A Subject List Towards the Baikal "KM3" Proposal

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Abstract

The paper lists some issues of particle physics, cosmic ray physics and neutrino astrophysics associated with the project to build a 1 km^3 underwater muon and neutrino laboratory in lake Baikal.

Introduction

It is beyond question that the 1 km^3 underwater muon and neutrino telescope in lake Baikal being discussed in this workshop, must be a multi-purpose system. Still, before proceeding with the model design of this system, there is a need to set the priorities for the scientific problems which might be concurrently investigated with the telescope, since the ultimate goals dictate the specific configuration and infrastructure of the telescope, general requirements upon the electronics, choice of the phototube characteristics, physical triggers, and so on.

If, for instance, our prime interest is with the super-high energy neutrino astronomy, then very high energy thresholds and the maximum (depending on the optical properties of the medium) spacing between the optical modules (bunches) will be sufficient. But if we plan to investigate neutrino oscillations using a neutrino beam from a collider (say, from UNK), the telescope must have a resonable low energy threshold (of the order of 100 GeV) and a fairly dense lattice of the bunches, with the geometry defined, to a certain extent, by the neutrino beam direction.

Consider one further extreme. To get out of a great part of the muon-induced background and, incidentally, organic precipitation, one would be tempted to point all optical modules downwards. But together with the background, this solution practically cuts out the muon physics.

Besides, there are some objective (native) restrictions which cannot be obviated. In particular, due to the comparatively shallow depth of the lake, the setup cannot expand downwards and will have to grow horizontally. A geometry of this sort somewhat constrains the scientific exploration area. On the other hand, the shallow water and, more importantly, the availability of a strong ice sheet for much of the spring, make it possible to modify the detector configuration with relative ease, as the situation requires, even if the detector is in operation.

In my opinion, prior to choosing the optimum (in every respect) set of subjects for the scientific program of the future telescope, it would be well to look into a representative list of the topical problems of particle physics, cosmic ray physics, astrophysics and cosmology which could be *in principle* investigated with the telescope. analysis and superfluous elements. What's more, we must have at hand a full data base for simulation and analysis of the future experiments plus a clear notion of the confidence of these data. Thus it is instructive to include all relevant issues into the subject list.

One trivial comment can be made in this connection. Often it is almost impossible (or undesirable) to separate a research problem from the problem of initial data. This is especially true regarding the parameter ranges which were previously beyond the reach of the experiment. For example, one of the most important task for every large-scale neutrino telescope is to test the validity of the standard model predictions for the neutrino-matter interactions at $\sqrt{s} \sim m_W$ and above, using terrestrial and extraterrestrial neutrino fluxes. At the same time, the νN and $\overline{\nu} N$ cross sections are the indispensable inputs for all experiments in neutrino astrophysics. Similarly, a central problem of cosmic ray physics is the primary spectrum. But it is impossible to calculate the atmospheric muon and neutrino fluxes without resorting to some model of the primary spectrum and composition. So, the parameters of the primary cosmic ray flux are both the subjects of the study and the input data, simultaneously. The atmospheric muons and neutrinos are in turn the major sources of background to neutrino astronomy as well as the subjects for many fields.

Below, something like a table of contents is proposed, with the various sections of astroparticle physics relating, in one way or another, to the future project. From the above reasoning the items (supplemented by some comments) are grouped without any ranking and without direct indications of their belonging to the category of the subjects of investigation or the inputs for the simulation and data processing. To my regret, I have not attempted to make a list of references, because it would be many times longer than the subject list.

I am not at all sure this is the best form of presentation. But the subject list will hopefully be a skeleton to a handbook for experimentalists and students, which might in time be written by a skilled author's collective. I hope also that some sizable portion of the issues from this list will be included into the physics part of the future Proposal to construct a 1 km^3 underwater muon and neutrino laboratory in lake Baikal. also involve a wide program for the physics-related limnological studies in lake Baikal (hydrodynamics, hydrooptics, hydroacoustics) together with a review of the current results and outstanding questions in this field, and possibly some relevant issues from geophysics and glaciology.

