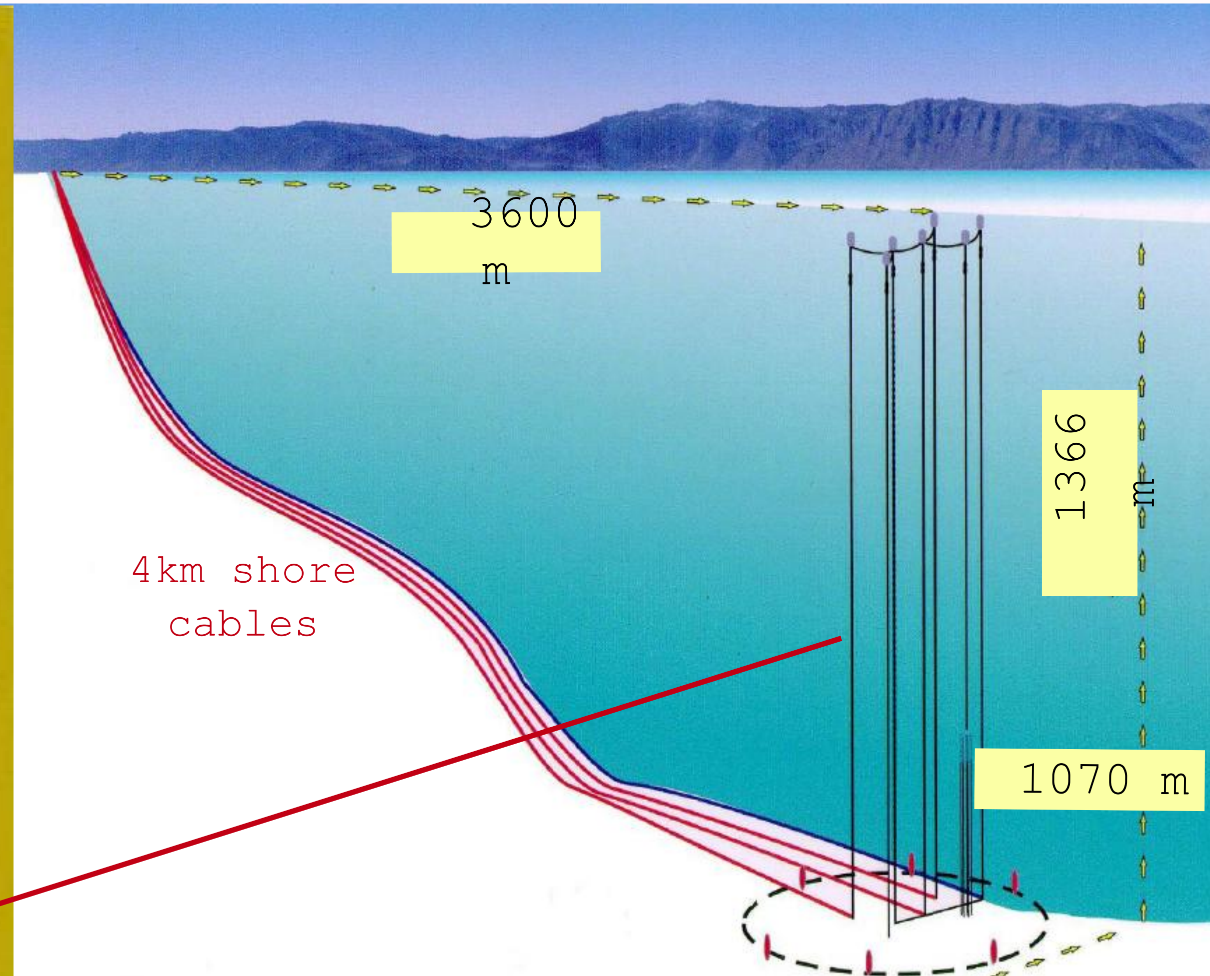
Ba

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

The Baikal Detector

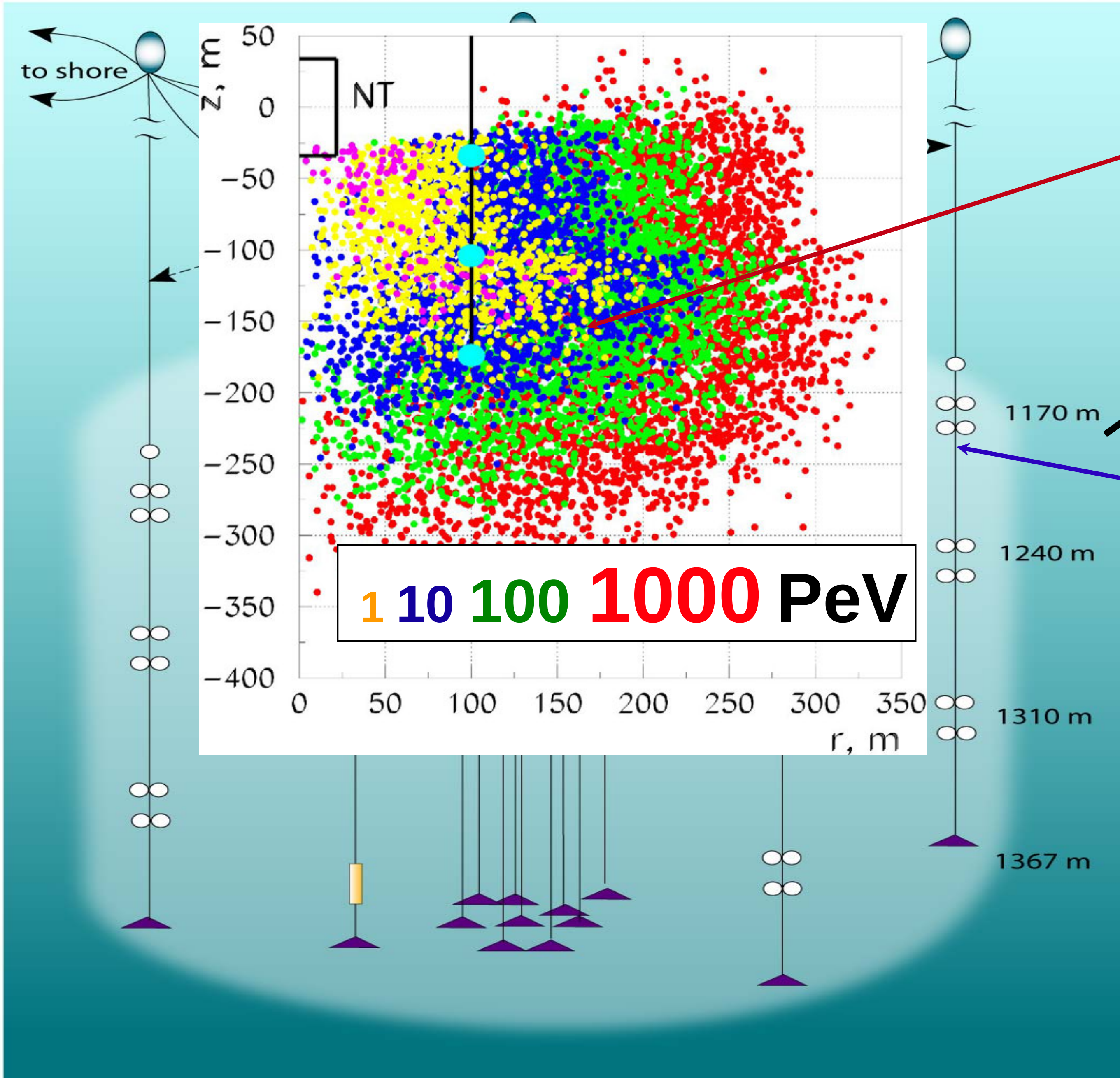
NT-200: 192 PMTs on 8 strings, commisioned in 1998





First underwater array: μ reconstruction, first ν events, verify BG-suppression, check MC/Water/..

Upgrade to NT200+ in 2005



NT200:

192 optical modules
- pair-wise coincidence
→ 96 space points

Height = 70m ∅ = 40m

New NT200+

adding three new strings with 36 PMTs → improve sensitivity by factor 4 to cascades with sparse additional instrumentation

NT200+ might be a step ("prototype") towards a Baikal-km^3 : 91 strings with 1308 OMs

