Papers submitted or accepted

Measurement of geo-neutrinos from 1353 days of Borexino

Lifetime measurements of 214Po and 212Po with the CTF liquid scintillator detector at LNGS

Precision Measurement of the Neutron Beta-Decay Asymmetry

Borexino calibrations: Hardware, Methods, and Results
e-Print: arXiv:1205.2989 [hep-ex]

Solar neutrino physics with Borexino I
e-Print: arXiv:1205.2989 [hep-ex]

Light Yield in DarkSide-10: a Prototype Two-phase Liquid Argon TPC for Dark Matter Searches
FERMILAB-PUB-12-619-E

A Study of the Residual 39Ar Content in Argon from Underground Sources
e-Print: arXiv:1204.6011 [physics.ins-det]

Light Sterile Neutrinos: A White Paper
89 Citations

Papers in refereed journals (citations from inSPIRE or Web of Knowledge – only ≥ 20 reported)

High precision Be-7 solar neutrinos measurement and day night effect obtained with Borexino
Borexino Collaboration

We report the direct measurement of the ^7Be solar neutrino signal rate performed with the Borexino detector at the Laboratori Nazionali del Gran Sasso and the search for a day-night asymmetry of this interaction rate. The interaction rate of the 0.862MeV ^7Be neutrinos is 46+/−1.6(stat)−1+1.5(syst) counts/(day . 100ton). The hypothesis of no oscillation for this solar neutrinos is inconsistent with our measurement at the 5.8@5 C.L. Our result is the first direct measurement of solar neutrinos with an accuracy better than 5%. We report the survival
probability for solar $\theta_{\tau e}$ in the transition region between matter-enhanced and vacuum-driven oscillations. The measured day-night asymmetry is $A_{\odot}=0.001^{+/-0.012 \ (\text{stat})}^{+/-0.007 \ (\text{syst})}$, in agreement with the prediction of MSW-LMA neutrino [13] oscillations. This result discourages MSW oscillations with mixing parameters in the LOW region at more than 8.5σ, meaning that this region is, for the first time, strongly rejected without the assumption of CPT symmetry. The result can also be used to constrain some neutrino oscillation scenarios involving new physics.

**Artificial neutrino source experiment in Borexino**
Borexino Collaboration

*J.Phys.Conf.Ser. 375 (2012) 042066*

An experiment with an artificial neutrino source in Borexino is presented. The neutrino source can be located outside the detector or eventually, at the end of the solar neutrino phase, could be deployed inside. The physics case for the source experiment includes the search for short-baseline neutrino oscillations, neutrino-electron scattering at sub-MeV range, neutrino magnetic moment. Preliminary predictions of the sensitivity are reported for the sterile neutrino search.

**Measurement of CNGS muon neutrino speed with Borexino**
Borexino Collaboration


We have measured the speed of muon neutrinos with the Borexino detector using short-bunch CNGS beams. The final result for the difference in time-of-flight between a $<E>=17$ GeV muon neutrino and a particle moving at the speed of light in vacuum is $\delta t = 0.8^{+0.7}_{-0.2}\text{stat}^{+1.9}_{-2.9}\text{syst}$ ns, well consistent with zero.

**Measurement of the neutron $\beta$-asymmetry parameter $A_0$ with ultracold neutrons**
UCNA Collaboration


We present a detailed report of a measurement of the neutron $\beta$-asymmetry parameter $A_0$, the parity-violating angular correlation between the neutron spin and the decay electron momentum, performed with polarized ultracold neutrons (UCN). UCN were extracted from a pulsed spallation solid deuterium source and polarized via transport through a 7-T magnetic field. The polarized UCN were then transported through an adiabatic-fast-passage spin-flipper field region, prior to storage in a cylindrical decay volume situated within a 1-T $2 \times 2\pi$ solenoidal spectrometer. The asymmetry was extracted from measurements of the decay electrons in multiwire proportional chamber and plastic scintillator detector packages located on both ends of the spectrometer. From an analysis of data acquired during runs in 2008 and 2009, we report $A_0 = -0.11966 \pm 0.00089^{(-0.00140)}^{+(+0.00123)}$, from which we extract a value for the ratio of the weak axial-vector and vector coupling constants of the nucleon, $\lambda = g_A/g_V = -1.27590 \pm 0.00239^{(-0.00377)}^{+(+0.00331)}$. Complete details of the analysis are presented.