And last, but not least. The "KM3" Baikal project has no an official name yet. Let me use below the abbreviation **BANT** (**B**aikal **A**dvanced **N**eutrino **T**elescope). 'Bant', a rarely used English verb, means 'to be on a starvation diet'; in a sense it defines the present-day state of the science in Russia. In Russian transcription, 'bant' means 'bow', that is, a toy. Nevertheless let us hope the BANT Collaboration will hold a serious position in the BAND community.

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THE SUBJECT LIST

1 Trends and Methods in Astroparticle Physics

- Physics Capabilities of Underground Detectors.
  A review of the experiments in the "low-energy" astroparticle physics [cosmic-ray muon physics, detecting of atmospheric and solar neutrinos, neutrino signal from SN 1987A, searches for neutrino oscillations and decay, anomalous (electromagnetic) properties of the neutrino, proton decay, $n\overline{n}$ transitions in nuclei, magnetic monopoles, cold dark matter, etc].
  A summary of the past, present and future large underground detectors [BST, Fréjus, KAMIOKANDE, IMB, SOUDAN 2, LVD, MACRO, SUPERKAMIOKANDE; detectors

for solar neutrinos: Chlorine (Homestake), Gallium (SAGE, GALLEX), and some other projects (SNO, BOREXINO, ICARUS, HERON, HELLAZ, ...)].

- Astroparticle Physics with Large Underwater Telescopes. Why a 1 km^3 detector?
  A list of the most important problems of particle physics, cosmic ray physics, astrophysics and cosmology which can be investigated with the future large-scale water-Cherenkov detectors.

- Current Projects for Underwater/Ice Muon and Neutrino Telescopes.
  The main physics characteristics and potentialities of the detectors under construction. R & D status. Summary of the current results. What are the prospects?

  - AMANDA.
  - DUMAND.
  - NESTOR.
  - Baikal NT-200.
  - Earlier KM3 Proposals. The BAND.

- BANT: a 1 km^3 Underwater Muon and Neutrino Laboratory in Lake Baikal.
  A brief description of the present project.

- BANT $\Longleftrightarrow$ NT-200 $\Longleftrightarrow$ BAND Relation.

- Survey of Another Projects and Methods for Muon and Neutrino Detection.

  - Cherenkov detectors for near surface lakes, ponds or pools *[Blue Lake Project, GRANDE, LENA, NEVOD, NET, PAN].*
  - Acoustic wave detection *[SADCO, acoustic DUMAND and AMANDA].*
  - Microwave detection *[RAMAND, ICEMAND].*

2 Primary Cosmic Rays

A summary of the present-day direct and indirect data on nuclear component of primary cosmic rays at high energies (spectrum, chemical composition, anisotropy). An overview of the most popular models for the origin of cosmic rays (galactic and metagalactic sources). The "knee" problem and AGN contribution. The primary spectrum around and beyond the relic (Greisen–Zatsepin–Kuźmin) cutoff.

3 Interactions of High Energy Muons with Matter

Muon electrodynamics at high and super-high energies (a short summary). Detailed compilation of the (calculational) data on the muon energy losses and cross sections for the muon interactions with air, rock and water.

- Main Energy Loss Processes.

  - Ionization and δ electron production.

- Direct e^+e^- pair production.
- Bremsstrahlung.
- Photonuclear interaction.

• Minor Corrections and Contributions.

- α^3 corrections to the ionization.
- Coulomb corrections to the radiative processes.
- Direct $\mu^+\mu^-$ and $q\overline{q}$ pair production.

• Hypothetical and Poorly Studied Contributions.

- Nuclear Gamma-Cherenkov Radiation. *[Amplitudes of γN Compton scattering, Cherenkov bands in nuclear matter and Cherenkov thresholds (CB-I: $140-300$ MeV, $E_\mu > 1.7$ GeV; CB-II: $50-500$ GeV, $E_\mu > 200$ GeV). Muon NGCR differential cross section for oxygen.]*
- Minijet production mechanism *[possible contribution to the total photoproduction cross section as a result of the gluonic structure of high-energy photon; accelerator limits; restrictions from underground and EAS experiments].*
- LPM effect and longitudinal density effect (dielectric suppression) *[super-high (EeV) energies, $v \lesssim 10^{-5}$].*

• Multiple Coulomb Scattering.

