The Baikal Neutrino Telescope - Results and Plans

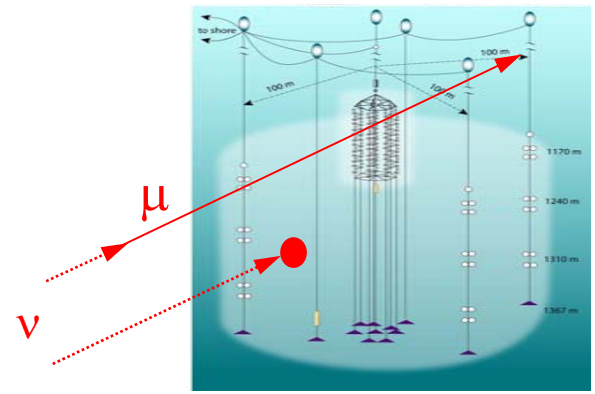
Outline:

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

Ralf Wischnewski

DESY

- for the Baikal Collaboration -



The Baikal Collaboration

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

~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

1998: NT200 commissioned

2005/06:
Upgrade to NT200+ completed; operating

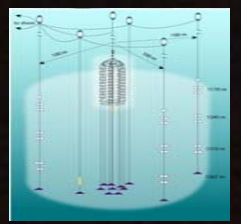
>2006: R&D activity for a Km3 detector in Lake Baikal
(„Gigaton Volume Detector")

