14th Lomonosov Conference on Elementary Particle Physics

Baikal Neutrino Experiment: from NT200 to NT1000

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Moscow, August 20, 2009

Collaboration

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- Irkutsk State University, Russia.
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- DESY-Zeuthen, Zeuthen, Germany.
- Joint Institute for Nuclear Research, Dubna, Russia.
- Nizhny Novgorod State Technical University, Russia.
- St.Petersburg State Marine University, Russia.
- Kurchatov Institute, Moscow, Russia.

OUTLINE

Introduction

Neutrino telescope NT200+

Design and Selected Physics Results

Future Gigaton-Volume (GVD) detector NT1000

Preliminary Design
Prototype string for BAIKAL-GVD detector (2008-2009)

Summary

Baikal - Milestones

Since 1980 Site tests and early R&D started

1990 Technical Design Report NT200

1993 NT36 started: the first underwater array
the first neutrino events.

1998 NT200 commissioned: start full physics program.

2005 NT200+ commissioned (NT200 & 3 outer strings).

2006 Start R&D for Gigaton Volume Detector (GVD) – NT1000.

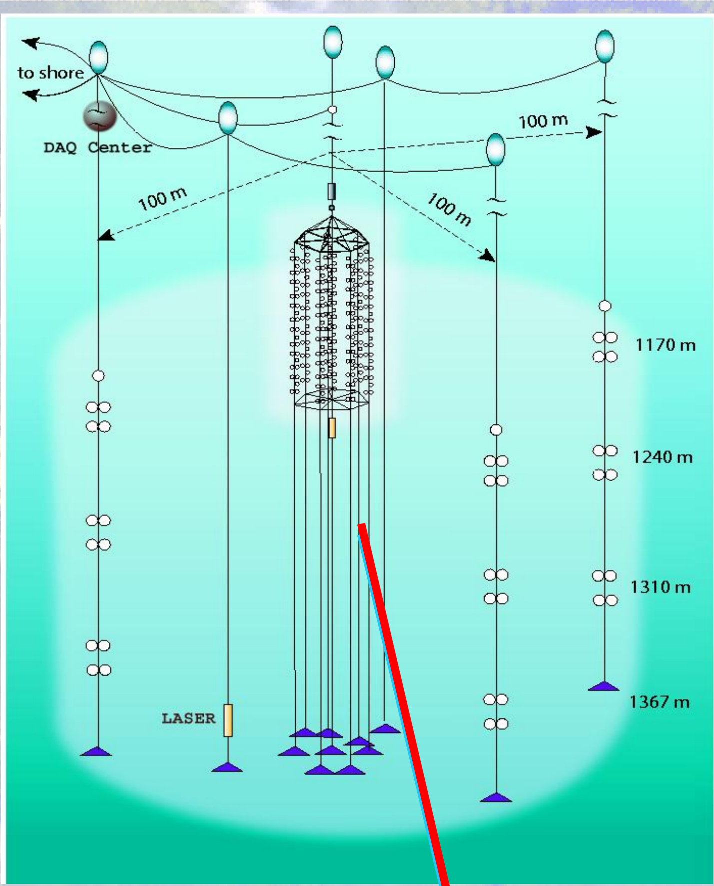
2008 In-situ test NT1000 electronics: 6 new technology optical modules

2009 Prototype string for NT1000: 12 optical modules

2011 GVD cluster (3 strings), Technical Design Report

Status of NT200+

NT200+ is operating now in Baikal lake



Quasar photodetector (∅=37cm)

LAKE BAIKAL

~ 3.6 km to shore, 1070 m depth

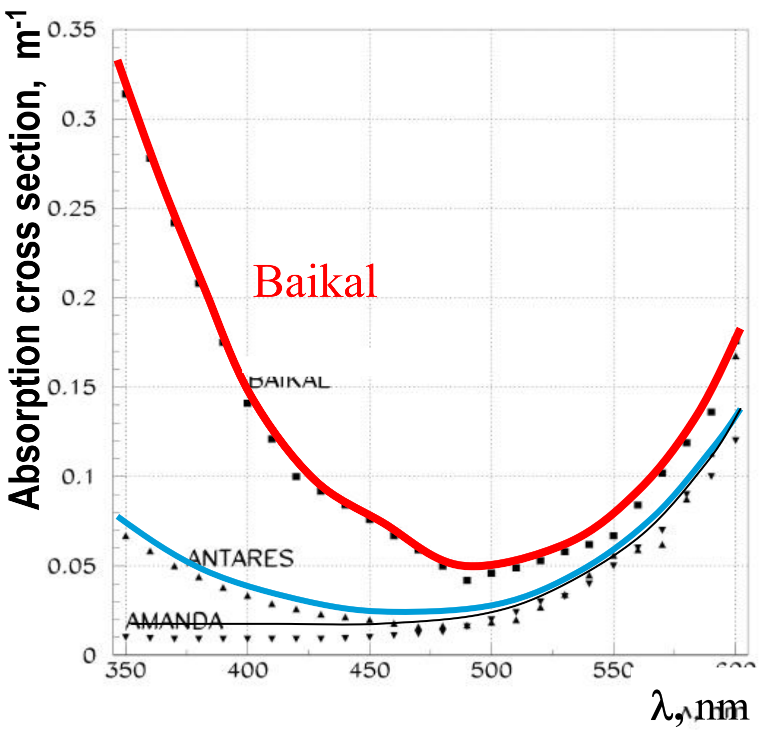
NT200: 8 strings (192 optical modules)
Height x ∅ = 70m x 40m, $V_{inst}=10^5 m^3$
Effective area: 1 TeV~2000m²
Eff. shower volume: 10 TeV~ 0.2 Mton

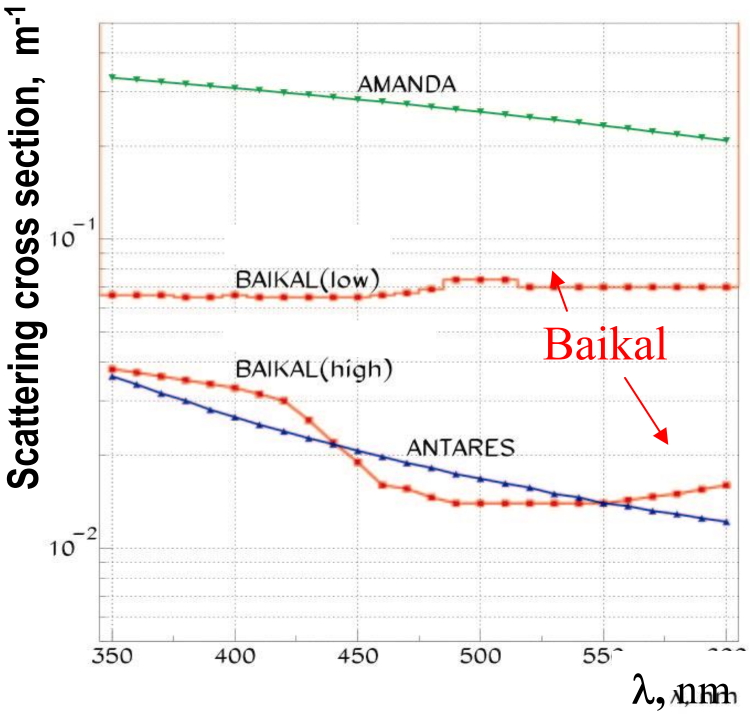
NT200+ = NT200 + 3 outer stringw (36 optical modules)
Height x ∅ = 210m x 200m, $V_{inst}=4\times10^6 m^3$
Eff. shower volume: 10^4 TeV ~ 10 Mton