**Cosmic-muon flux and annual modulation in Borexino at 3800 m water-equivalent depth**
Borexino Collaboration


We have measured the muon flux at the underground Gran Sasso National Laboratory (3800 m w.e.) to be $(3.41^{+0.01}_{-0.01}) \times 10^{-4}$ m$^{-2}$ s$^{-1}$ using four years of Borexino data. A modulation of this signal is observed with a period of (366 ± 3) days and a relative amplitude of $(1.29^{+0.07}_{-0.07})\%$. The measured phase is $(179^{+6}_{-16})$ days, corresponding to a maximum on the 28th of June. Using the most complete atmospheric data models available, muon rate fluctuations are shown to be positively correlated with atmospheric temperature, with an effective coefficient $\alpha = 0.93^{+0.04}_{-0.04}$ °C. This result represents the most precise study of the muon flux modulation for this site and is in good agreement with expectations.

**Search for Solar Axions Produced in $p(d,3He)A$ Reaction with Borexino Detector**
Borexino Collaboration

A search for 5.5-MeV solar axions produced in the $p+d\rightarrow\rm{^3He}+A (5.5 \ \rm{MeV})$ reaction was performed using the Borexino detector. The Compton conversion of axions to photons, $\rm{\gamma}\rightarrow e+\gamma\text{m}A$, the axio-electric effect, $\rm{\gamma}\rightarrow e+Z\rightarrow e+Z\text{m}A$, the decay of axions into two photons, $\rm{A}\rightarrow 2\gamma$, and inverse Primakoff conversion on nuclei, $\text{m}A\rightarrow \gamma+Z\text{m}A$, are considered. Model independent limits on axion-electron ($g_{\text{Ae}}$), axion-photon ($g_{\text{A\gamma}}$), and isovector axion-nucleon ($g_{\text{AN}}$) couplings are obtained: $|g_{\text{Ae}} \times g_{\text{AN}}| \leq 5.5 \times 10^{-13}$ and $|g_{\text{A\gamma}} \times g_{\text{AN}}| \leq 4.6 \times 10^{-11} \ \text{GeV}^{-1}$ at $m_A <$ 1 MeV (90% c.l.). These limits are 2-4 orders of magnitude stronger than those obtained in previous laboratory-based experiments using nuclear reactors and accelerators.

Absence of day – night asymmetry of 862 keV $^7\text{Be}$ solar neutrino rate in Borexino and MSW oscillation parameters

By Borexino Collaboration


We report on a search for the day-night asymmetry of the Be-7 solar neutrino rate measured by Borexino at the Laboratori Nazionali del Gran Sasso (LNGS), Italy. The measured value, $Adn=0.001 \pm 0.012$ (stat) $\pm 0.007$ (syst), shows the absence of a significant asymmetry. This result alone rejects the so-called LOW solution at more than 8.5 sigma. Combined with the other solar neutrino data, it isolates the Large Mixing Angle (LMA) -- MSW solution at DeltaChi2 > 190 without relying on the assumption of CPT symmetry in the neutrino sector. We also show that including the day-night asymmetry, data from Borexino alone restricts the MSW neutrino oscillations to the LMA solution at 90% confidence level.

First evidence of pep solar neutrinos by direct detection in Borexino.

By Borexino Collaboration


We observed, for the first time, solar neutrinos in the 1.0-1.5 MeV energy range. We measured the rate of pep solar neutrino interactions in Borexino to be $[3.1+0.6(\text{stat})+0.3(\text{syst})]$ counts/(day x 100 ton) and provided a constraint on the CNO solar neutrino interaction rate of <7.9 counts/(day x 100 ton) (95% C.L.). The absence of the solar neutrino signal is disfavored at 99.97% C.L., while the absence of the pep signal is disfavored at 98% C.L. This unprecedented sensitivity was achieved by adopting novel data analysis techniques for the rejection of cosmogenic 11C, the dominant background in the 1-2 MeV region. Assuming the MSW-LMA solution to solar neutrino oscillations, these values correspond to solar neutrino fluxes of $[1.6-0.3] \times 10^8$ cm$^{-2}$s$^{-1}$ and $7.7 \times 10^8$ cm$^{-2}$s$^{-1}$ (95% C.L.), respectively, in agreement with the Standard Solar Model. These results represent the first measurement of the pep neutrino flux and the strongest constraint of the CNO solar neutrino flux to date.