~2010: expected start of Km3 deployment

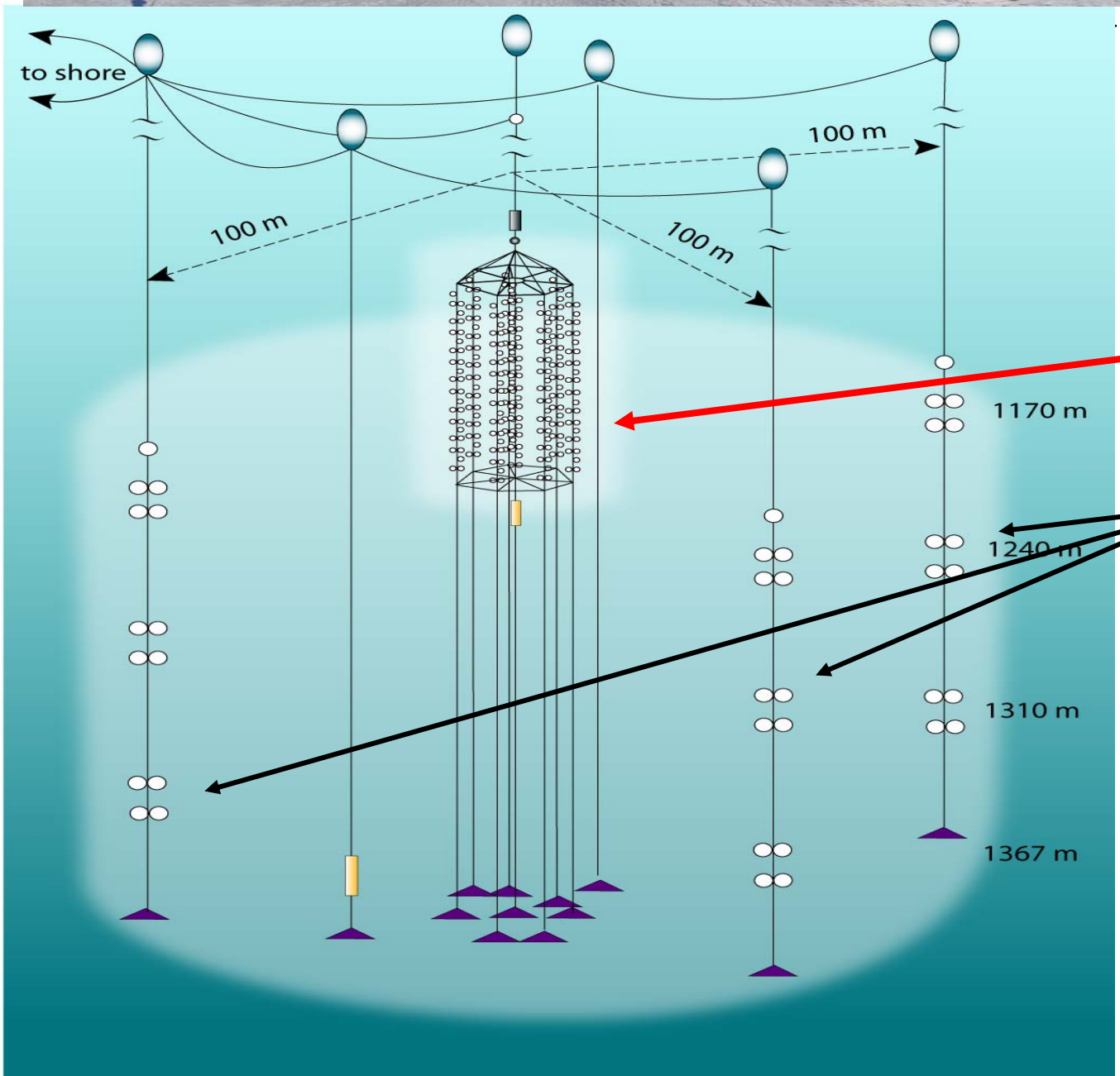

Baikal

Shore Station

4km OffShore
Depth: 1366m



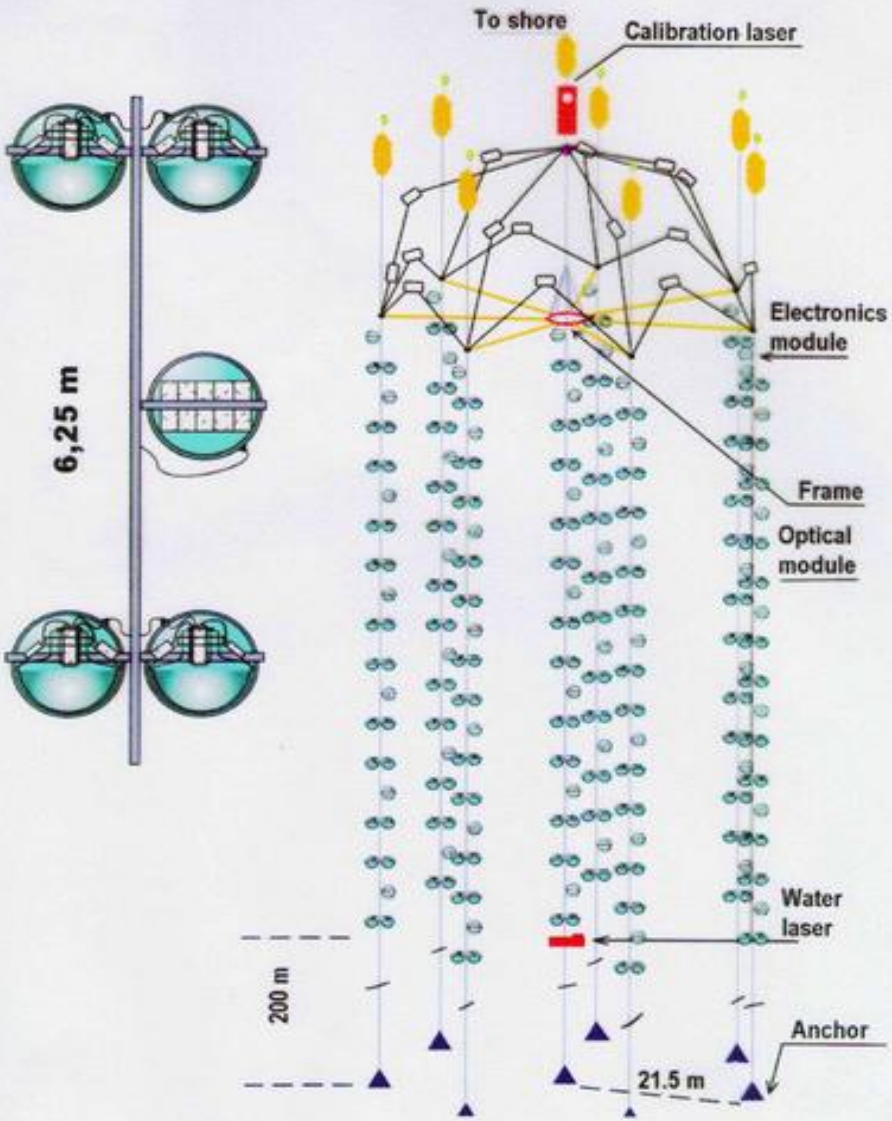
Lake Baikal



NT200+
=
NT200
+
3 long outer strings

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

NEUTRINO TELESCOPE NT-200



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

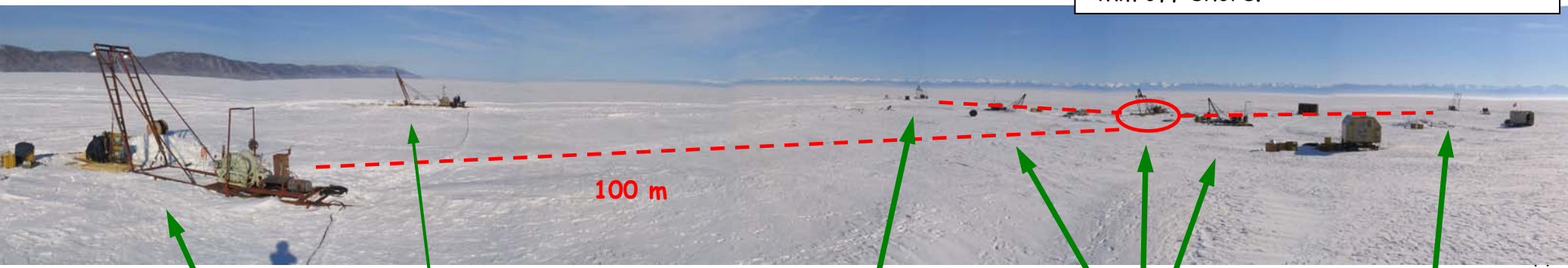
Effective area: 1 TeV ~ 2000 m²
Eff. Shower volume: 10 TeV ~ 0.2 Mton
1 PeV ~ 1 Mton !

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

Quasar PMT: d=37cm (14.6")

Advantages (1): Ice – a Perfect Deployment Platform

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



ExtString 1 New ShoreCable

ExtString 3

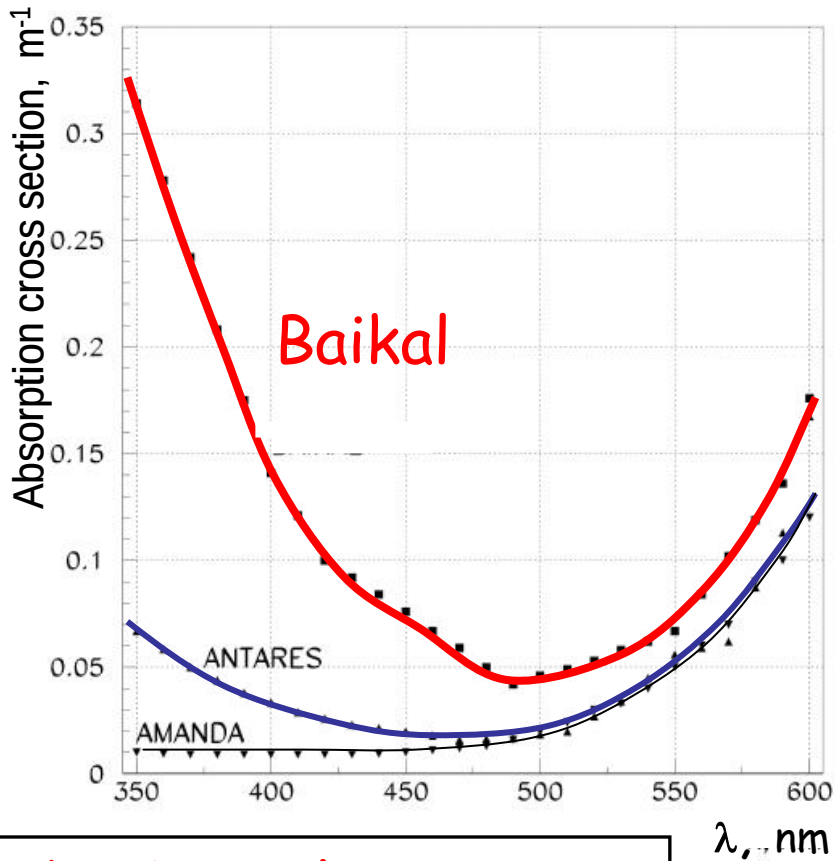
NT200
Central+Outer Str.

ExtString 2

R.Wischnewski TEV-

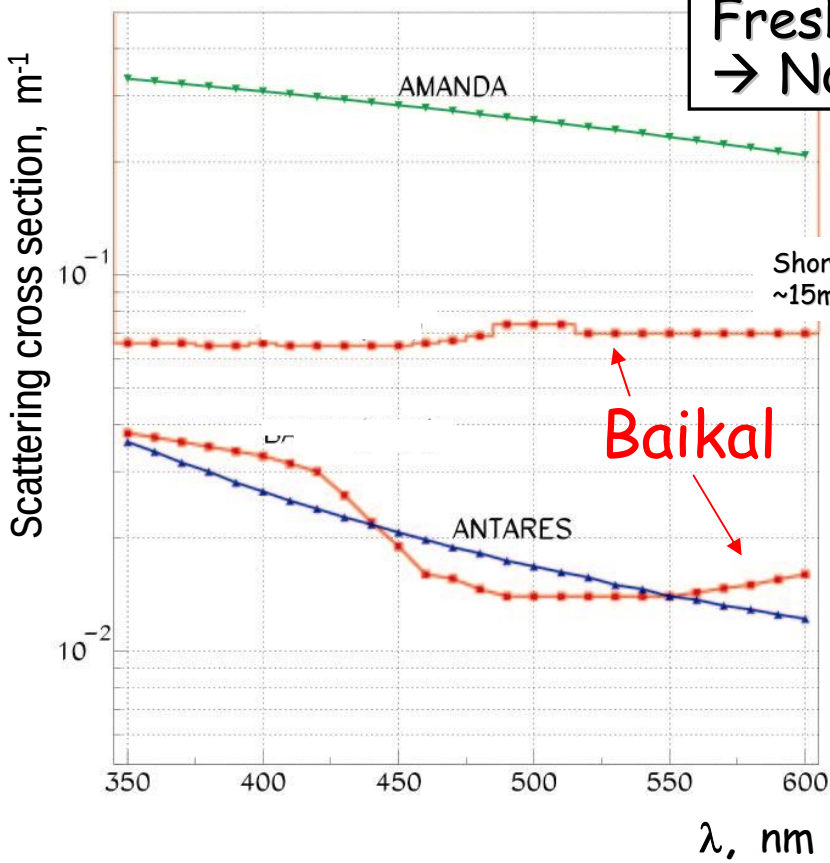
- Ice is available for 6-8 winter-weeks/year :
  - Telescope upgrades & maintenance
  - Test & installation of new equipment
  - Operation of surface detectors (EAS, acoustics,…)
  - Electrical winches used for deployment operations;
    All connections done dry.

