JINR Neutrino Program

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June 15, 2015

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   - Knowns and Unknowns about neutrino
   - Short Review of JINR Neutrino Program
2. Neutrino Program In More Details
   - BOREXINO
   - SOX
   - OPERA
   - Daya Bay
   - JUNO
   - NOVA
   - GEMMA
   - SuperNEMO
   - GERDA
   - νGEN
   - DANSS
   - BAIKAL GVD
   - Theory Support
3. Possible Brasilia-JINR Collaborations
   - Baikal GVD
   - R&D
   - Education and Outreach
   - DLNP Day: June 18 2015

Known

- Spin ½. Weak and gravitation interactions
- Lepton generations do mix in interactions with $W^{\pm}$. All mixing angles are now measured. NuFit values:

$$\theta_{12}[^\circ] = 33.48^{+0.77}_{-0.74}$$
$$\theta_{23}[^\circ] = 42.2^{+0.1}_{-0.1} \text{ or } 49.4^{+1.6}_{-2.0}$$
$$\theta_{13}[^\circ] = 8.52^{+0.20}_{-0.21}$$
$$\delta_{\mathrm{CP}}[^\circ] = 251^{+67}_{-59}$$

- Neutrino is massive
  - From neutrino oscillations:

$$\Delta m^2_{21} = (7.65^{+0.23}_{-0.20}) \times 10^{-5}\ \mathrm{eV}^2,$$
$$\Delta m^2_{31} = (2.43^{+0.12}_{-0.11}) \times 10^{-3}\ \mathrm{eV}^2.$$

  - From tritium decays:

$$m_\beta = \sqrt{\sum_i |V_{ei}|^2 m_i^2} < 2.2\mathrm{eV}$$

- From cosmology (model dependent):

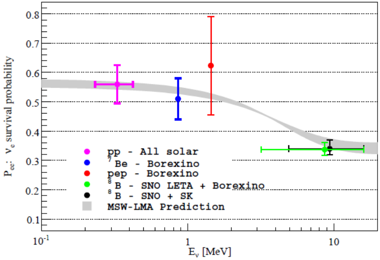
$$\sum_i m_i < 0.320 \pm 0.081\ \mathrm{eV}$$

Unknown

- Dirac or Majorana?
- Neutrino mass hierarchy (MH)
- CP-violation phase δ
- Unitarity of neutrino mixing matrix or do exist sterile neutrinos?
- The mass of the lightest neutrino
- Presence of non standard interactions? (NSI)
- Origin of UHE neutrinos
- Relic neutrinos

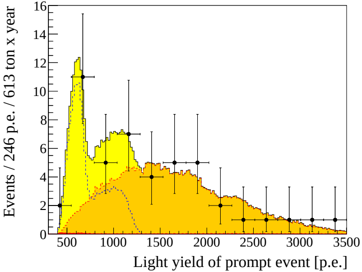
JINR Neutrino Program widely covers major neutrino topics

- **NOVA:** Accelerator neutrino and antineutrino. Mass Hierarchy determination. Matter effects
- **OPERA:** Accelerator neutrino. $\theta_{23}, \Delta m^2_{32}, \nu_\tau$ appearance
- **BAIKAL GVD:** Astrophysical and atmospheric neutrino. Matter effects. $\theta_{23}, \Delta m^2_{32}$. Reach potential.
- **BOREXINO**: Solar, geo-neutrino, matter effects, $\theta_{12}, \Delta m^2_{21}$, rare processes
- **SOX**: Radioactive source. Sterile neutrino search.
- **SuperNEMO:** Dirac or Majorana vs $0\nu2\beta$
- **GERDA:** Dirac or Majorana vs $0\nu2\beta$
- **Daya Bay:** Reactor antineutrino. $\theta_{13}, \Delta m^2_{ee}$, sterile neutrino, reactor flux measurement
- **JUNO:** Reactor antineutrino. Mass Hierarchy determination. Precise (better than 1%) measurement of $\theta_{12}, \Delta m^2_{21}, \Delta m^2_{32}$, SN neutrinos, reach program.
- **DANSS:** Reactor antineutrino. Sterile neutrino. Reactor monitoring.
- **GEMMA-2:** Reactor antineutrino. μ_ν anomalous neutrino magnetic moment
- **νGEN:** Coherent Neutrino Germanium Nucleus Elastic Scattering