Precision measurement of the 7Be solar neutrino interaction rate in Borexino.

By Borexino Collaboration


A direct measurement of the 0.862 MeV 7Be solar neutrino interaction rate performed with the Borexino detector at the Laboratori Nazionali del Gran Sasso yields $46.0^{+1.6}_{-1.5} \ \text{count/100 tons}$. Our result is the first direct measurement of a sub-MeV solar neutrino rate with an accuracy better than 5%. The hypothesis of no oscillation for 7Be solar neutrinos is rejected at 4.985 sigma C.L. Using the latest Standard Solar Model (SSM) flux predictions, the result leads directly to a precise determination of the survival probability for solar $\nu_e$'s in vacuum, and permits us to probe with unprecedented sensitivity the transition between the matter-enhanced and vacuum-dominated neutrino oscillation regimes characteristic of the MSW-LMA solution to the solar neutrino problem.

Muon and Cosmogenic Neutron Detection in Borexino.

By Borexino Collaboration
Borexino, a liquid scintillator detector at LNGS, is designed for the detection of neutrinos and antineutrinos from the Sun, supernovae, nuclear reactors, and the Earth. The feeble nature of these signals requires a strong suppression of backgrounds below a few MeV. Very low intrinsic radiogenic contamination of all detector components needs to be accompanied by the efficient identification of muons and of muon-induced backgrounds. Muons produce unstable nuclei by spallation processes along their trajectory through the detector whose decays can mimic the expected signals for isotopes with half-lives longer than a few seconds, the dead time induced by a muon-related veto becomes unacceptably long, unless its application can be restricted to a sub-volume along the muon track. Consequently, not only the identification of muons with very high efficiency but also a precise reconstruction of their tracks is of primary importance for the physics program of the experiment. The Borexino inner detector is surrounded by an outer water-Cherenkov detector that plays a fundamental role in accomplishing this task. The detector design principles and their implementation are described. The strategies adopted to identify muons are reviewed and their efficiency is evaluated. The overall muon veto efficiency is found to be 99.992% or better. Ad-hoc track reconstruction algorithms developed are presented. Their performance is tested against muon events of known direction such as those from the CNGS neutrino beam, test tracks available from a dedicated External Muon Tracker and cosmic muons whose angular distribution reflects the local overburden profile. The achieved angular resolution is 3-5 deg and the lateral resolution is 35-50 cm, depending on the impact parameter of the crossing muon. The methods implemented to efficiently tag cosmogenic neutrons are also presented.

Study of solar and other unknown anti-neutrino fluxes with Borexino at LNGS.

By Borexino Collaboration
We report on the search for anti-neutrinos of yet unknown origin with the Borexino detector at the Laboratori Nazionali del Gran Sasso. In particular, a hypothetical anti-neutrino flux from the Sun is investigated. Anti-neutrinos are detected through the neutron inverse $\beta$ decay reaction in a large liquid organic scintillator target. We set a new upper limit for a hypothetical solar $\bar{\nu}_e$ flux of 760 $(\text{cm}^{-2}\text{cm}^{-2}\text{s}^{-1})$, obtained assuming an undistorted solar $^8$B energy spectrum. This corresponds to a limit on the transition probability of solar neutrinos to anti-neutrinos of $1.3\times10^{-4}$ (90% C.L.) for $E_{\bar{\nu}}>1.8$ MeV, covering the entire $^8$B spectrum. Best differential limits on anti-neutrino fluxes from unknown sources are also obtained between the detection energy threshold of 1.8 MeV and 17.8 MeV with more than 2 years of data.

