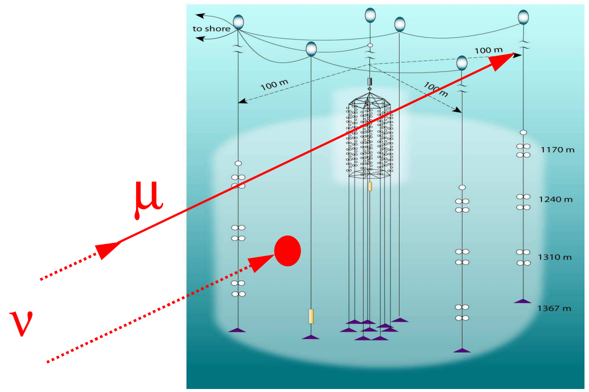
The Baikal Neutrino Telescope - Results and Plans

Outline:

- The Detectors: NT200 and NT200+
- Physics Results from NT200
  → Diffuse cosmic neutrino search, WIMPs
- The Km3 Baikal Detector Project
  ("Gigaton Volume Detector")

Ralf Wischnewski
DESY
- for the Baikal Collaboration -



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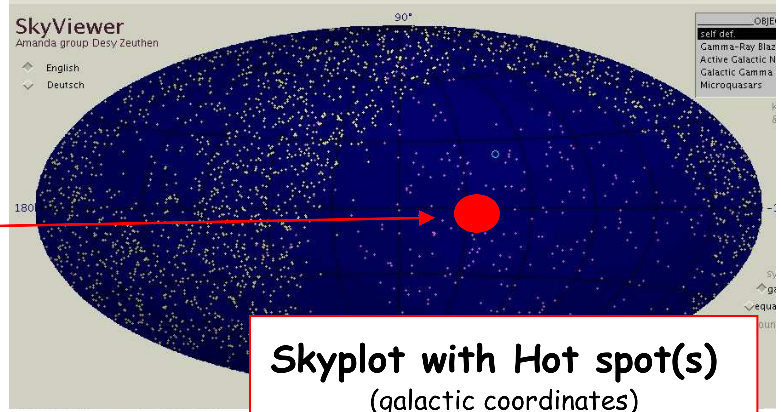
Astrophysical ν's: Two detection methods

Physics Background: atmospheric neutrinos

A. Point Sources

"Find the sources on the sky"



Skyplot with Hot spot(s)
(galactic coordinates)

Charged Current (CC) $\nu_\mu N \rightarrow \mu X$

+ clean experimental signal
- needs strong enough single sources

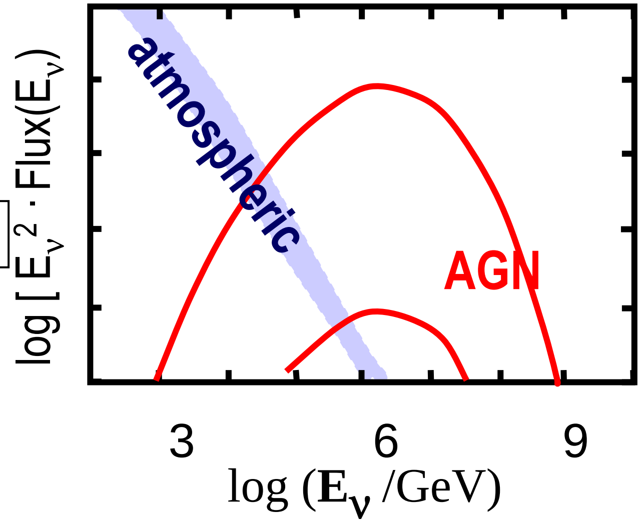
B. Unresolved Sources / Diffuse Flux

"Signatures in atmospheric ν-spectra"

Electron / hadron cascades from
CC + NC $\nu_e / \nu_\tau / (\nu_\mu)$

ν_μ CC is also used

+ all (eg.weak) point sources add up; all flavors
+ theoretical predictions ~ exper.sensitiv.
- atm.nu: theor. precision (prompt!)
- exp. systematics



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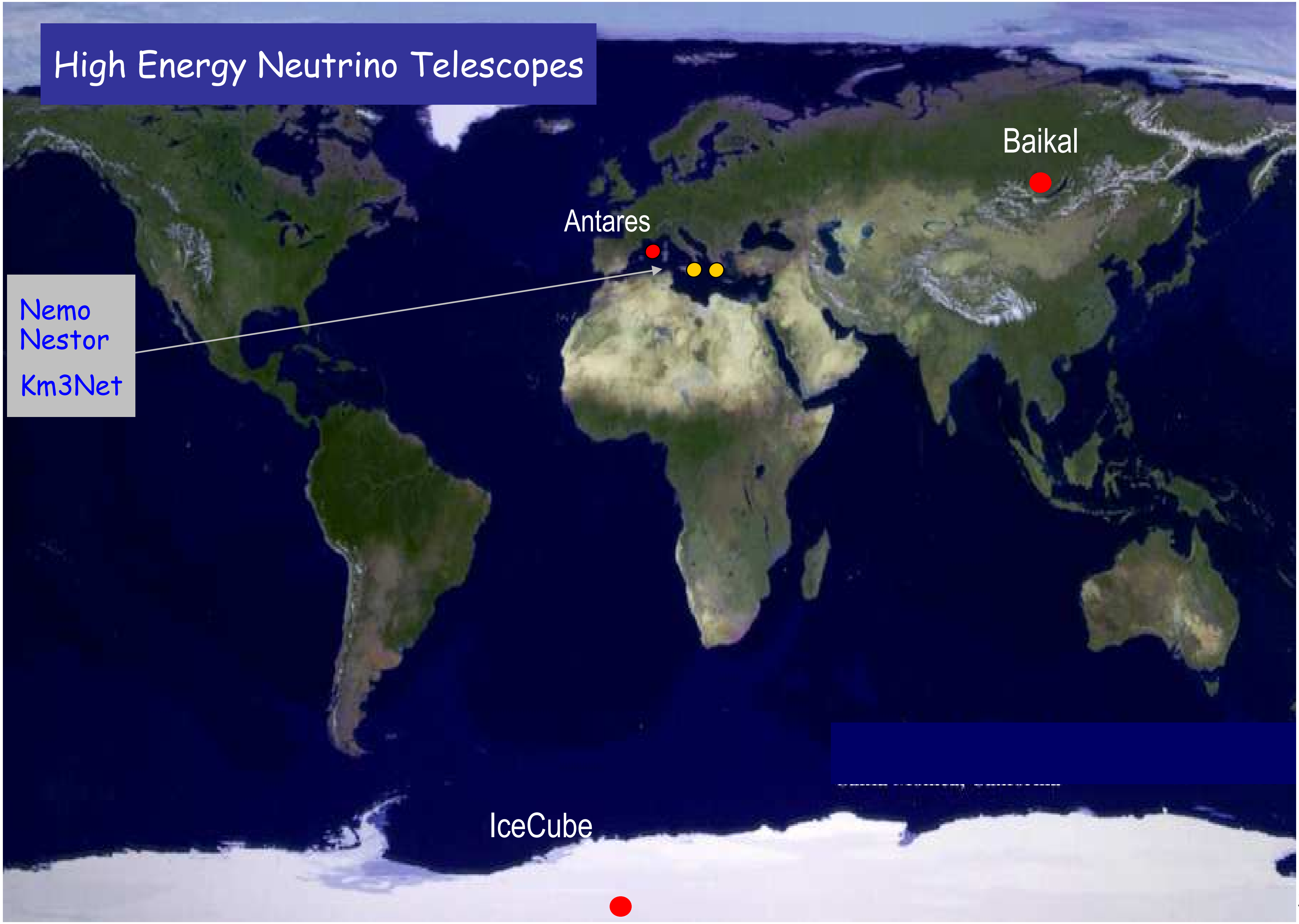
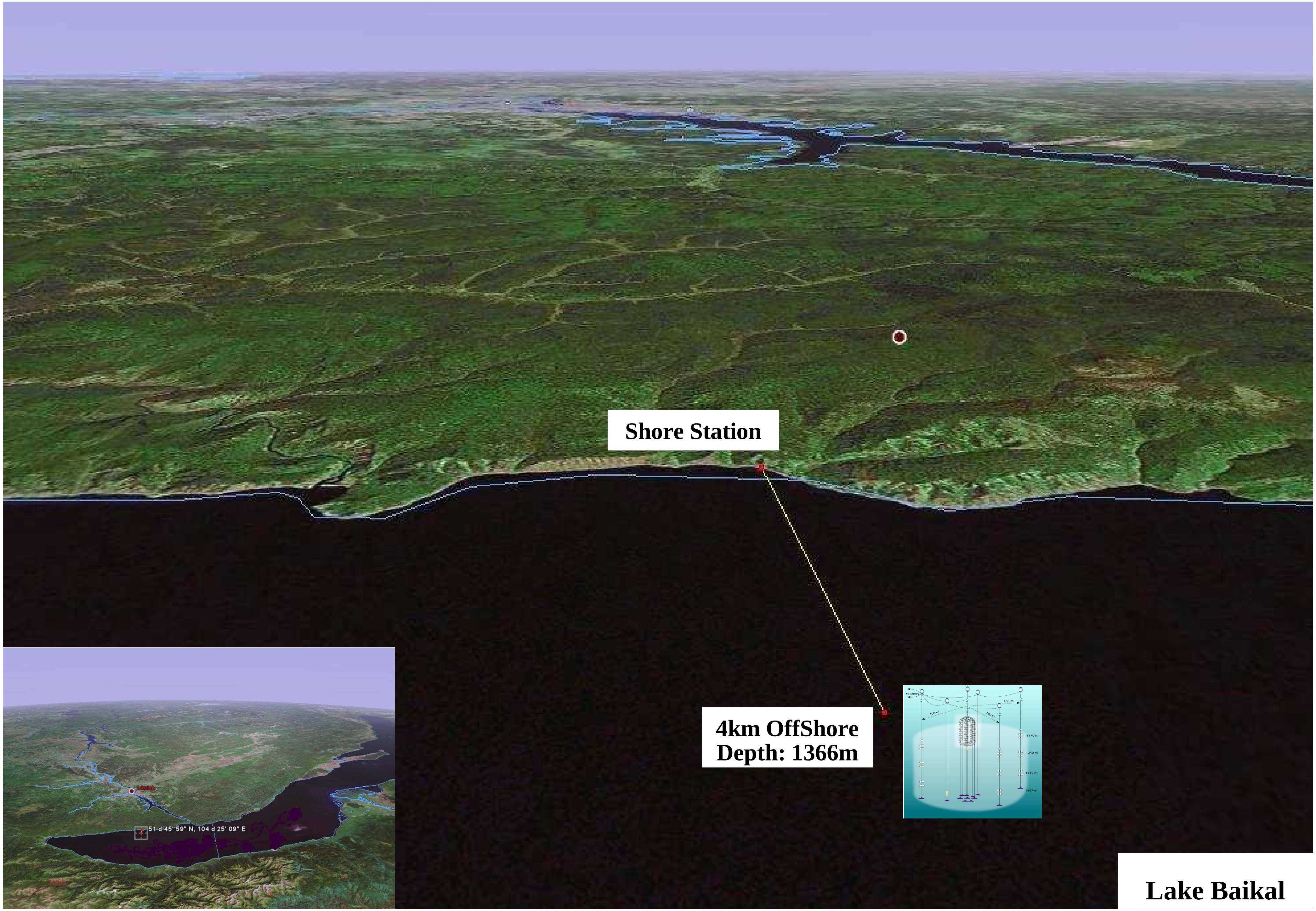
High Energy Neutrino Telescopes