→ ***~4 times better sensitivity***

→ ***Improve cascade reconstruction***

BAIKAL Water Optical Properties



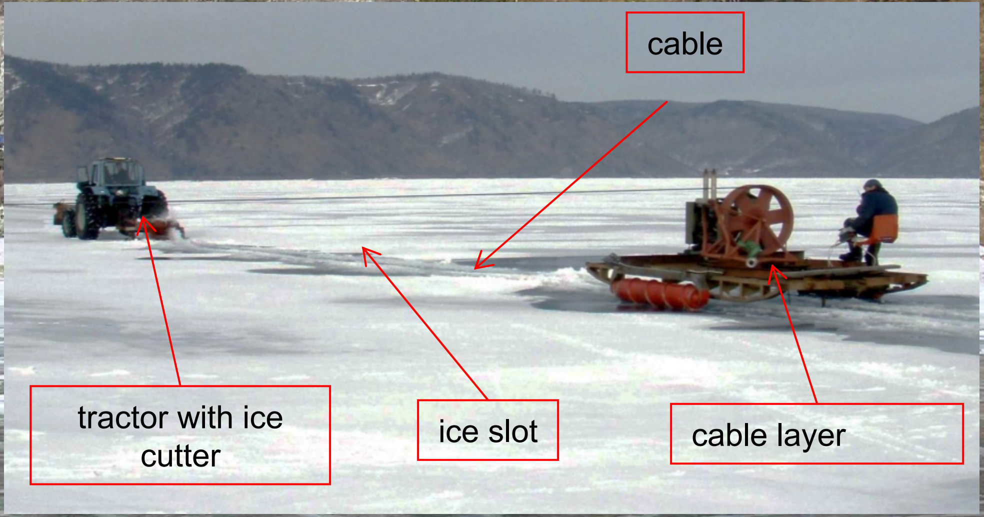


Abs.Length: 22 ± 2 m

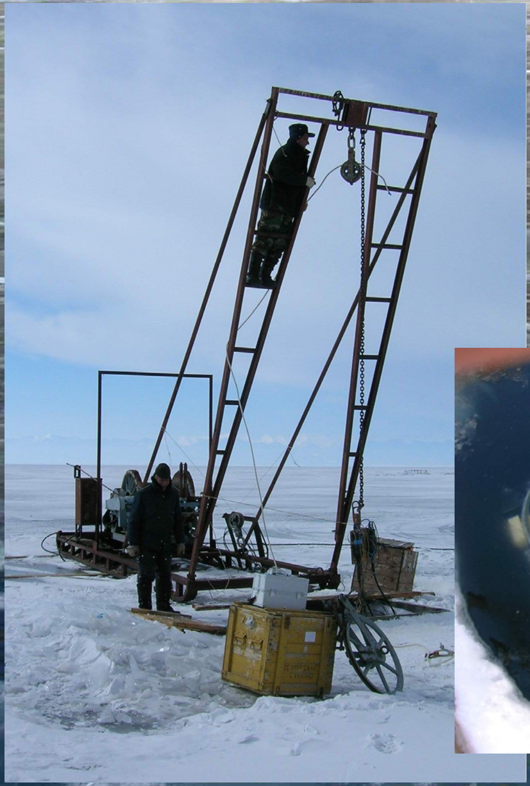
Scat.Length: 30-50 m
<cosθ>: 0.85-0.90

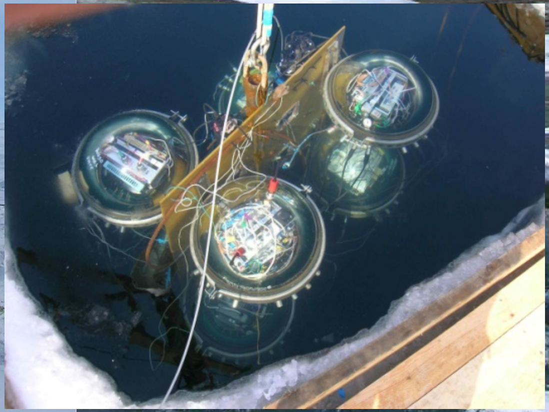
No high luminosity bursts from biology

Ice as a natural deployment platform



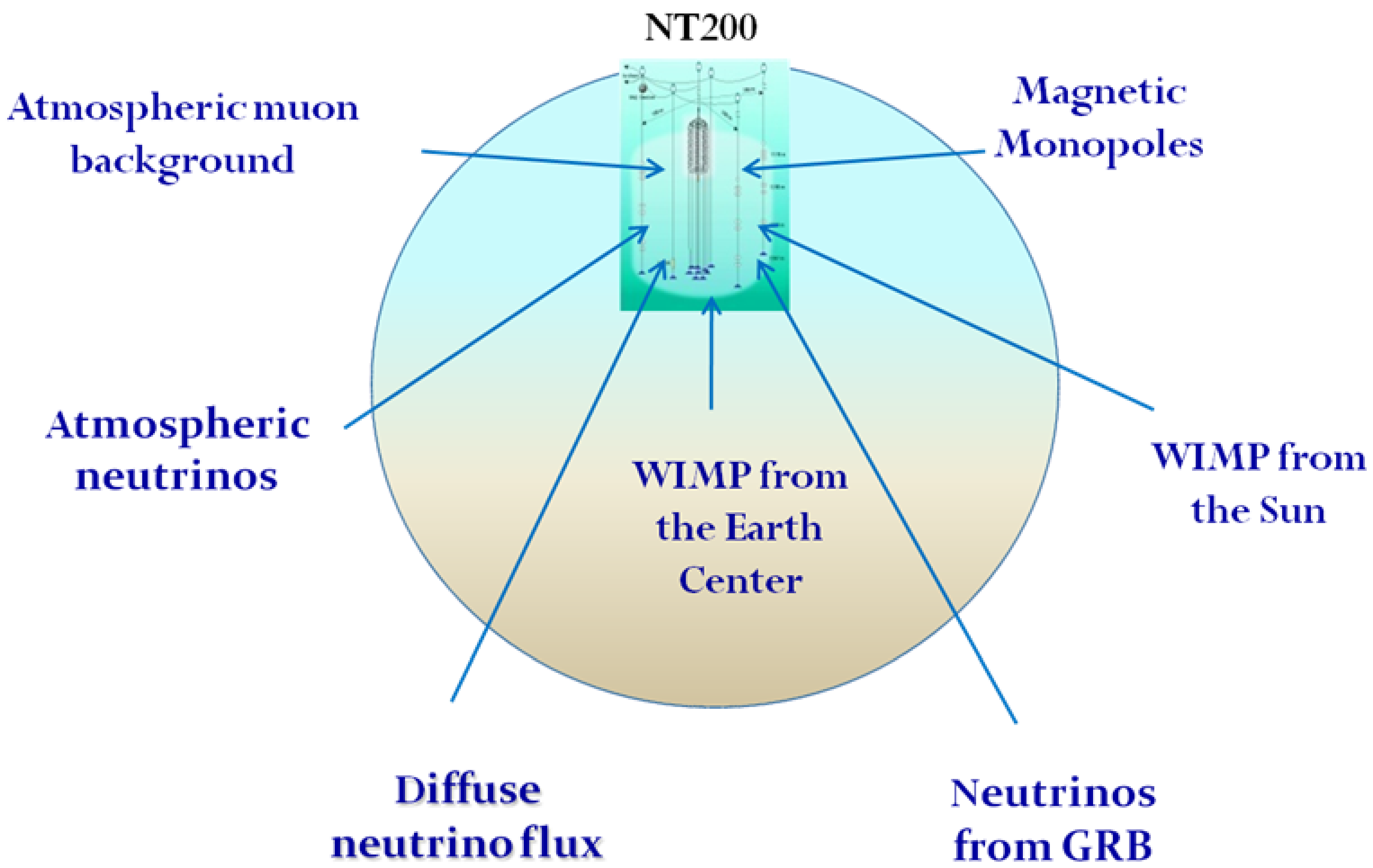
Shore cable mounting





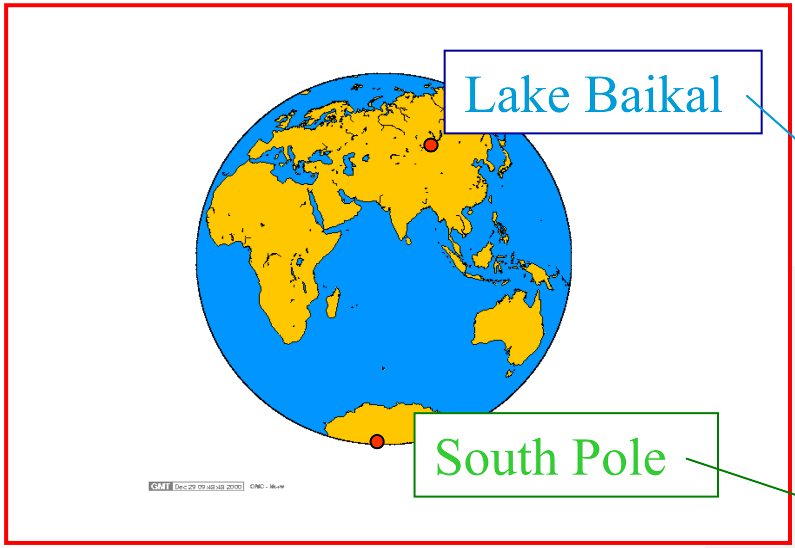
Deployment with winches

Selected Physics Results



Low energy muon neutrinos

Lake Baikal (NT200) & South Pole (Amanda)
Complete sky coverage including central parts of Galaxy

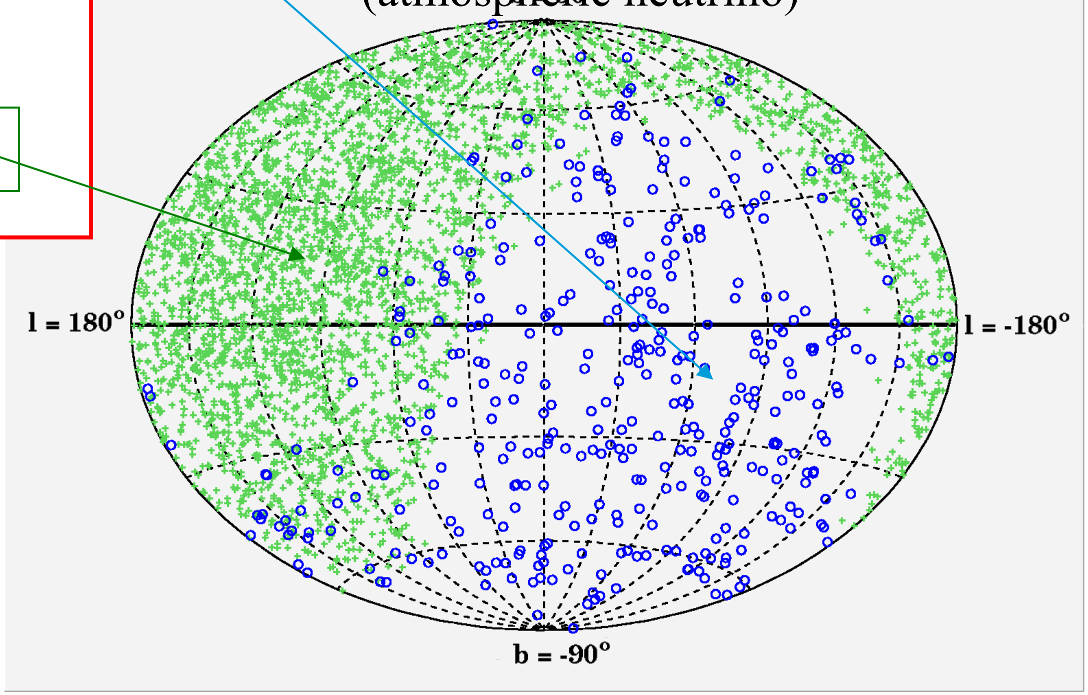


Skyplot of NT200 neutrino events (galactic coordinates)