• Large Angle Scattering.

• Muon-Induced Electromagnetic and Hadronic Bursts in Water.
Measurable characteristics of single showers due to direct pair production, bremsstrahlung and (photo)nuclear interaction vs energy (repetition rate, energy release, space-time structure, etc). Muon tracking. Cherenkov response. The muon energy reconstruction problem.

4 Interactions of High Energy Neutrinos with Matter

• Neutrino Interactions with Atomic Electrons.

- The basic exclusive processes on electron targets *[$\nu_\mu e \to \mu e$, $\nu_e e \to \nu_e e$, $\overline{\nu}_e e \to \overline{\nu}_\mu \mu$, $\overline{\nu}_e e \to \overline{\nu}_e e$, $\nu_\mu e \to \nu_\mu e$, $\overline{\nu}_\mu e \to \overline{\nu}_\mu e$].*
- Glashow resonance in $\overline{\nu}_e e$ annihilation. *[Resonant W^- production with regard to radiative corrections. The Berezinsky–Gazizov reaction $\overline{\nu}_e e^- \to$ hadrons. Distinctive features of charm showers in the Wilczek subprocess $\overline{\nu}_e e^- \to W^- \to \overline{c}s$.]*
- Hadronic resonances in $\overline{\nu}_e e$ annihilation. *[The Mikaelian–Zheleznykh subprocesses with formation of vector (ρ, D_s^*, $(b\overline{t})_{J=1}$) and pseudoscalar (π, K^*) $q\overline{q}$ states.]*

• Standard Charged and Neutral Current Induced Neutrino Interactions with Nucleons.
Current accelerator data. Cross sections for the CC and NC induced νN ($\overline{\nu}N$) interactions at very high energies evaluated in light of recent data about nucleon structure functions. Nuclear effects.

- Multiple Production of Gauge and Higgs Bosons in νN ($\overline{\nu} N$) Interactions.
  Expected nonperturbative behaviour in the electroweak sector of the standard model at energies above a threshold $\sqrt{\hat{s}_0} \gg m_W$.

- Neutrino Interactions Beyond the Standard Model.
  Some phenomenological consequences of the minimal supersymmetric extension of the standard model (MSSM), left-right symmetric models (with a seesaw mechanism for neutrino masses), supergravity models, etc.

  - Processes with production of supersymmetric particles and with an exchange of light leptoquarks.
  - Off-diagonal neutral currents.

- Neutrino Induced Hadronic and Electromagnetic Bursts in Water.
  The measurable characteristics of the single showers due to $\nu N/\overline{\nu} N$ *and* $\nu e/\overline{\nu} e$ *(standard and speculative) interactions in water vs energy (repetition rate, energy release, space-time structure, etc). The LPM effect. Cherenkov response. The neutrino energy reconstruction problem.*

5 Atmospheric Muons and Neutrinos

- Muon and Neutrino Production in the Atmosphere.

  - π and K production in hadron-nucleus and nucleus-nucleus interactions. *[Theoretical and experimental boundaries for the partial moments of the inclusive cross sections ("Z factors") and total inelastic cross sections vs energy. The scaling violation problem.]*
  - Charm production and the prompt lepton problem. *[Modern approaches to the charm hadroproduction problem (the models with intrinsic charm, like the recombination quark-parton model; quark-gluon string model; pQCD-like models; selected semiempirical models). Nuclear effects. Comparison with the accelerator data.]*
  - Semileptonic decay of charmed hadrons. *[A summary of the charm decay problem.]*

- The Standard Atmosphere.
  Data on chemical composition, temperature and density distributions.

- Secondary Hadrons in the Atmosphere.
  World data on the high energy p, n, π, *and* K *fluxes. Comparison with calculations.*

- Muon Transport through the Atmosphere. Atmospheric & Geomagnetic Effects.