Shore Station
4km OffShore
Depth: 1366m
Irkutsk
51 d 45' 59" N, 104 d 25' 09" E
Lake Baikal

The Baikal Collaboration

- Institute of Nuclear Research, Moscow
- Moscow State University
- Irkutsk State University
- Nishni Novgorod State Techn. Univ.
- State Marine Techn. Univ. St.Petersburg
- Kurchatov Institute, Moscow
- JINR, Dubna
- DESY

~45 authors

Project Milestones

>1983: Site / Water studies;
R&D: large area PMT, underwater technology,
Small Physics setups (exotics search)

1993: NT36 – the first underwater array operates

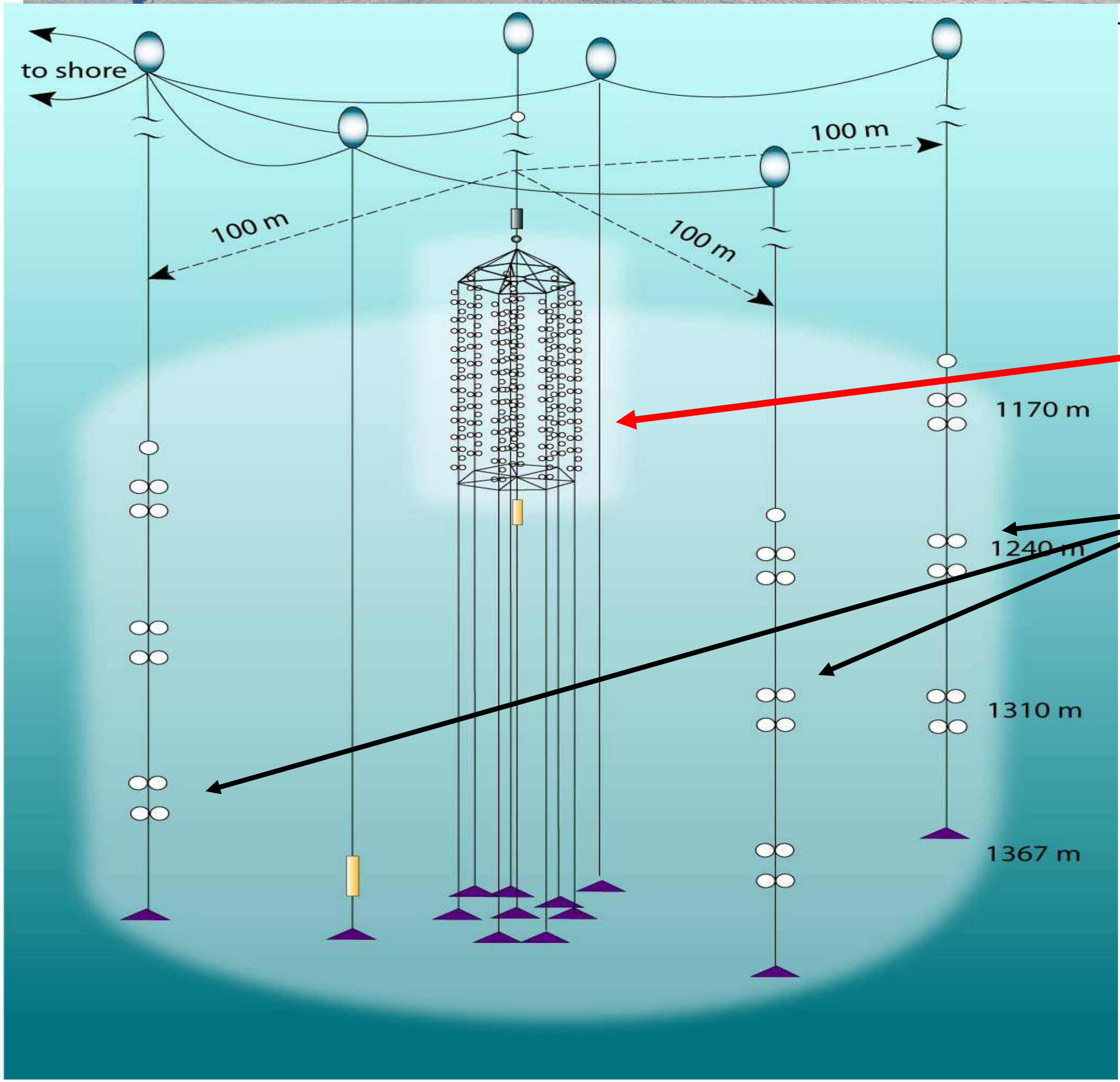
... stepwise upgraded (w/ physics operation)

1998: NT200 commissioned

2005/06:
Upgrade to NT200+ completed; operating

>2006: R&D activity for a KM3 detector in Lake Baikal
(„Gigaton Volume Detector")

~2010: expected start of KM3 deployment (string #1 ?)



NT200+
=
NT200
+
3 long outer strings

- Height = 210m
- ∅ = 200m
- Geom.Volume ~ 5 Mton

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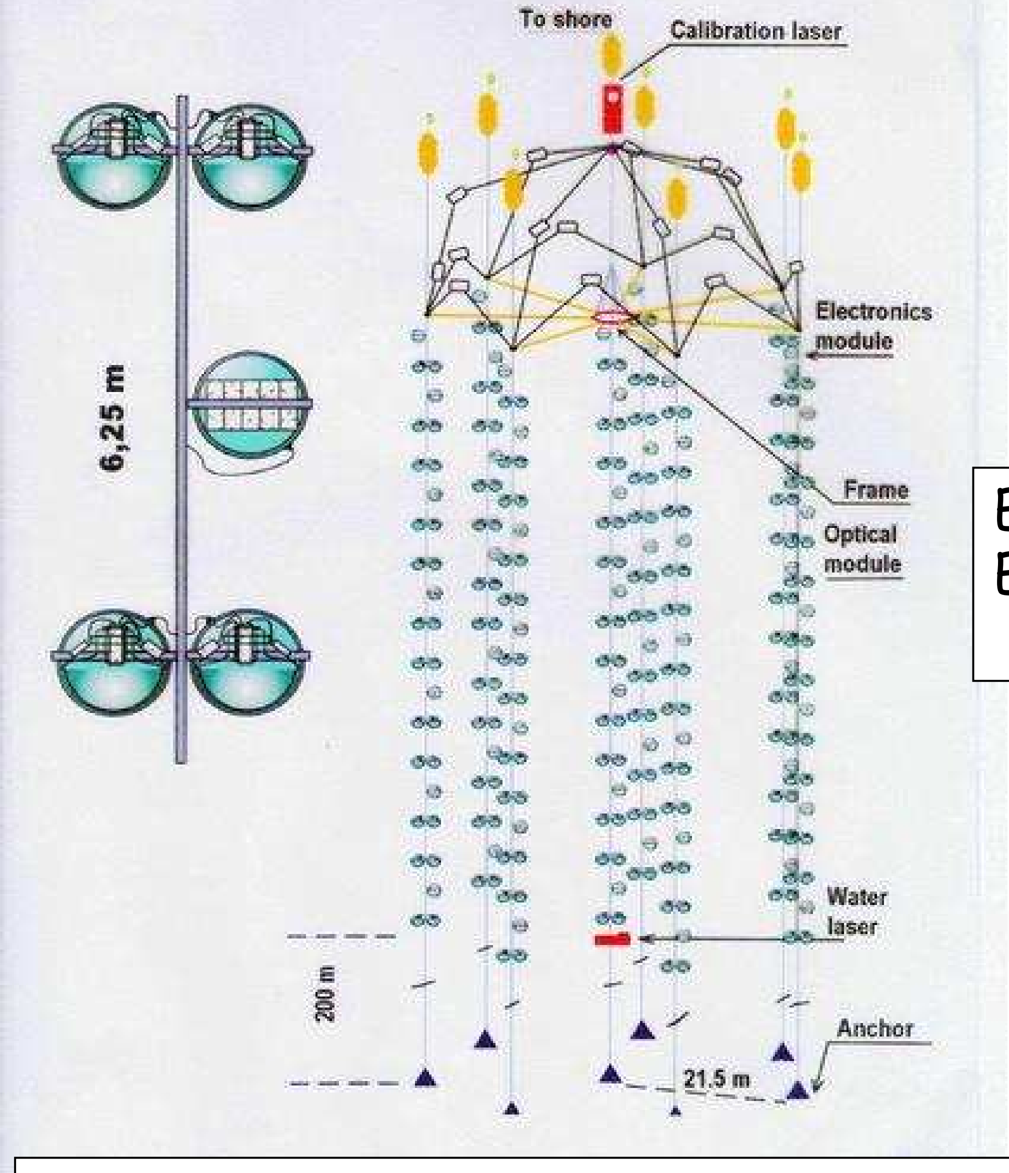
NEUTRINO TELESCOPE NT-200



Height = 70m, ∅ = 42m → V_{inst} = 0.1 Mton

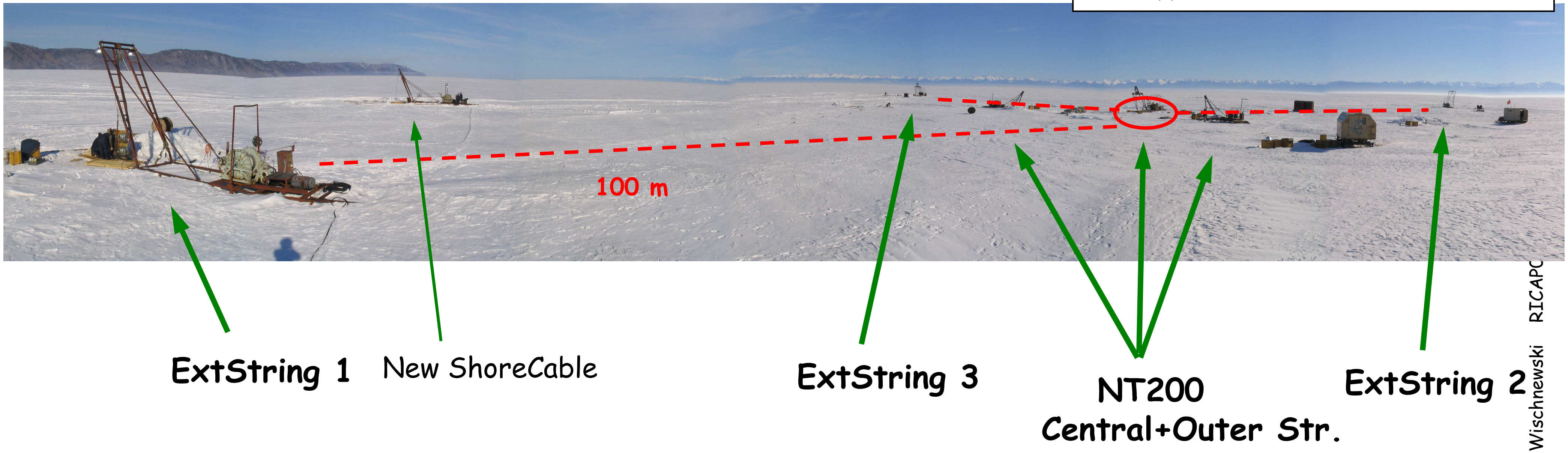
- 8 strings
- 192 optical modules
  = 96 pairs (coincidence)
- Time + Charge measured
  - σ_T ~ 1 ns
  - dyn. range ~ 1000 p.e.