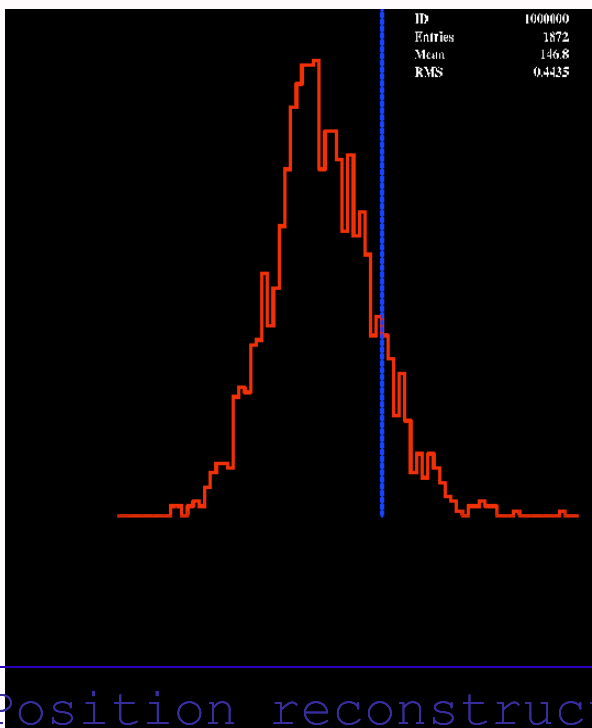
First Signs of Life in NT200+

New laser: imitation of 10...500 PeV cascades, $>10^{13}$ photons/pulse

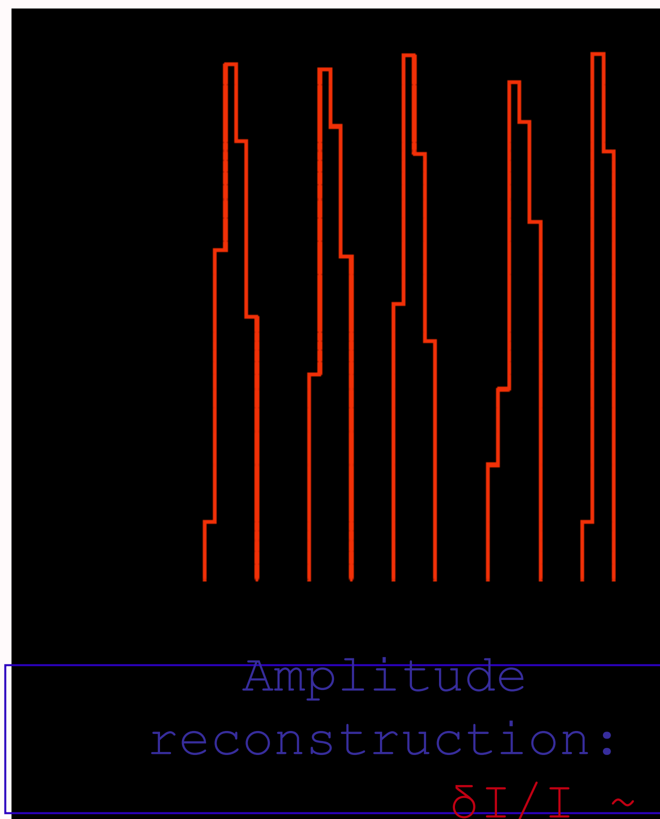
Very preliminary

ifferences NT200 to outer string measured: jitter has rms 3ns

time synchronization (3 lasers, atmospheric μ, L

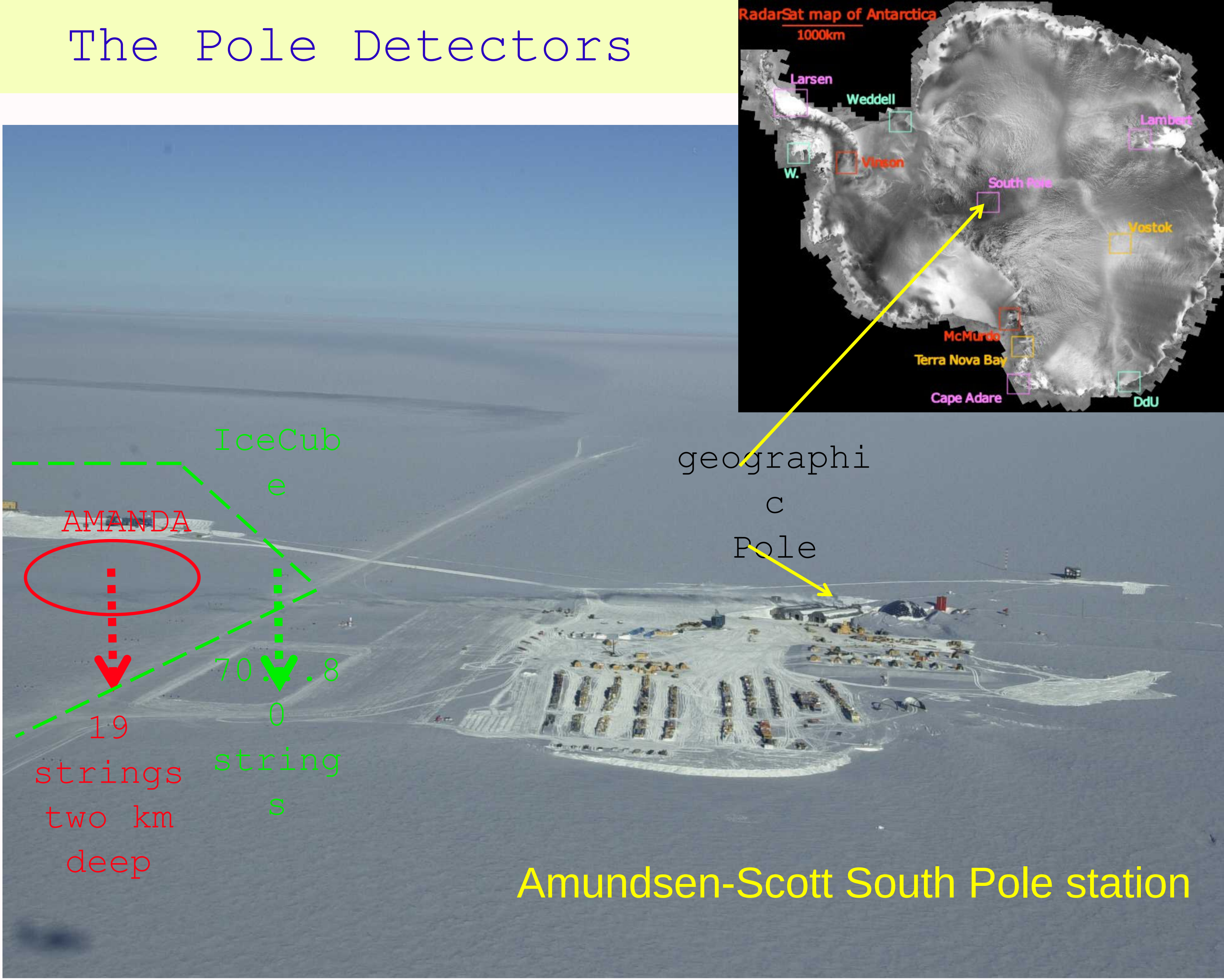


Position reconstruction (arrival times): δr < 1 m

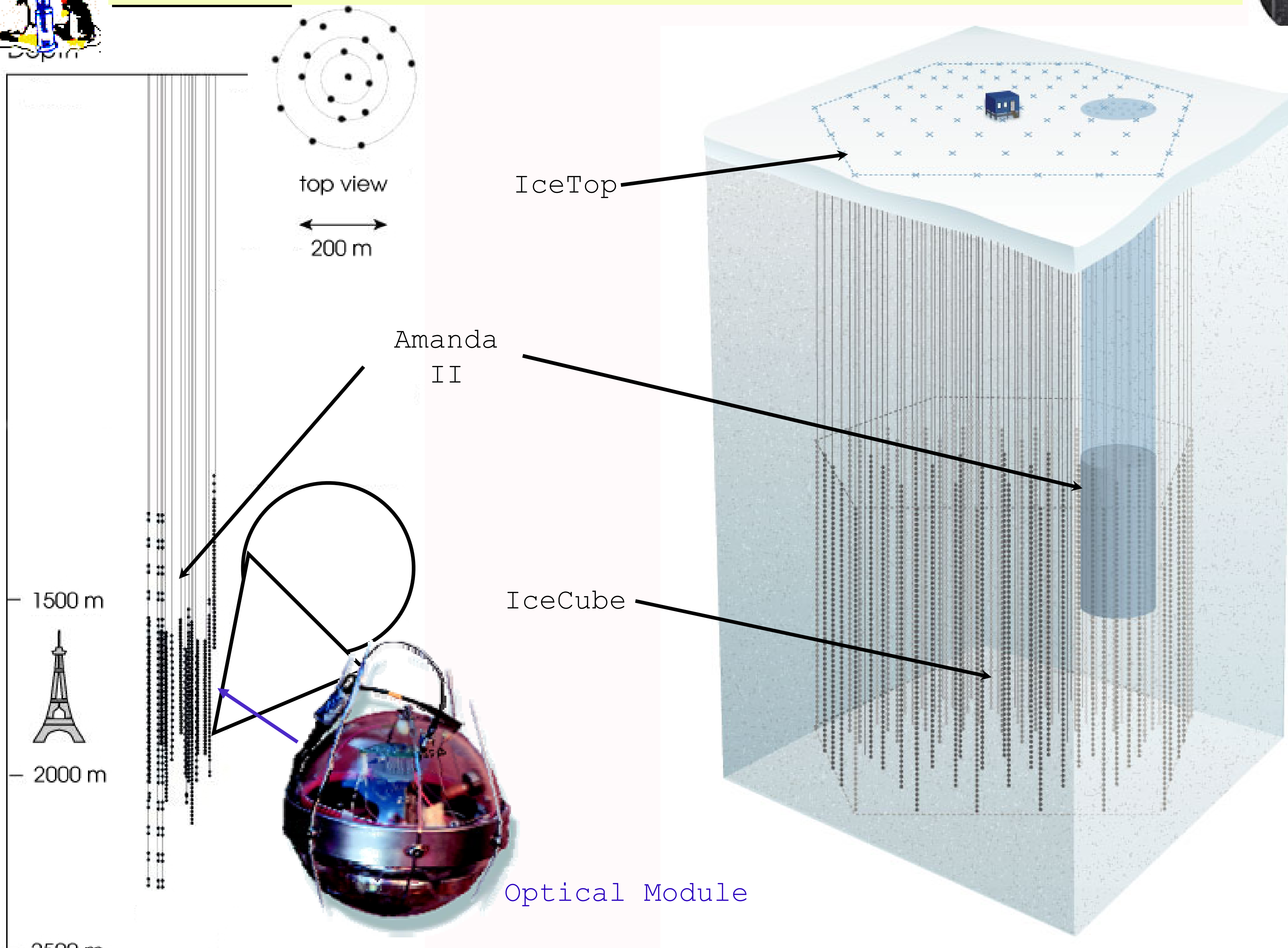


Amplitude reconstruction: δI/I ~ 6%

The Pole Detectors

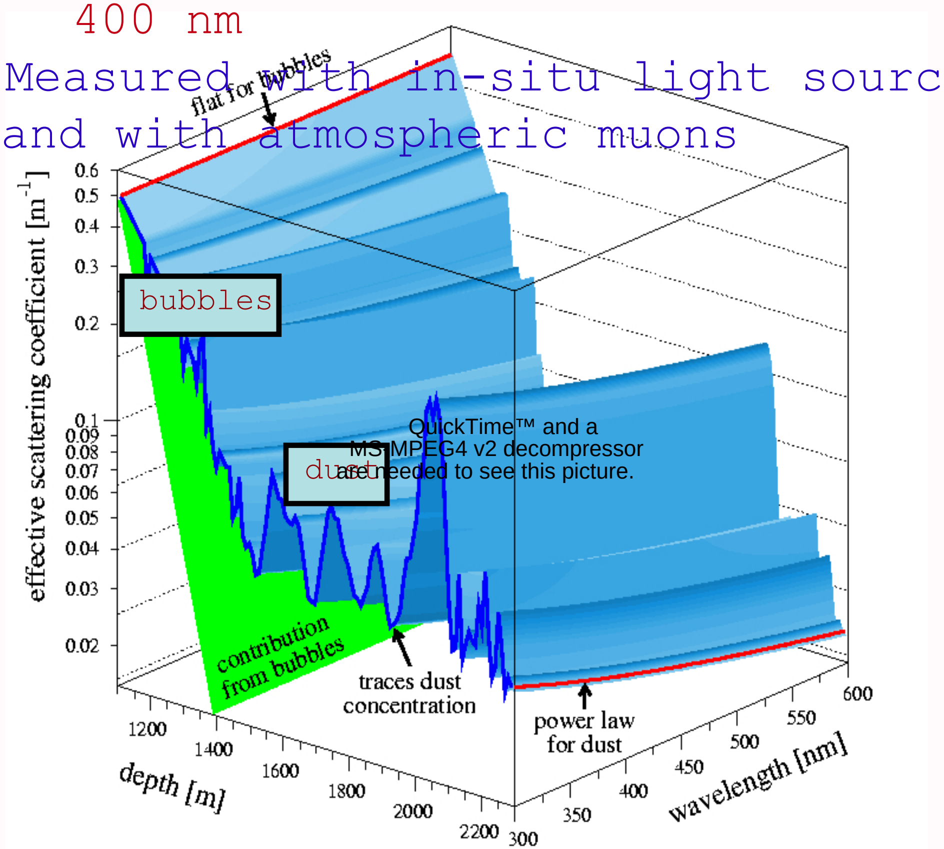


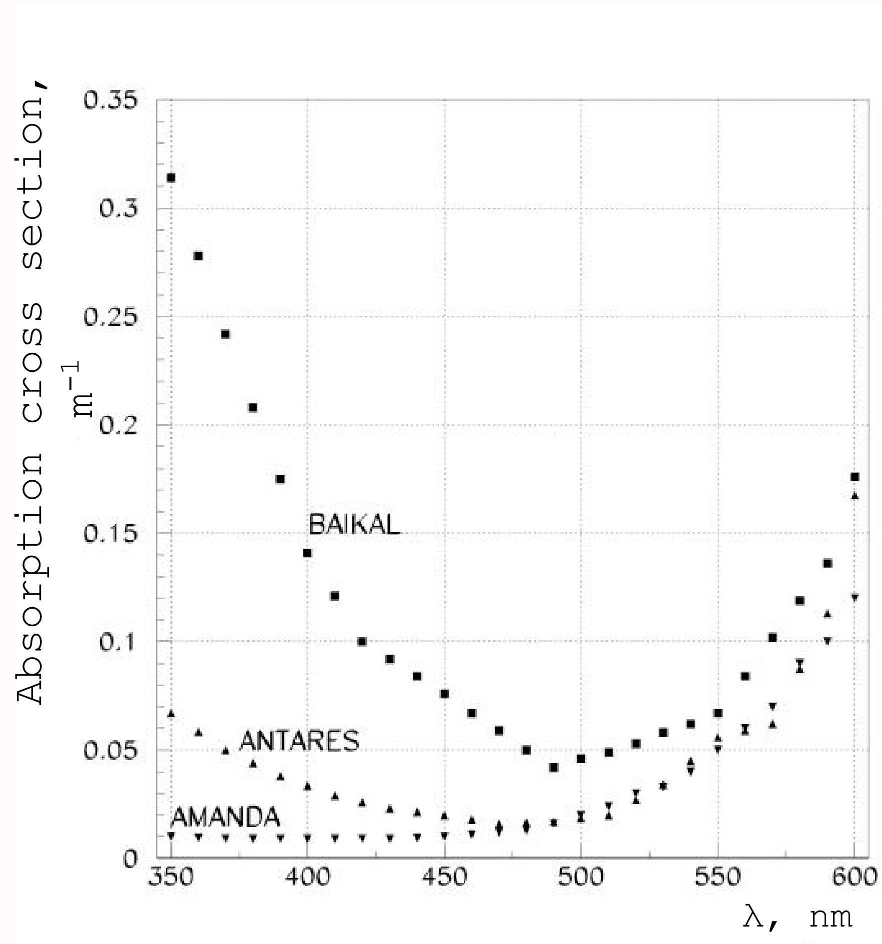
The Detectors



Understanding the Medium

- *South Pole ice at AMANDA depths :*
- Very transparent with a depth and wavelength dependence – average values
  - Absorption length ~ 110 m at 400 nm
  - Scattering length ~ 20 m at 400 nm
- Measured with in-situ light sources and with atmospheric muons





Scatt. Length Baikal ~ 30-50 m

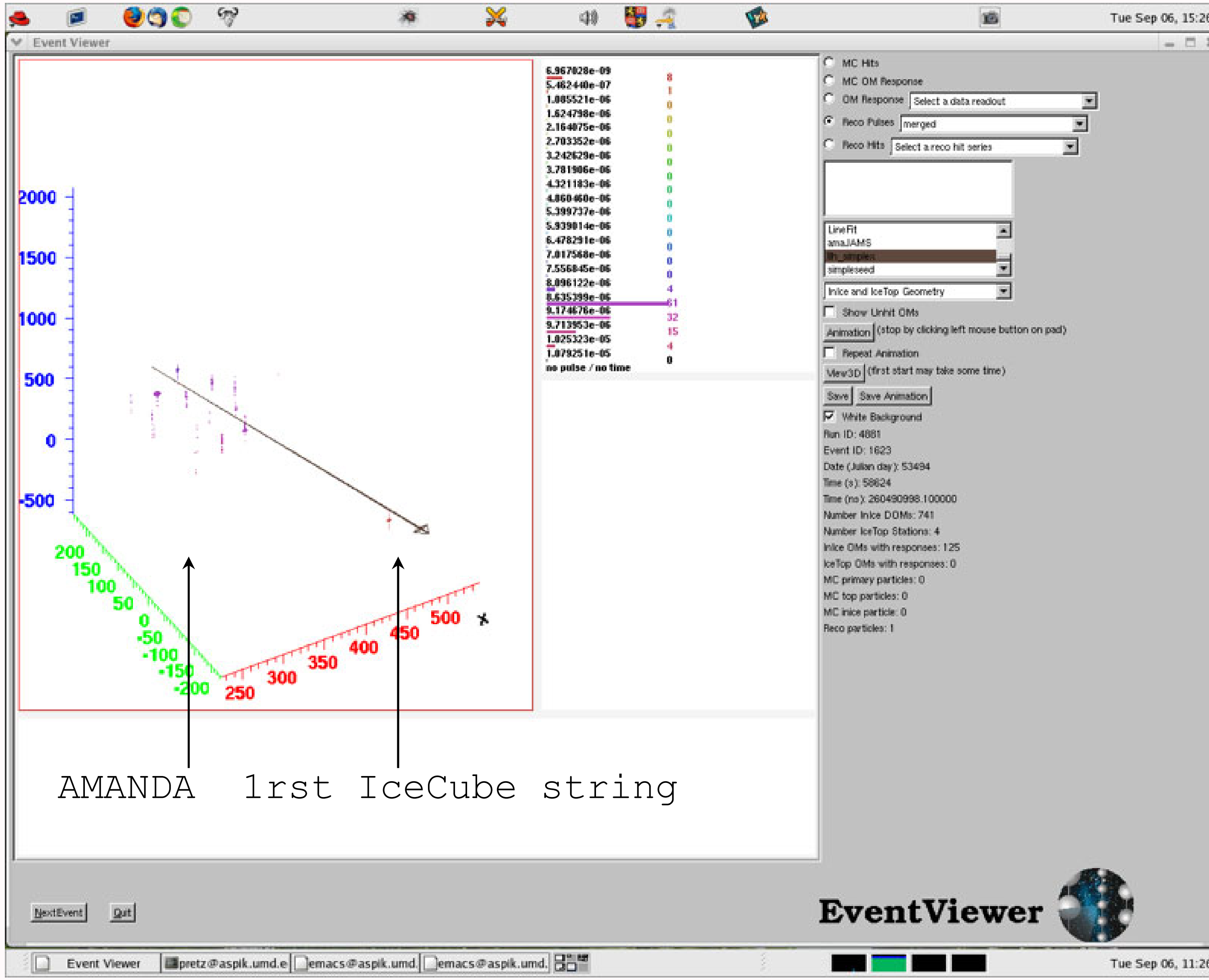
IceCube under Construction

- Full NSF funding since February 2004 for 12 US groups
- Belgium (4 groups), Sweden (2), Japan (1), NewZealand (1),
  Netherlands (1), German unversities (4) and DESY