  - Muon polarization and depolarization mechanisms. *[Kinematic depolarization, depolarization due to the muon energy loss and geomagnetic field. The KAMIOKANDE result.]*
  - Muon range struggling effect for near-horizontal directions. *[Fluctuations of the muon radiative & photonuclear energy loss in the atmosphere.]*
  - Meteorological (barometric & temperature) effects. *[Expected magnitude of the day-night and seasonal variations of the atmospheric muon flux.]*

  - Deflection of high-energy muons in the geomagnetic field. *[Expected magnitude of the azimuthal anisotropy in the atmospheric muon flux at large zenith angles.]*

- Muon Energy Spectra, Angular Distributions and Charge Ratio at Ground Level.
  A summary of the experimental and theoretical results.

- Ground-Level Neutrino and Antineutrino Energy Spectra and Angular Distributions.
  A summary of the experimental and theoretical results for muon and electron neutrinos and antineutrinos. Upper limits from EAS and underground experiments.

- Prompt τ Neutrinos.
  Mechanisms of ν_τ production [hadroproduction and decay of charmed strange mesons (D_s), bottom mesons (B), and other resonances containing heavy quarks (b, t)]. An estimate of the atmospheric τ neutrino flux.

6 High-Energy Muons Under Thick Layers of Matter

- Single Muon Depth–Intensity Relation.
  - Muon Range Straggling in Dense Matter. *[Fluctuations of the muon energy losses in water and rock (a summary of some theoretical results).]*
  - Current deep underground data. *[Results obtained with the Utah, ERPM, KGF detectors, detectors from the Mont Blanc Lab. (SCE, LSD, NUSEX), Baksan Lab. (BST), Fréjus, SOUDAN 1-2, and with the largest detectors located in the Gran Sasso Lab. (LVD, MACRO).]*
  - Current underwater data. *[Results obtained with small "closed" detectors, and with the DUMAND, NESTOR, and NT-200 prototypes.]*
  - Extrapolations to the sea-level muon spectrum. *[With regard to the data from shallow depths (detector COLLAPSE in Artyomovsk, X-ray emulsion chambers of the Moscow University) and the Baksan calorimetric experiments.]*
  - Physics outcome. *[The primary spectrum around the "knee", charm production cross section, $\sigma_{\gamma A}$, etc.]*
  - Using the muon DIR for a normalization of the atmospheric neutrino flux.

- Single Muon Energy Spectra and Angular Distributions Deep Underwater.
  The muon spectra at different depths in water (for vertical and oblique incidences) calculated with alternative models for the primary spectrum/composition, charm production, etc. The effect of variations of the muon photonuclear cross section.

- Muon Bundles and Search for the Primary Composition.
  Theoretical expectations and a summary of the recent data from the largest underground detectors (BST, SOUDAN 2, LVD, EAS-TOP – MACRO).
  - Muon bundles from nucleon-nucleus and nucleus-nucleus interactions.
  - Muon multiplicity distributions for different models of the primary spectrum and composition.

- Spatial distributions *["decoherence function" (the rate of muon pairs per unit area, per steradian, per pair separation determined on a plane orthogonal to the pair direction), "decorrelation function" (the average of relative angle within muon pairs vs their separation), and so on].*
  - Clusterization in High Multiplicity Muon Events. *[Clusters in the muon bundles produced by nucleons and heavy nuclei. Energy distribution and expected spacing between the clusters.]*
  - DIR for the muon bundles.

- Spatial Anisotropies and Time Variations in the Underwater Muon Flux.
  Methodical and calibration studies. Looking for unexpected.
  - Search for possible large angular scale anisotropies *[due either to the galactic plane or to known motions of the solar system through the Galaxy, towards the local supercluster or relative to the cosmic microwave background].*
  - Search for anomalous temporal variations *[against the background of small seasonal variations conditioned by the atmospheric effects (see Sec. 5)].*
  - Search for large angle muon scattering. *[The prime objective is to reduce the upgoing event missidentification to a minimum.]*
  - The Moon and the Sun shadows. *[The 9 mrad shadow zones in motion as a test for the detector angular resolution.]*
  - The shore shadow. "Muon terminator". *[An added window for ν astronomy.]*

7 Atmospheric Neutrino Transit through the Earth

- The Earth Interior.
  A summary of the geological data and recent models for the global Earth structure.