Effective area: 1 TeV ~ 2000 m^2
Eff. Shower volume: 10 TeV ~ 0.2 Mton
1 PeV ~ 1 Mton !

Quasar PMT: d=37cm (14.6”)

Advantages (1): Ice – a Perfect Deployment Platform

NT200+ deployment from 1m thick ice, 4km off-shore.



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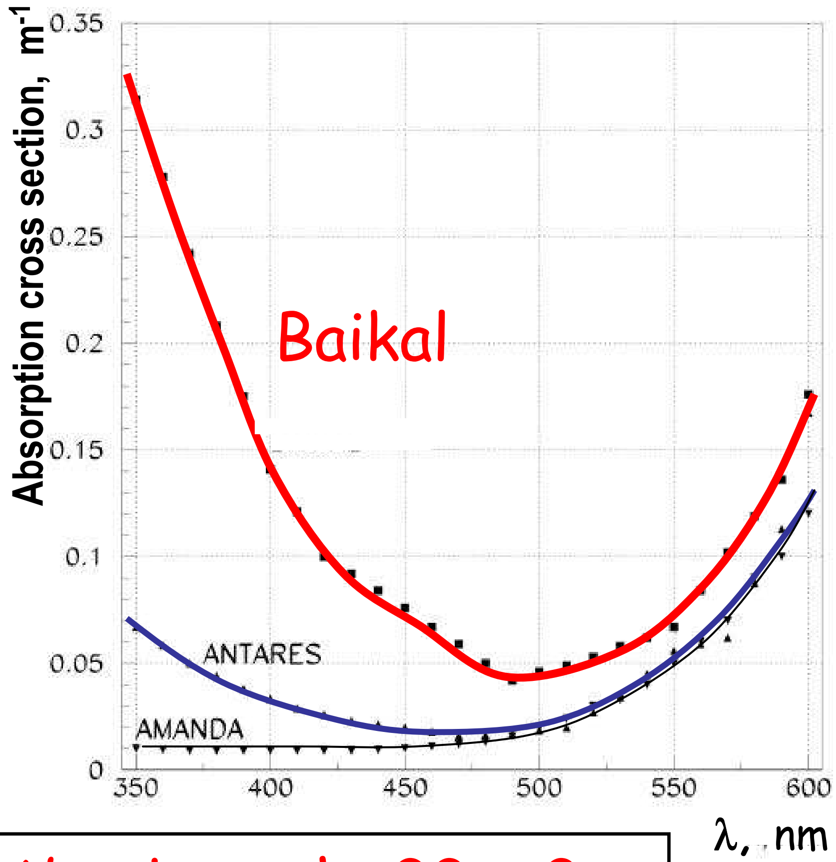
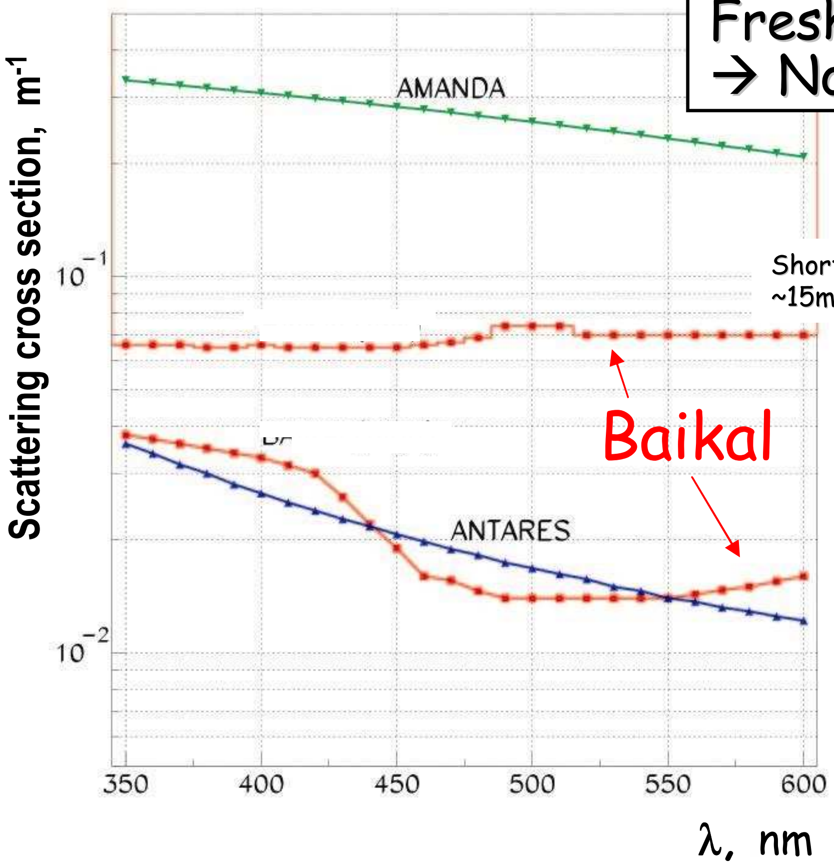
- Ice is available for 6-8 winter-weeks/year :
  - Telescope upgrades & maintenance
  - Test & installation of new equipment
  - Operation of surface detectors (EAS, acoustics,…)
  - Electrical winches used for deployment operations;
    All connections done dry.

Advantages (2): Water – Good Optical Properties





Baikal:
Fresh water
→ No K40 BG

Short periods of ~15m possible.

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Abs. Length: 22 ± 2 m

Scatt. Length ~ 30-50 m (geom.scatt.L.)
⟨cos Θ⟩ ~ 0.85-0.9

In-situ measurements over many years

Note: IceCube's „effective" (diffusion) scattering is ~30m
→ for Baikal: ~300 - 500m !

NT200 - Selected Results

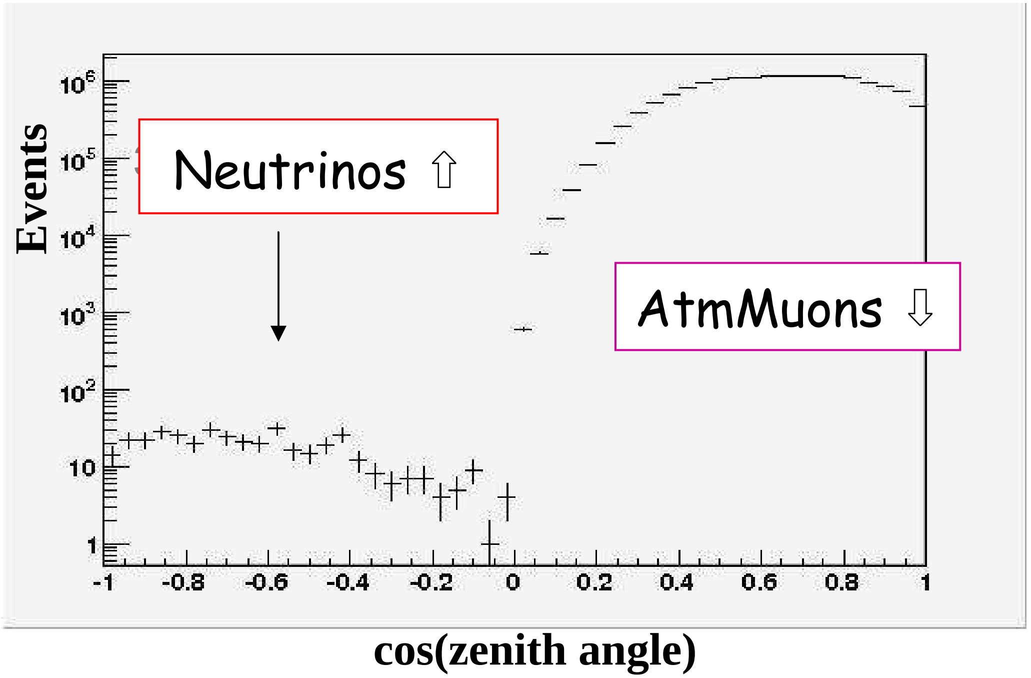
Data sample:
1998-2002 (Apr/98-Feb/03)
= 1038 live days

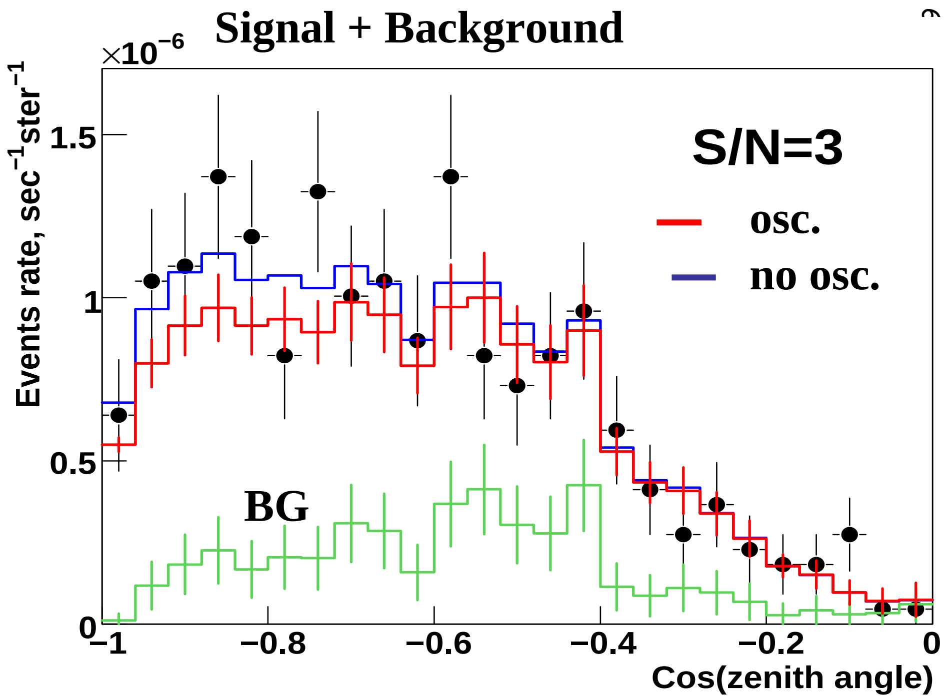
- Low energy phenomena
  - Atmospheric neutrinos
  - WIMP Neutrinos
    - from Earth center
    - from the Sun — *new*
- Search for exotic particles
  - Relativistic Magnetic monopoles
- High energy phenomena
  - Diffuse neutrino flux — *new*
  - GRB Neutrinos — *new*
  - Prompt muons and neutrinos
  - Exotic HE muons