- Deployment of 4200+ Digital Optical Modules on 70+ strings and 140+ DOMs in 70+ IceTop stations until 2010
- Installed in January 2005: one string with the full chain from DOM to surface electronics, event builder, trigger, data handling, data verification, reconstruction, analysis
- This season →2006: ~10 strings
- AMANDA will be integrated

The first Events

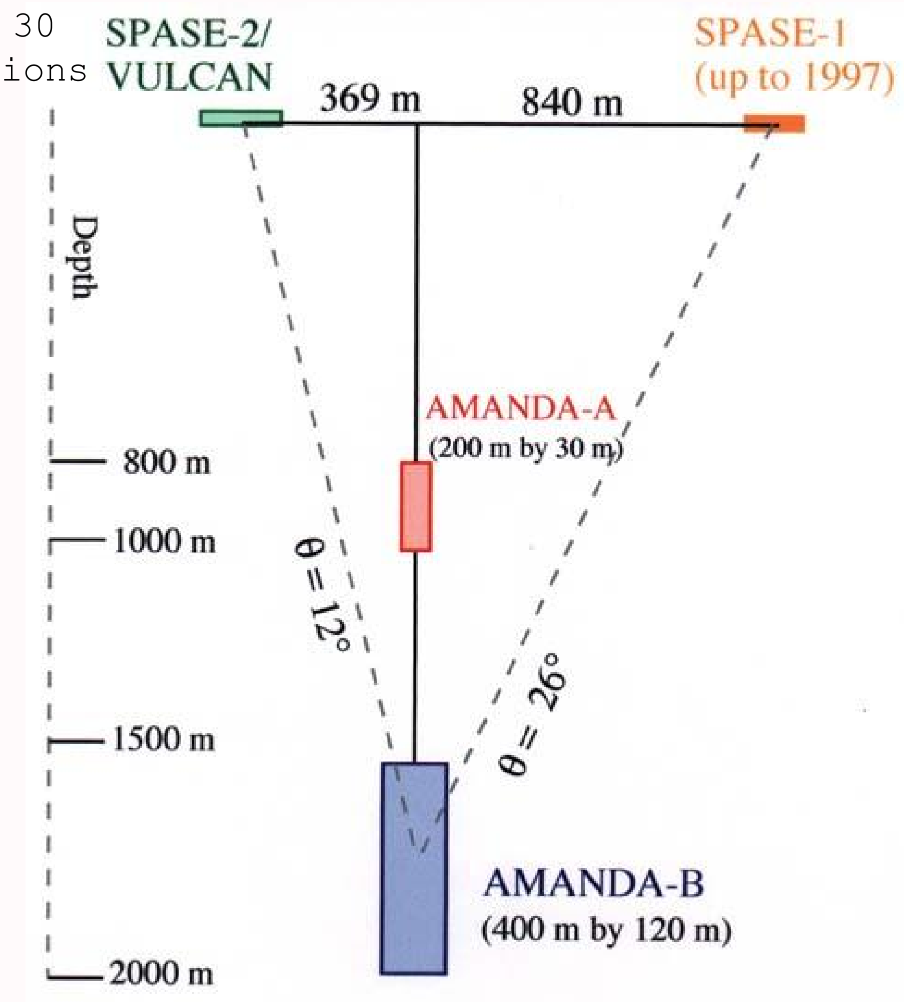
QuickTime™ and a
GIF decompressor
are needed to see this picture.



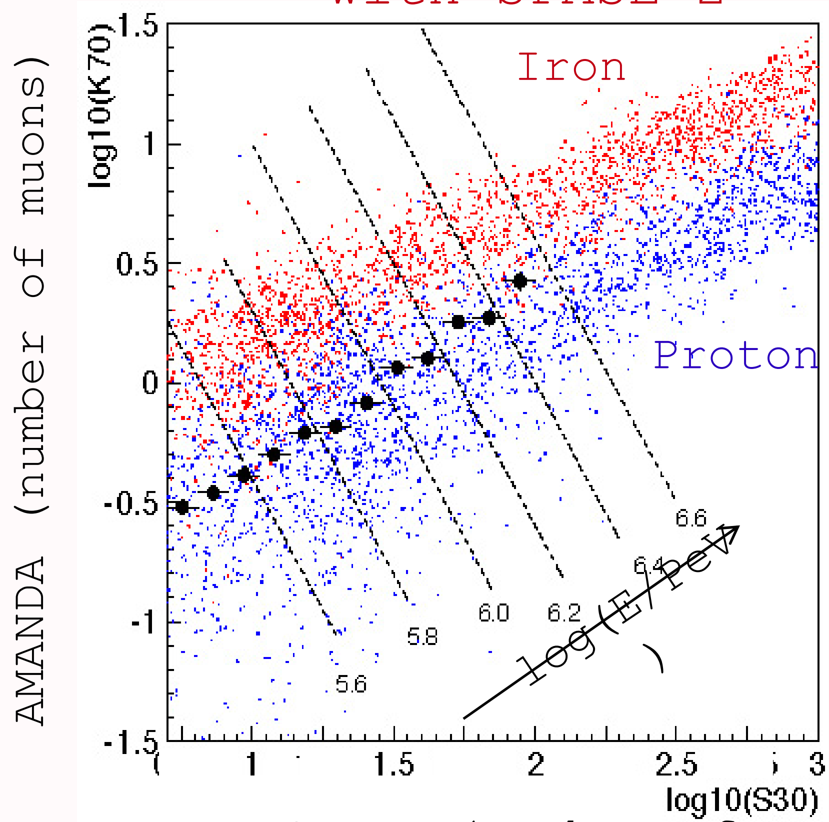
Cosmic Ray Composition

What is coming from the cosmos?

30m grid
of 30
stations



Unique
combination
with SPASE-2

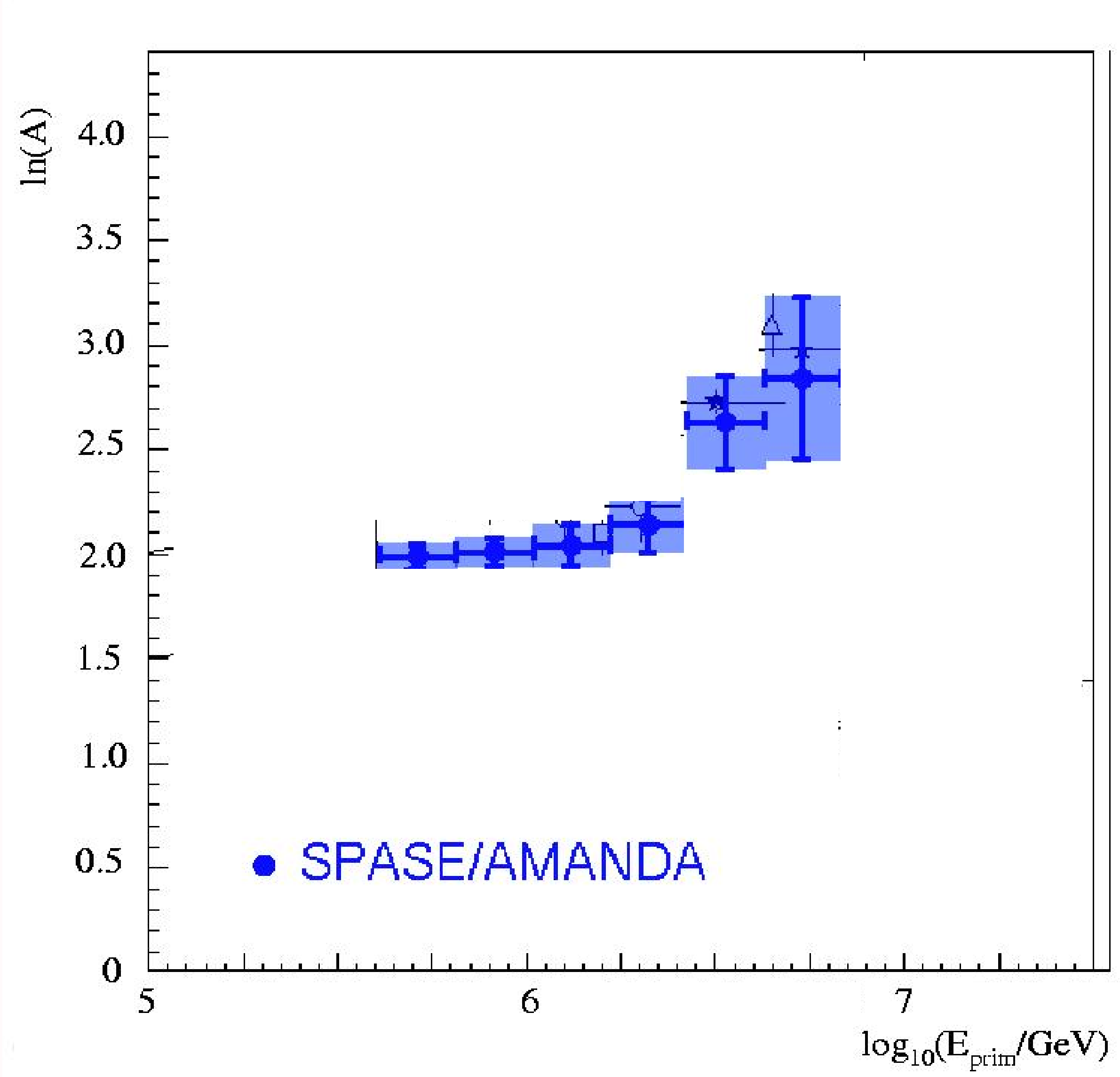


Spase (number of
electrons)

Cosmic Ray Composition

- resolution ~7% in $E_{primary}$
- mean ln(A) normalized to direct measurements (normalization bin not shown)

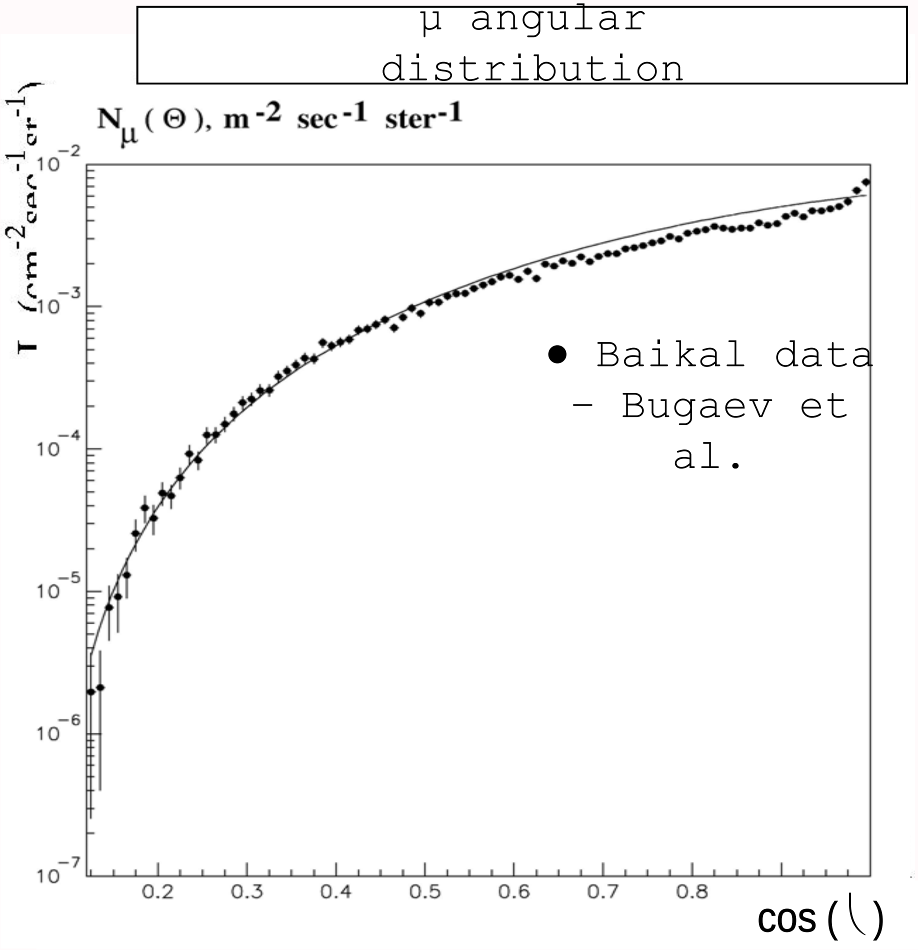
Cosmic ray spectrum becomes heavier around the knee