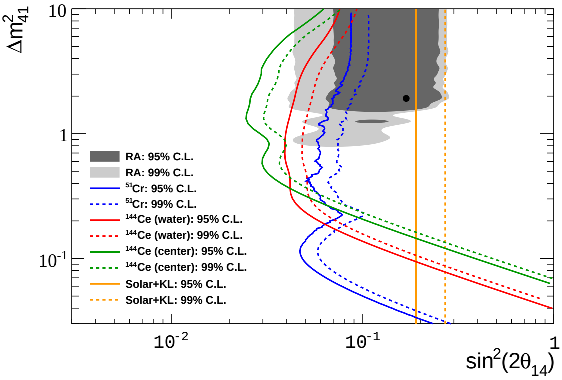
- Measured flux of ^{7}Be, pep and ^{8}B neutrinos
- Measured Day/Night asymmetry
- Upper limit on the effective magnetic moment of neutrinos
- Neutrinos from CNO cycle are limited
- Seasonal variations of neutrino flux are studied

- Geo-neutrinos are observed for the first time by BOREXINO and KamLAND

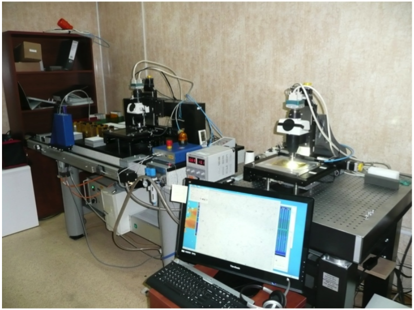


JINR contribution consists in the data taking and data analysis with major contributions to all reported here analyses

- Good energy and spatial resolutions of BOREXINO are of great importance here
- External source of mono-energetic neutrino ^{51}Cr:
  - ✓ 5-10 MCu
  - ✓ Second phase (2014-2015)
- Internal source of mono-energetic antineutrino ^{144}Ce:
  - ✓ 50-100 kCu
  - ✓ After finishing second phase (2016-2017) — need to modify the detector



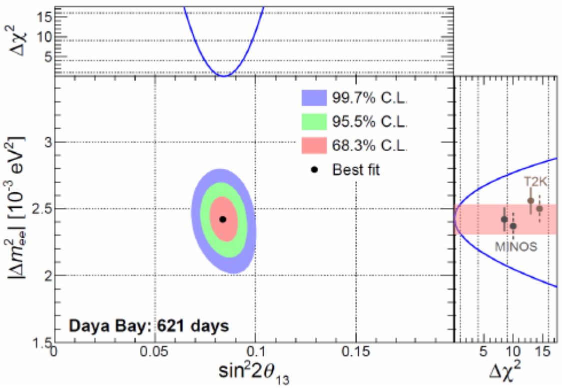
JINR contribution consists in the data taking and data analysis.



- First proof of ν_τ appearance! 5 τ candidates are found
- Data analysis is performed also at the emulsion level in the automatic scanning laboratory created at JINR.

JINR contribution:

- Scintillator strip production, assembly of the Target Tracker planes, their calibration and installation.
- Electronic detectors analysis, neutrino vertex location in the detector
- Simulation & reconstruction
- Data taking and data analysis
- Data taking is stopped in 2012



- Discover of non-zero θ_{13}
- Most precise measurement of $\sin^2 2\theta_{13}$ and comparable to MINOS of Δm^2_{ee}
- Precise measurement of reactor spectra
- Most stringent limit on existence of sterile neutrino in $10^{-3} < \Delta m^2_{41} < 0.1$ eV^2.