E_{THR} 15-20 GeV

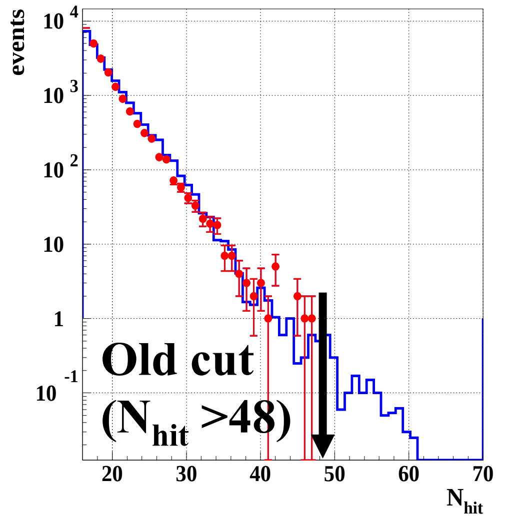
372 Neutrinos in 1038 Days (1998-2003)

385 events from Monte-Carlo (atmospheric neutrino)



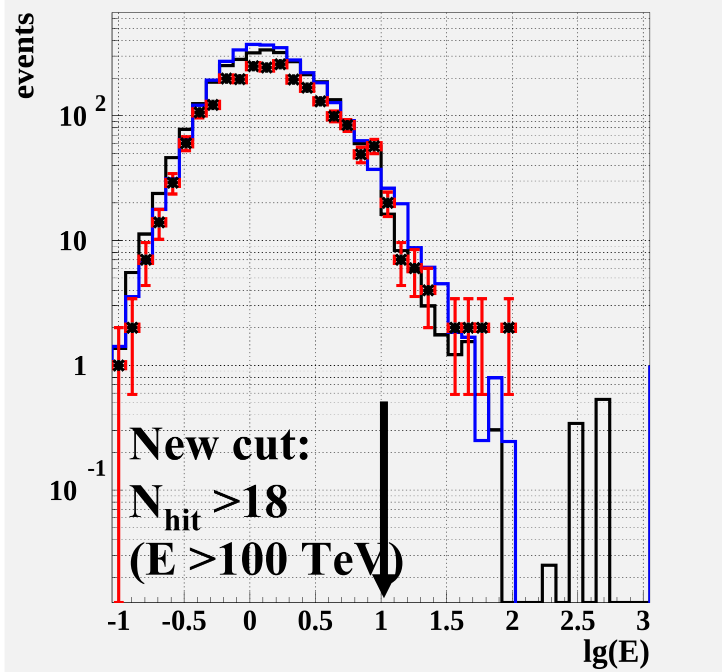
High energy neutrino: searching for diffuse neutrinos based on cascades reconstruction

New analysis of existing data with vertex, energy and direction reconstruction of cascades: improvement of published limit by a factor



Hit channel multiplicity

Cascade reconstruction:
dlgE ~ 10%;
dr ~ (5-10)%;
dΨ ~ 5°



Energy distribution of experimental (red), generated (blue) and reconstructed (black) events from atmospheric muons.

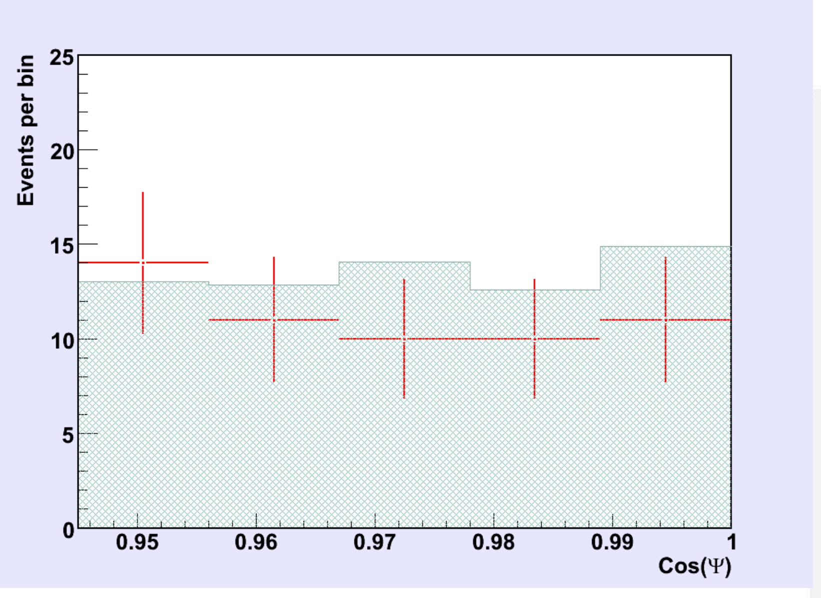
The 90% C.L. "all flavour" limit, $\nu_e:\nu_\mu:\nu_\tau = 1 : 1 : 1$
Cut E>10 TeV for up-going cascades
Cut E>100 TeV for down-going cascades

$E^2 \Phi_n < 2.9 \cdot 10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1} (Cascades Baikal, 2008)

$E^2 \Phi_n < 2.2 \cdot 10^{-7}$ GeVcm^{-2} s^{-1} sr^{-1} (Muons AMANDA-II

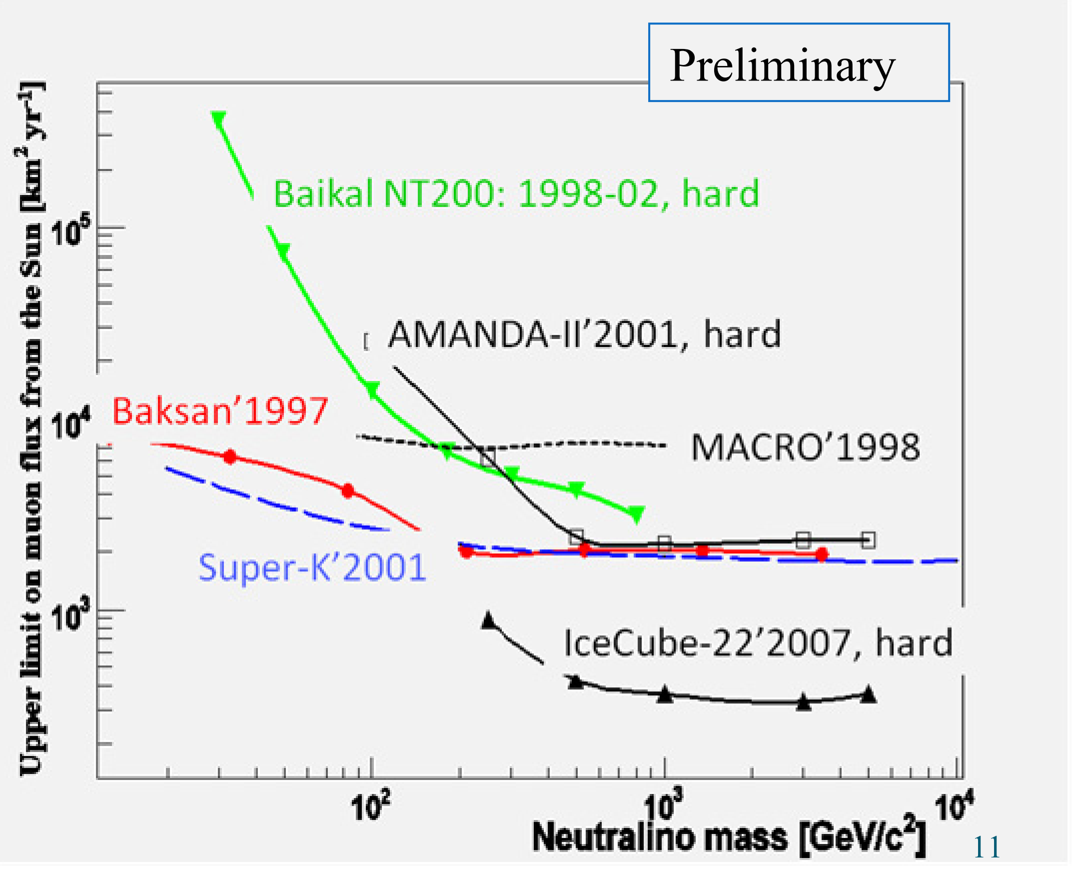
WIMP Neutrinos from the Sun

- Neutralino (WIMP) as favored Dark Matter candidate
- Gravitationally trapped in the Sun (or Earth)
- the Sun would be a neutrino-source (annihilation) →"Indirect" WIMP searches



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

No excess of events above atm. ν BG → Flux Limits



Search for fast monopoles

For a Dirac charge g = 68.5 e, Cerenkov radiation emitted by monopoles is 8300 times more that of a muon.

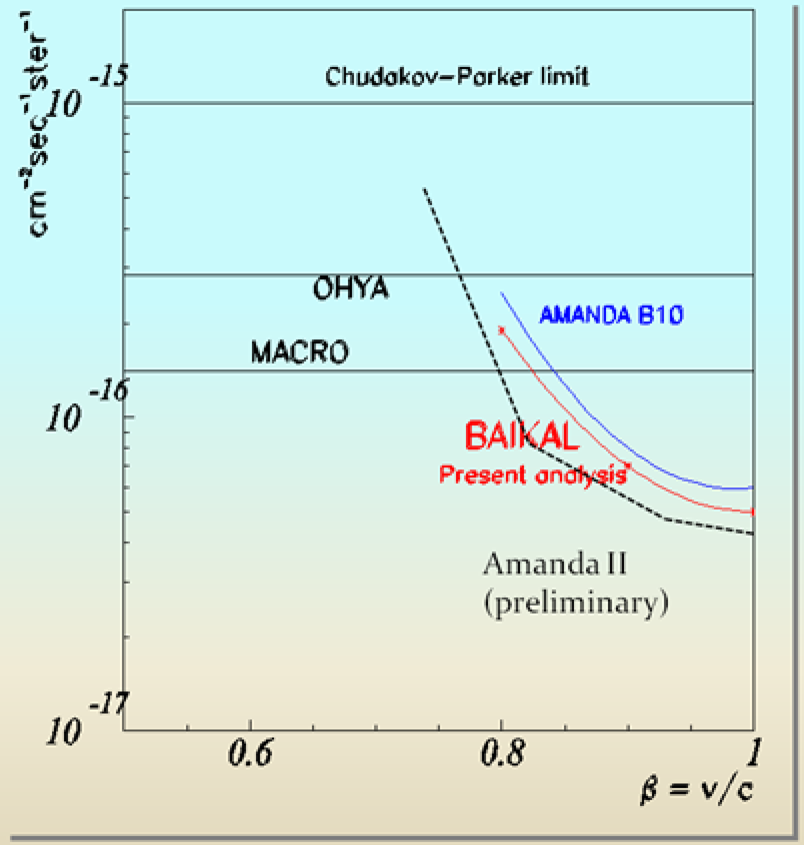
Event selection criteria:

1.Hit channel multiplicity :
   >30 pairs of PMTs hit.