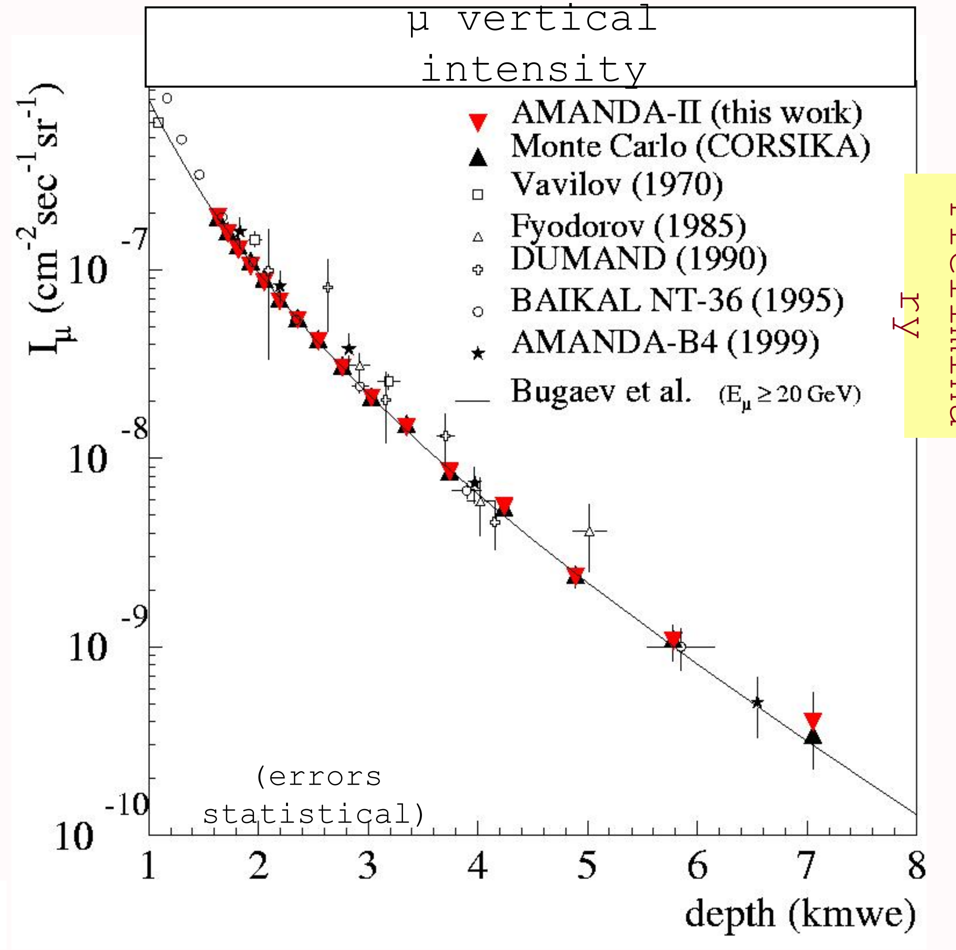


1998 data set

Measurement of atmospheric Muons

Unfold a clean data set of ten hours of 2000 data: δθ=2.4°...1.5°



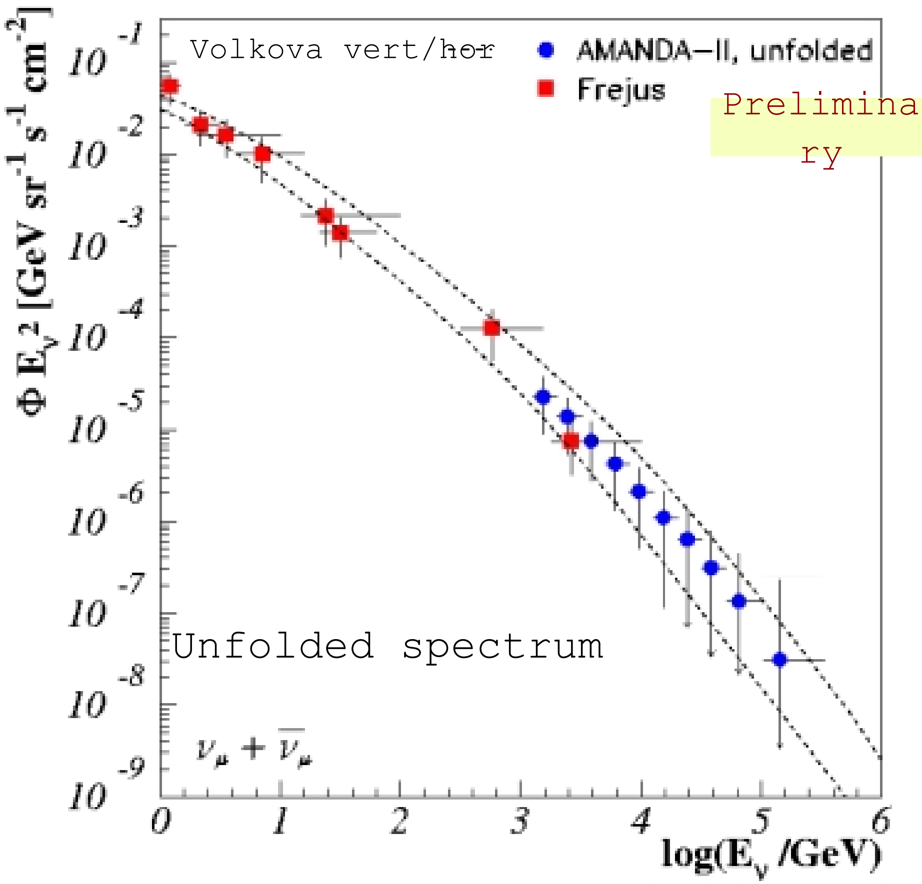


Data exceed theoretical calculation by 30...50%
(theory and true simulated distributions agree)

Atmospheric Neutrinos

Test beam of neutrinos (and background)

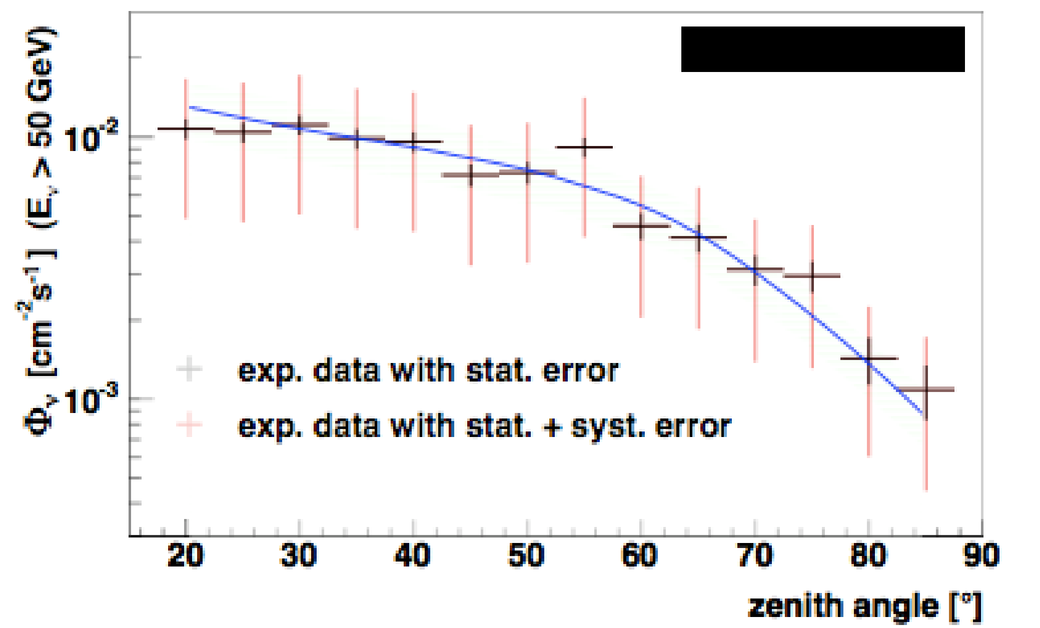
rch for extra-terrestrial comp



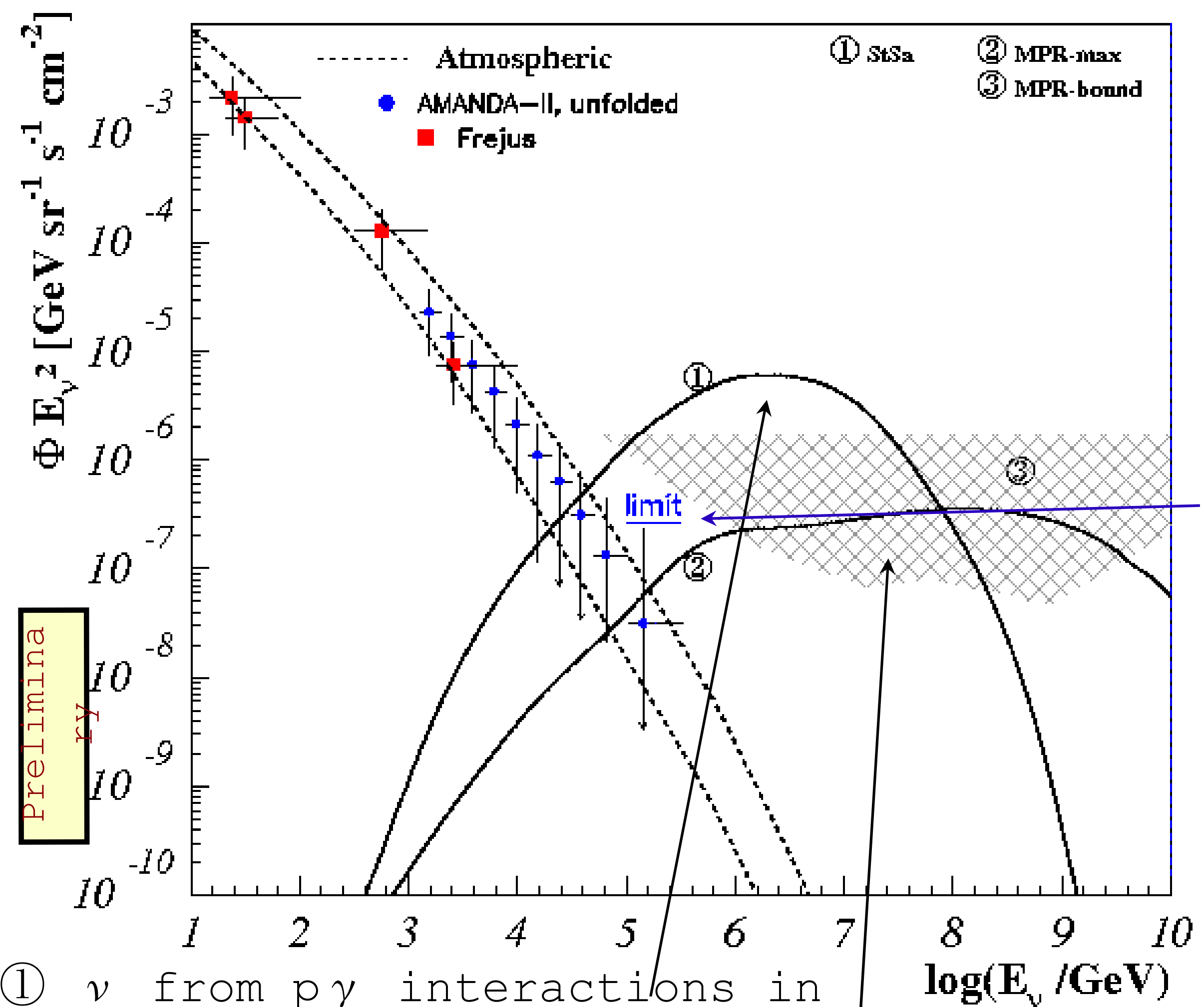
First spectrum above 3 TeV matches lower-energy Frejus data

Search for neutrino oscillation

Full simulation of atmospheric neutrino flux (Lipari), muon propagation through earth and ice including oscillation



Search for diffuse Neutrino Source



Use the unfolded atmospheric neutrino spectrum

How much E^{-2} cosmic ν signal allowed within uncertainty?