JINR contribution:

- PPO production and delivery
- Liquid Scintillator measurements and optimization: Light Yield, Transparency, Energy Resolution, Neutron capture for Gd loaded LS
- Simulation and reconstruction software
- IBD selection
- Data analysis: oscillation, sterile, reactor spectra

Large θ_{13} opened a window to study mass hierarchy and δ

Brief Summary

- 20 ktons of LS
- Energy resolution $3\%/\sqrt{E}$
- Thermal power 36 GWt
- 40 neutrinos per day
- Sensitivity to MH: $4-5\sigma$
- Measure PMNS matrix to 1% accuracy (similar to quarks)

Reach Physics Case

- SN detection: 3500 events (<15 kpc)
- Geoneutrinos
- Diffuse supernova neutrinos
- Solar neutrinos
- Atmospheric neutrinos
- Proton decay
- Sterile neutrino

JINR contribition (ongoing work)

- Intelligent HV system
- PMT protection against Earth magnetic field
- Construction of a dedicated laboratory for large PMT tests and LS studies
- μ-Target Tracker based on OPERA plastic scintillator (together with European colleagues)
- Detector design
- Simulation & reconstruction
- Data analysis

Brief Summary

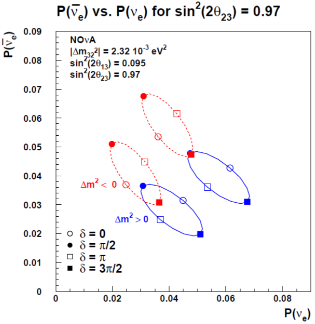
- NuMI off-axis beam
- Near (0.3 tons) and Far (14 ktons) detectors with plastic strips fillied by LS
- 810 km baseline
- $E_\nu \approx 2$ GeV
- $3\nu + 3\bar{\nu}$ data taking
- Matter effects play major role in MH sensitivity

Reach Physics Case

- MH determination, constrain δ
- Resolve θ_{23} octant
- Precision measurement of $\Delta m^2_{32}, \theta_{23}$
- Cross-section measurement
- Sterile, SN, monopoles

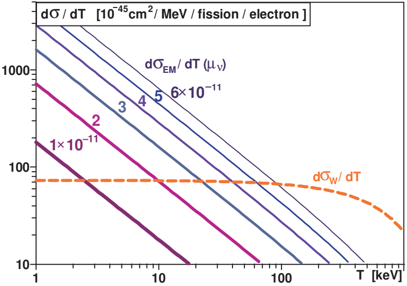
JINR contribition (ongoing work)

- Detector assembling, calibration
- Data quality control
- Reconstruction
- Theoretical description of $\sigma_{\nu N}$ and matter effects
- Simulation
- Data analysis

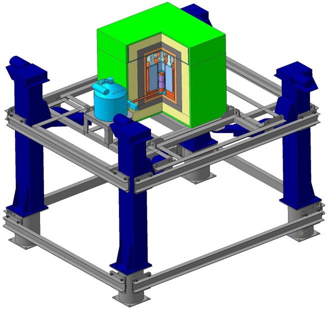


GEMMA = **G**ermanium **E**xperiment Searching for **M**agnetic **M**oment of **A**ntineutrino

- Standard Model:
  $\mu_\nu = 10^{-19} \frac{m_\nu}{\text{eV}} \mu_B$
- Extensions of SM:
  $\mu_\nu = 10^{-11 \div 12} \mu_B$ (Majorana) and
  $\mu_\nu < 10^{-14} \mu_B$ (Dirac)
- An observation of the
  $\mu_\nu > 10^{-14} \mu_\text{B}$ = New Physics + Majorana.

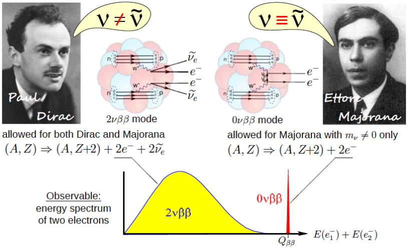


- Kalinin Nuclear Power Plant
- GEMMA result:
  $\mu_\nu < 2.9 \cdot 10^{-11} \mu_B$
- GEMMA-2 sensitivity:
  $\mu_\nu = 1.0 \cdot 10^{-11} \mu_B$
- Movable platform



JINR contribution: Everything (almost)