Advantages (2): Water – Good Optical Properties



Abs. Length: 22 ± 2 m

Baikal:
Fresh water
→ No K40 BG



Scatt. Length ~ 30-50 m
⟨cos Θ⟩ ~ 0.85-0.9

(geom.scatt.L.)

R.Wischnewski TEV-III, Venice, 2007

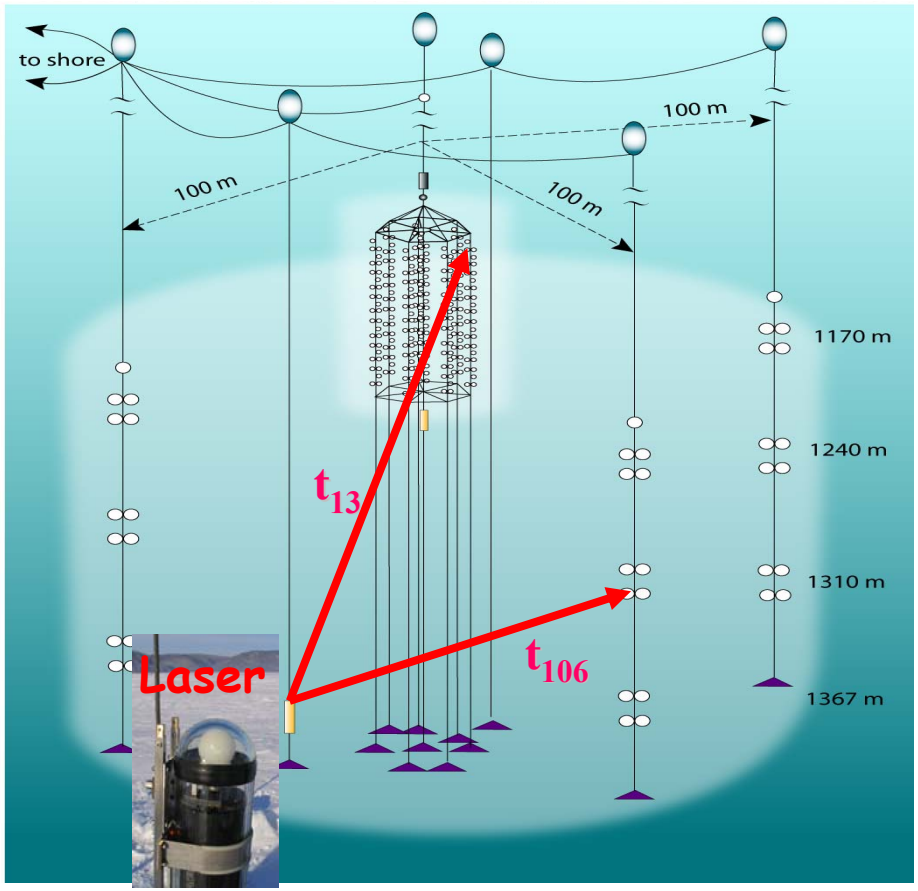
In-situ measurements
over many years

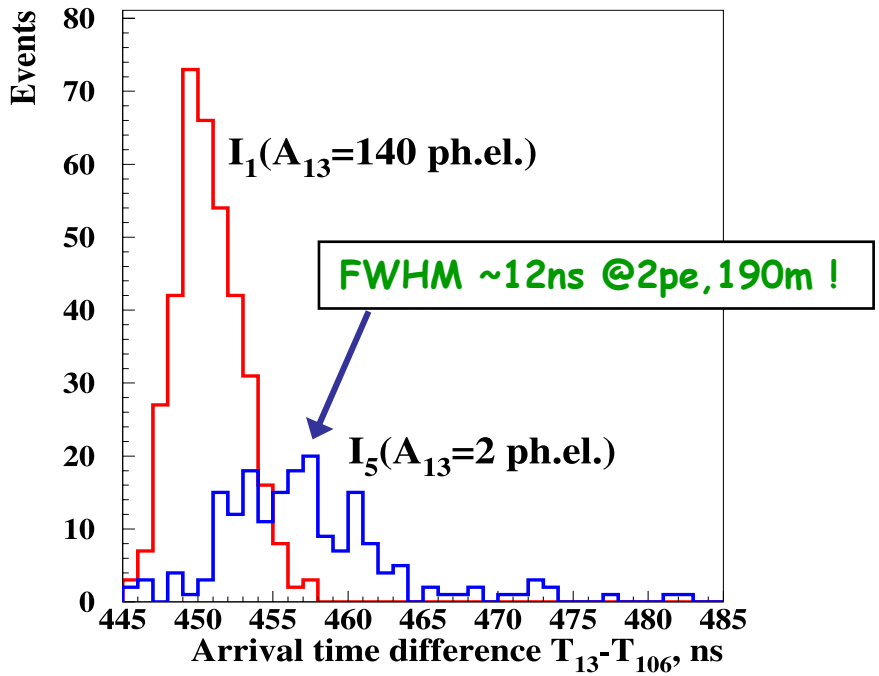
Note: IceCube's „effective" (diffusion) scattering is ~30m
→ for Baikal: ~300 - 500m !

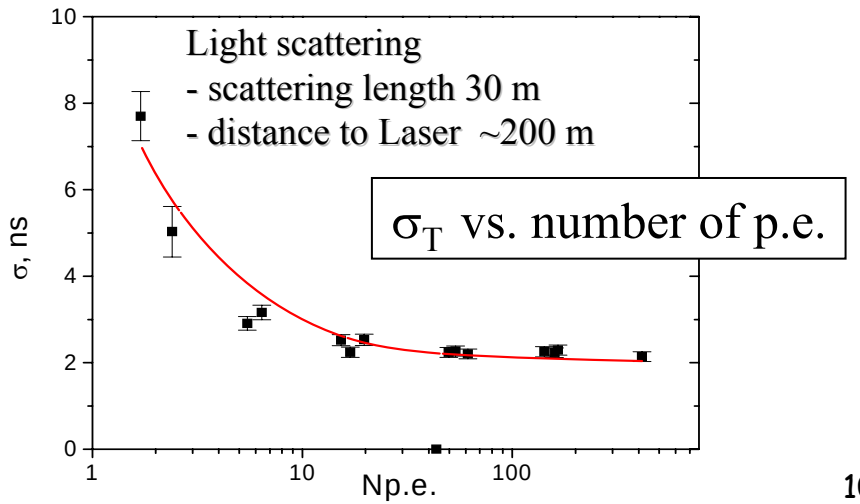
In-situ: Verification of Scattering @ large distances