- Energy Spectrum and Angular Distribution of Neutrinos after their Passage through the Earth.
  Calculations with regard to the neutrino absorption and regeneration in the Earth, including possible nonstandard interactions (Sec. 4).

- Neutrino Induced Muon Flux.
  Calculations of the upgoing muon spectrum and angular distributions. A compilation of the "low-threshold" data (KGF, Utah, ERPM, BST, IMB, KAMIOKANDE, NUSEX, Fréjus, MACRO, LVD). Current limits from underwater experiments.

- "Muon-like" and "Electron-like" Contained Events.
  Predicted rates for the ν_μ ($\overline{\nu}_\mu$) and ν_e ($\overline{\nu}_e$) induced contained and partially-contained events vs energy and zenith angle.

8 Extraterrestrial Neutrinos & Neutrino Astronomy

- Galactic and Extragalactic Accelerators.
  - Cosmic beam dump: pp and $p\gamma$ neutrinos and associated γ radiation.

  - Generic γ-transparent, γ-opaque, and pulsed sources.

- Point Neutrino Source Candidates.
  Expected neutrino intensities and spectra from the most likely candidates.

  - Young supernova remnants *[due to cosmic ray acceleration by shock waves from supernova explosions.]*
  - Accreting neutron stars and black holes.
  - Binary (multiple) systems *[pulsar + giant, pulsar + star filling its Roche lobe, white dwarf + (super)giant, etc].*
  - The Galactic center. *[Within the model of a supermassive accreting black hole.]*
  - Active galactic nuclei *[Seyfert galaxies, N galaxies, quasars, Lacertae (BLLac objects), blazars (radio-loud AGNs); particle acceleration in extragalactic jets from radio-quiet and radio-loud AGNs].*

- Diffuse Neutrino Backgrounds[1].

  - Galactic neutrinos *[including the neutrinos arising from the primary cosmic ray interactions with a spherical halo of baryonic dark matter (see Sec. 10)].*
  - Quasi-diffuse background from AGN's.
  - Neutrinos from intergalactic space *[in particular, UHE neutrinos from the tip of the cosmic ray spectrum (due to the GZK cutoff)]*[2].
  - Pregalactic neutrinos and neutrinos from the bright phase of galaxy evolution.

- Speculative Sources of the Highest-Energy Neutrinos and Science Fiction.

  - Topological defects *[ultra-heavy particle emission and acceleration by saturated superconducting cosmic strings, cusp radiation from ordinary cosmic strings, vortons, textures, global monopoles, etc].*
  - Paczynski–Xu γ ray bursters *[γ quanta and neutrinos arise from decay of pions produced in shock front collisions].*
  - Mini-black-hole evaporation.
  - Decay of super-heavy exotic particles *[such as long-lived Big Bang relics or the Planck mass objects (planckeons $\sim$ fridmons $\sim$ maximons $\sim$ cosmions)].*

- Neutrino Propagation through the Galactic and Intergalactic Medium.
  [Including the effects of the UHE neutrino absorption by the relic thermal neutrino background and by neutrino dark matter in galactic halos (Sec. 10).]

- Neutrino Propagation Through the Earth.

  - Neutrino induced muon fluxes from different neutrino sources. *[Calculations with account for the standard and non-standard neutrino interactions and muon range struggling.]*

[1] Among the low-energy backgrounds of interest for future underground experiments are supernova neutrinos, the relic neutrinos from decay of primordial black holes and from the non-radiative decay of 4-th generation neutrinos in the early Universe.

[2] The high-energy extragalactic neutrino background due to neutralino decays is a subject of Sec. 10.

  - Contained event rates and signatures.
  - Mapping the earth's interior with astrophysical neutrinos. *(See also Sec. 13.)*

- VHE Neutrinos from Cosmic Ray Interactions with the Solar Atmosphere and with the Moon[3].

9 High Energy Gamma Ray Astronomy with BANT

- Highlights of High Energy γ Astronomy.
  Current observational data. A list of the high energy γ-ray discrete-source candidates (the Crab Nebula, pulsars, binaries, AGNs, etc). and interpretation). Cosmic γ-ray bursters. (Quasi)diffuse high-energy γ-ray backgrounds.