2. Upward moving light patterns:
   time-vertical-coordinate correlation.

Background - atmospheric muons.
No excess over the expected background was found.

Limit on a flux of relativistic magnetic monopoles (1003 days of live time):
$F < 4.6\ 10^{-17}\ cm^{-2}\ sec^{-1}\ sr^{-1}$



90% C.L. upper limit on the flux of fast monopole

Search for neutrinos from Gamma-Ray Bursts with NT200

Analysis of time and directional correlations between NT200 events and GRB

Experimental data

NT200 data from April 1998 to May 2000

GRB data:

- basic BATSE 4B catalog (triggered bursts): 155
- non-triggered GRB: 148

Signal search:

Time window: $(t_{GRB} + T_{90} + 5s) - (t_{GRB}-5s)$

Half angle of observation cone: $\Psi = 5^o$

Background:

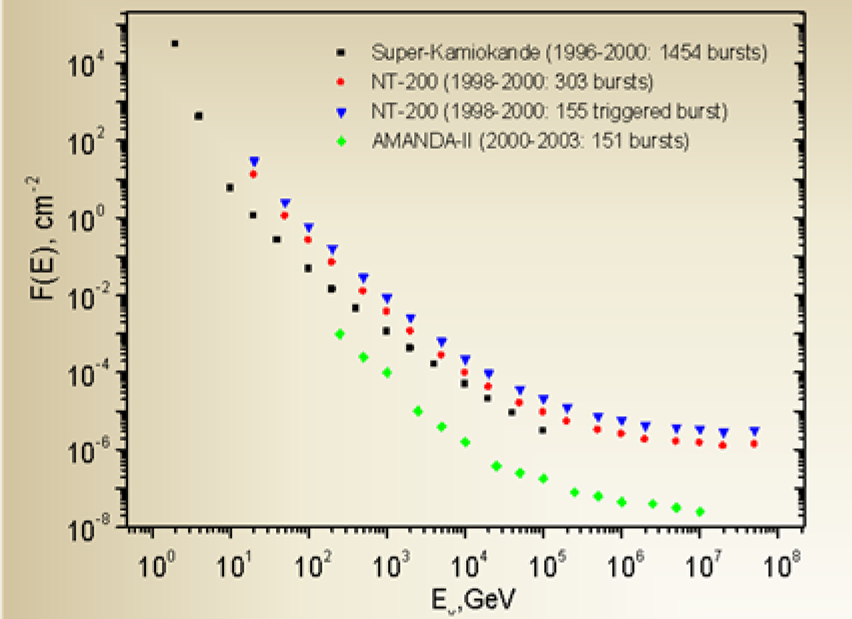
Time interval $(t_{GRB} + 1000s) - (t_{GRB}-1000s)$ (excluding signal window); $\Psi=10°$.

GRB	*Signal*	*Backgr.*	μ_{90}	N_{90}
All GRB	**1**	**2.7**	**2.1**	**1.0×10^{-2}**
Ttrig. GRB	**1**	**1.6**	**2.8**	**2.3×10^{-2}**

μ_{90} - event upper limit

N_{90} - 90% C.L. upper limit on the number of events per GRB

$F(E_\nu)=N_{90} / S_{eff}(E_\nu)$

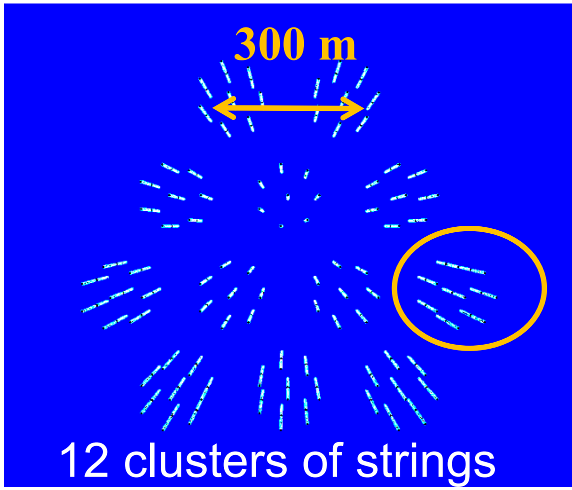


90% C.L. upper limits on the GRB neutrino fluence Green's function for NT200, Super-Kamiokande and AMANDA

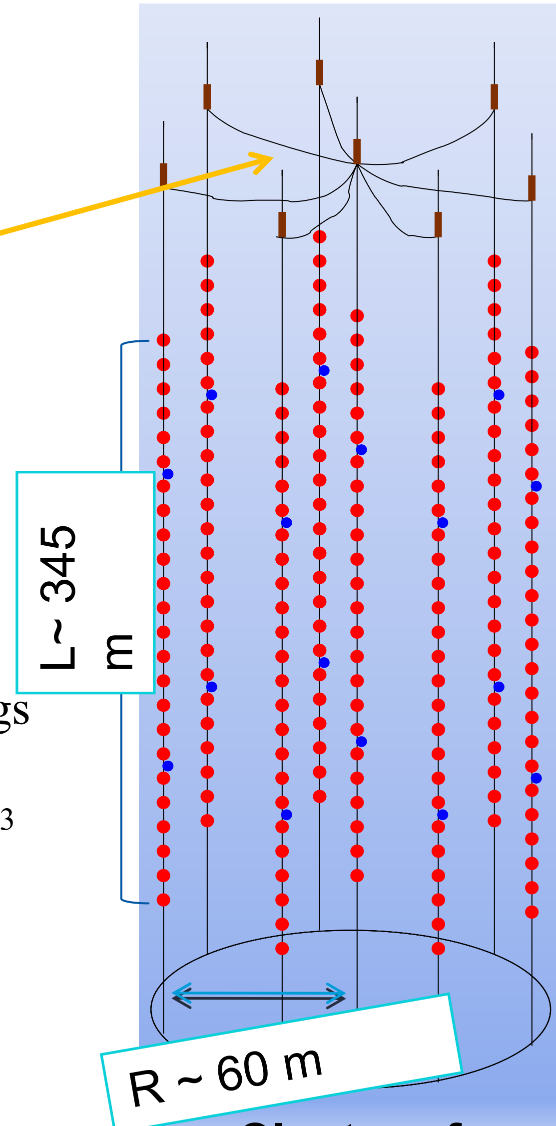
For Waxman – Bahcall spectrum and triggered GRB

$E_\nu^2\Phi_\nu \leq 1.1\times10^{-6}$ GeVcm^{-2} s^{-1} sr^{-1}, for E_ν>100 TeV.

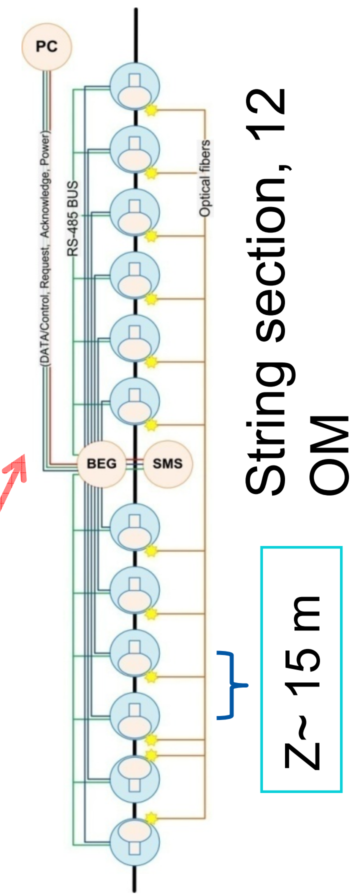
Gigaton Volume Detector in Lake Baikal – NT1000 Preliminary design



NT1000: top view



Cluster of strings



Layout:

2304 Optical Modules (OM) at 96 String

String: 24 OM → 2 Sections with 12 OM

Strings are combined in Clusters → 8 strings

Cascades (E>100 TeV): V_{eff}~0.3–0.8 km^3

δ(lgE) ~0.1, $\delta\theta_{med}$~ 2°- 4°

Muons (E>10 TeV): S_{eff} ~ 0.2 – 0.5 km^2

$\delta\theta_{med}$~ 0.5°-1°

Optimisation of NT1000 configuration

Basic parameters for optimization:

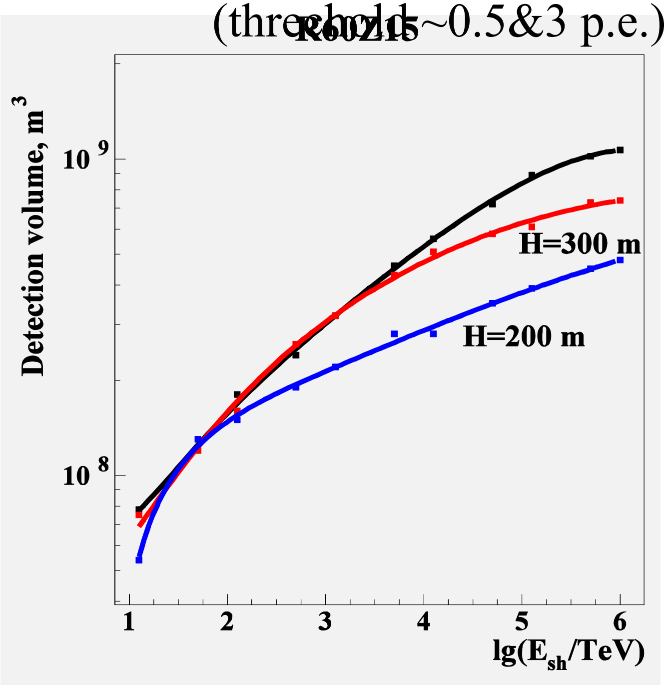
Z – vertical distance between OM

R – distance between string and cluster centre

H – distance between cluster centres

Trigger: coincidences of neighbouring OM on string

(threshold ~0.5&3 p.e.)