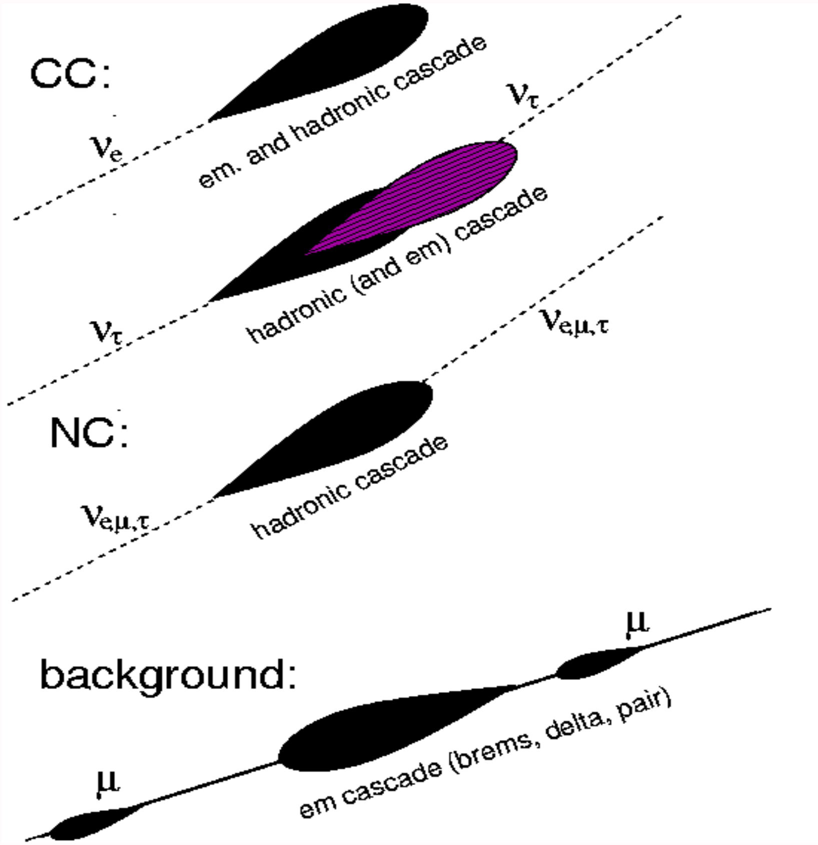
① ν from p γ interactions in AGN cores
②, ③ ν from p γ interactions from blazars

Set limit on diffuse E^{-2} ν_μ flux (100-300 TeV):

$$E^2 \Phi_{\nu_\mu}(E) < 2.6 \cdot 10^{-7} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

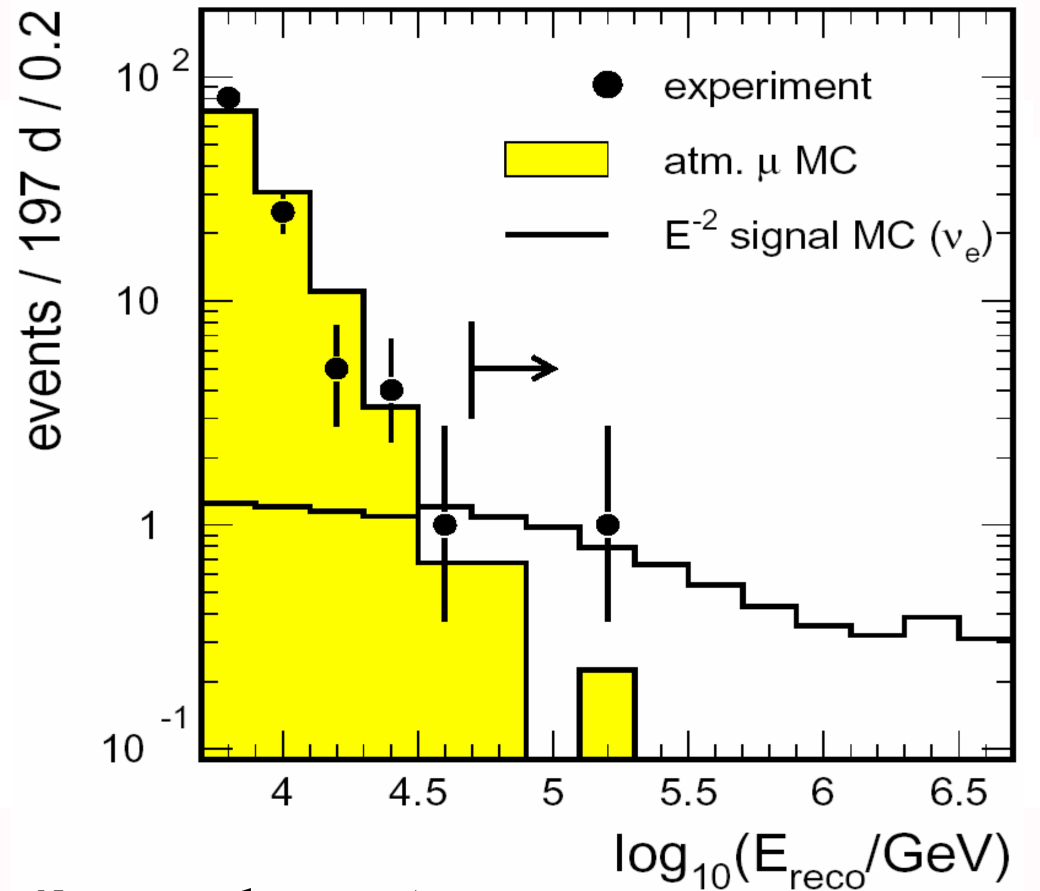
Search for Neutrinos of all Flavours

Electromagnetic and hadronic cascades



τ neutrino regeneration (double structure) will be visible in IceCube

Sensitivity to all three flavours



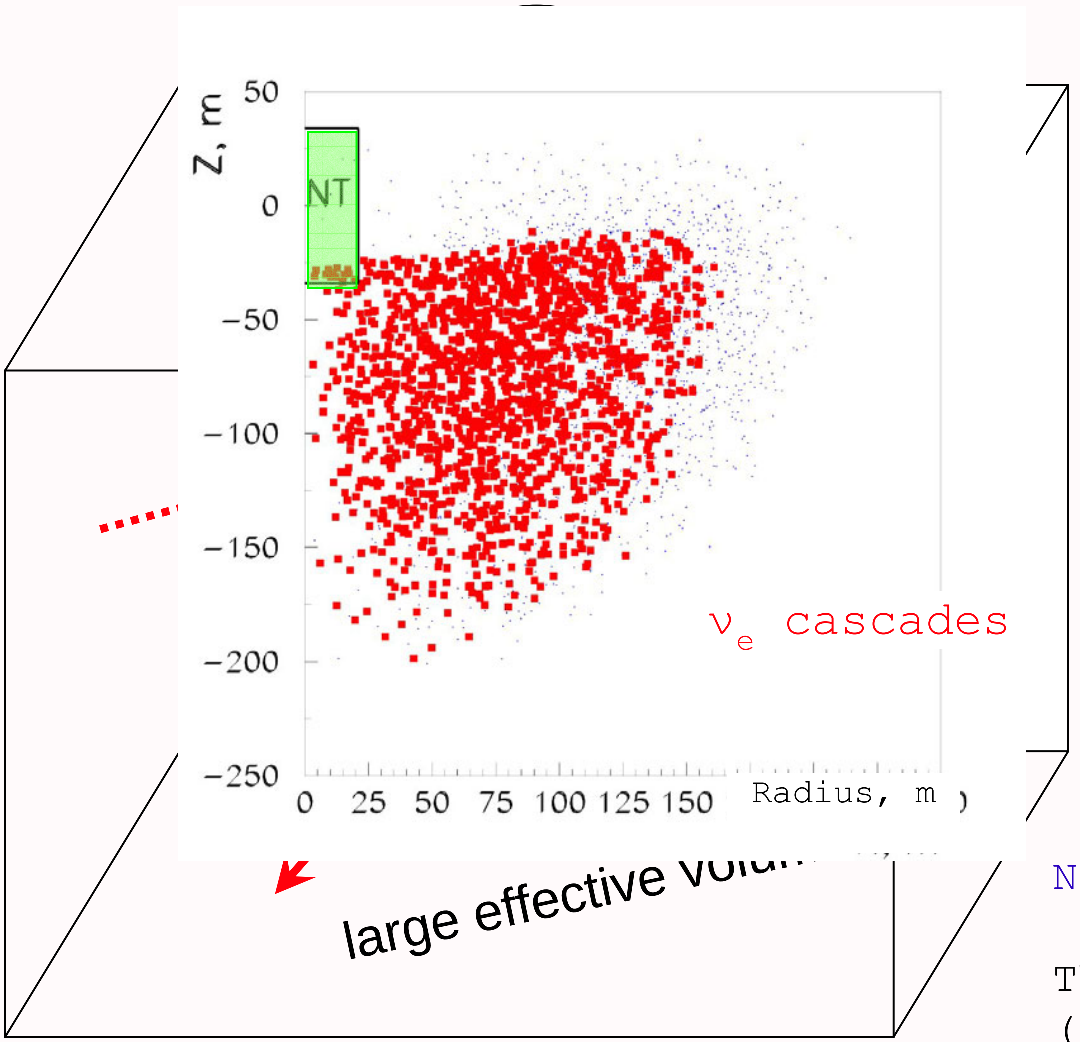
N_{obs} = 1 event

N_{bg} = 0.96+0.7−0.3 events

$E^2\,\Phi_{all\ \nu}(E) < 0.87 \cdot 10^{-7}\ \mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}}$

(equal mix of all flavors)

Search for high Energy Cascades



Look for upward moving li fronts

Signal: isolated cascades from neutrino interactions

Background : brems-showers on down-ward muons →

final bg rejection by energy cut (N_{hit})

- NT-200 is used to watch the volume below for cascades
  - (Λ_{scatt}=30-50 m)

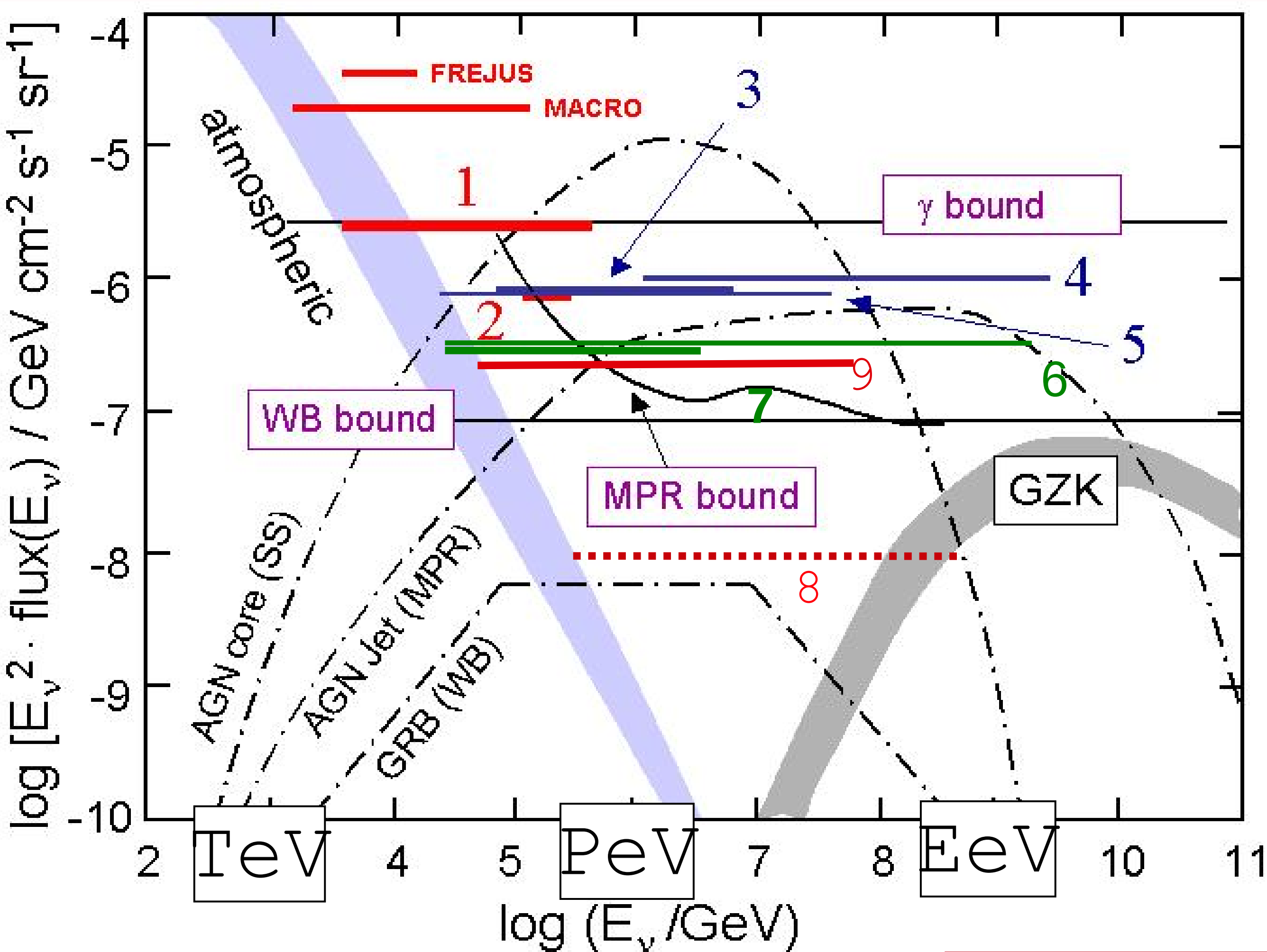
No events observed

The 90% C.L. "all flavour" limit (780 days)

for a =2 spectrum $\Phi \sim E^{-2}$ (10 < E < 10^4 TeV), ratio and assuming ν ratio of 1:1:1 at Earth