Calibration Laser ~ 10^{12} – 5 10^{13} γ/pulse (1 ns)
⟶ E_Shower ~ 10 – 500 PeV

- Measure:
  Photon arrival times on Chan13 @187m distance
- Time Jitter = Scattering + Electronics







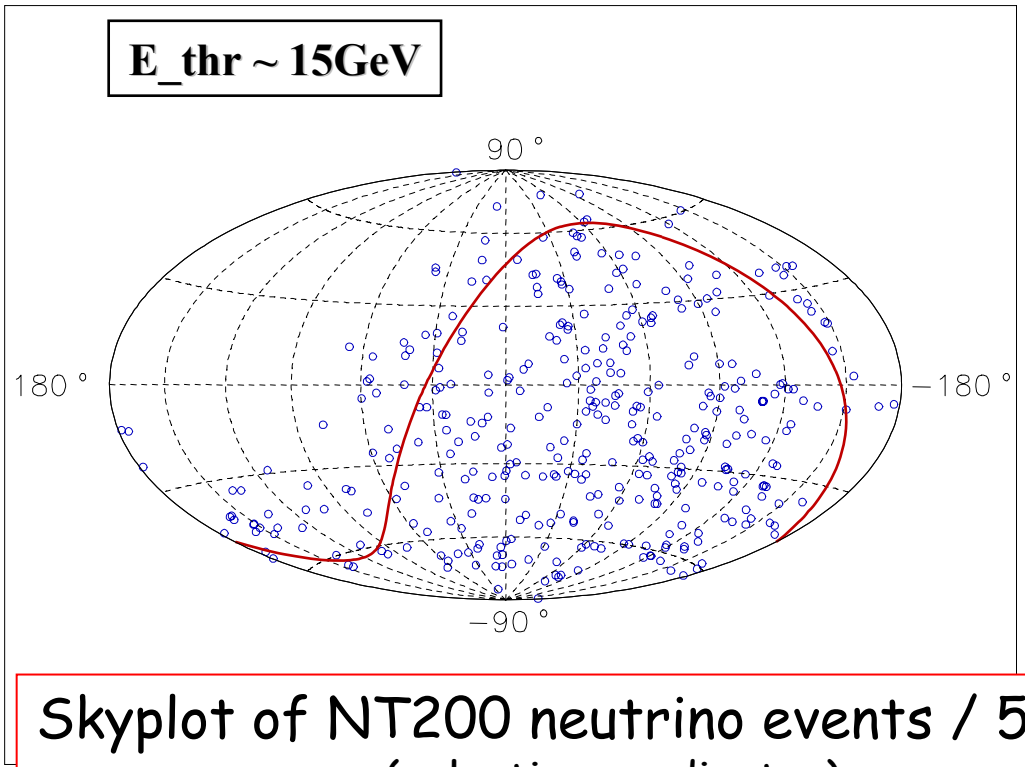
R.Wischnewski TEV-III, Venice, 2007

NT200 - Selected Results

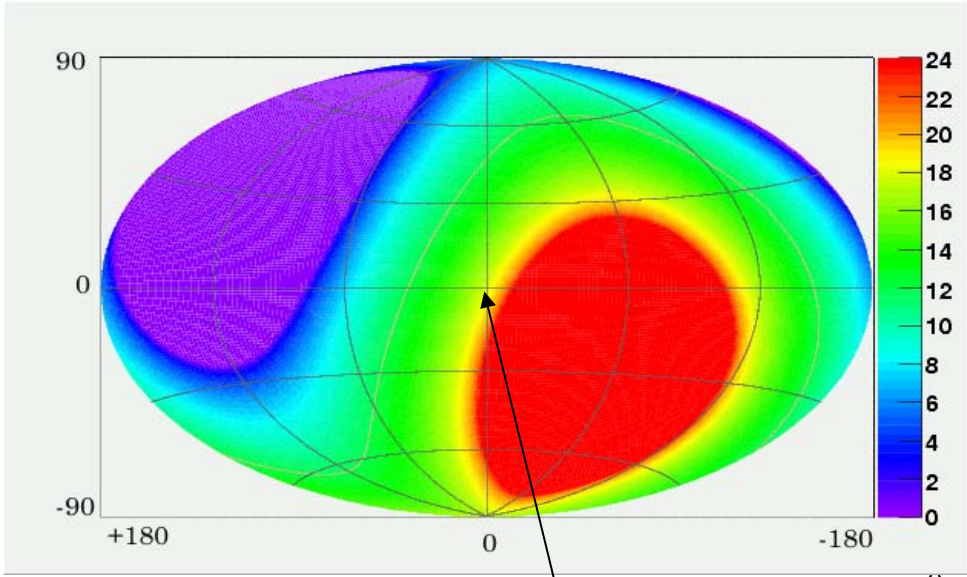
Data sample:
1998-2002 (Apr/98-Feb/03)
1038 days

- Low energy phenomena
  - Atmospheric neutrinos
  - WIMP Neutrinos
- Search for exotic particles
  - Relativistic Magnetic monopoles
- High energy phenomena
  - Diffuse neutrino flux
  - Neutrinos from GRB
  - Prompt muons and neutrinos
  - Exotic HE muons

Atmospheric Muon-Neutrinos



Skyplot of NT200 neutrino events / 5 years
(galactic coordinates)



Galactic center
visible 18 hours per day

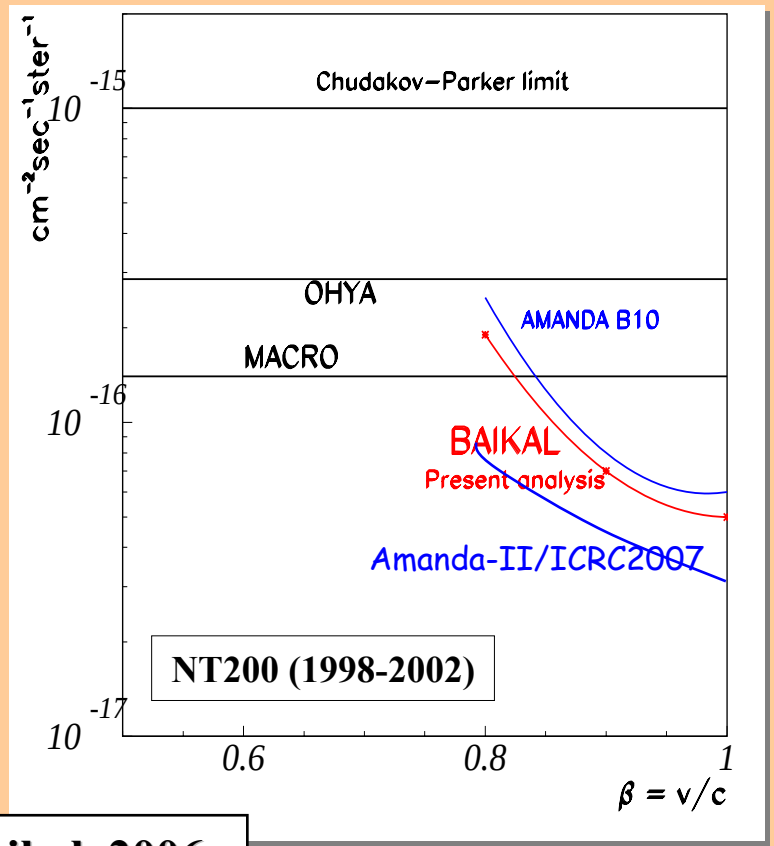
- Data: 372 upward ν events (1998-2002).
- MC: 385 ev. expected (15%BG).