Atmospheric Muon-Neutrinos

Upward-going muons from atm. neutrinos (1038 live days)

Reconstructed high-quality muon tracks -
Zenith angle distribution :





Analysis-dependent: nu-Signal/Background = S/N = (true nu's) / (fake events) .
(optimized for sensitivity, …)

For details on Reconstruction & Neutrino Filtering:
See eg. Belolaptikov etal., APP, 7 (1997) 263; Belolaptikov, 2007

1998-2002 (1038 live days)

Atmospheric Muon-Neutrinos

Muon trck reconstruction
+
High-quality filtering

Neutrinos ⇧

AtmMuons ⇩

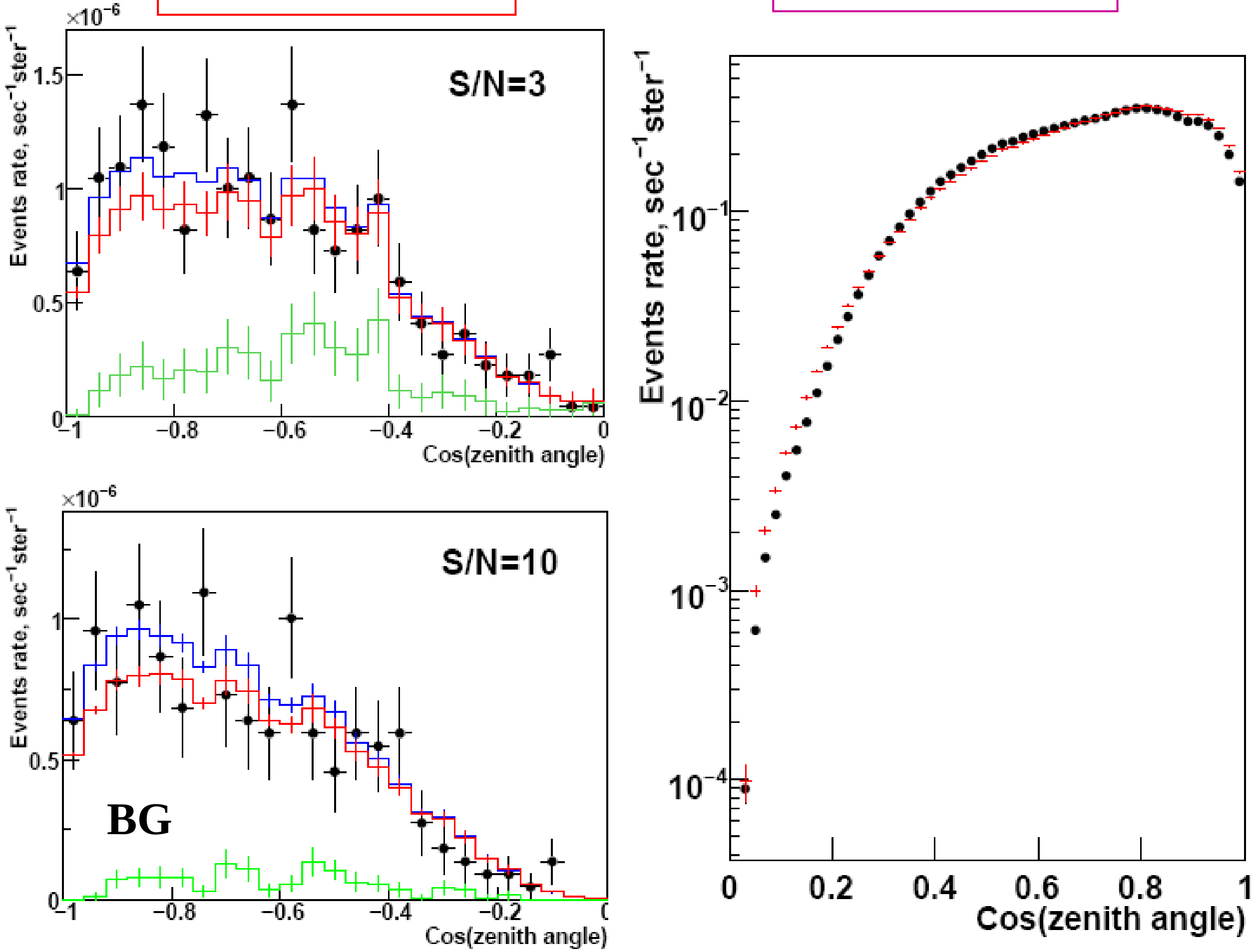
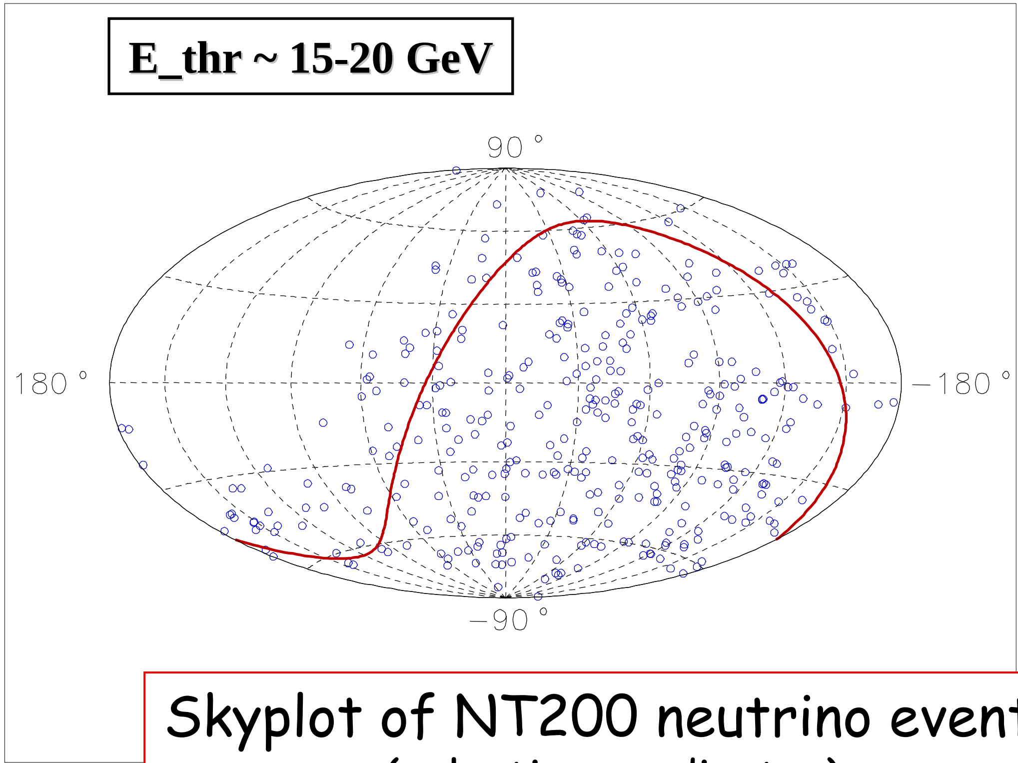


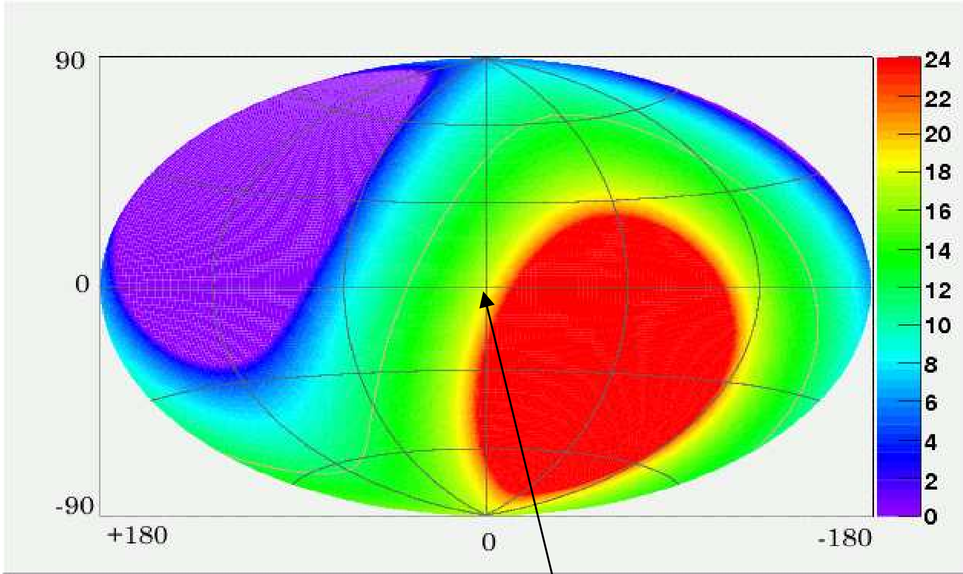
Fig. 3. Distribution of cos(zenith) for muon events. Left: neutrino event samples (data - symbols, MC - histograms (from top): sig+bkg for non-osc., oscillation and bkg); Right: downward atmospheric muons (data - symbols, MC - histogram).