Brief Summary

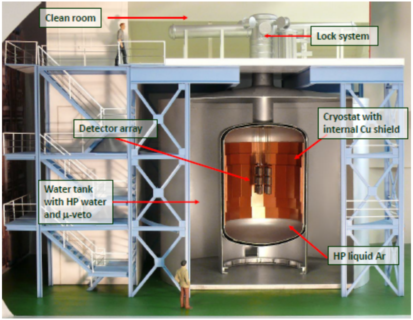


- NEMO could detect $\beta\beta$ with tracking and calorimetric techniques.
- limit on the $0\nu\beta\beta$-decay of ^{100}Mo and upper limit on the effective neutrino mass: $T_{1/2}(0\nu\beta\beta) \geq 1.1 \times 10^{24}$y, $\langle m_\nu \rangle < 0.3 \div 0.9$ eV.
- The SuperNEMO be an order of magnitude more sensitive to m_ν

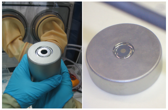
JINR contribution

- MC simulation, detector design.
- Tracking software, $\beta\beta$ selection, background.
- Databases, dAQ, slow control, data analysis.
- Development and creation of the calorimeter and veto systems based on plastic scintillators.
- Calibration and monitoring system on the basis of JINR radioactive sources.
- Low background measurements for JINR HPGe-detector (600 cm^3).
- Production electromagnetic source of mono-energetic electrons for quality control of plastic scintillators used in the calorimeter and the veto system.
- Participation in the development and creation of the ultra low-background BiPo-3 spectrometer aimed to measure radiopurity of $\beta\beta$-decay source foils.

Brief Summary



- Check Heidelberg-Moscow claim with 21 kg yr.
- The limit $T^{0\nu}_{1/2} > 2.1 \times 10^{25}$y (90% CL) does not support HM claim



JINR contribution

- JINR was responsible for design, production, testing and installation of plastic muon veto system on the top of GERDA cryostat. This veto will be also used for Phase II.
- JINR specialists participate heavily in the development of LAr instrumentation.
- Physicists from JINR are strongly involved in the analysis of GERDA data, especially for Phase II (BEGe) detectors and this contribution will be increased.
- JINR members play the central and leading role in the core of GERDA experiment operations with bare germanium detectors.

Detection Coherent **N**eutrino–**Ge N**ucleus Elastic Scattering (KNPP).

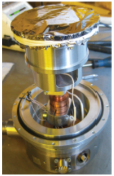
Brief Summary

- $\nu + A \rightarrow \nu + A$ **Coherent Neutrino Nucleus Scattering** (CNNS)
- Recoil energy < 1 keV. JINR **low-threshold HPGe detectors** with energy threshold of **350 eV**.

- The background $\simeq$ 0.5 events/kg/keV/day.
- 10m from reactor core = 10 events per day.

JINR contribution

- Expertise in the production of unique low-threshold HPGe detectors



- This is JINR proposal
- Unique experience in conducting low-background $0\nu2\beta$-search experiments and low-threshold experiments (search for neutrino magnetic moment) at the KNPP.

Expects to detect the coherent neutrino-nucleus scattering and measure CNNS cross-section in Ge during the nearest 3–5 years.

Detector of the Reactor **A**nti**N**eutrino based on **S**olid **S**cintillator

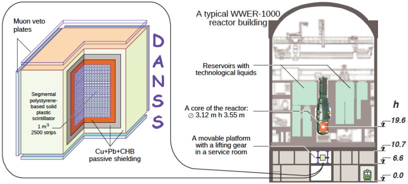
Brief Summary

- Main Tasks:
  - ✓ Sterile Neutrino Search
  - ✓ Reactor Spectra Measurement and Tomography
  - ✓ Monitoring of ^{239}Pu: 3–4% per 5 days
- Detector
  - 1 m^3, 13 t
  - $\sim 10^4$ IBD-events/day at 11 m
  - Background: 40-50 events/day
  - Energy resolution: FWHM $\leq$ 30% at $E_\nu = 4$ MeV
  - IBD detection efficiency: $\sim$72%
  - Movable detector (9.7 m $\rightarrow$ 12.2 m)

Expect data taking in 2016.