- Muon photoproduction. Muon Content in γ Initiated Atmospheric Showers.
  - Photoproduction of pions and kaons followed by decay to muons.
  - Photoproduction and decay of charmed hadrons, $c\bar{c}$, and $b\bar{b}$ resonances.
  - Direct photoproduction of $\mu^+\mu^-$ pairs *[The Bethe–Heitler and Drell–Yan mechanisms].*
  - Hypothetical processes *[in particular, the minijet production mechanism (Sec. 3)].*

- "Muon Astronomy".
  Expected downgoing muon intensities and energy spectra from different gamma source candidates. Evaluation of the event rates.

- Using the BANT–Tunka Tandem[4].

10 BANT as a Dark Matter Detector

- CDM, HDM, MDM.
  Experimental and theoretical status of the dark matter problem. Cold, hot, and mixed dark matter in galaxies, galactic groups, clusters, and superclusters. Global cosmological parameters and the "$\Lambda \neq 0$ cosmology". Massive halo objects (self-trapped clumps) and gravitational microlensing.
  - Baryonic dark matter candidates *[dust, gas (e.g., molecular hydrogen), massive compact nonluminous objects (jupiters, brown dwarfs, black holes, strange or hybrid stars), hypothetical microobjects, like quark globes, skyrmions, etc].*
  - Nonbaryonic dark matter candidates
    [massive neutrinos, axions, majorons, mirror matter, techniquark matter, topological defects (strings, vortons, textures, monopoles), cosmions, WIMPs, etc].

- Why LSPs are Favoured CDM Candidates?

[3] The spectra of the VHE neutrinos generated in the earth atmosphere and in the heliosphere are different due to known distinctions between the compositions and density profiles of the atmospheres. The Moon is a source of prompt neutrinos (in particular, ν_τ). At the same time, UHE neutrinos are taken up by the Sun and the Moon. Among other things, the angular resolution better than 0.5° is necessary to see these effects.

[4] See Sec. 15 for a description of the Tunka telescope.

- SUSY Phenomenology and Terminology.
  [R parity, supermultiplets, sparticles, neutralinos, charginos, and all that.]
- Excluded Regions in the MSSM Parameter Space. *[Accelerator and underground (BST, KAMIOKANDE) data, cosmological and astrophysical limits. The $\chi\chi$ annihilations in the dark galactic halo and the restrictions from the cosmic-ray data on the e^+/e^-, $\overline{p}/p$ and γ fluxes.]*

- Neutrino Flux from Annihilation of Neutralinos Captured in the Earth and the Sun.
- Weak R Parity Violation and Neutrino Flux from Decay of Intergalactic Neutralinos[5].
- Equilibrium Neutrino Induced Muon Flux.
  Expected energy spectra and spatial distributions vs MSSM parameters.
- Signatures and Rates of the "SUSY" Contained Events. Sensitivity to the MSSM Parameters and LSP Mass.

11 Atmospheric Neutrino Oscillations

- Phenomenology of Neutrino Oscillations.
  - Overview of neutrino masses and mixing. *[Theoretical expectations. Current data on the Dirac and Majorana neutrino masses and CKM parameters from accelerator and reactor experiments. Cosmological and astrophysical limits (among them the limits from SN 1987 A). Data from the experiments on β decay and neutrinoless $\beta\beta$ decay. Allowed regions of the parameters from the solar neutrino data (Homestake, KAMIOKANDE, GALLEX, SAGE) based on the MSW effect and vacuum (long-wavelength) oscillations. Some alternative interpretations[6].]*
  - Three-neutrino oscillations in vacuum and matter. MSW mechanism. *[The most essential ideas and formulas necessary for the following analysis. Some calculational results for the (atmospheric) neutrino oscillations in the atmosphere and in the Earth.]*
  - Oscillations to sterile neutrinos.
- Current Results from Underground Experiments.
  - Upgoing throughgoing muons. *[Excluded regions in the parameter space obtained in the BST, KAMIOKANDE, IMB, Fréjus, and MACRO experiments. Basic sources of uncertainties.]*
  - Neutrino flavor anomaly at low energies.
    [The data on contained and partiallycontained neutrino induced events in the sub-GeV and multi-GeV energy ranges from the "optimistic" (KAMIOKANDE, IMB, SOUDAN 2) and the "pessimistic" (NUSEX, Fréjus) experiments. Interpretation of the data in terms of neutrino oscillations for competitive models of the AN flux. The Mann–Kafka–Leeson hypothesis ($p \to$

[5] The channel $\chi \to$ majoron $+ \nu$ strongly dominates over all others, for the spontaneous R parity breaking with the massless Goldstone boson remaining as the physical majoron. The $\nu_e(\overline{\nu}_e)$-induced events have a clear signature.