1998-2002 (1038 live days)

Atmospheric Muon-Neutrinos



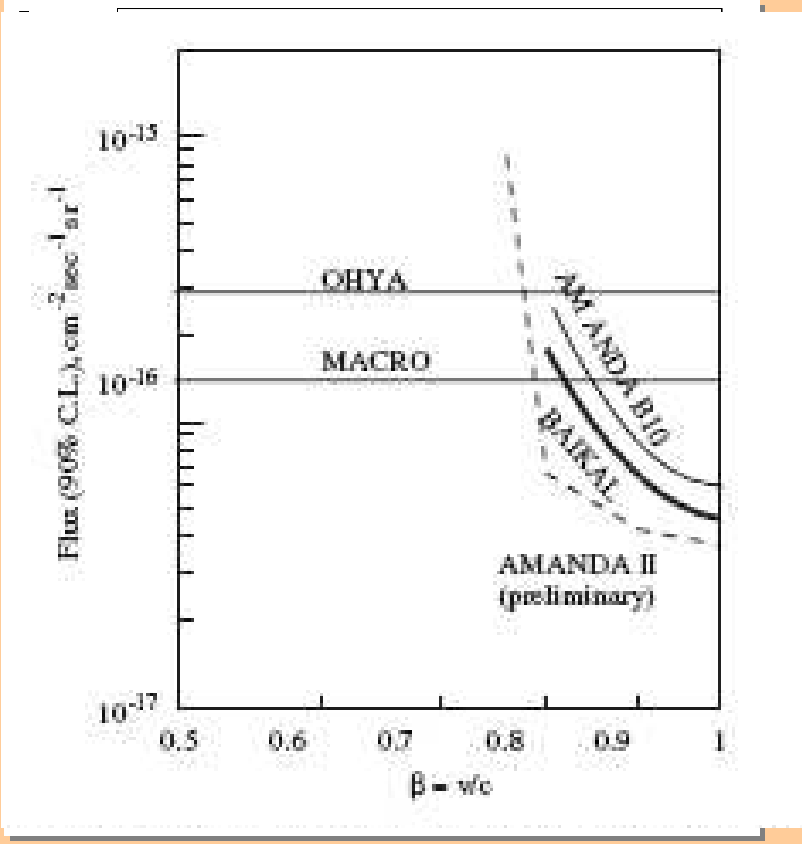
Skyplot of NT200 neutrino events
(galactic coordinates)



Galactic center
visible 18 hours per day

- Data: 372 upward ν events (1998-2002).
- MC: 385 ev. expected (20%BG).
- Angular resolution ~2.2 degrees
- No indication for Point Sources found.

Search for Fast Monopoles ($\beta > 0.8$)



$\Phi < 4.6\ 10^{-17}\ cm^{-2}\ sec^{-1}\ sr^{-1}$

90% C.L. flux limit for fast monopoles.

See: Aynutdinov et.al, APP, 9 (2008) 366

$N_\gamma(\lambda) = n^2 (g/e)^2 N_{\gamma\mu}(\lambda) = 8300\ N_{\gamma\mu}(\lambda)$ (!!)

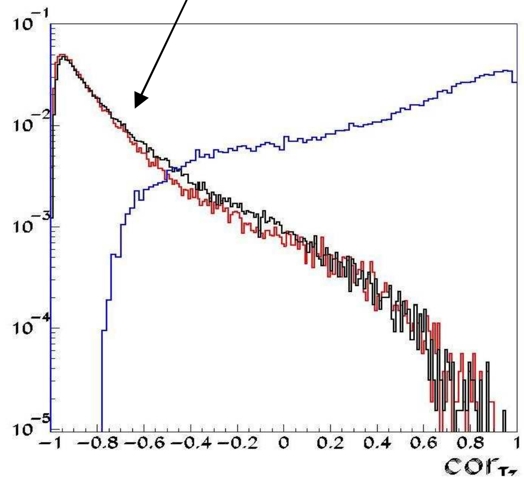
$g = 137/2,\ n = 1.33$

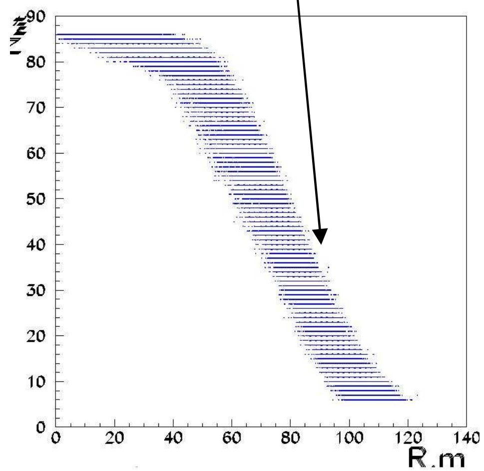
→Monopoles are bright Cerenkov light sources, like HE-muons $\sim E_\mu = 10^7$ GeV

Monopole selection criteria:

- **large hit channel multiplicity: $N_{hit} > 35$ ch**
- **clearly upward going track**

Background : atmospheric muons (downward)





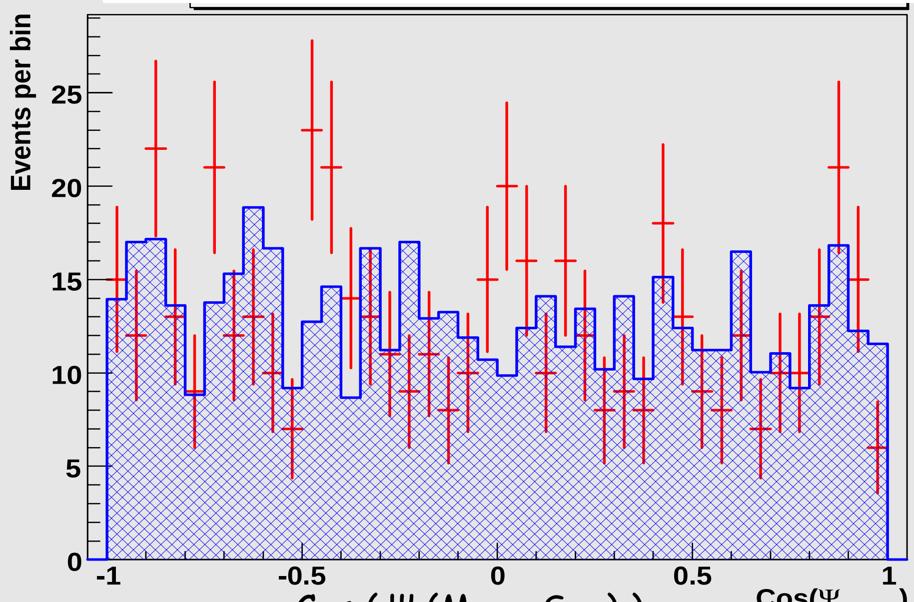
N_{hit} vs distance

Dark Matter: WIMP Neutrinos from the Sun

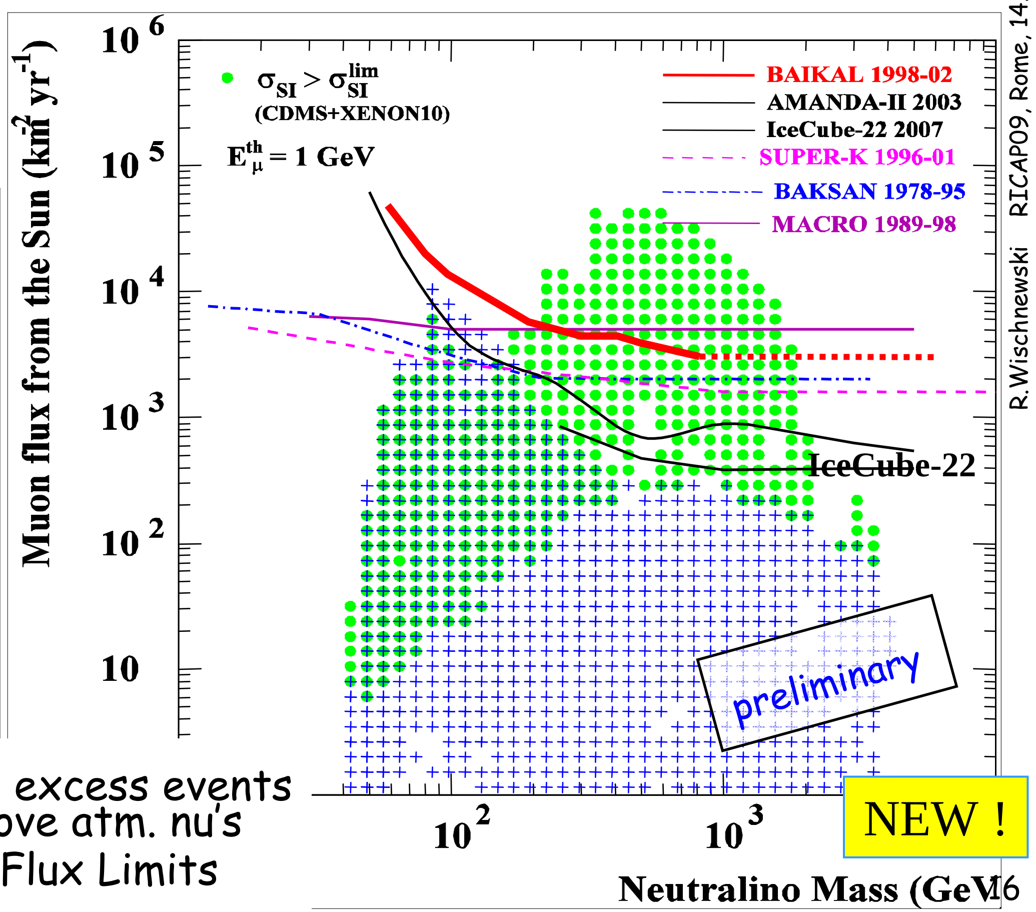
- Neutralino (WIMP) as DarkMatter candidate in galactic halo;
- Gravitationally trapped in Sun (or Earth):
- Sun would be a neutrino-source (annihilation) → „Indirect" WIMP searches

Two upward muon samples:
low/high BG - 510 / 2400 evts (θ> 100°)
1038 live-days

→ Sun-mismatch angle Ψ (Muon/Sun):
data and background (histogram).