$E^2 \Phi_\nu < 8.1 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}

Summary of diffuse all Flavour Limits



AMANDA
1: B10, 1997, ↑μ
2: A-II, 2000, unfolding
3: A-II, 2000, cascade
4: B10, 1997, UHE
6: A-II, 2000, UHE sensitivity
7: A-II, 2000-03, ↑μ sensitivity

5: NT200, 98-03, cascade
9: NT200+, 3year

8: IceCube, 3 years

oscillation assumed

Several models of AGN neutrino emission are ruled out by current measurements
→ precise flux measurement needs km^3-scale detector

Search for Neutrino Point Sources

Select up-going events: maximize ↑ν and minimize ↓

Optimize cuts in each declination band for $E^{-2...-3}$ signal spectrum

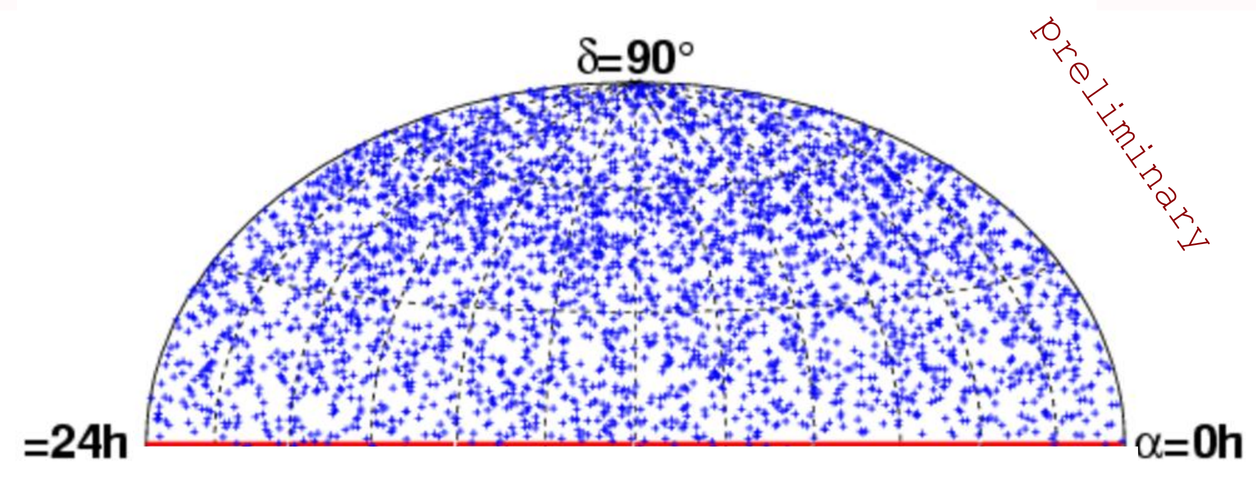
Sensitivity ~independent of direction

Published analyses on:

– 1997 data
  Astrophys.J. 583(2003)1040
– 2000 data
  PRL 92(2004) 071102

Newer results with different strategies:

– 2000-01 and 2002 data

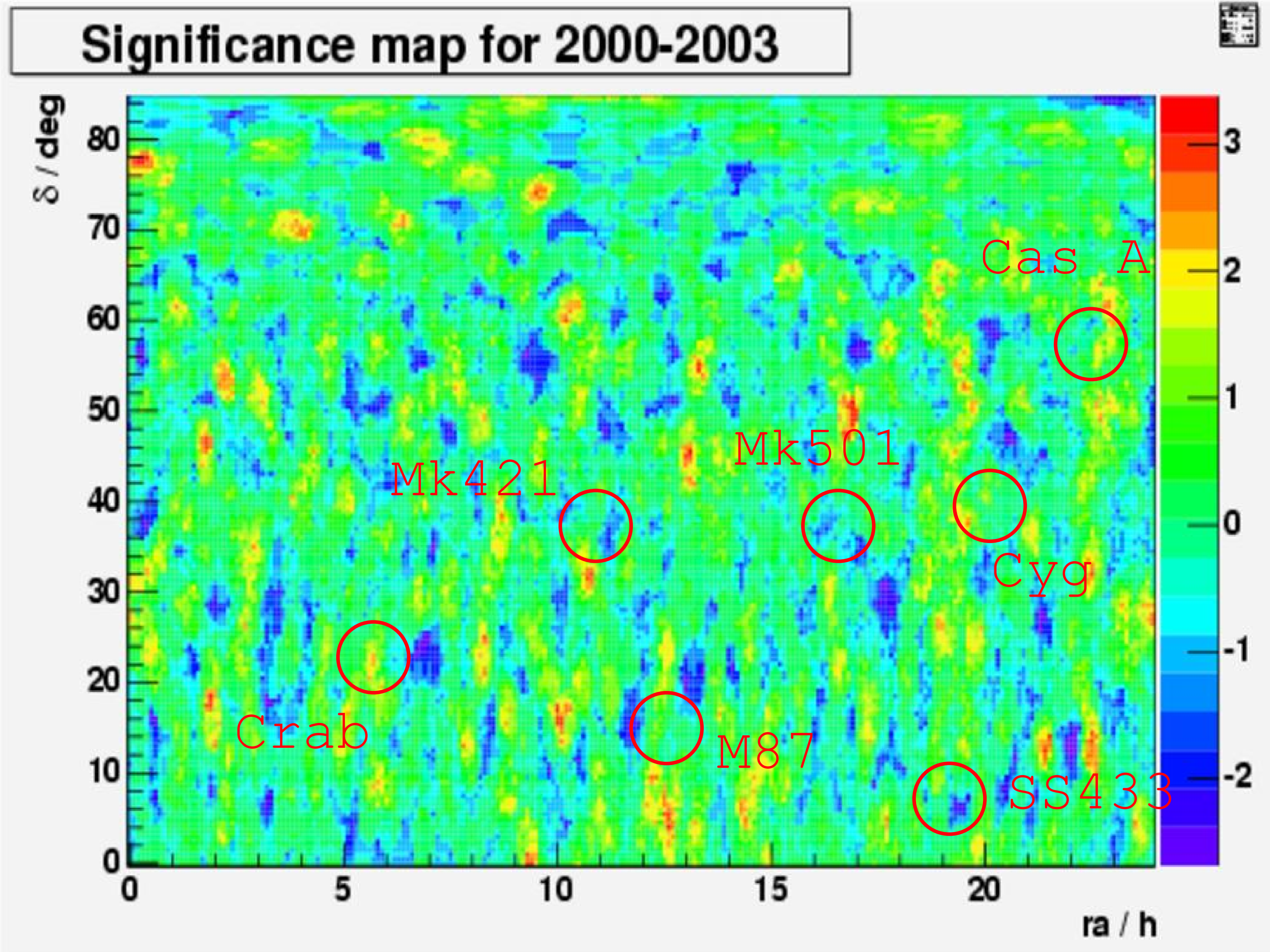


3329 ν events in 2000-03 data (807 days)

(sensitivity ~3 higher as 2000)

No clustering in skyplot observed,
i.e. the measurement looks compatible with atmospheric ν's
⇒ statistical analyses

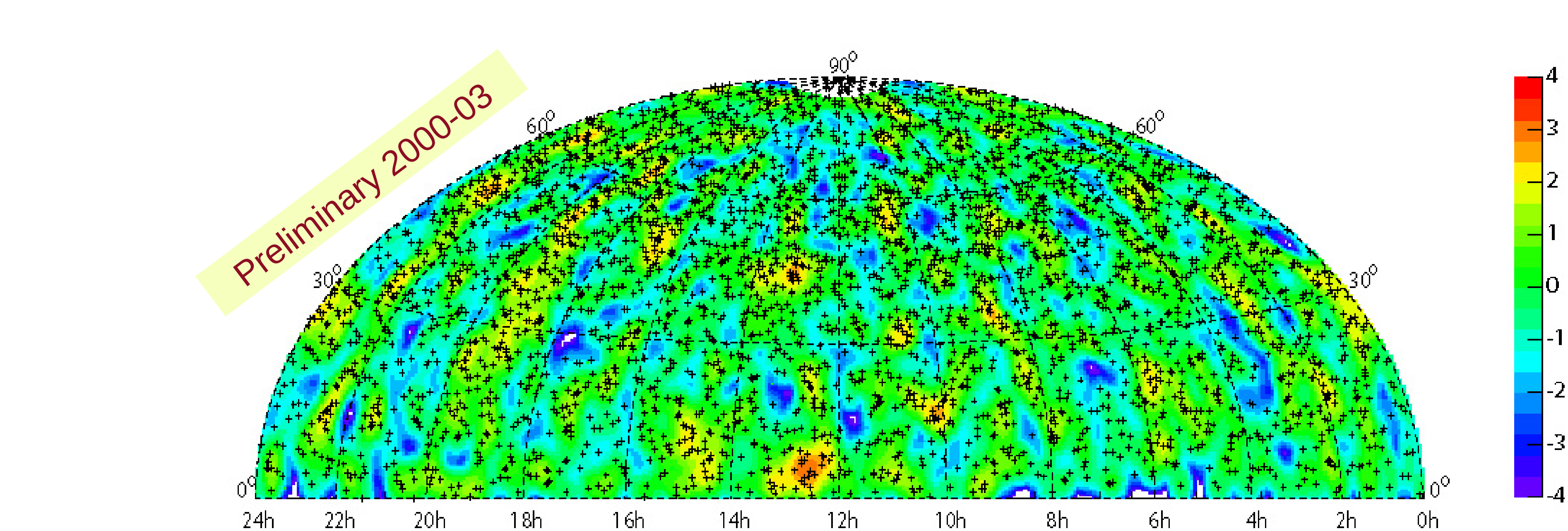
Neutrinos from known Sources?



Search for Neutrino Point Sources

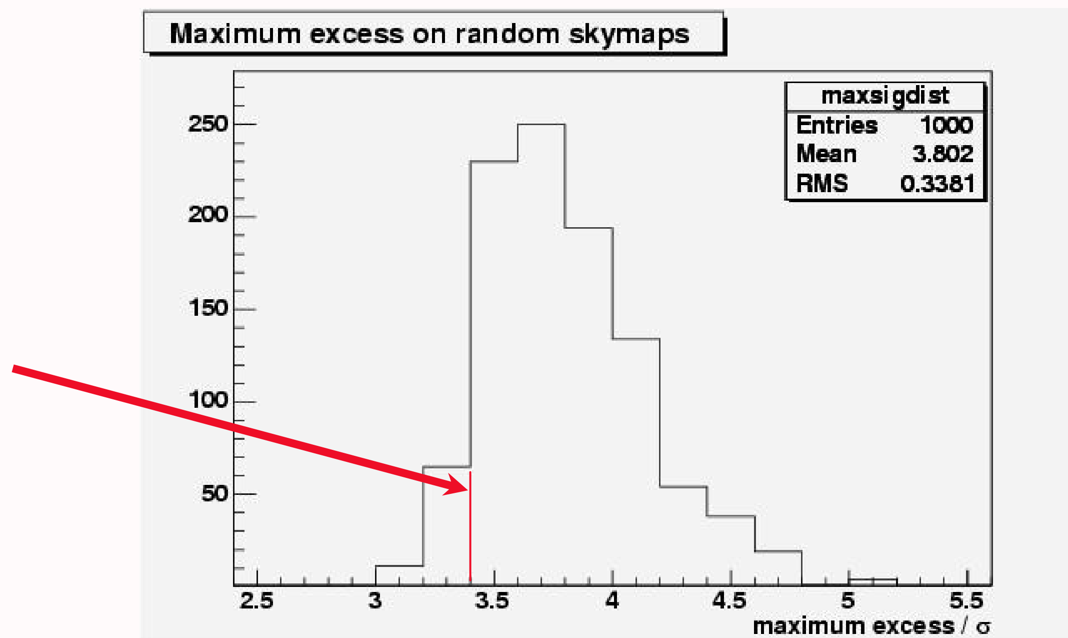
Blind-Analysis:

• Analysis



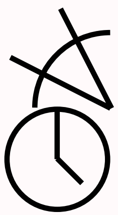
of local fluctuations from expectation of atmospheric neutrinos

- un-binned statistical analysis
- maximum of 3.4 σ - compatible with background fluctuation



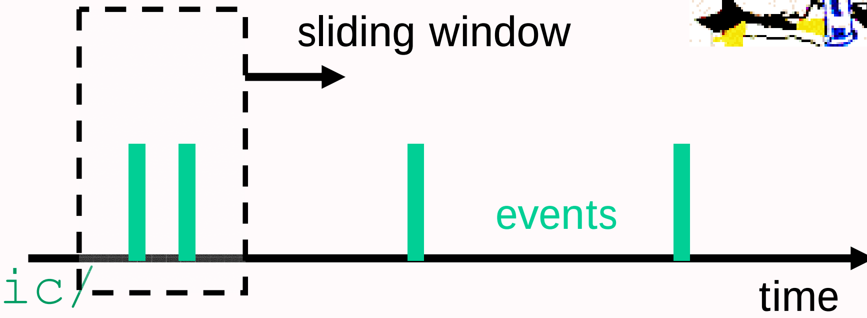
Search for Neutrino Flares

Search for excesses in time-sliding windows:



= 2.25°-3.75°

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



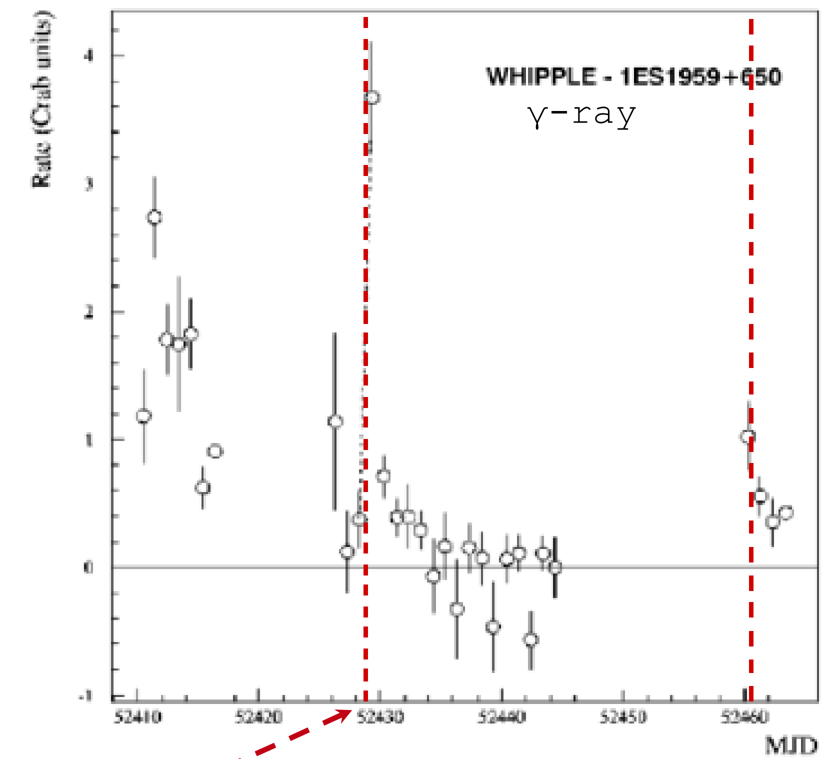
Source	Nr. of ν events (4 years)	Expected backgr. (4 years)	Period duration	Nr. of doublets	Probability for highest multiplicity
Markarian 421	6	5.58	40 days	0	Close to 1
1ES1959+650	5	3.71	40 days	1	0.34
3EG J1227+4302	6	4.37	40 days	1	0.43
QSO 0235+164	6	5.04	40 days	1	0.52
Cygnus X-3	6	5.04	20 days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

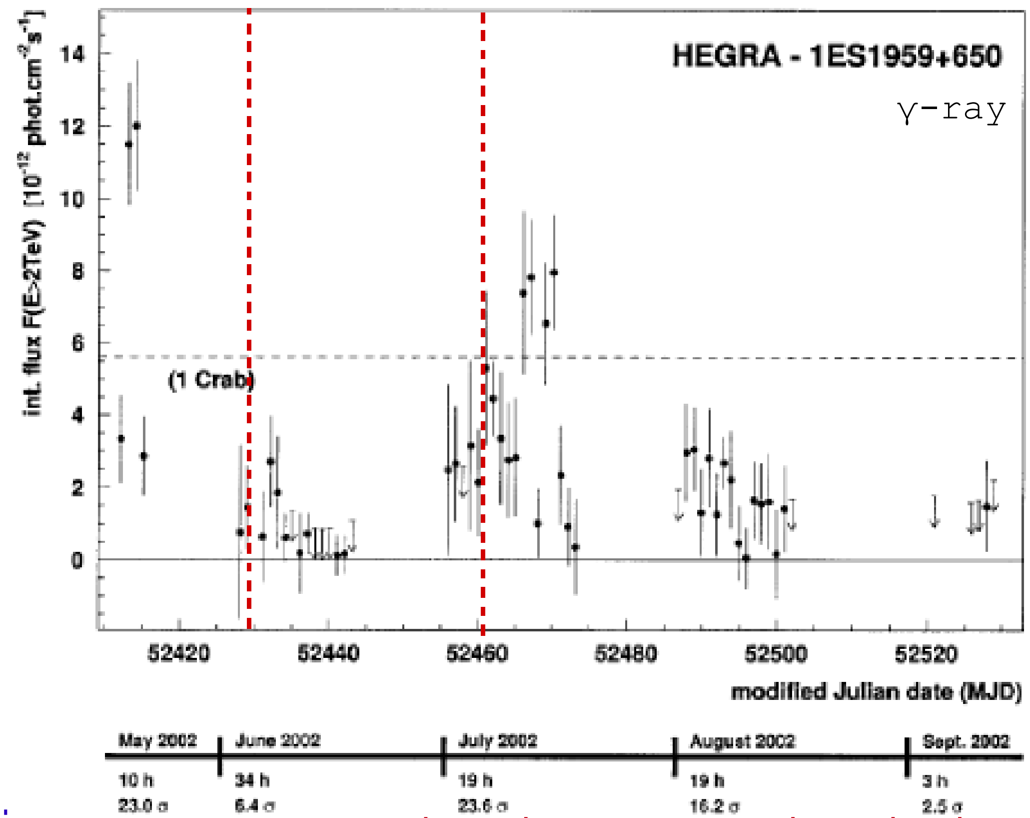
… out of **12** sources: No statistical significant effect observed

Preliminary

Neutrinos from 1ES1959+650 ?

"A posteriori" knowledge: 3 (of 5) ν events in 66 days within a period of a major outburst, measured in 2002 in a multi-wavelength campaign

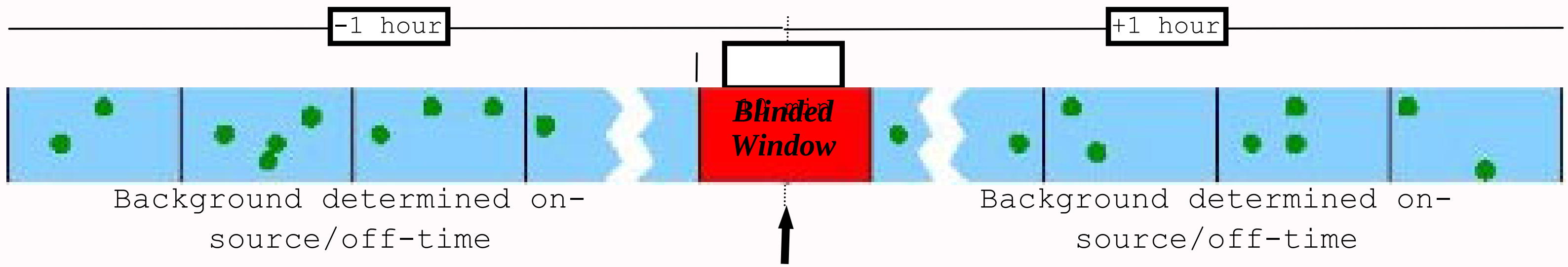




One (of the 5) event is within a few hours of the orphan flare: γ-ray flare from a blazar without accompanying X-ray counterpart ⇄ some interpret this as hadronic acivity in the blazar jet

Not a statistically significant results ⇛ but interesting observation ⇛ will lead to a modified search strategy and a close collaboration with the γ-ray

Association of Neutrinos with GRBs



Low background analysis due to space and time coincidence!

BATSE (non) triggered, IPN3 & GUSBAD GRB catalogs

blind analysis

	Year	#GRBs	obs/ bg
muon	97-00	312	0/ 1.3
muon	01-03	51	0/ 0.2
cascade	00	73	0/ 0

Prelimina ry

bad pointing but 4π

No coincident events observed

flux limit at Earth: 97-00 μ $E^2\Phi_\nu < 4\cdot10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}, all μ $3\cdot10^{-8}$, cascade $9.5\cdot10^{-8}$

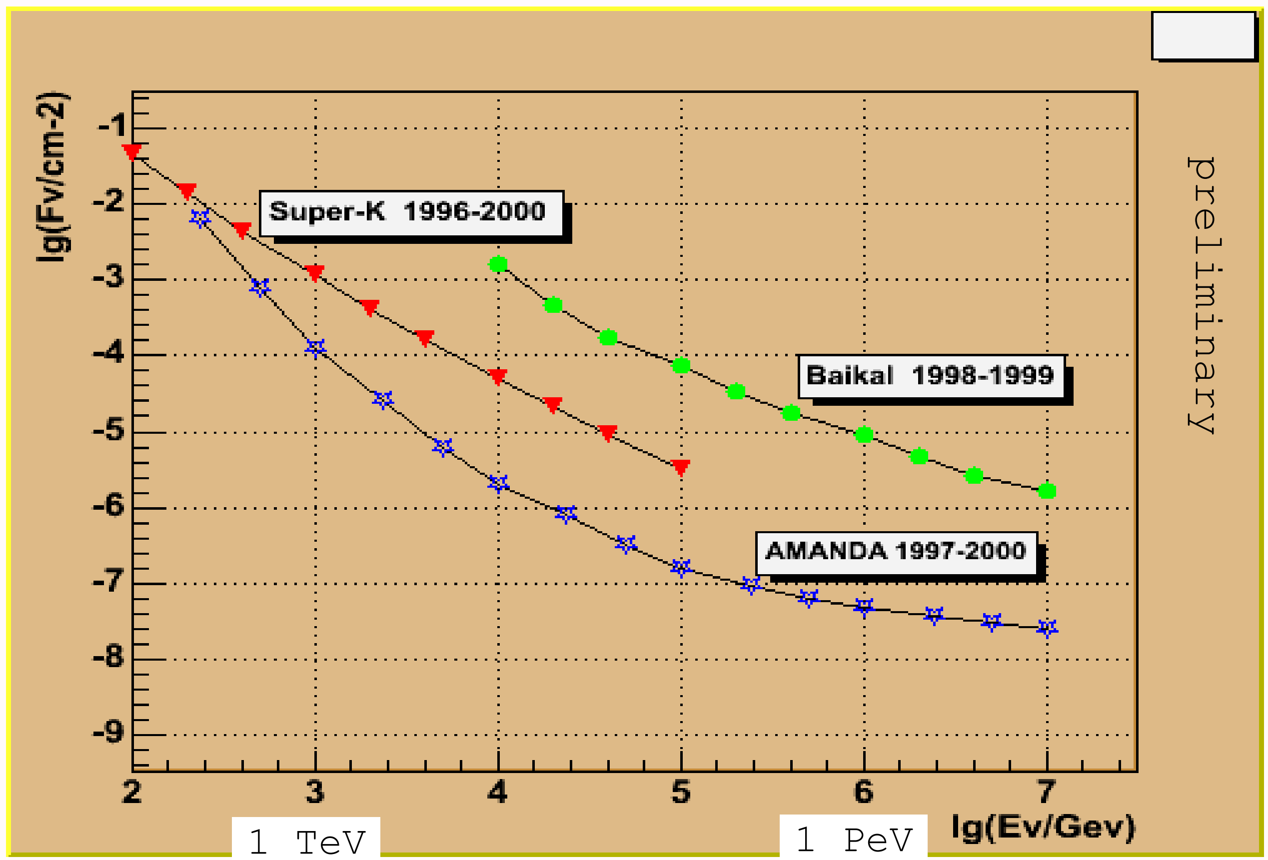
for bursts assuming WB broken power-law spectrum (E_{break}= 100 TeV, Γ_{bulk}= 300)

Neutrinos from GRBs cont'd

cascades in concidence with BATSE GRBs
t_{BATSE} -100 s < t < t_{BATSE} +100 s 722 evts Apr 98 - Feb 00

N	Triggered GRB obs / bg	All GRB obs / bg
15	91/ 94	172/ 167
25	1/ 2.8	5/ 5.2
35	0/ 0.3	1/ 0.5

Data consistent with expected μ at BG 90% C.L. → differential flux limits



Neutrinos from Active Galactic Nuclei

AGNs grouped in classes of potential high energy neutrino sources

assumption: ν flux is linearly correlated with γ luminc

Optimized a search strategy for classes in different energy bands
- using 2000 data
- using a source stacking method with optimized #sources (optimum 8-12) and bin sizes (typical 2.8°)

⇒ no excess events over background found

⇒ set limits
f_{lim} = integral flux for E^{-2} above 10 GeV in units 10^{-8} cm $^{-2}$ s $^{-1}$

sample	f_{lim}
IR blazars	2.0
keV blazars (ROSAT)	1.6
keV blazars (HEAO-A)	2.8
GeV blazars	4.0
unid. GeV sources	5.6
TEV blazars	2.8
GPS and CSS	4.3
FR-I galaxies	1.3
FR-I without M87	2.7
FR-II galaxies	2.7
radio-weak quasars	1.3