JINR contribution

- design and creation of the entire mechanical structure (detector strips with WLS fibers, passive and active shielding, lifting system),
- light extraction system,
- PMT front-end electronics, DAQ



Brief Summary

- 1 km^3 scale by 2023
- Flexible structure (upgrade and re-arrangemenet)
- High accuracy in reconstruction of direction, good energy reconstruction and flavour decomposition
- 2304 PMTs
- Baikal was a pioneer in the field. Huge experience is accumulated
- New life began in 2014. A need for a 1 km^3 detector is clear to identify the sources.
- 27 astrophysical neutrinos to be detected by 2020.
- First cluster “Dubna” is installed in 2015

JINR contribution

- Assembly and test of deep water components.
- Continuous monitoring of the detector operation and remote control.
- Online and Offline
- Databases, DAQ
- Detector calibration and mass processing of data.
- Simulations, reconstruction, selection.
- Data analysis
- Additional 5.5M$/year for next 5 years are approved by JINR Directorate to build the detector.

BAIKAL GVD Collaboration is now quickly expanding with Russian and Foreign Participants. Welcome to join us!

In close collaboration with BLTP

- Quantum Mechanical Theory of Neutrino Oscillations in vacuum and matter
- Quantum Field Theory of Neutrino Oscillations in vacuum and matter (with wave packets)
- GNA: Global Neutrino Analysis. A software tool under development on neutrino oscillation global data analysis + sensitivity projections
- KLIN: Global fits of νN cross-sections (QEL, DIS, RES, ...)
- Neutrino less Double Beta Decay Theory
- Statistical Analisis Tools

- Calorimetry of detection systems, e.g. a new-generation high-granularity "Shashlyk" EM calorimeter (for project NICA, COMPASS, etc)
- MicroMegas, "Straw-tube" detectors, Micropixel avalanche photodiodes
- High-purity and low-threshold germanium detectors
- Development and production of accelerators (for applied science)
- A new, very promising, metrology with a laser beam (CLIC, ATLAS, etc). practice.
- A new modern laboratory for assembling and testing PMTs (JUNO, GVD, etc) started to work at DLNP in 2015.
- *Detector DANSS will be used for measuring the actual reactor power and the actual fuel composition; on-line reactor monitoring (tomography). Especially important in view of the future non-proliferation (prevent unauthorized extraction of 239-Pu).*
- Our famous Medical Research on Phasotron inevitably sooner or latter must be over. A new project, to continue our medical research, is under study.

DLNP laboratory for PMT tests was created in 2014

An example: JUNO + NOVA young stars

We organized and hold regularly:

- Baikal School on Physics of Elementary Particles and Astrophysics (Big Cats, Irkutsk region)
- Pontecorvo Neutrino School
- Weekly DLNP seminar on neutrino physics and astrophysics
- “Nobel Prizes” in physics — seminar for junior researchers

We participate in various schools, conferences and workshops

- HEP and astrophysics conferences and workshops
- Reading lectures for school teachers
- Reading lectures for school students

Working with young people

- Our groups are growing up mainly due to new young students who become important players after several years
- Many diploma and PhD theses in last 10 years defended in our group

9.30 D.V. Naumov (DLNP JINR) **”Baikal GVD and TAIGA – perspectives in neutrino and gamma astronomy”**

10.00 D.S. Shkirmanov (BLTP JINR) **”Quantum Field Theory of Neutrino Oscillations and Reactor AntiNeutrino Anomaly”**

10.30 S.A. Kotov (DLNP JINR) **”R&D of particle detectors”**

11.00-11.20 Coffee-break

11.20 N.V.Anphimov (DLNP JINR) **”R&D of ECAL and Photo-Detectors”**

11.50 G.V. Mitsin (DLNP JINR) **”Applied Research: Radiotherapy and associated diagnostics”**

12.20 Yu. A. Usov (DLNP JINR) **”Method to reach Ultra Low Temperatures and its use in Experimental Physics”**

12.50-15.00 Lunch

15.00 Round Table: Discussion of possible collaborations between DLNP JINR and Brasilia

17.30 Excursion to Phasotron and Medical Technical Complex for proton Therapy (DLNP JINR)