($N_\mu(>15GeV)/N_\mu(>1GeV)\sim 1/7$)

→ A high statistics neutrino sample

for Point-Source Search, incl. GalCenter. **No evidence for non-atmosph. ν's.**

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



Baikal, 2006

90% C.L. upper limit on the flux of fast monopoles (1003 livedays).

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

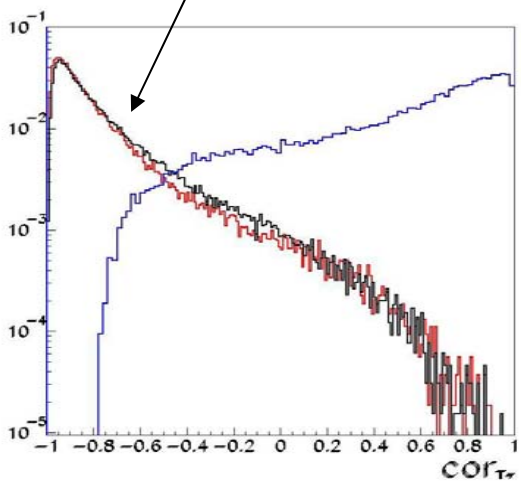
$g = 137/2,\ n = 1.33$

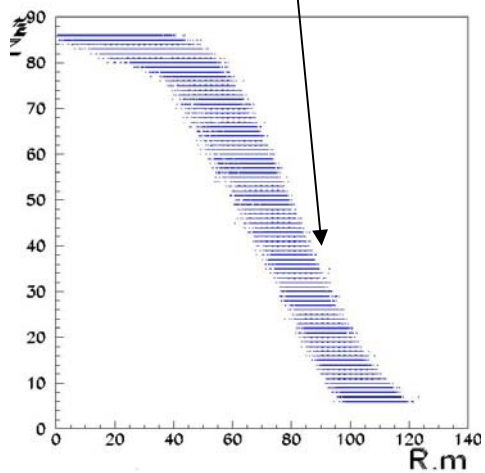
→ Bright light source, like muons $\sim E_\mu = 10^7$ GeV

Monopole selection criteria:

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

Background : atmospheric muons (downward)

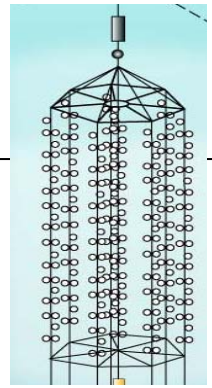




N_{hit} vs distance

R.Wischnewski TEV-III, Venice, 2007

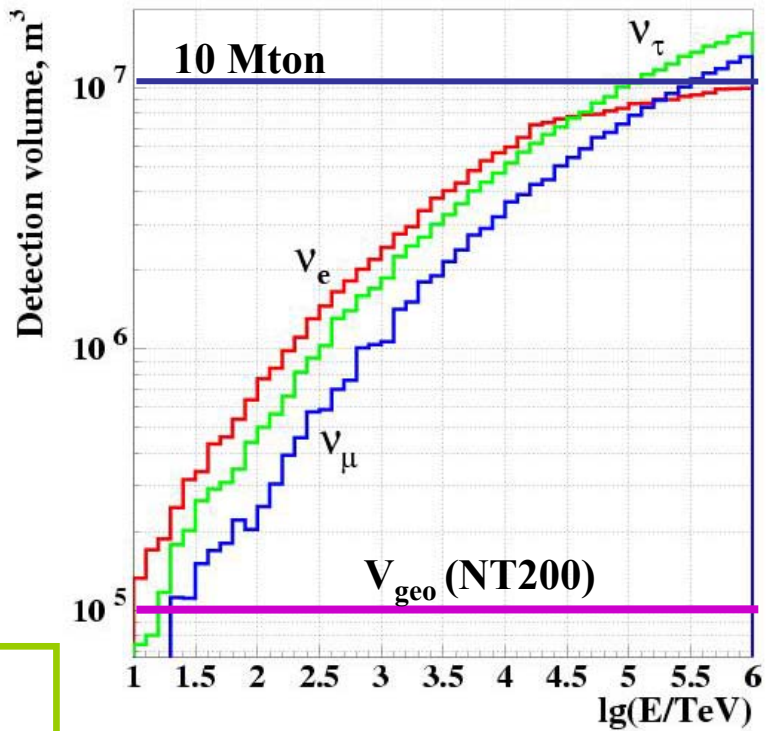
Search for High Energy Diffuse Cascades



NT200

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

Effective Volume vs. Energy



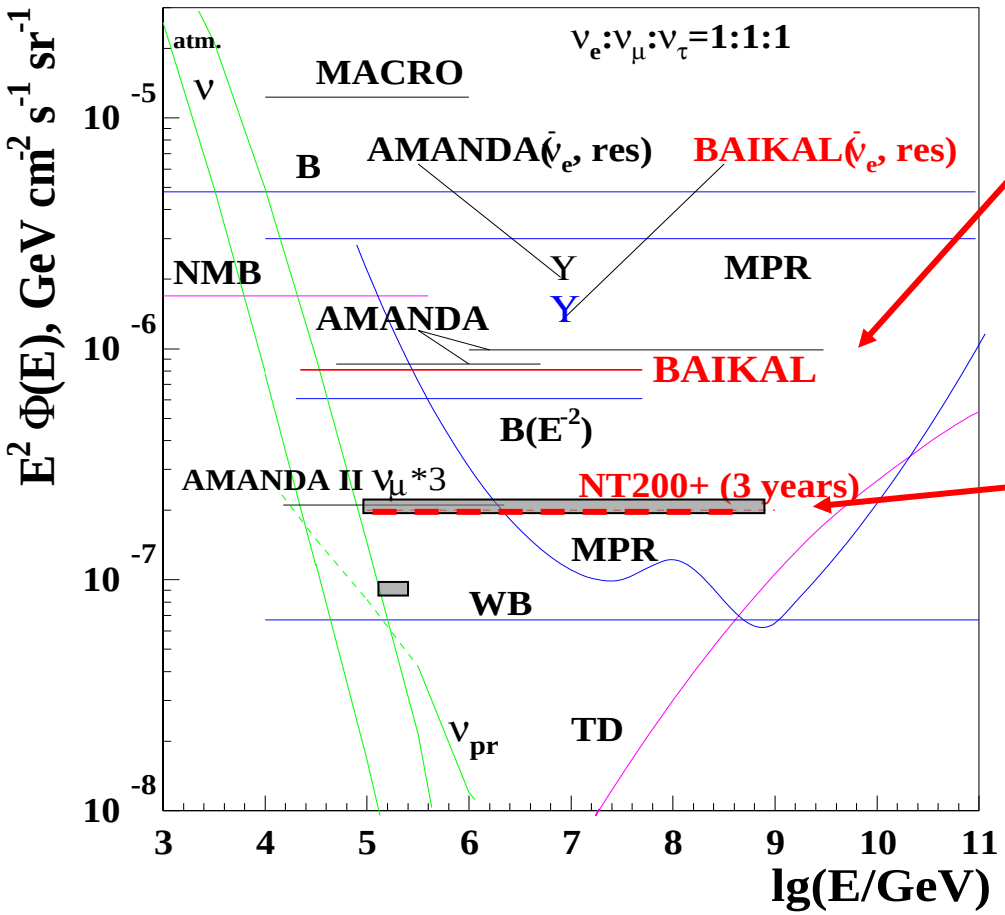
V_{det} > 1 Mton at 1 PeV

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

R.Wischnewski TEV-III, Venice, 2007

Diffuse Flux Limits

Exp. Limits, model predictions, and atmospheric ν-BG.