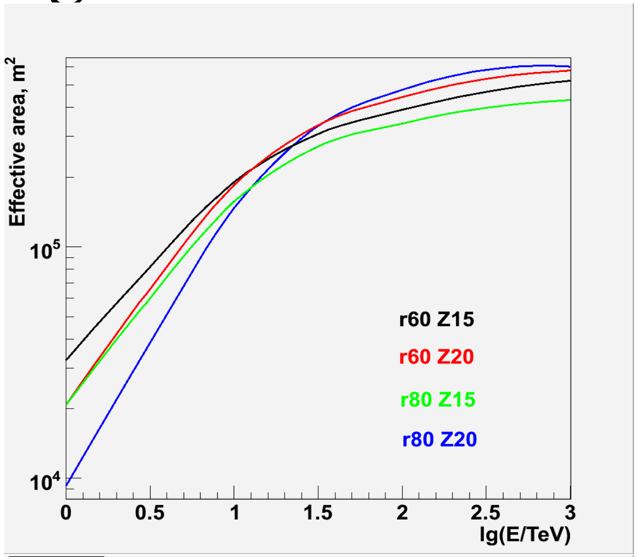
Cascade detection volume

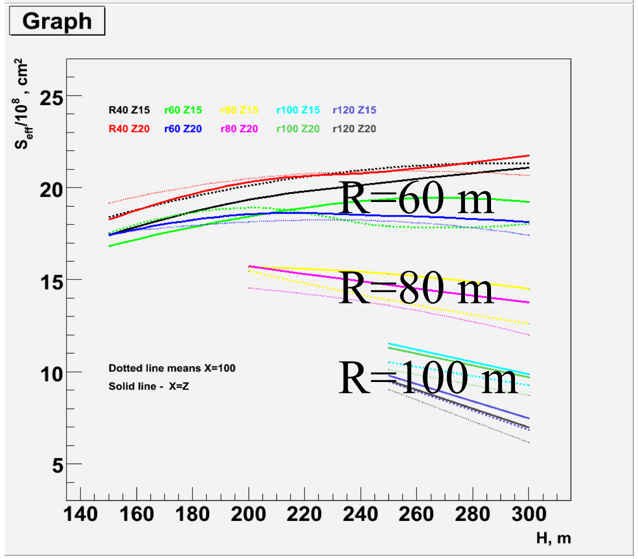
The compromise between cascade detection volume and muon effective area:

H=300 m

R = 60 m

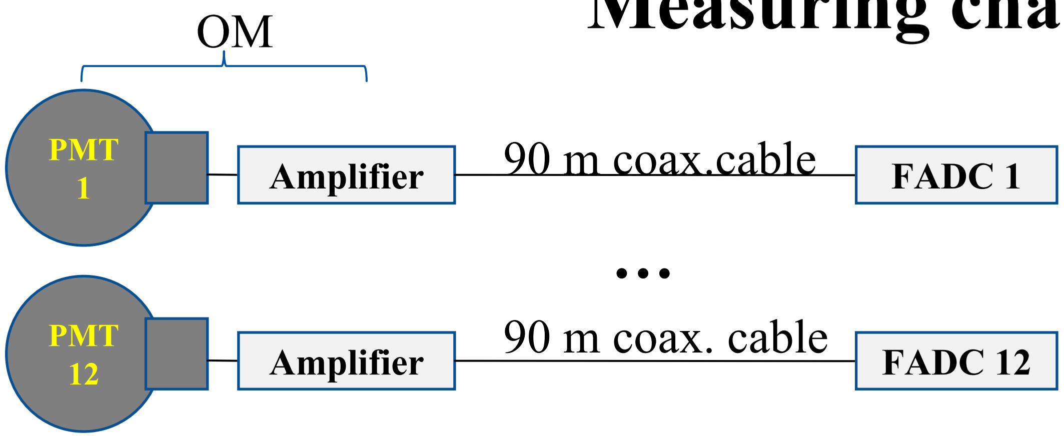
Z = 15 m

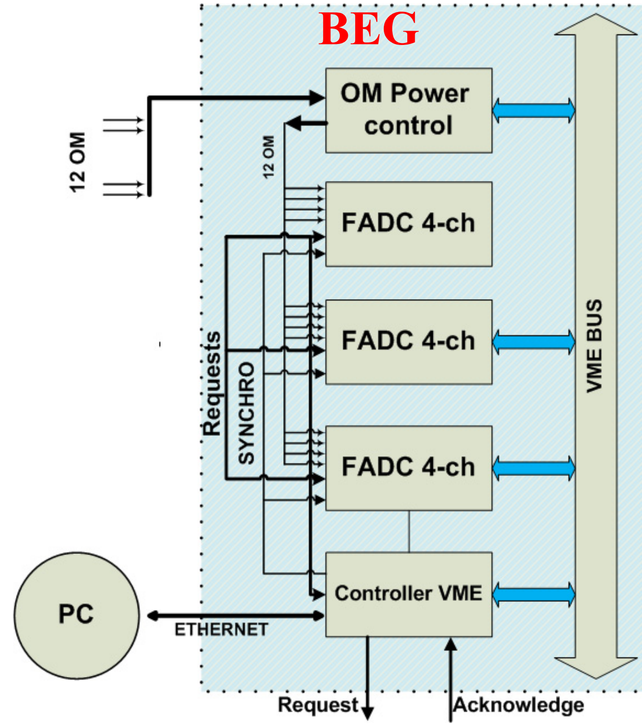




Muon effective area

Measuring channels





The new generation Baikal Optical module

PM: XP1807(12”), R8055(13”), R7081HQE(10”)

QE ~0.24 QE ~0.2 QE~0.3

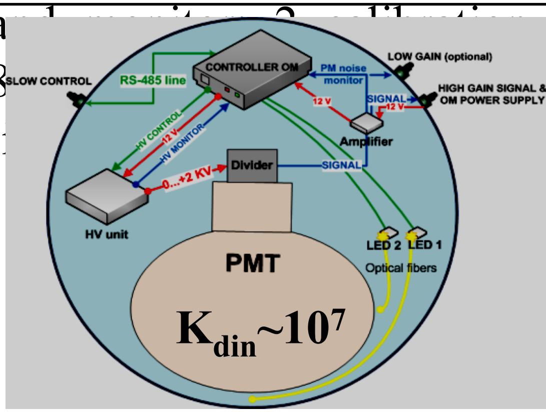
HV unit: SHV12-2.0K 1000N, TracoPower

OM controller: PM pulse counter; HV control

a… LEDs; RS-

48…

Ampl… r), K_{amp}~10



BEG (FADC Unit):

3 FADC-board: 4-channel, 12 bit, 200 MHz;

OM power controller: OM power on/off;