[6] Among the competitive interpretations are spin-flavor precession due to anomalous magnetic or transition magnetic moments of the neutrino, neutrino decay, and non-standard (flavor-changing) neutrino interactions. The list of more exotic explanations includes nonzero electric charge and pseudo-Dirac statistics of neutrinos, duotron and nuclei with an extra quark, Goldstone neutrinos and a host of other witty speculations.

$e^+\nu\nu$ decay). The Ryazhskaya hypothesis (muon induced neutron background). Basic sources of uncertainties (pion production cross sections etc).]

- General Methods for Studying Atmospheric Neutrino Oscillations with an Underwater Neutrino Detector.
  - Changes in the total rate of the neutrino induced (partially-) contained events.
  - Changes in the energy spectra and angular distributions of upgoing muons and single showers.
  - Analysis of the muonless to muonfull event ratio.
- Expected Limits on the Δm_{ij}^2 and CKM Mixing Parameters from Throughgoing and Contained Events in BANT.
- Expected Limits for Non-standard Neutrino Interactions.

12 A Long Baseline Neutrino Experiment

- Current Long Baseline Projects.
  - KEK – SUPERKAMIOKANDE.
  - Fermilab – DUMAND.
  - Brookhaven – SOUDAN 2.
  - CERN – Gran Sasso – NESTOR.
- A Long Baseline Neutrino Beam UNK – Baikal.
  - Characteristics of the neutrino beam from the Serpukhov UNK *[the ν and $\overline{\nu}$ energy spectra and flavor composition, beam collimation, etc].*
  - The event rate at BANT. *[Cumulative z and radial distributions for the events inside the fiducial area, energy spectrum of the neutrino interactions.]*
  - Sensitivity to Δm_{ij}^2 and mixing angles.
  - Sensitivity to neutrino life time and non-standard neutrino interactions.

13 Astrophysical Neutrino Oscillations at PeV Energies

- ν_τ Content in the Standard Astrophysical Sources. Cosmic ν_τ Backgrounds.
- Learned–Pakvasa Process.
  The topology and kinematics of the double bang event (hadronic shower from an initial ν_τ $\mapsto \sim 90\,m$ τ track $\mapsto$ second particle cascade). Super-long baseline experiment.
- τ Lepton Interactions at PeV Energies.
  - Direct $\ell\bar{\ell}$ & $q\overline{q}$ pair production and bremsstrahlung.
  - Photonuclear interaction.

- Cascades from τ decay in water.

- Sensitivity to Neutrino Masses and Mixing Parameters for AGN Neutrinos.

- Background Events.

  - Double bang events from muon neutrino interactions. *[ν_μ CC events with big delay of the muon catastrophic energy break.]*
  - Production (and decay) of D_s and B mesons in the atmospheric neutrino interactions. *[NC interactions of ν_e and ν_μ, CC interactions of ν_e, diffractive production of D_s via the charm changing CC reaction $\nu_e N \to e D_s X$.]*
  - Atmospheric muons and other noises.

- Possible Future Applications.
  "Tau-astronomy" (search for exotic τ neutrino sources) and "tau-tomography".

- What if τ Neutrinos are Unstable?
  Theoretical expectations for the 3ν oscillations with an unstable ν_3. Predictions for the super-long baseline experiment at different scenarios. Sensitivity to the ν_3 life time.

14 Exotic and Scarce Events

List of some hypothetical particles and rare or speculative phenomena which could be investigated with large water Cherenkov and/or acoustic detectors. Peculiar features. Estimating the event rates and backgrounds. Summary of the hints and limits from the earlier experiments.