Low-Background gamma counting at the Kimballton Underground Research Facility.
P. Finnerty, et al.
The next generation of low-background physics experiments will require the use of materials with unprecedented radio-purity. A gamma-counting facility at the Kimballton Underground Research Facility (KURF) has been commissioned to perform initial screening of materials for radioactivity primarily from nuclides in the 238U and 232Th decay chains, 40K and cosmic-ray induced isotopes. The facility consists of two commercial low-background high purity germanium (HPGe) detectors. A continuum background reduction better than a factor of 10 was achieved by going underground. This paper describes the facility, detector systems, analysis techniques and selected assay results.

Study of solar and other unknown anti-neutrino fluxes with Borexino at LNGS.
We report on the search for anti-neutrinos of yet unknown origin with the Borexino detector at the Laboratori Nazionali del Gran Sasso. In particular, a hypothetical anti-neutrino flux from the Sun is investigated. Anti-neutrinos are detected through the neutron inverse $\beta$ decay reaction in a large liquid organic scintillator target. We set a new upper limit for a hypothetical solar...
\[ \bar{\nu}_e \text{ flux of } 760 \text{ cm}^{-2}\text{s}^{-1}, \text{ obtained assuming an undistorted solar } ^{8}\text{B energy spectrum. This corresponds to a limit on the transition probability of solar neutrinos to anti-neutrinos of } 1.3 \times 10^{-4} \text{ (90\% C.L.) for } E_{\bar{\nu}} > 1.8 \text{ MeV, covering the entire } ^{8}\text{B spectrum. Best differential limits on anti-neutrino fluxes from unknown sources are also obtained between the detection energy threshold of 1.8 MeV and 17.8 MeV with more than 2 years of data.} \]

**Determination of the Axial-Vector Weak Coupling Constant with Ultracold Neutrons.**

UCNA Collaboration (J. Liu et al.).


A precise measurement of the neutron decay $\beta$-asymmetry $A_0$ has been carried out using polarized ultracold neutrons (UCN) from the pulsed spallation UCN source at the Los Alamos Neutron Science Center (LANSCE). Combining data obtained in 2008 and 2009, we report $A_0 = -0.11966 \pm 0.00089 \times (0.00140)^+\!-\!0.00123\times$, from which we determine the ratio of the axial-vector to vector weak coupling of the nucleon $g_A/g_V = -1.27590 \times (0.00445)^+\!-\!0.00409\times$.

20 Citations

**Observation of Geo-Neutrinos.**

Borexino Collaboration (G. Bellini et al.)


Geo-neutrinos, electron anti-neutrinos produced in beta decays of naturally occurring radioactive isotopes in the Earth, are a unique direct probe of our planet’s interior. We report the first observation at more than 3\(\sigma\) of geo-neutrinos, performed with the Borexino detector at Laboratori Nazionali del Gran Sasso. Anti-neutrinos are detected through the neutron inverse beta decay reaction. With a 252.6 ton-yr fiducial exposure after all selection cuts, we detected $9.9 \times (4.1)^{+\!-\!3.4}\times \times (14.6)^{+\!-\!8.2}$ geo-neutrino events, with errors corresponding to a 68.3\% (99.73\%) C.L. From the $\ln L_{\text{cal}}$ profile, the statistical significance of the Borexino geo-neutrino observation corresponds to a 99.997\% C.L. Our measurement of the geo-neutrinos rate is $3.9^{+\!+\!1.6}_{-\!-\!1.3}\times \times (5.8)^{+\!-\!3.2}$ events/(100 ton-yr$^{-1}$). This measurement rejects the hypothesis of an active geo-reactor in the Earth’s core with a power above 3 TW at 95\% C.L. The observed prompt positron spectrum above 2.6 MeV is compatible with that expected from European nuclear reactors (mean base line of approximately 1000 km). Our measurement of reactor anti-neutrinos excludes the non-oscillation hypothesis at 99.60\% C.L.

54 Citations

**Results from the Borexino experiment.**

Borexino Collaboration (M. Misiaszek et al.).