Cos (Ψ (Muon,Sun))



No excess events above atm. nu's
→ Flux Limits

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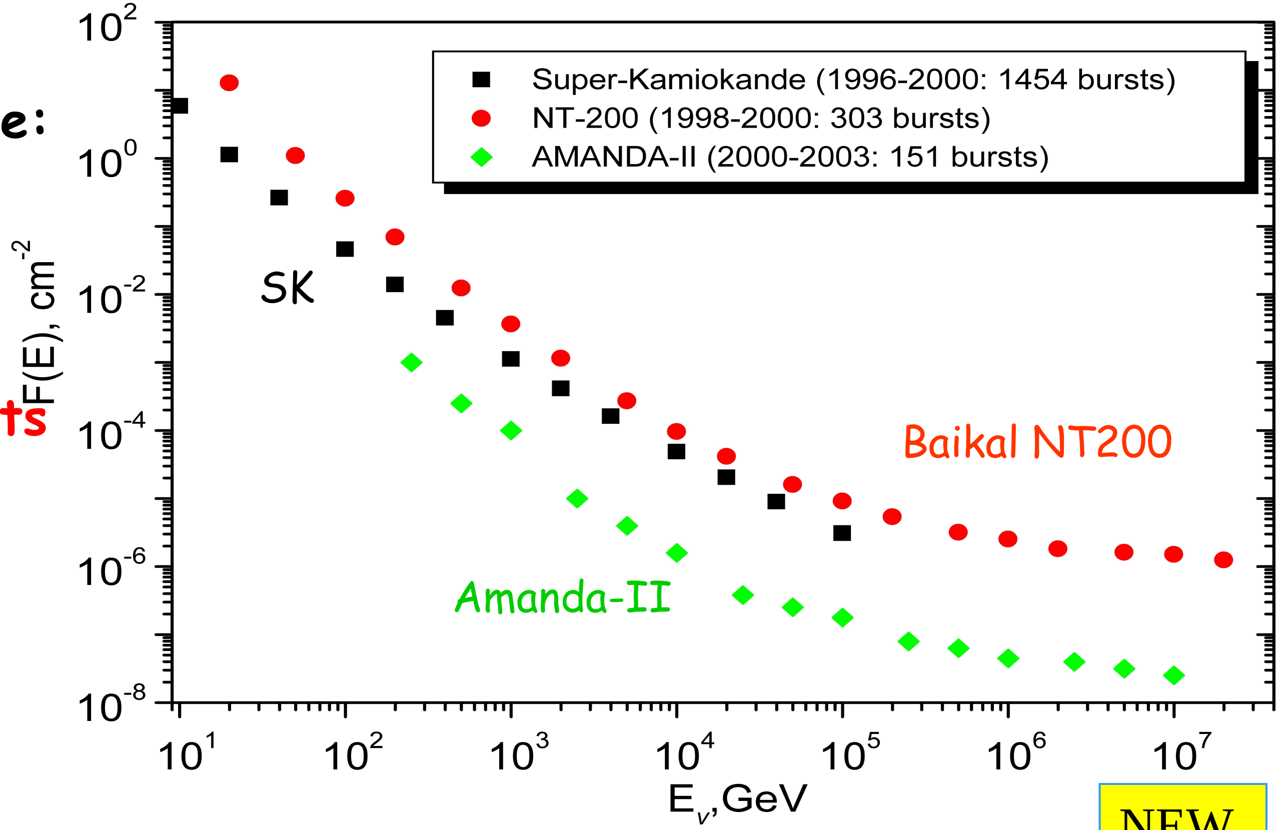
GRB Neutrino Search

Search for direction + time correlations with 303 GRBs observed by BATSE in 1998-2000, using the upward-going muon data sample.

Time window:
(t_{GRB} + T_{90} + 5s) - (t_{GRB}-5s)
Half angle of observation cone:
Ψ = 5°

Observed number of events
- 1 event
Expected number of bg. events
- 2.7 events

"Green's function" Upper Limits on GRB neutrino fluence (model independent)



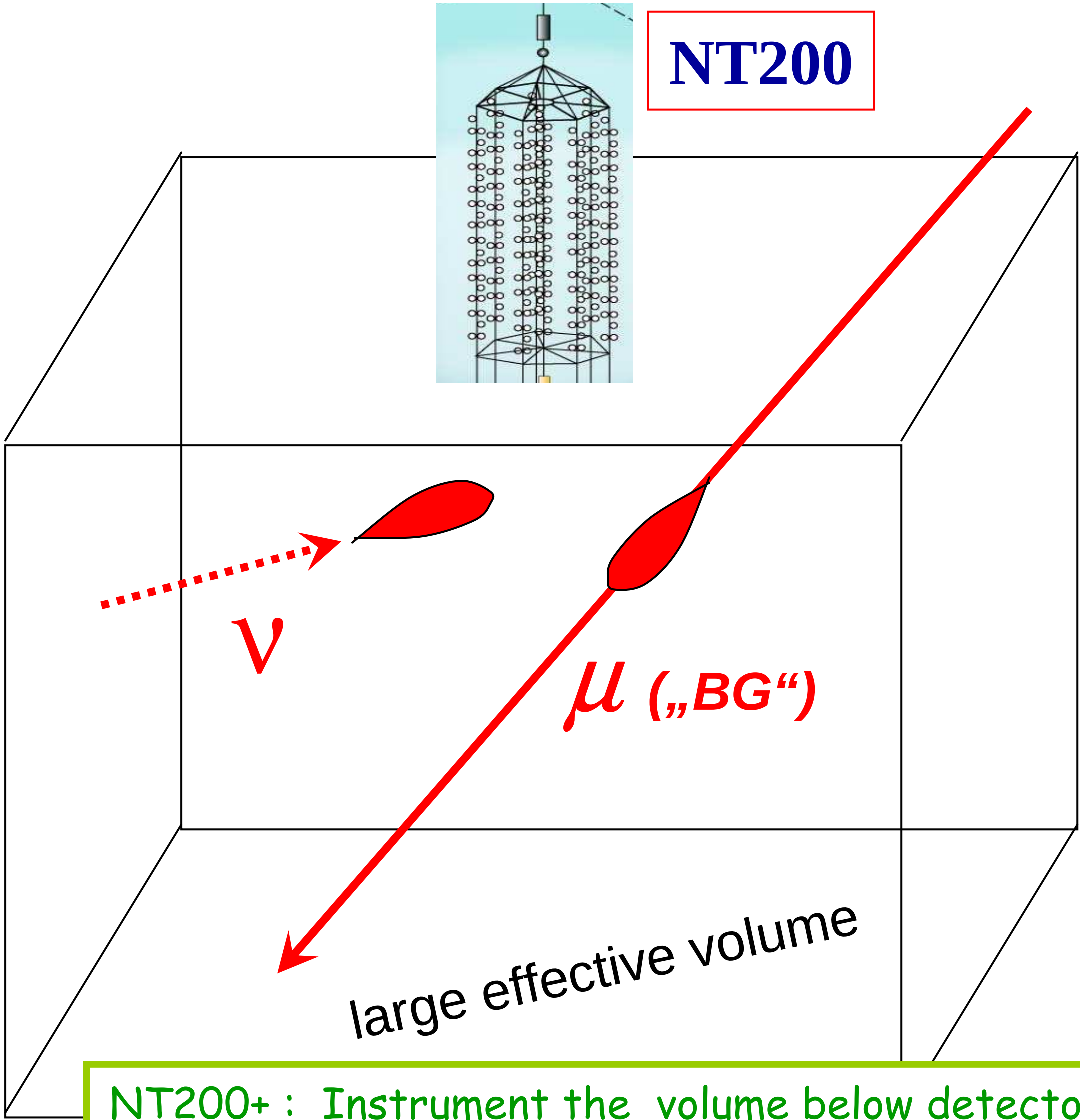
NEW

e, 14.5.2009

Search for High Energy Diffuse Cascades

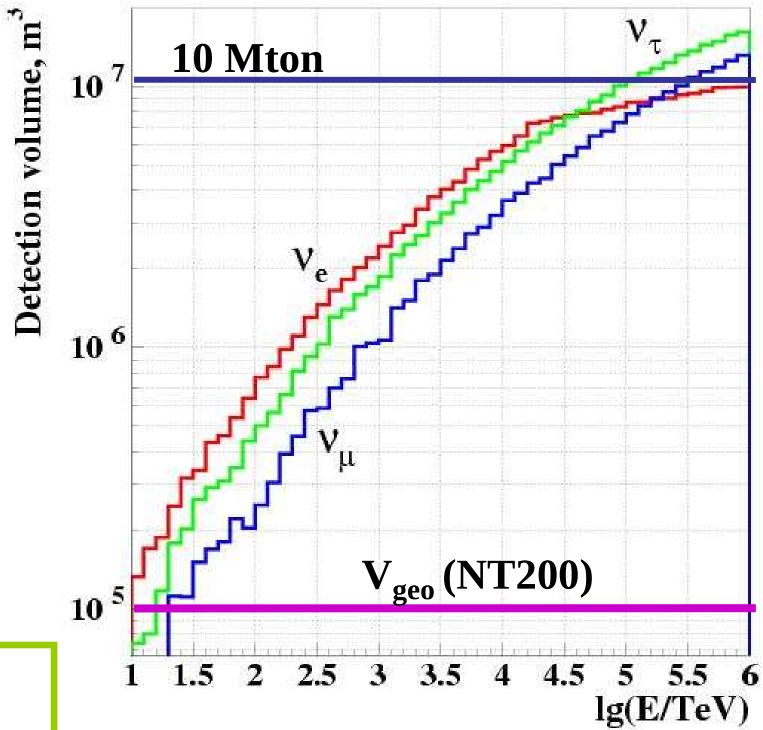
Search within non-instrumented volume below NT200 detector for cascades = Upward moving light fronts.

New: shower location,directio + energy reconstructed → BG suppression.



NT200+ : Instrument the volume below detector
→ better BG suppression and improved physics.

Effective Volume vs. Energy



V_{det} > 1 Mton at 1 PeV

Diffuse Flux Limits

NEW

New analysis of existing data with full event Reconstruction (E, Vertex, direction): published limit improved by factor ~3 !

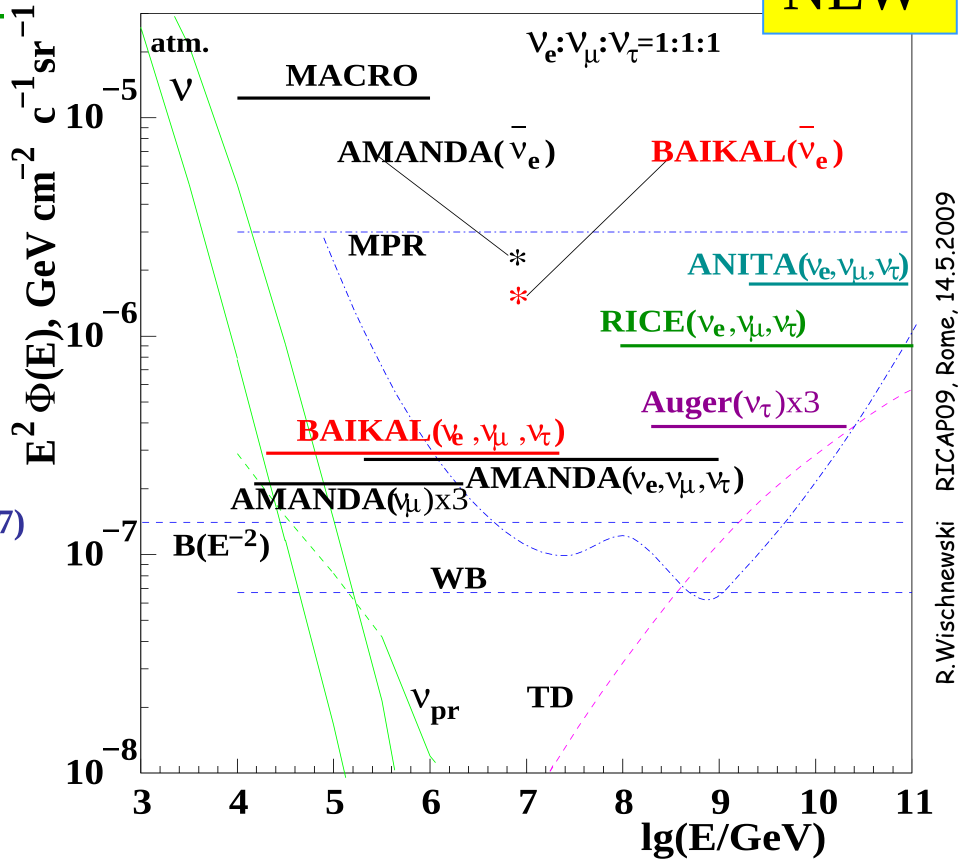
The 90% C.L. "all flavour" limit, $\nu_e:\nu_\mu:\nu_\tau = 1:1:1$
(20 TeV < E < 20 PeV)

$$E^2 \Phi_\nu < 2.9 \cdot 10^{-7} \text{ GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$$