VME controller: trigger logic, data readout from

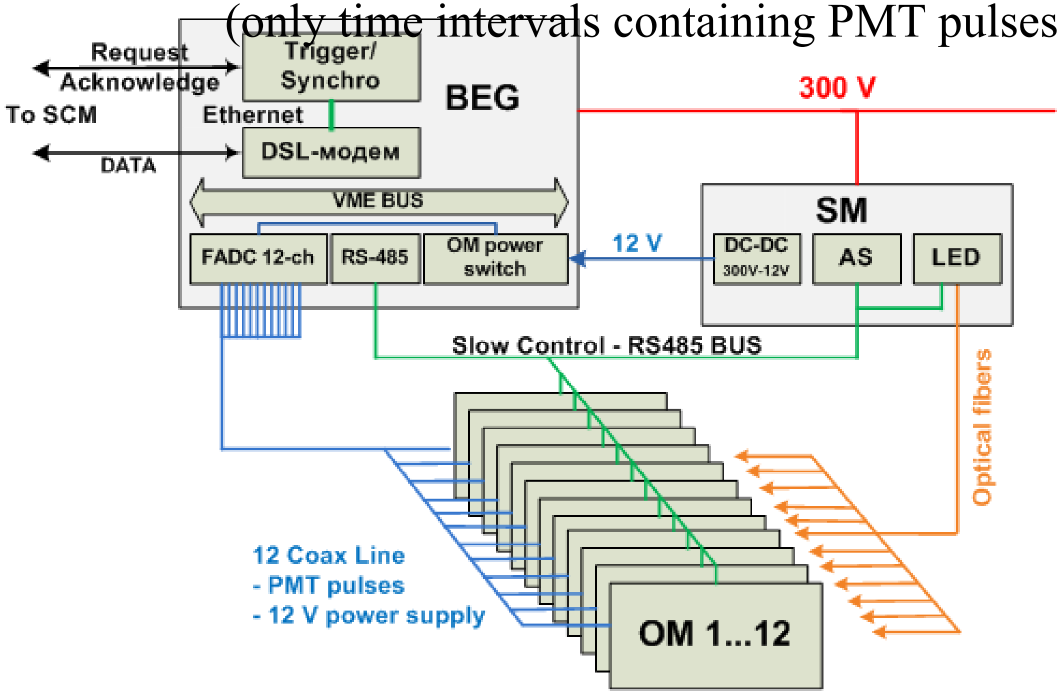
FADC-boards and connection via local

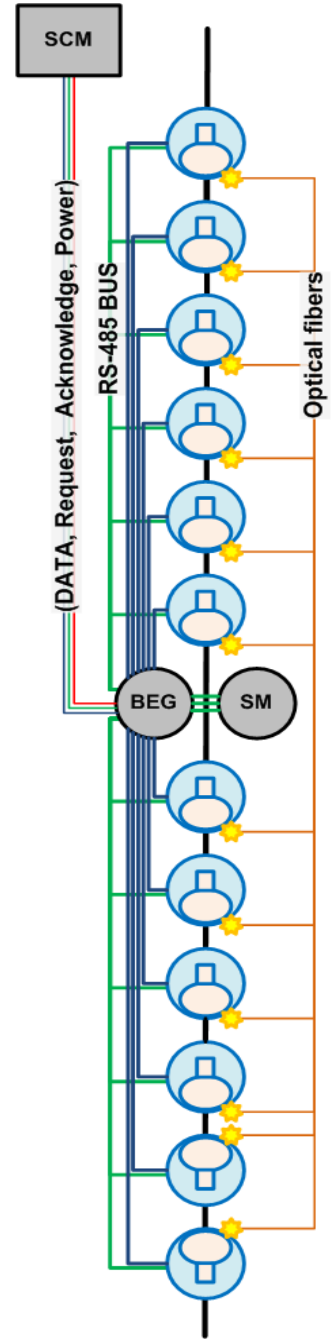
Section of OM – basic cell of NT1000

Section consists of :
12 Optical Modules
1 BEG with 12 FADC channels
1 Service Module (SM) with LED, OM power supply, and acoustic coordinate system.

Trigger: coincidences of neighbouring OM (threch. ~0.5&3 p.e.)
count rate ~ 100 Hz

Data Communication - DSL-modem: dataflow ~0.5Mbit/s
(only time intervals containing PMT pulses are transmitted)



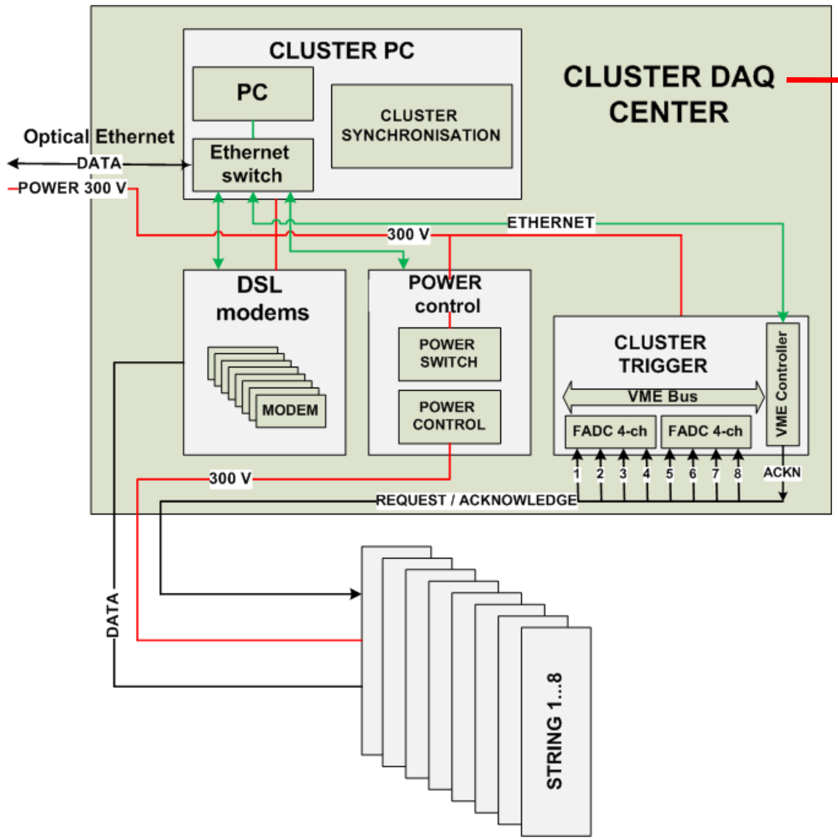


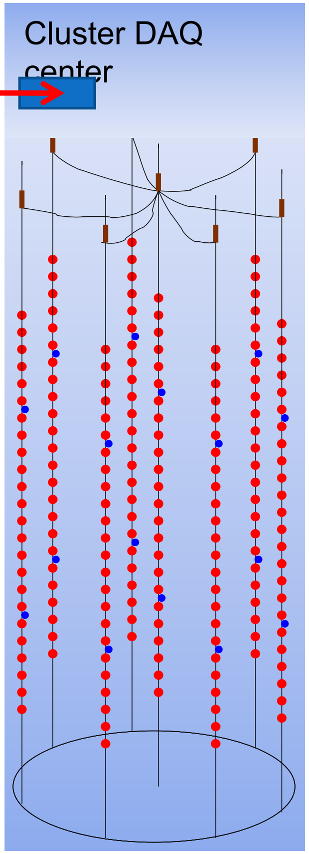
Cluster of strings

Cluster: 8 strings × 24 OM

Cluster DAQ Centre:

PC module with optical Ethernet communication to shore;
Trigger module with 8 FADC channel for the measure of string trigger time;
DSL-modems for communication with all strings
Power control system.



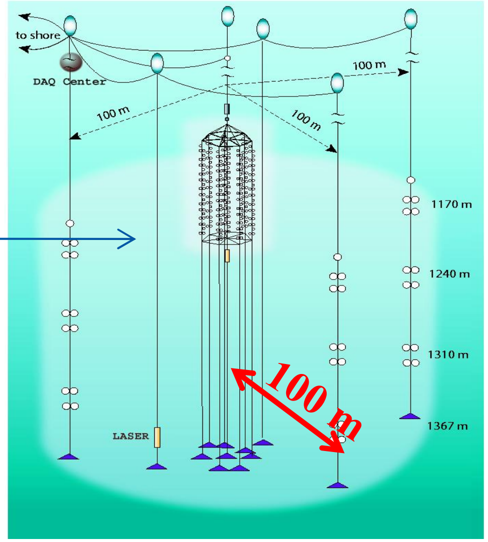


NT1000 R&D

NT200+ array is a first step toward NT1000

NT200+ has approximately same scale as a cluster of NT1000 and has allowed to verify detector response simulation, communication and synchronization systems.

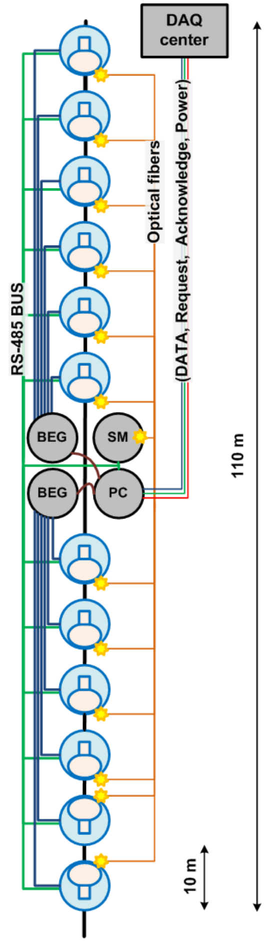
- NT1000 optimization on the basis of simulation program tested with NT200+;
- New communication system on the basis of underwater Ethernet and DSL-modems was development and studied with NT200+.
- String time synchronization with laser light source was tested with NT200+.



NT200+

In-situ tests of new measuring system with prototype string

The basic goals: investigation and in-situ test of basic elements of the future detector – new optical modules, DAQ system, cabling system, triggering approaches.



Prototype string

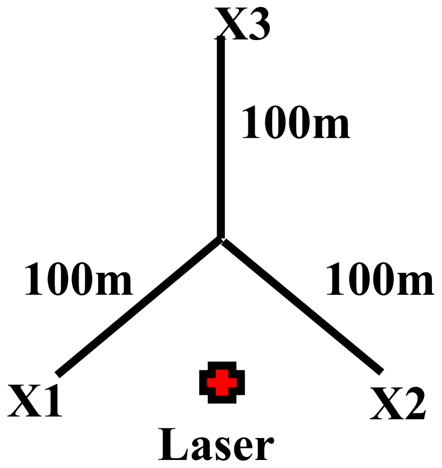
NT200+ time sinchronization with Laser

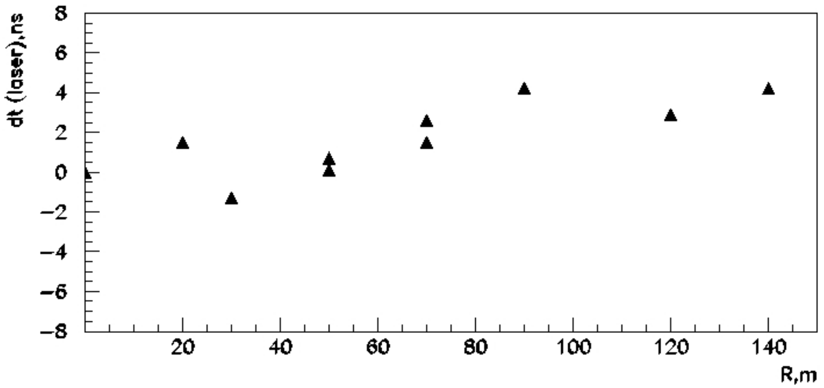
NT200+ allows to test the time synchronization between the channels of different strings