We report on the search for anti-neutrinos of yet unknown origin with the Borexino detector at the Laboratori Nazionali del Gran Sasso. In particular, a hypothetical anti-neutrino flux from the Sun is investigated. Anti-neutrinos are detected through the neutron inverse $\beta$-decay reaction in a large liquid organic scintillator target. We set a new upper limit for a hypothetical solar $\bar{\nu}_e$ flux of 760 cm$^{-2}$s$^{-1}$, obtained assuming an undistorted solar $^8$B energy spectrum. This corresponds to a limit on the transition probability of solar neutrinos to anti-neutrinos of $1.3 \times 10^{-4}$ (90\% C.L.) for $E_{\bar{\nu}} > 1.8$ MeV, covering the entire $^8$B spectrum. Best differential limits on anti-neutrino fluxes from unknown sources are also obtained between the detection energy threshold of 1.8 MeV and 17.8 MeV with more than 2 years of data.

New experimental limits on the Pauli forbidden transitions in C-12 nuclei obtained with 485 days Borexino data.

Borexino Collaboration (G. Bellini et al.).

The Pauli exclusion principle (PEP) has been tested for nucleons ($n, p$) in $^{12}\text{C}$ with the Borexino detector. The approach consists of a search for $\gamma$, $n$, $p$ and $\beta^\pm$ emitted in a non-Paulian transition of $1S_{3/2}$-shell nucleons to the filled $1S_{1/2}$ shell in nuclei. Due to the extremely low background and the large mass (278 t) of the Borexino detector, the following most stringent up-to-date experimental bounds on PEP violating transitions of nucleons have been established: $\tau({^{12}\text{C}}\to{^{12}\widetilde{\text{C}}}+\gamma) \geq 5.0\cdot10^{31}$ y, $\tau({^{12}\text{C}}\to{^{11}\widetilde{\text{B}}}+ p) \geq 8.9\cdot10^{29}$ y, $\tau({^{12}\text{C}}\to{^{11}\widetilde{\text{C}}}+ n) \geq 3.4\cdot10^{30}$ y, $\tau({^{12}\text{C}}\to{^{12}\widetilde{\text{N}}}+ e^- + \widetilde{\nu}_e) \geq 3.1\cdot10^{30}$ y, and $\tau({^{12}\text{C}}\to{^{12}\widetilde{\text{B}}}+ e^+ + \nu_e) \geq 2.1\cdot10^{30}$ y, all at 90% C.L. The corresponding upper limits on the relative strengths for the searched non-Paulian electromagnetic, strong and weak transitions have been estimated: $\delta^2_{\gamma} \leq 2.2\cdot10^{-57}$, $\delta^2_N \leq 4.1\cdot10^{-60}$ and $\delta^2_{\beta} \leq 2.1\cdot10^{-35}$.

GEM*STAR: The Alternative Reactor Technology Comprising Graphite, Molten Salt, and Accelerators

(accepted: Handbook of Nuclear Engineering, Vol III, Chapter on Molten Salt Reactor Design; Springer; June 2010).

The technology of nuclear power could be quite different from today’s if it had been practical in the beginning to supplement fissile neutrons with accelerator-produced neutrons. The purpose of this chapter is to illustrate the benefits possible by implementing supplementary neutrons from accelerators in an optimized reactor. GEM*STAR (Green Energy Multiplier*Subcritical Technology for Alternative Reactors developed by Accelerator Driven Neutron Applications [ADNA Corp]) is a subcritical thermal-spectrum reactor operating with molten salt fuel in a graphite matrix and in a continuous flow mode initially at $k_{\text{eff}} = 0.99$. The model described is able to use natural uranium as fuel and generate twice as much electric power as a Light Water Reactor (LWR) generates from the same mined uranium. GEM*STAR at $k_{\text{eff}} = 0.99$ also can be fueled with unreprocessed LWR spent fuel, and generate as much electricity as the LWR had generated from the same fuel. Because GEM*STAR uses liquid fuel, it can recycle its own fuel at $k_{\text{eff}} = 0.95$ without any operations on the fuel. This recycle can be repeated several more times, always without reprocessing, as accelerator or fusion neutron generation technology development reduces the cost of neutrons. GEM*STAR therefore increases the electricity from mined uranium many times while avoiding the serious problems of current nuclear-power technology arising from enrichment, reprocessing, fast reactor deployment, and near term high level waste storage. GEM*STAR also offers technology for nuclear energy generation that promises reductions in nuclear electricity cost and eliminates major proliferation concerns. The technology can use a modest source of intermittent “green” electricity such as wind or solar as input power to drive an accelerator that in effect multiplies the green energy by a factor of about 30 with 24-7 continuity and without compromising any environmental objectives of green energy sources. This chapter is not a complete history of molten salt, graphite, and accelerator technologies, but a description of how these orphan elements of nuclear power development may be integrated for a GEM*STAR solution to the main barriers that constrain the full deployment of today’s nuclear power technology.