For a γ=2 spectrum $\Phi_\nu \sim E^{-2}$ the Baikal NT200 limit is (20 TeV < E < 50 PeV):

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

Astropart.Phys. 25 (2006) 140

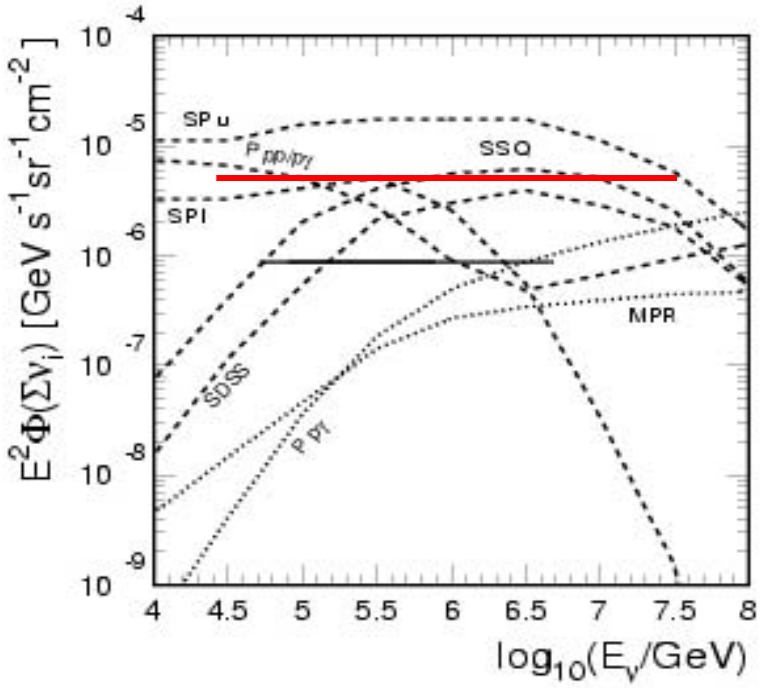
NT200+ sensitivity (~ Amanda-II)

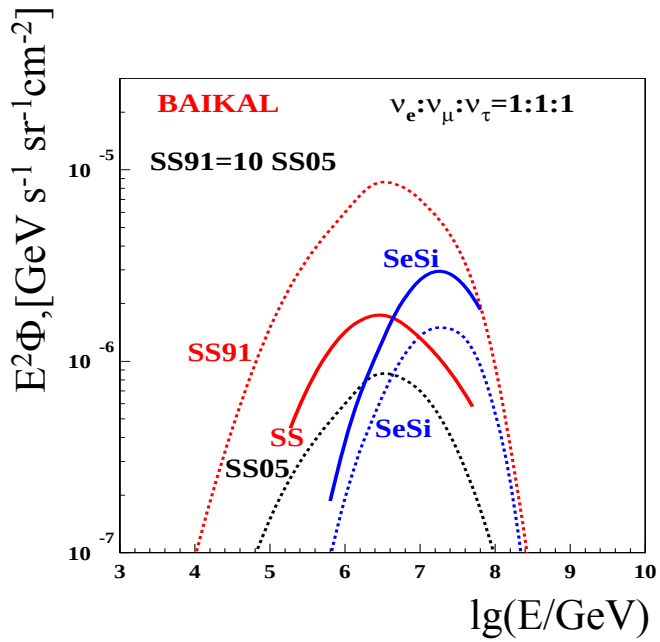
Amanda-II, see talk by G.Hill

limits given for all-flavors

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

Exp. ν_μ limits are multiplied x3





Neutrinos from Quasar Cores

SS – Stecker, Salamon (91,05)

SP – Szabo, Protheroe (92)

Neutrinos from Blazars

M pp+pγ - Mannheim (95)

P pγ - Protheroe (96)

MPR - Mannheim, Protheroe, Rachen (01)

SeSi - Semikoz, Sigl (03)

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

The New Project:

A Km3 – size Detector in Lake Baikal

("Gigaton Volume Detector")