Laser intensity : cascade energy

(10^{12} – 5 10^{13}) γ : (10 – 500) PeV

➔ Laser is visible >200m with high Ampl





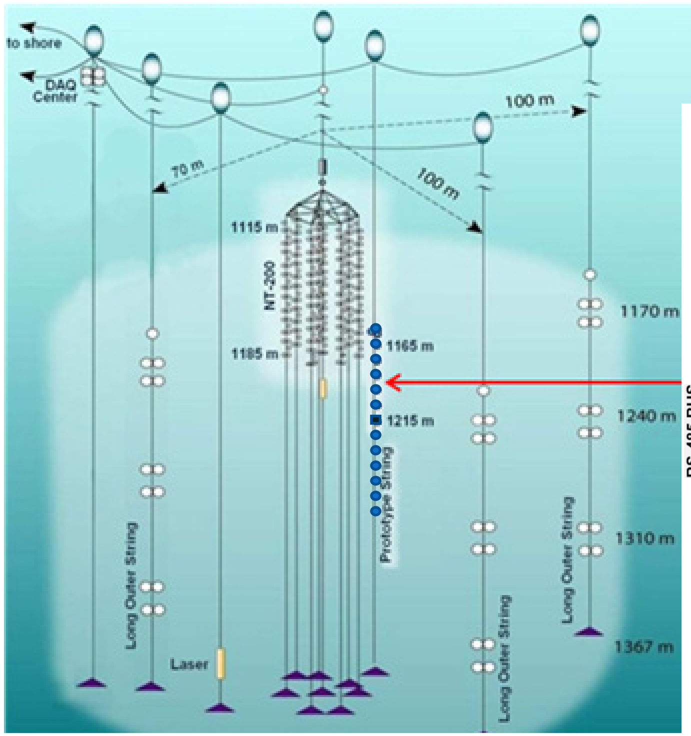
Precision of time synchronization 3…4 ns up to distances ~150 m

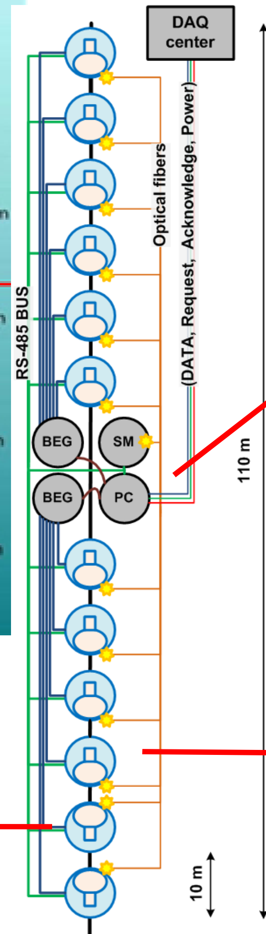
Deviation of time differences between two NT200+ channels measured with laser from expected value in dependence on distances between channels.

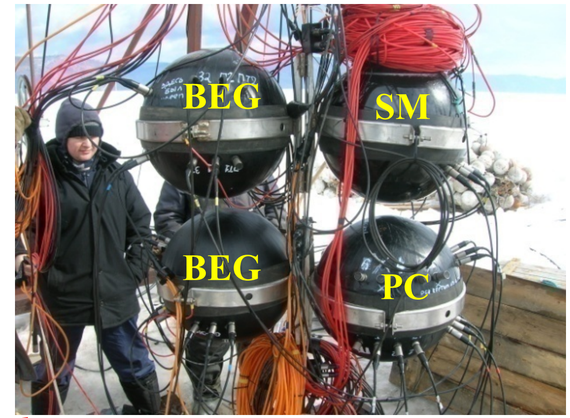
NT1000 prototype string

April 2009: Start of prototype string operation as a part of NT200+
2 Sections with 6 OM, two BEGs with FADC, PC Module, Service Module

NT200+ with experimental string







String communication center

Optical module

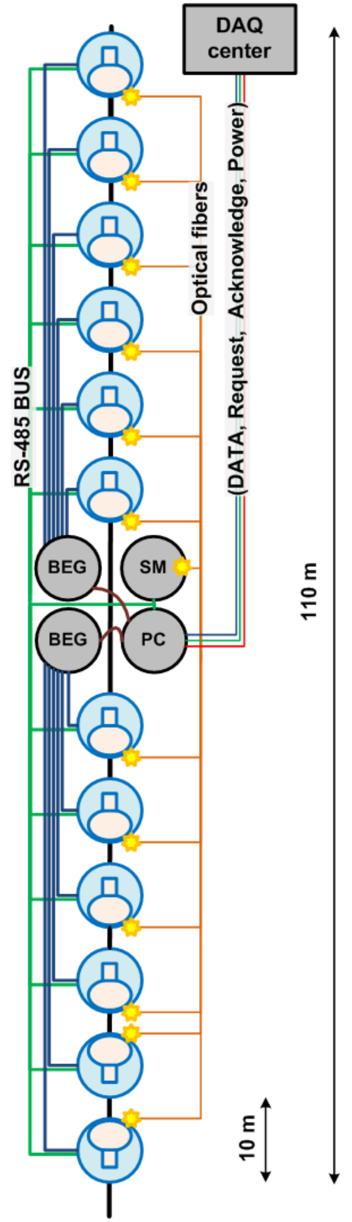
Basic parameters of experimental string - 2009

String length: **110 m**
Number of Optical Modules: **12**
Number of OM Sections: **2 (6 OM, 6 FADC channels)**
Number of FADC channels: **12**
Type of PMT: **Photonis XP1807 (12”) : 6**
Hamamatsu R8055 (13”) : 6
FADC Time Window: **5 mks**
FADC frequency: **200 MHz**
LED - Optical Fiber calibration system: **1**

Data analysis in progress now

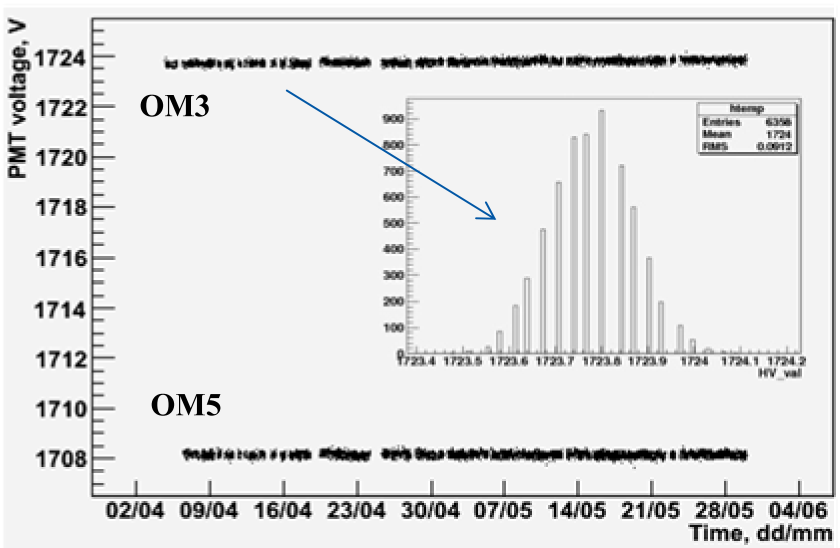
1. **Monitoring of the optical module operation.**
2. **Test of the string with LED and LASER.**

Experimental data: April – Jun 2009

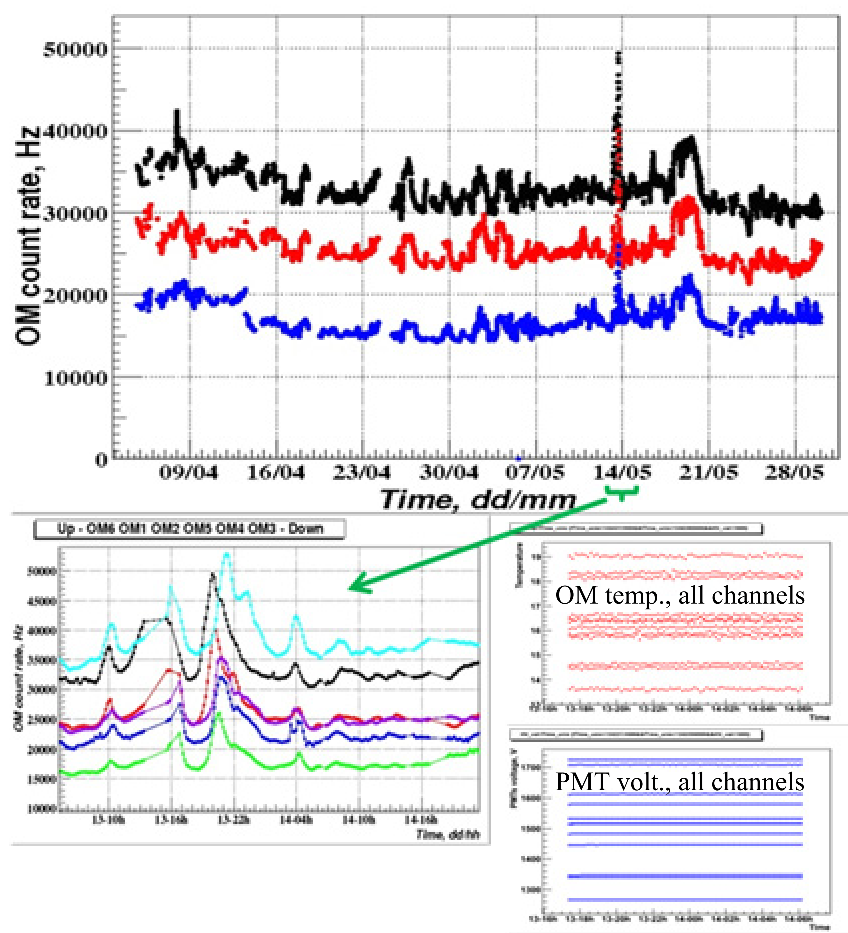


Monitoring of Optical Module operation

OM monitoring parameters:
- PMT voltage
- PMT count rate
- Temperature
- OM voltages: 12 V, 5 V, -5 V