The Liquid Handling Systems for the Borexino Solar Neutrino Detector

(Borexino Collaboration)


The successful deployment of the Borexino solar neutrino detector required assorted physical and chemical operations to produce exceptional pure fluids and fill multiple detector zones. The composition and flow rates of high purity gases and liquids had to be precisely controlled to maintain liquid levels and pressures. The system was required to meet exceptional requirements for cleanliness and leak-tightness. A large scale modular system connecting fluid receiving, purification and fluid delivery processes was developed for Borexino. At the core is a flow control
A system that delivers scintillator components to plants for purification, and then fills the Borexino detector volumes with ultrahigh purity buffer or ultrahigh purity scintillator. The liquid handling system maintains precise control over the liquid levels and differential pressures between the different volumes of the detectors that are separated by flexible nylon vessels. The preparation, commissioning and operation of the system for filling the Borexino detector with scintillator is described.

First Measurement of the Neutron Beta-Asymmetry with Ultracold Neutrons
(UCN-A Collaboration)
We report the first measurement of angular correlation parameters in neutron β-decay using polarized ultracold neutrons (UCN). We utilize UCN with energies below about 200 neV, which we guide and store for \( \sim 30 \) s in a Cu decay volume. The \( \mu \cdot \vec{B} \) potential of a static 7 T field external to the decay volume provides a 420 neV potential energy barrier to the spin state parallel to the field, polarizing the UCN before they pass through an adiabatic fast passage (AFP) spin-flipper and enter a decay volume, situated within a 1 T, \( 2 \times 2 \pi \) superconducting solenoidal spectrometer. We determine a value for the β-asymmetry parameter \( A_0 \) proportional to the angular correlation between the neutron polarization and the electron momentum, of \( A_0 = -0.1138 \pm 0.0051 \).

20 Citations

The Borexino Detector at the Laboratori Nazionali del Gran Sasso
(Borexino Collaboration)
Borexino, a large volume detector for low energy neutrino spectroscopy, is currently running underground at the Laboratori Nazionali del Gran Sasso, Italy. The main goal of the experiment is the real-time measurement of sub MeV solar neutrinos, and particularly of the mono energetic (862 keV) Be7 electron capture neutrinos, via neutrino-electron scattering in an ultra-pure liquid scintillator. This paper is mostly devoted to the description of the detector structure, the photomultipliers, the electronics, and the trigger and calibration systems. The real performance of the detector, which always meets, and sometimes exceeds, design expectations, is also shown. Some important aspects of the Borexino project, i.e. the fluid handling plants, the purification techniques and the filling procedures, are not covered in this paper and are, or will be, published elsewhere (see Introduction and Bibliography).

60 Citations

Direct Measurement of the Be-7 Solar Neutrino Flux with 192 Days of Borexino Data
(Borexino Collaboration)
We report the direct measurement of the \(^7\text{Be}\) solar neutrino signal rate performed with the Borexino detector at the Laboratori Nazionali del Gran Sasso. The interaction rate of the 0.862 MeV \(^7\text{Be}\) neutrinos is 49\(+3\)\(-4\) (stat)\(+4\)\(-3\) (syst) counts/(day \( \ast \) 100ton). The hypothesis of no oscillation for \(^7\text{Be}\) solar neutrinos is inconsistent with our measurement at the 4sigma level. Our result is the first direct measurement of the survival probability for solar \( \nu_e \) in the transition region between matter-enhanced and vacuum-driven oscillations. The measurement improves the experimental determination of the flux of \(^7\text{Be}\), \( \nu_p \), and CNO solar \( \nu_e \), and the limit on the magnetic moment of neutrinos.