(Cascades Baikal, 2008, Astronomy Letters, in press;
was APP/2006: 8.4 $\cdot 10^{-7}$)

$E^2 \Phi_\nu < 2.2 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1} **(Muons AMANDA-II, 2007)**

Model	BAIKAL	AMANDA
Stecker05	3.4	1.6
Szabo,Protheroe u	0.03	0.05
Szabo,Protheroe l	0.19	0.28
Mannheim(95) pp+pγ	1.4	1.2
Protheroe(96) pγ	0.5	0.3
Mannheim,ProtheroeRachen(01)	1.8	0.9
Semikoz,Sigl(03)	1.0	-

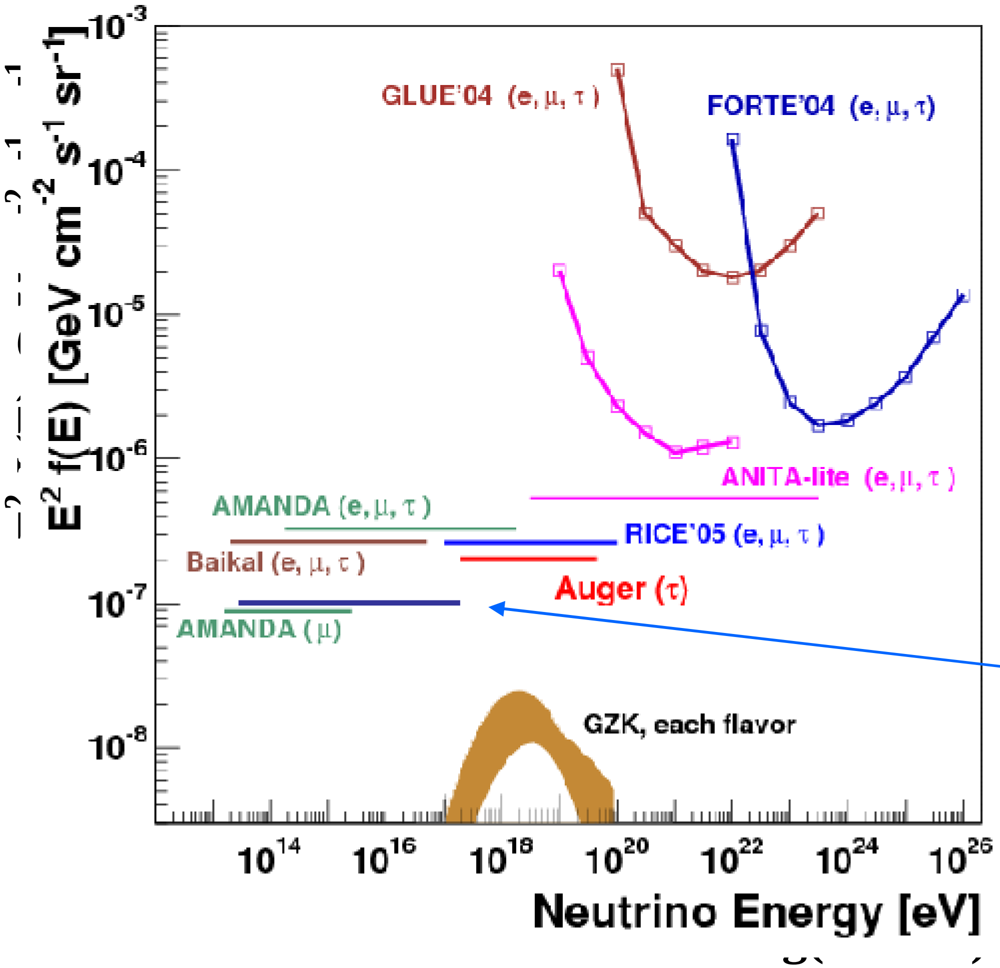


Limits given for all-flavors

Assume 1:1:1 flavor flux ratio@earth / source1:2:0

Model rejection factor $n_{90\%} / N_{model}$

Diffuse Flux Limits (2)



Auger-Plot (2007), updated.

New Baikal Limit, 2008, in print

limits given for single flavor

1:1:1 flavor flux ratio @earth assumed (source1:2:0)

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The New Project:

A Km3 – size Detector in Lake Baikal

("Gigaton Volume Detector")

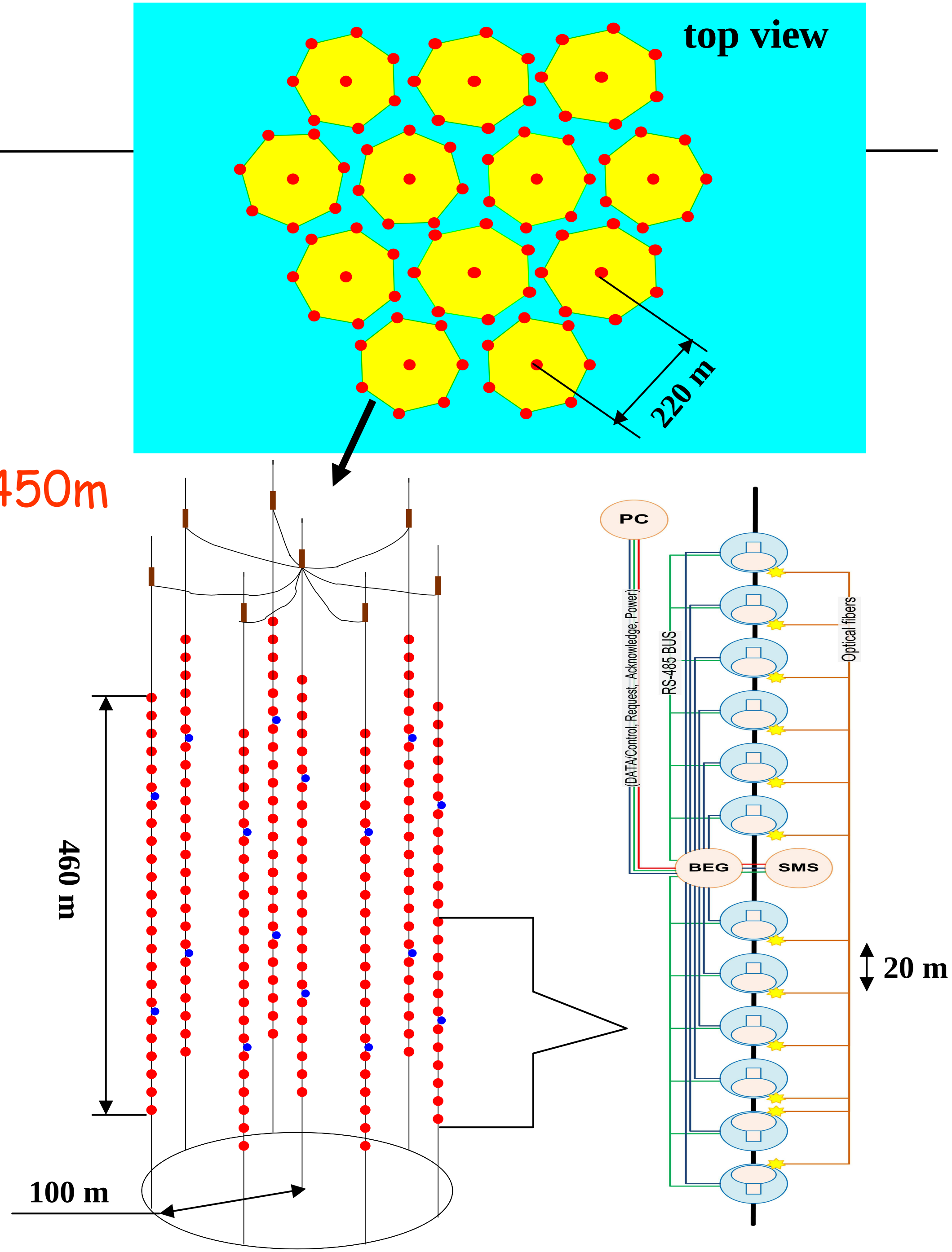
Gigaton Volume (Km3) Detector in Baikal

- Sparse instrumentation:
  (basic minimal configuration)

- 12 clusters each 8 strings
  = 96 strings with 22 – 24 OMs 450m
  = 2100 – 2300 OMs total

- Cascades effective volume for
  >100 TeV ~ 0.5 -1.0 km^3
  $\mathrm{dlg}(E) \sim 0.1$, $d\theta_{med} < 4^o$

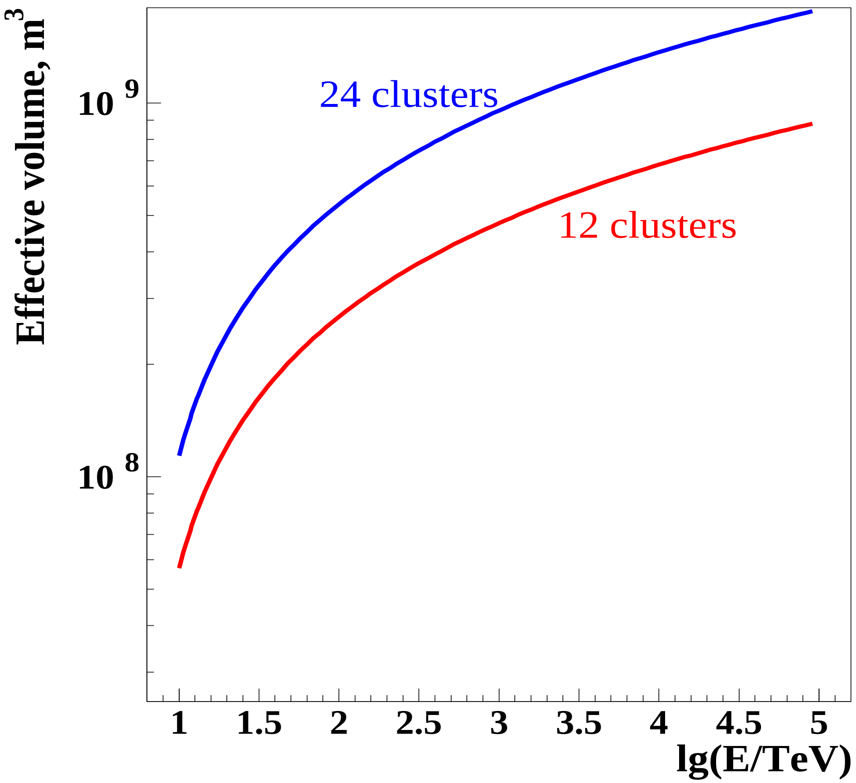
- Muon detection with
  energy > 10 - 30TeV
  $d\theta_{med} \sim 0.5^o$