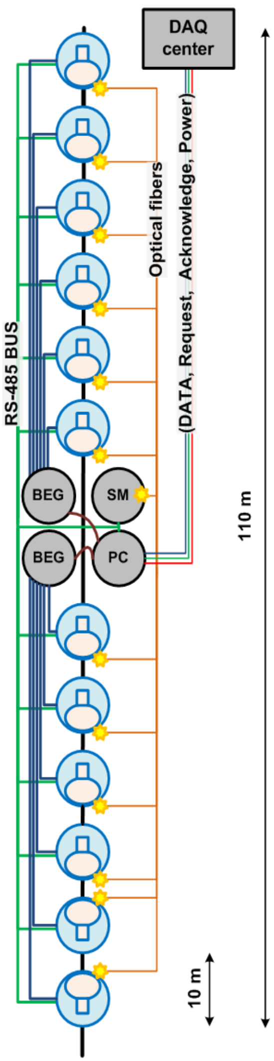


Disrtribution on PMT voltage, two month exposition 2009



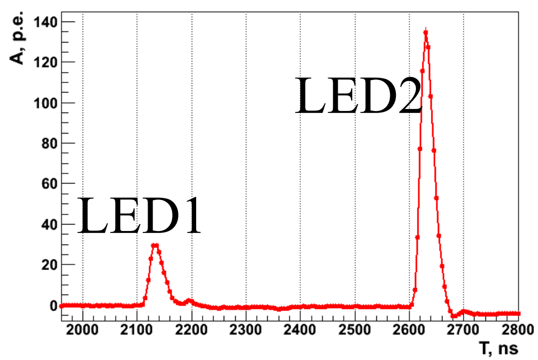
Examples of PMT count rate monitoring:
- Two month exposition 2009
- Selected time interval ~ 1 day
- PMT voltage and OM temperature during this period for all OM of the string

Time resolution of measuring channels

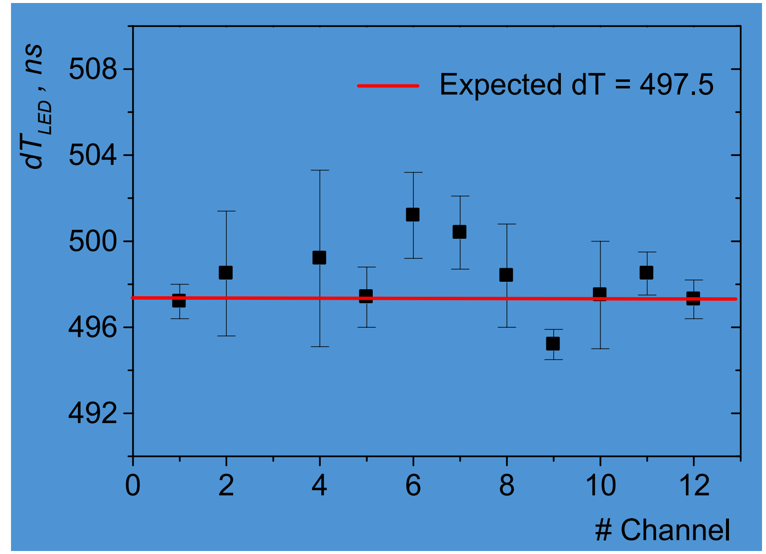


LED flasher produces pairs of delayed pulses. Light pulses are transmitted to each optical module (channel) via individual optical fibers. Delay values are calculated from the FADC data for all channels.

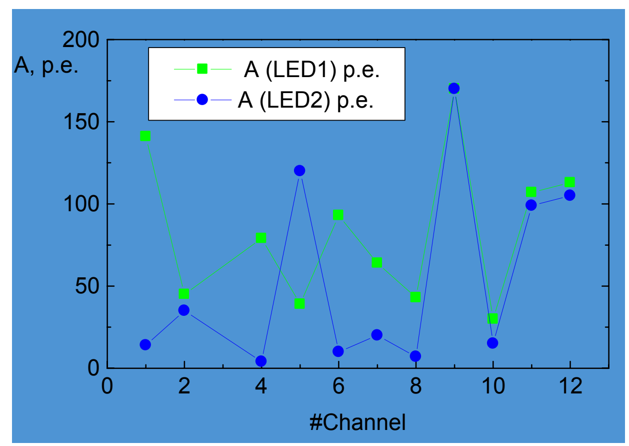
dT(Expected)=497.5 ns
dT(Experement) = 498.3 ns
σ(dT)=1.6 ns



Example of a two-pulse LED flasher event (channel #5)



Delay between two LED pulses dT measured for all measuring channel



LED1 and LED 2 pulse amplitude

String time resolution

$\sigma T_{STRING} \rightarrow \sigma T_{CHANNEL}$ & σT_{SHIFT}

σT_{SHIFT} - accuracy of compensation of channel delay differences measured with LED flasher:

$T_{SHIFT} \rightarrow$ DelayPMT(HV) + DelayCable +DelayADC

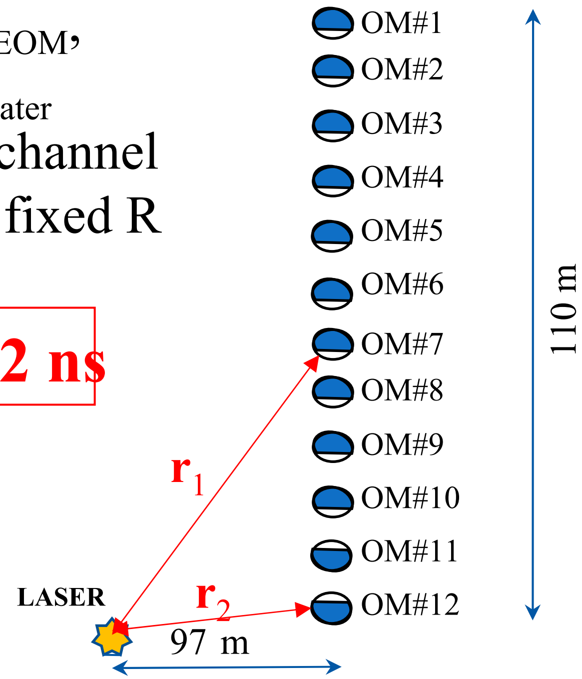
Test of σT_{STRING} with LASER

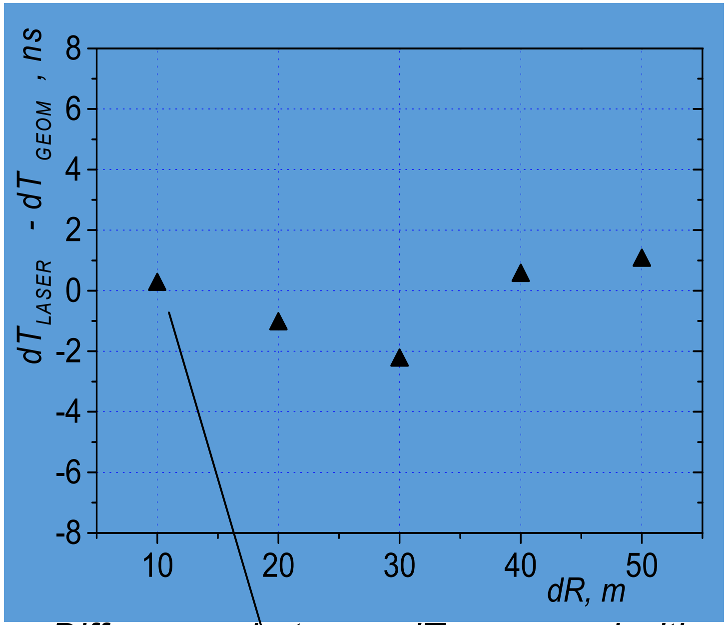
$dT = dT_{LASER} - dT_{GEOM}$,

$dT_{GEOM} = (\mathbf{r}_2 - \mathbf{r}_1) \times c_{water}$

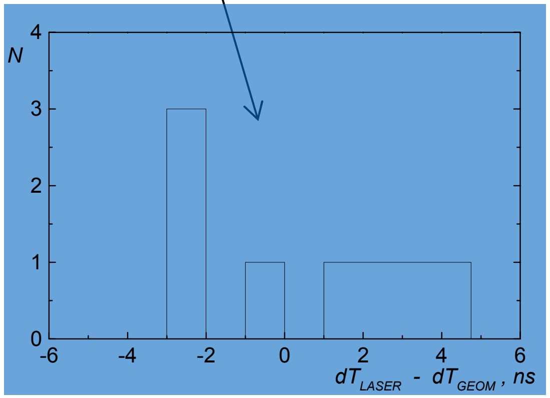
dT averaged on all channel combinations with fixed R

$\sigma\ T_{STRING}$ ~2 ns





Differences between dT measured with Laser and calculated dT in dependence on distances between channels dR



dT distribution on channel combination

CONCLUSION

1. BAIKAL lake experiment is successfully running since 1993
   - The First Underwater Array
   - First Neutrino Candidates

2. NEW configuration NT200+ starts work at April 2005
   - Improved cascade reconstruction, increased effective volume for cascades;
   - NT200+ gives good possibilities to optimise the design and to investigate the key elements of future NT1000 detector.

3. Start R&D for Gigaton Volume (km3-scale) Detector NT1000
   - A "new technology" prototype string was installed: 12 OMs with 12"/13" PMT
   - Preliminary in-situ tests of the prototype string with underwater laser and LED flasher shows good performance of all string elements.
   - NT1000 Technical Design Report is expected at 2011


THANK YOU