221 Citations

Measurement of the solar 8B neutrino rate with a liquid scintillator target and 3 MeV energy threshold in the Borexino detector
(Borexino Collaboration)
We report the measurement of electron neutrino elastic scattering from 8B solar neutrinos with 3 MeV energy threshold by the Borexino detector in Gran Sasso (Italy). The rate of solar neutrino-induced electron scattering events above this energy in Borexino is 0.217 \(+0.038\) (stat) \(-0.008\)
(syst) cpd/100 t, which corresponds to the equivalent unoscillated flux of $(2.4 \pm 0.4 \text{ (stat)} \pm 0.1 \text{ (syst)}) \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}$, in good agreement with measurements from SNO and SuperKamiokande. Assuming the 8B neutrino flux predicted by the high metallicity Standard Solar Model, the average 8B neutrino survival probability above 3 MeV is measured to be $0.29 \pm 0.10$. The survival probabilities for 7Be and 8B neutrinos as measured by Borexino differ by 1.9 sigma. These results are consistent with the prediction of the MSW-LMA solution of a transition in the solar electron neutrino survival probability between the low energy vacuum-driven and the high-energy matter-enhanced solar neutrino oscillation regimes.

Reducing Parasitic Thermal Neutron Absorption in Graphite Reactors by 30%.


Two experiments described here show that the diffusion length $D$ for thermal neutrons in graphite studied is 24% larger than expected from classical experiments and that the boron equivalent absorption is smaller and consistent with zero boron absorption. Taken together, the results indicate a reduction in parasitic thermal neutron absorption in graphite reactors by about 30%. The first experiment measured the z-dependence of thermal neutron flux in a column of ten tons of granular graphite with a neutron source at the bottom. A second measurement was made by pulsing the column with a neutron source at its center and measuring the neutron decay rate as a function of time after a pure exponential decay had been established. The diffusion coefficient $D$ adjusted to a density of 1.60 g/cm$^3$ is $1.05 \pm 0.03$ cm compared with the commonly accepted value of $0.85 \pm 0.013$ cm. The absorption in our graphite owing to impurities was found to be less than 10% of that from carbon alone. The parameter $\Sigma/\lambda$ that measures neutron loss was determined to be $0.000235 \pm 0.000026$ cm$^{-2}$ for a density of 1.60 and it may be compared with the commonly accepted value of 0.000340. The performance of graphite thermal spectrum reactors constructed using our graphite would be significantly enhanced over present expectations as neutron loss to graphite is a major factor in the neutron economy of graphite-moderated thermal reactors.

Pulse-shape discrimination with the counting test facility.

(Borexino Collaboration)


e-Print: arXiv:0705.0239 [physics.ins-det]

Pulse-shape discrimination (PSD) is one of the most distinctive features of liquid scintillators. Since the introduction of the scintillation techniques in the field of particle detection, many studies have been carried out to characterize intrinsic properties of the most common liquid scintillator mixtures in this respect. Several application methods and algorithms able to achieve optimum discrimination performances have been developed. However, the vast majority of these studies have been performed on samples of small dimensions. The Counting Test Facility, prototype of the solar neutrino experiment Borexino, as a 4 ton spherical scintillation detector immersed in 1000 tons of shielding water, represents a unique opportunity to extend the small-sample PSD studies to a large-volume setup. Specifically, in this work we consider two different liquid scintillation mixtures employed in CTF, illustrating for both the PSD characterization results obtained either with the processing of the scintillation waveform through the optimum Gatti's method, or via a more conventional approach based on the charge content of the scintillation tail. The outcomes of this study, while interesting per se, are also of paramount importance in view of the expected Borexino detector performances, where PSD will be an essential tool in the framework of the background rejection strategy needed to achieve the required sensitivity to the solar neutrino signals.

Study of phenylxylylethane (PXE) as scintillator for low energy neutrino experiments

(Borexino Collaboration)

We report on the study of a new liquid scintillator target for neutrino interactions in the framework of the research and development program of the Borexino solar neutrino experiment. The scintillator consists of 1,2-dimethyl-4-(1-phenylethyl)-benzene (phenyl-o-xylylethane, PXE) as solvent and 1,4-diphenylbenzene (para-Terphenyl, p-Tp) as primary and 1,4-bis(2-methylstyryl)benzene (bis-MSB) as secondary solute. The density close to that of water and the high flash point makes it an attractive option for large scintillation detectors in general. The study focused on optical properties, radioactive trace impurities and novel purification techniques of the scintillator. Attenuation lengths of the scintillator mixture of 12 m at 430 nm were achieved after purification with an alumina column. A radiocarbon isotopic ratio of $^{14}\text{C}/^{12}\text{C} = 9.1 \times 10^{-18}$ has been measured in the scintillator. Initial trace impurities, e.g. $^{238}\text{U}$ at $3.2 \times 10^{-14}$ g/g could be purified to levels below $1 \times 10^{-17}$ g/g by silica gel solid column purification.