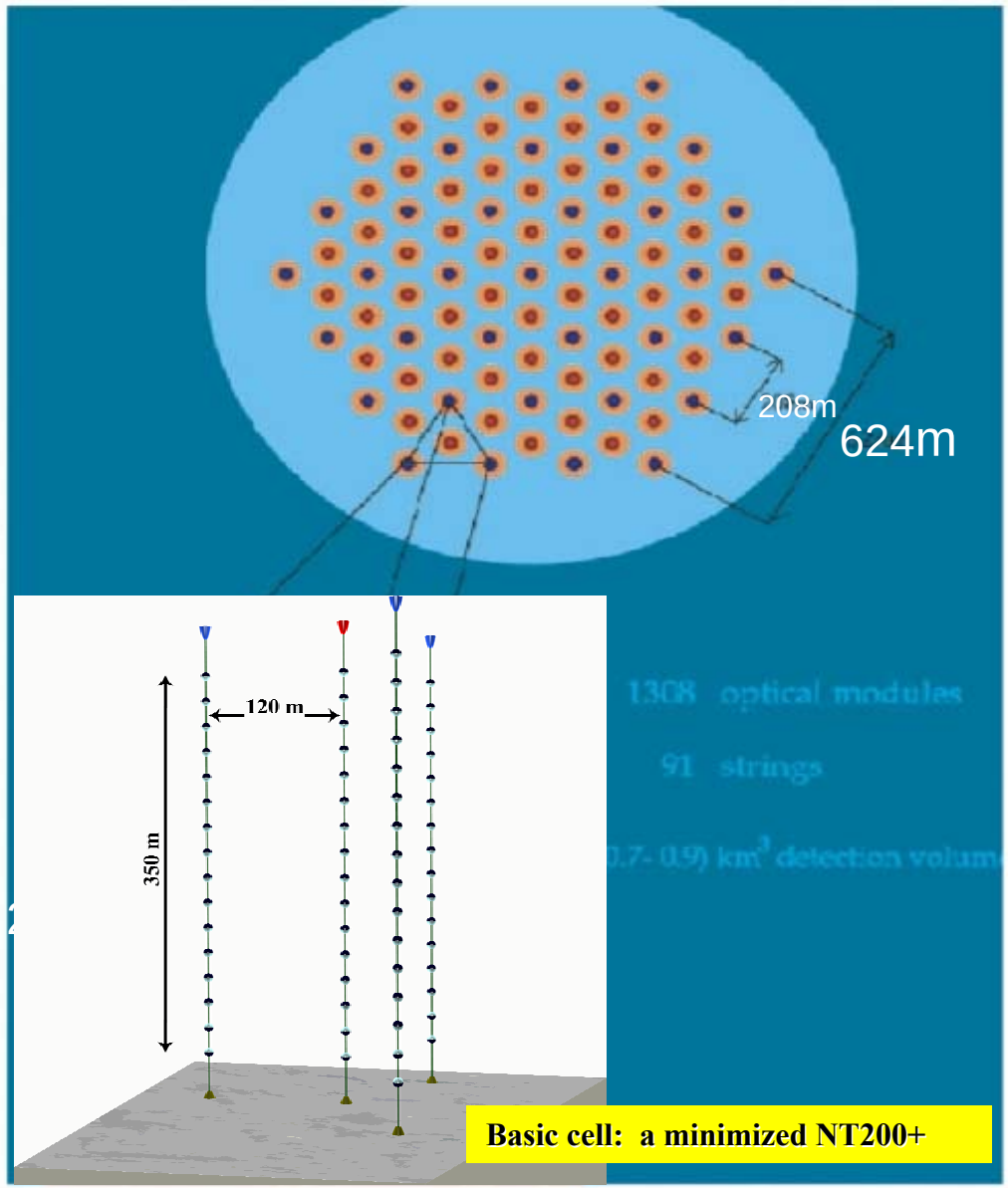
A Km3-scale Baikal Neutrino Detector

Sparsely instrumented array:

- 1300-1700 OMs
- 90-100 strings, 350m length
- 12-16 OM/string
- string distance ~120m *

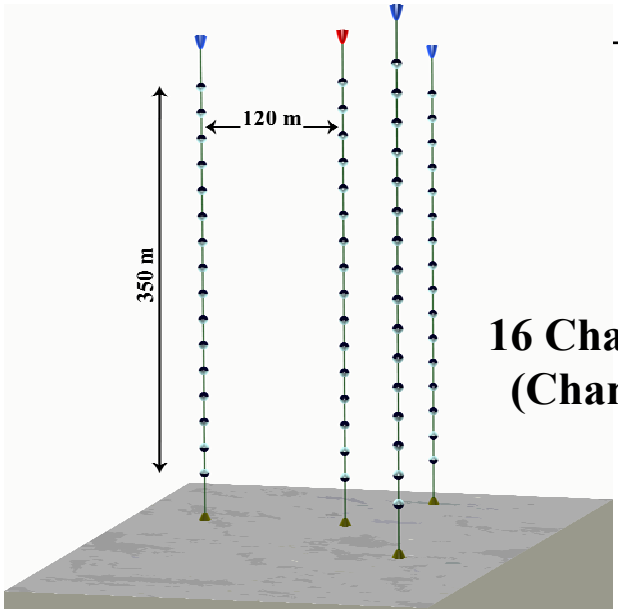
→ Casacde effective volume for
≥ 100 TeV: ~ 0.5-1 km³
$\delta \lg(E) \sim 0.1,\ \delta\theta_{med} < 4^{o}$

→ Muon detection from 10-30TeV

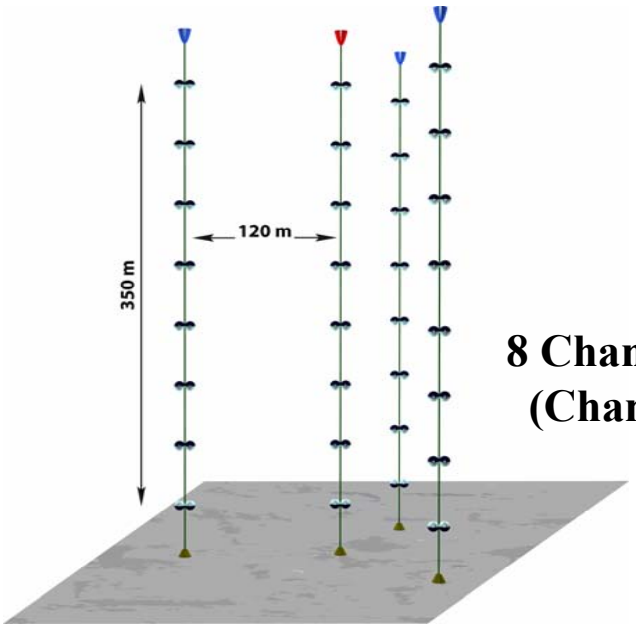


*Toy model (MC optimization in progress)

Km3 Design Studies (in progress)

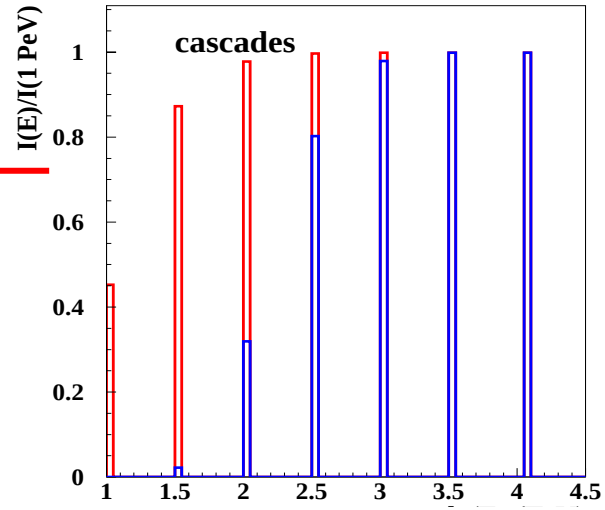


16 Channel / String
(Channel = 1 OM)



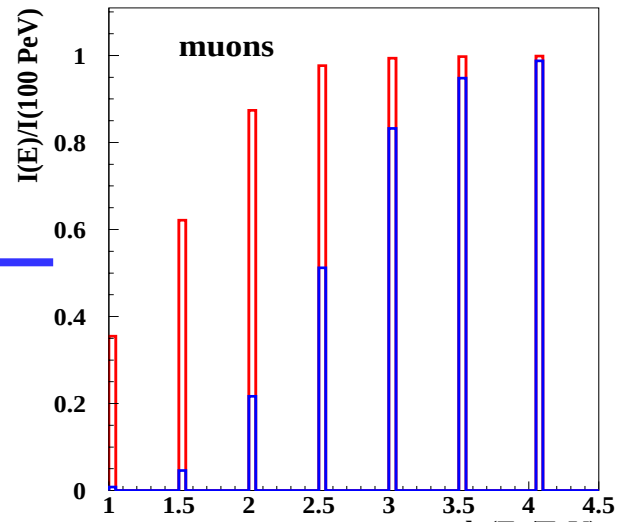
8 Channel / String
(Channel = 2 OM)

contained events



Cascades

instrumented volume
$V=3.5\ 10^8\ m^3$



Muons

$\langle S \rangle = 0.8\ 10^6\ m^2$

Km3 R&D: PMT Selection

Basic criteria of PM selection is effective sensitivity to Cherenkov light which depends on

Photocathode area × Quantum efficiency × Collection efficiency

and Optical Module design (FOV).