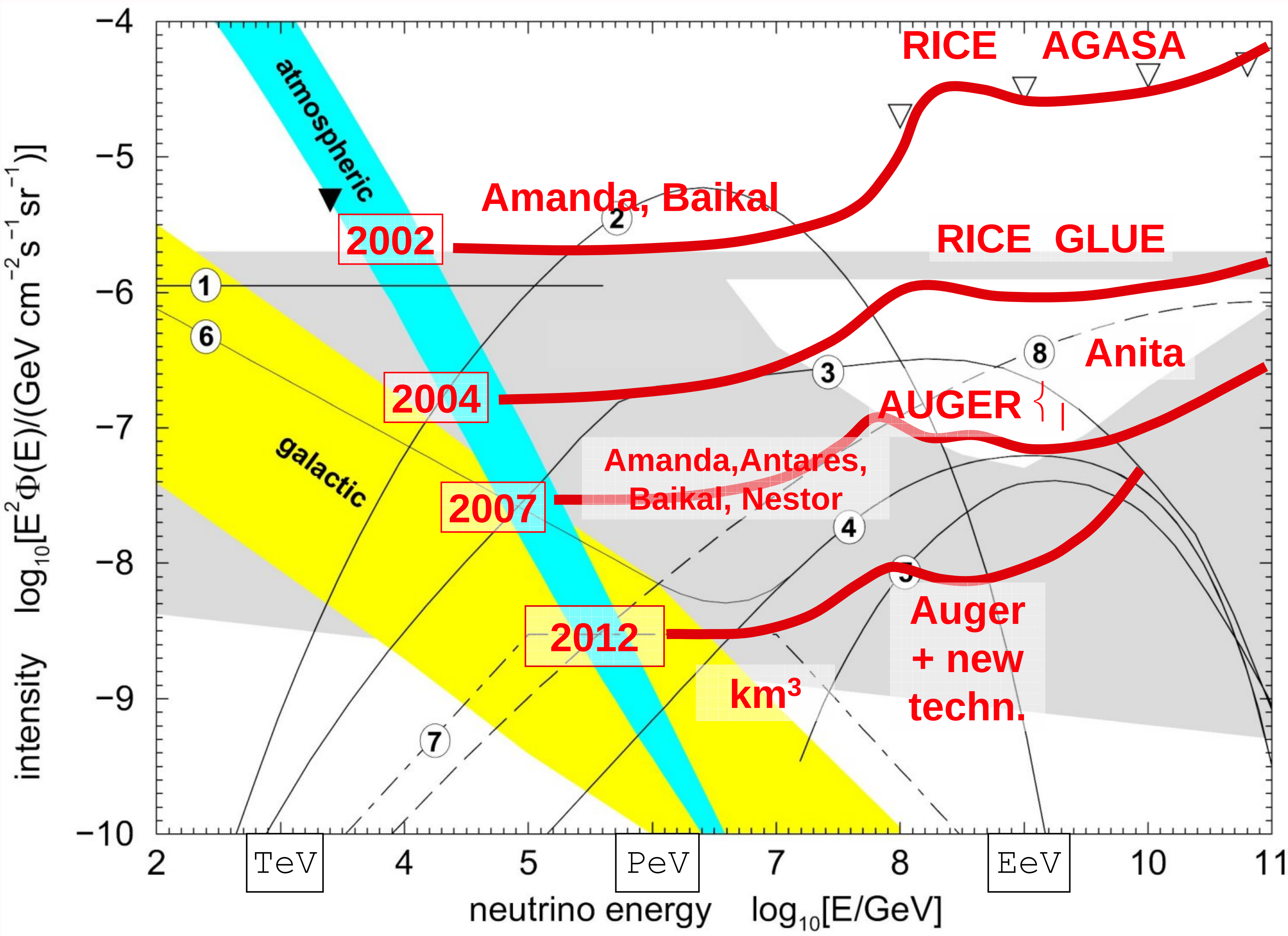
Go beyond km³ ?

- EeV neutrinos, particularly GZK ν, will be a valuable source for astro- and astro-particle physics
- At best a few ten neutrino per year and km^3 – IceCube can detect ~one GZK neutrino per year
- 10-100 GZK events would give a quantitative measurement will allow tests of cosmic ray production models and new physics
- Different projects (e.g. Rice2, ANITA, SalSA, Glue, Lofar, acoustics…) were and are actively seeking this goal
- IceCube joined the effort: proceed from a South Pole Acoustic Test Setup to a hybrid detector (IceCube + Acoustic + Radio) EeV Neutrino Array (if acoustic ice properties are measured to be as good as predicted)

properties of ice	optical	radio	acoustic
absorption [km]	0.1	1	~10 ?
energy threshold [eV]	~ 10^9	~ 10^{15}	~ 10^{18}

☞ Vortrag G Anton

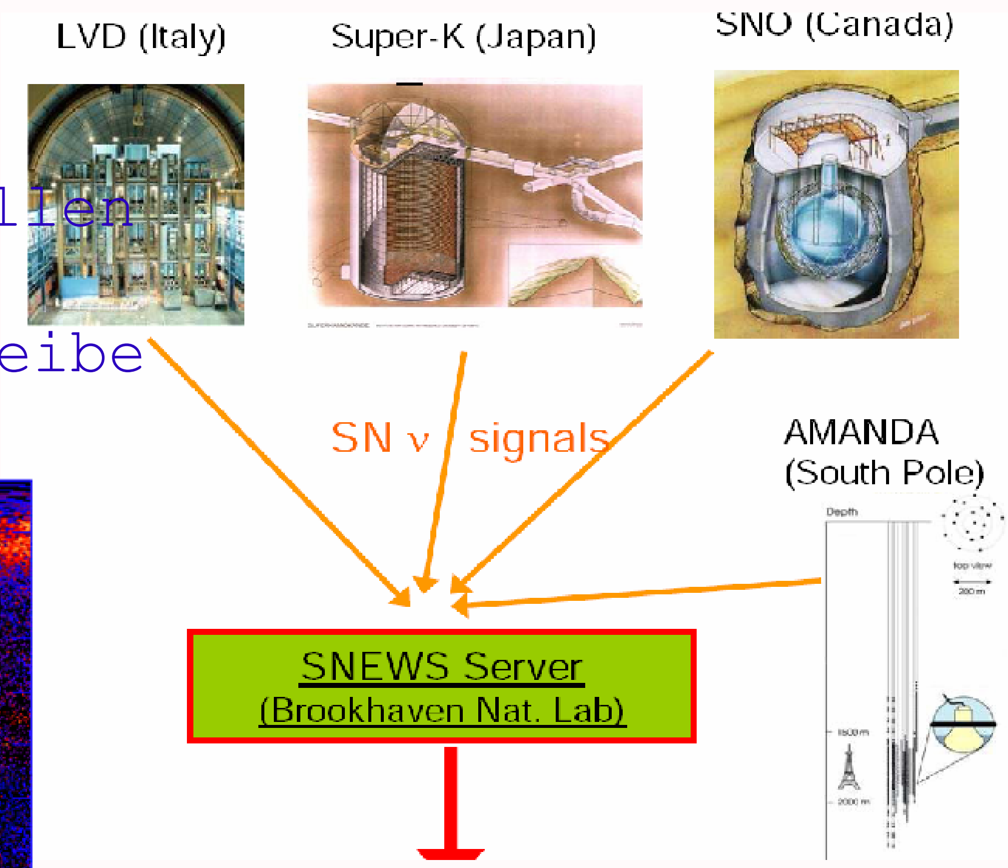
Diffuse Searches now and in the Future



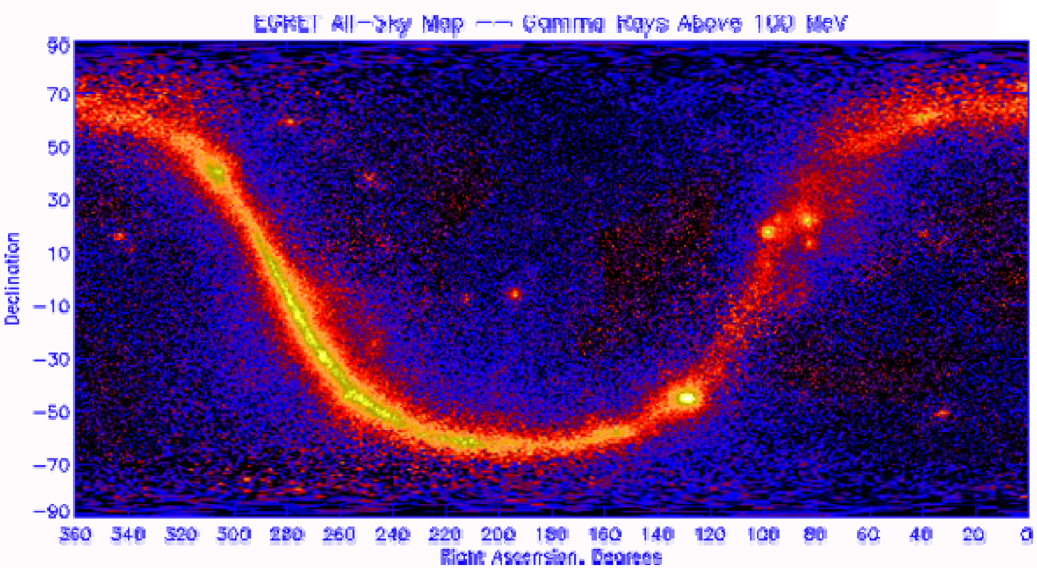
Nichtbehandelte Ergebnisse

Suchen nach:

- utralino Annihilation ☞ Vortrag D Elsässer
- Schnellen und langsamen Monopolen
- - Neutrinos von Supernovae



- Prompt μ’s aus charm-Zerfällen
- ν aus der Michstrassen-Scheibe



Siehe auch http://amanda.uci.edu, http://baikal1.jinr.ru

Zusammenfassung

AMANDA/ IceCube und Baikal sind komplementär

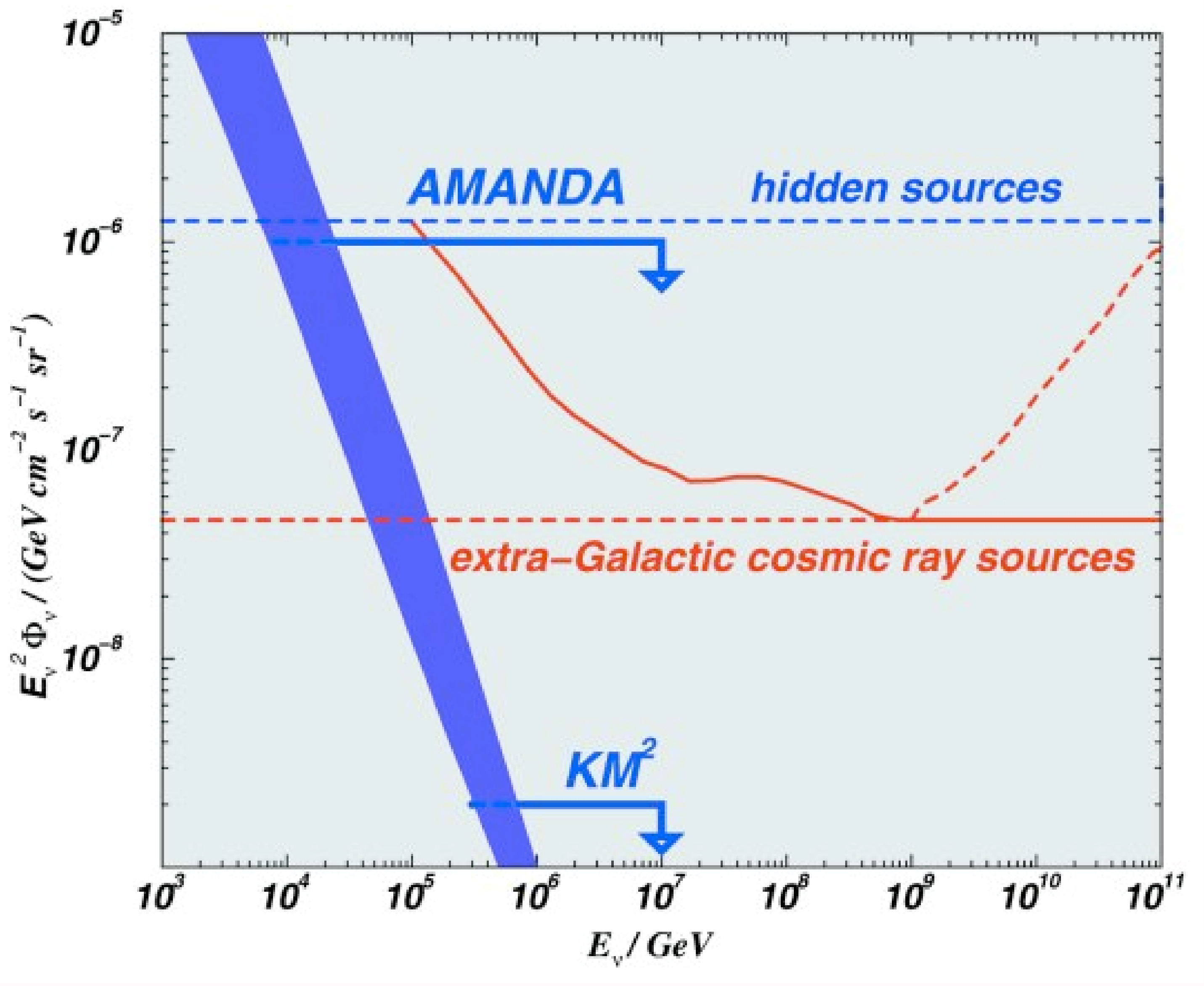
(Nördlicher/ Südlicher Himmel, Eis/ Wasser, verschiedene Analyse Techniken)

und haben ein reiches physikalisches Programm:

- Zusammensetzung der kosmischen Strahlung
- Verständnis der atmosphärischen μ's als Kalibrations-"Strahl"
- Messung des atmosphärischen Neutrino-Spektrums
- Grenzen auf diffuse Flüsse von extraterrestrisch TeV-EeV ν's
- Punktquellen Suche in den Daten von 1997 bis 2003
- Suche nach Neutrinos in Koinzidenz mit Gamma Ray Bursts und aktiven galaktischen Kernen
- Suche nach eingefangenen Neutralinos

Kein extra-terrestrisches ν Signal bis jetzt beobachtet

From Limits to Discoveries



Sonnenaufgang am Südpol