- Search for Low-Energy Neutrino Signals from Supernova Bursts.

- Search for Slowly Moving Bright Objects.

  - GUT magnetic monopoles and nucleon decay catalysis. *[The Callan–Rubakov mechanism. Model predictions.]*
  - Strange quark matter *[nuclearities ($A \gtrsim 10^6$) and SQM nuggets $\sim$ strangelets $\sim$ quark globs/lumps ($10^2 \lesssim A \lesssim 10^6$)].*
  - The limits obtained with the NT-200 prototypes.

- Search for Relativistic Objects.

  - Fast Dirac monopoles and dyons *[including monopole-proton and more complex bound states].*
  - Tachyons and tachyon monopoles. *[One way of studying the "leading events" is to use the BANT–Tunka tandem (Sec. 15).]*
  - Mirror cosmic rays (signals from the "shadow universe"). *[Distinguishable through the measuring the NC to CC event ratio vs energy and zenith angle.]*

- Conjectured Phenomena in Neutrino-Matter Interactions Well Beyond the PeV Energy Range.
  [Among the signs are localized energy deposition in the detector within a rather small volume, high hadron multiplicity, hard p_T distribution, and specific clusterization in near-horizontal (super)families.]
  - $B + L$ violation and multiple W, Z, and Higgs boson neutrinoproduction *(see Sec. 4)*.
  - Events generated by "composite neutrinos". *[The Domokos–Kovesi-Domokos scenario with a few TeV scale ("preon") level of quark & lepton compositeness.]*
- Thorny Subjects.
  - Neutrino electromagnetic interactions.
    - Radiative neutrino decay in matter[7].
    - Cherenkov radiation of neutrino intrinsic magnetic and electric dipole moments[8].
  - Esoteric matter *[random examples]*[9].
    - Ultrarelativistic WIMPs (VHE LSPs from decay of Big Bang relics etc).
    - Weakly interacting fractionally charged particles (WIFs).
    - Quasistable technicolor matter (technibaryons, technibaryon nuclei, technibaryon-nucleus atoms, etc).

15 Particle Physics with BANT and Tunka Surface Gamma Telescope

- The Tunka Array.
  A description of the array and its current results. The tandem geometry. Correlated observations of the surface (EAS) and underwater (muon) events.
- High p_T Physics.
  - Transverse momentum distributions of the high-energy secondaries in nucleon-nucleus, nucleus-nucleus, and γ-nucleus collisions *[the pQCD predictions and alternative model expectations]*.
  - Event signatures and rates. Sensitivity of the tandem to the high p_T events.

16 Detached Items and Questions

- Space-Time Structure and Peculiar Characteristics of LPM Electromagnetic and Hadronic Showers in Water. *[Important for many experiments with BANT.]*

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[7] There are no good proposals for the event identification.

[8] With $\mu_\nu^{\rm eff} = 10^{-10}\mu_B$, the solar neutrinos would emit around 50 optical photons per day in the BAND volume. This rate is below the light background if not hopelessly small. The event rate of the high-energy Cherenkov showers from terrestrial and extraterrestrial neutrinos is estimated to be immeasurable with BANT. Cherenkov radiation from the standard neutrino induced charge in water is completely negligible.

[9] Identification in BANT is highly conjectural.

- Muon Bundles from γ Initiated EAS. *[Is it possible to recognize these events among other downgoing muon bundles?]*

- Muon Bundles from UHE Neutrino Induced Near-Horizontal EAS. *[Are there some peculiarities for the recognizing?]*

- Range Struggling Effect for the Muons Generated by Neutrinos in the Surrounding Rock. *[Can be significant at very steep neutrino spectra, like ones expected from AGNs and some other sources (Sec. 8).]*

- Unstable Neutrino Oscillations in Vacuum and Matter. *[The theory is absent. Might be interesting for experiments on astrophysical ν_τ oscillations at PeV energies (Sec. 13).]*

- Neutrino Oscillations in Matter with Absorption and Regeneration. *[Important for many applications. There is only an incipient theory for the quasi-adiabatic three-flavour oscillations with absorption.]*