Baikal NT200+ (out of production)

IceCube
Antares
NEMO

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

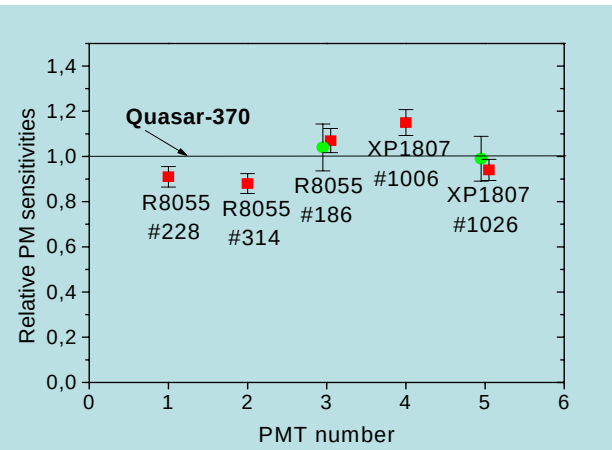
PMT development now is an active field with KM3NET/ BAIKAL-km3/… :
QE >30% , new Smart-PMT designs (QUASAR-like by Photonis/…?), …

Km3 R&D: PMT in-situ Tests (2007)

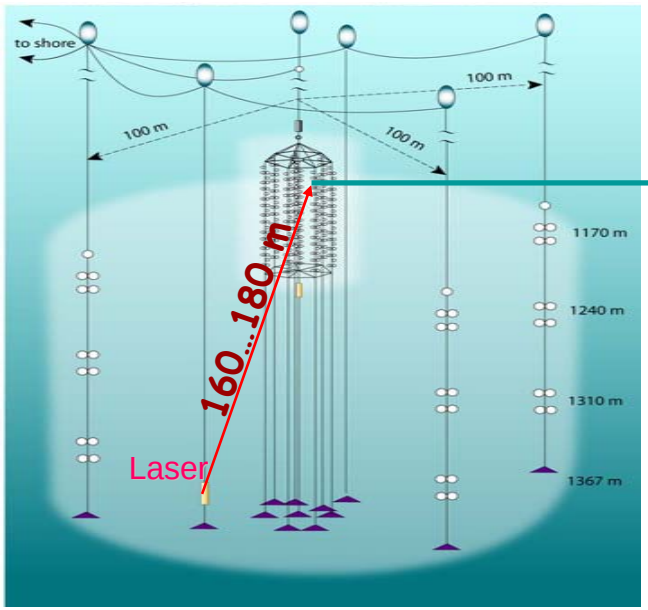
6 new PMTs installed in April 2007 inside NT200+:

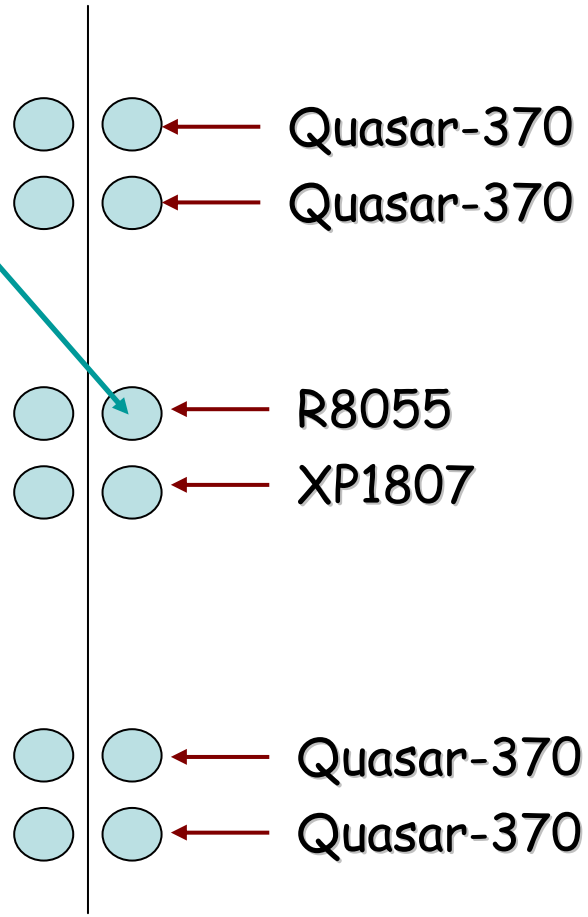
- 4 PM R8055 (Hamamatsu)
- 2 XP1807 (Photonis)

FADC readout for 2xR8055.



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





(NT200 - string)

R.Wischnewski TEV-III, Venice, 2007

Km3 R&D: Full prototype string for 2008

April 2008:
Installation of a "new technology" prototype string as part of NT200+

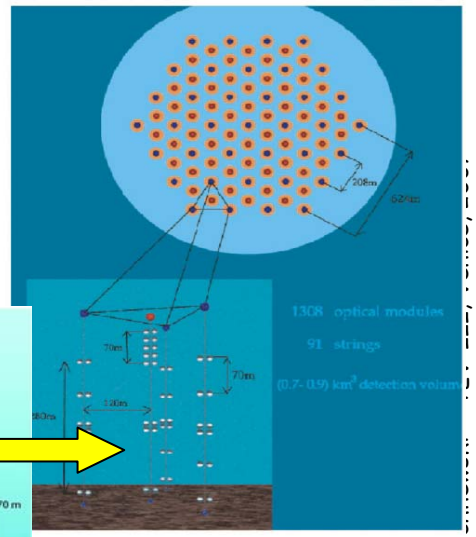
New: PMTs, electronics + trigger

- In-situ tests of all basic elements of the future detector:
  - Optical modules
  - DAQ system
  - new cable system

- Study of DAQ/Triggering concept for the km3-detector;
  e.g. "quasi-local coincidences"

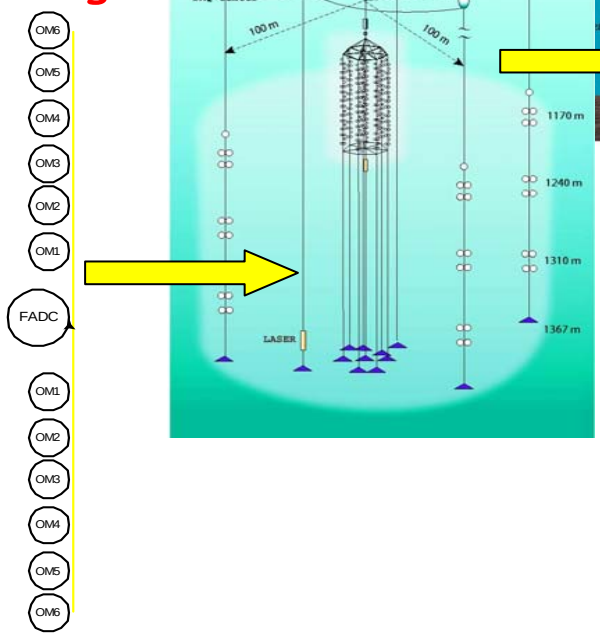
- Comparison of new FADC (200MHz) readout with classical TDC/ADC approach.

Km3 Baikal Project



NT200+ current status

Prototype string



Baikal – Km3: Possible Schedule

- 2006-07 R&D, Testing NT200+
- 08 Technical Design
- 08-14 Fabrication (OMs, electronics, cables…)
- 10-12 Deployment (0.1 – 0.3) km3
- 13-14 Deployment (0.3 – 0.6) km3
- 15-16 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+ : designed for diffuse cosmic ν-search.
  - 4x sensitivity gain; improved vertex, energy + direction for shower.
  - 5 Mton instrumented volume, V_eff > 10 Mton at 10 PeV.

- Baikal-Km3 activities started in 2006.
  - PMT choice & redesign of F/E & trigger electronics.
  - New technology km3-string for 2008.
    Design based on NT200+ experience and in-situ tests.

Thank you.

Final deployment step for NT200+. April, 2005.