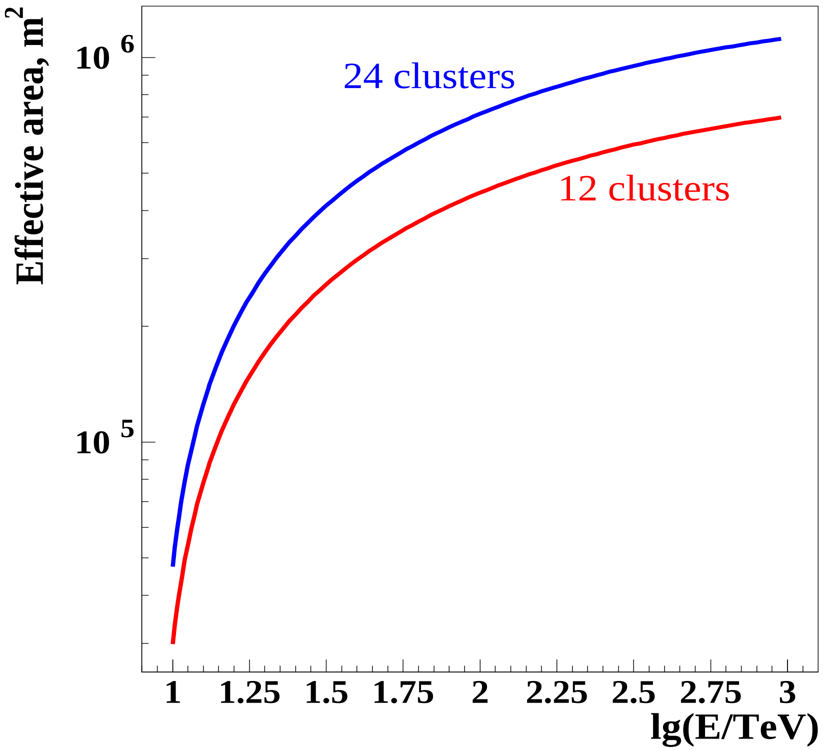
Cluster

Km3-MC optimization … in progress …

HE-cascades detection volume



HE-muons detection area



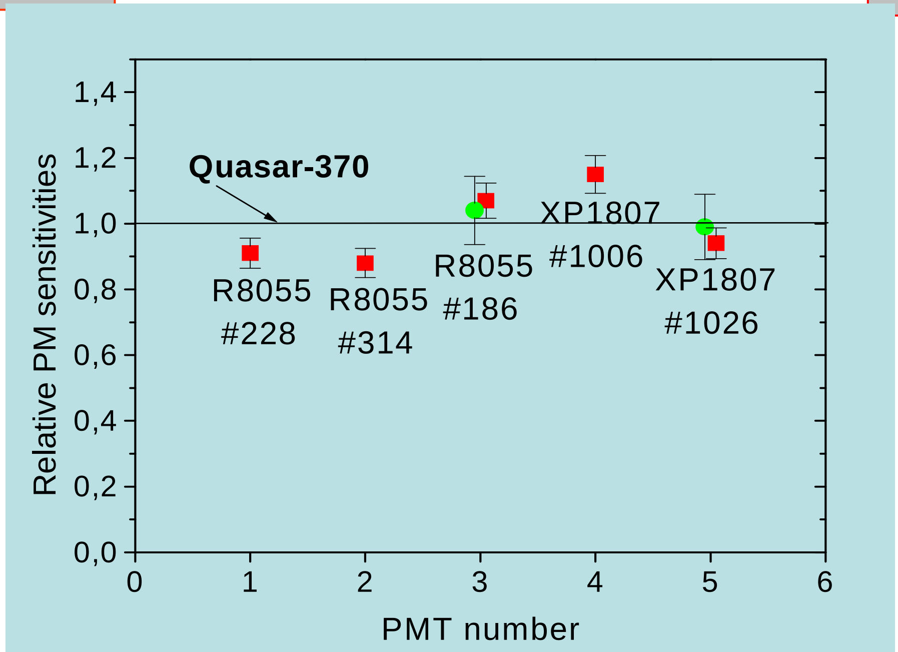
2006-2007: R&D of basic Km3 elements - PMT, …

Quasar-370 D ≈ 14.6”
Quantum efficiency ≈ 0.15

Hamamatsu R8055 D ≈ 13”
Quantum efficiency ≈ 0.20

Photonis XP1807 D ≈ 12”
Quantum efficiency ≈ 0.24

Smaller size (R8055, XP1807) tends to be compensated by higher photocathode sensitivities.



Relative effective sensitivities of large area PMs R8055/13” , XP1807/12” and Quasar-370/14.6”. Laboratory measurements (squares), in-situ tests (dots).

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2008 – Deployment of the prototype string in Lake Baikal

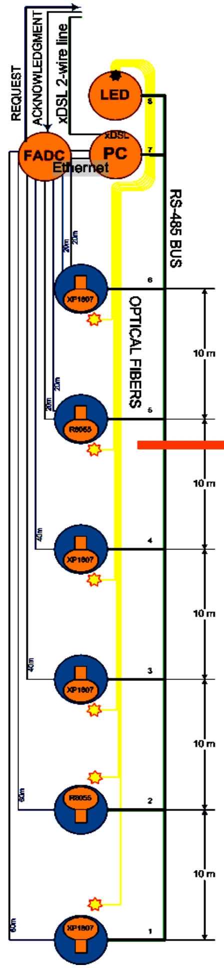
- In-situ tests of basic elements of the GVD: new optical modules, DAQ system, new cable communications.

- Studies of the basic DAQ/Triggering approach for the GVD.

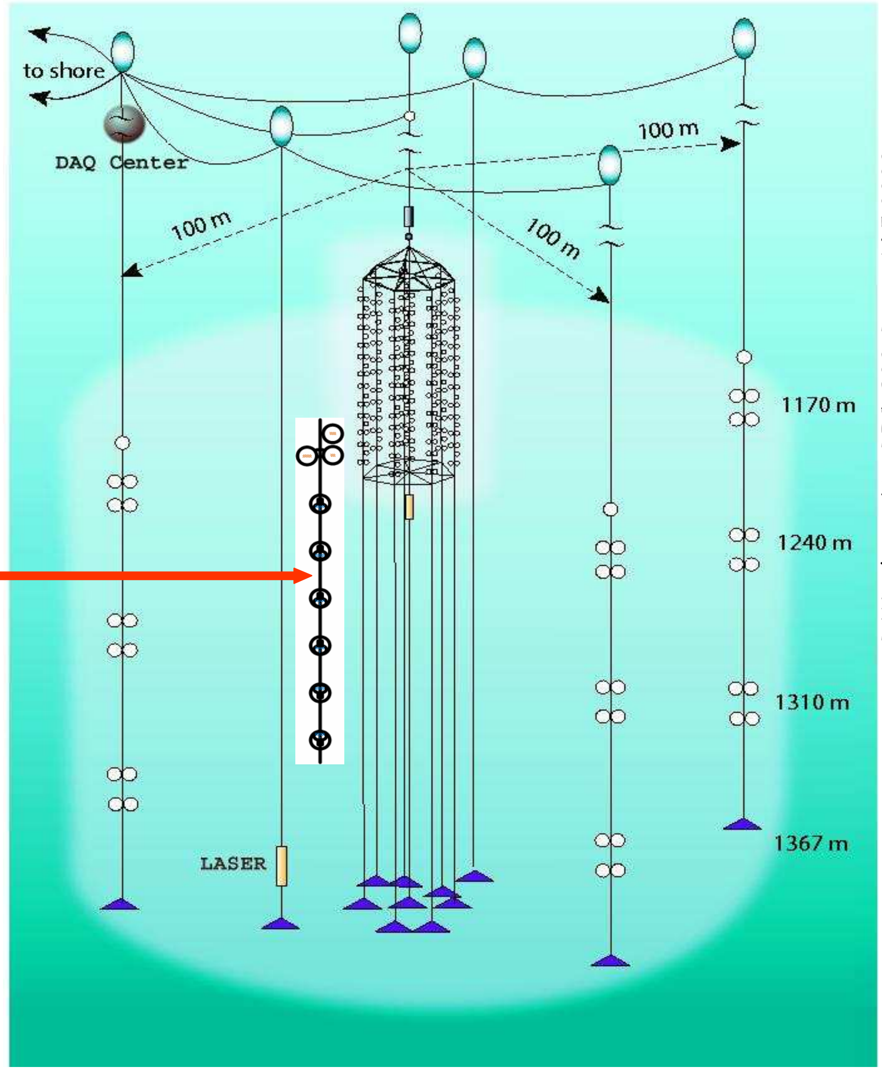
- Comparison of the classical TDC/ADC approach with a FADC-based full pulse shape readout.

- 2009: 12 PMT upgraded string.

Prototype string



NT200+ current status



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Baikal – Km3: A Possible Schedule

- 2006 - 07 R&D, Testing NT200+
- 08 - 10 Technical Design

- 10 - 11 First Cluster
- 08 - 14 Fabrication (OMs, electronics, cables…)

- 12 - 13 Deployment (0.1 – 0.3) km3
- 14 - 15 Deployment (0.3 – 0.6) km3
- 16 - 17 Deployment (0.6 – 0.9) km3

Summary

- The Baikal Neutrino Telescope operates successfully since 1998.

- NT200 : focusing on diffuse HE-neutrino search.
  - HE-diffuse search: A "Mton-detector" with only 100kton geometric volume.
  - Other: Magnetic Monopoles, WIMPs, HE-atm.μ

- NT200+ : in-situ check design principle + key elements for KM3
  - also: with 5 Mton instrumented volume V_eff > 10 Mton at 10 PeV reachable.

- R&D work for Baikal-KM3 is in progress
  - new technology string(s) deployed (13" PMTs, FADC, cables, …)
  - start installing first Km3-strings in 2010 (?)

Thank you.

Final deployment step for NT200+.   April, 2005.