**First real time detection of $^7\text{Be}$ solar neutrinos by Borexino**
(Borexino Collaboration)
This paper reports a direct measurement of the $^7\text{Be}$ solar neutrino signal rate performed with the Borexino low background liquid scintillator detector. This is the first real-time spectral measurement of sub-MeV solar neutrinos. The result for 0.862 MeV $^7\text{Be}$ is $47 \pm 7$ (stat) $\pm 12$ (sys) counts/(day x 100 ton), consistent with predictions of Standard Solar Models and neutrino oscillations with LMA-MSW parameters.

136 citations

**The Nylon Scintillator Containment Vessels for the Borexino Solar Neutrino Experiment.**
*Nuclear Instruments and Methods A582 (2007) pp 509-534*
e-Print: physics/0702162
Borexino is a solar neutrino experiment designed to observe the 0.86 MeV Be-7 neutrinos emitted in the pp cycle of the sun. Neutrinos will be detected by their elastic scattering on electrons in 100 tons of liquid scintillator. The neutrino event rate in the scintillator is expected to be low (~0.35 events per day per ton), and the signals will be at energies below 1.5 MeV, where background from natural radioactivity is prominent. Scintillation light produced by the recoil electrons is observed by an array of 2240 photomultiplier tubes. Because of the intrinsic radioactive contaminants in these PMTs, the liquid scintillator is shielded from them by a thick barrier of buffer fluid. A spherical vessel made of thin nylon film contains the scintillator, separating it from the surrounding buffer. The buffer region itself is divided into two concentric shells by a second nylon vessel in order to prevent inward diffusion of radon atoms. The radioactive background requirements for Borexino are challenging to meet, especially for the scintillator and these nylon vessels. Besides meeting requirements for low radioactivity, the nylon vessels must also satisfy requirements for mechanical, optical, and chemical properties. The present paper describes the research and development, construction, and installation of the nylon vessels for the Borexino experiment.

**CNO and pep neutrino spectroscopy in Borexino: Measurement of the deep-underground production of cosmogenic $^{11}\text{C}$ in an organic liquid scintillator**
*Physical Review C 74 (2006), pp 045805-04811*
Borexino is an experiment for low-energy neutrino spectroscopy at the Gran Sasso underground laboratories. It is designed to measure the monoenergetic $^7\text{Be}$ solar neutrino flux in real time, via neutrino-electron elastic scattering in an ultrapure organic liquid scintillator. Borexino has the potential to also detect neutrinos from the pep fusion
process and the CNO cycle. For this measurement to be possible, radioactive contamination in the detector must be kept extremely low. Once sufficiently clean conditions are met, the main background source is 11C, produced in reactions induced by the residual cosmic muon flux on 12C. In the process, a free neutron is almost always produced. 11C can be tagged on an event-by-event basis by looking at the threefold coincidence with the parent muon track and the subsequent neutron capture on protons. This coincidence method has been implemented on the Borexino Counting Test Facility data. We report on the first event-by-event identification of in situ muon-induced 11C in a large underground scintillator detector. We measure a 11C production rate of 0.130 ± 0.026(stat) ± 0.014(syst) day-1 ton-1, in agreement with predictions from both experimental studies performed with a muon beam on a scintillator target and ab initio estimations based on the 11C producing nuclear reactions.

Search for Electron Antineutrino Interactions with the Borexino Counting Test Facility at Gran Sasso
Electron antineutrino interactions above the inverse beta decay energy of protons (E-(nu) over bare > 1.8 MeV) were looked for with the Borexino counting test facility (CTF). One candidate event survived after rejection of background, which included muon-induced neutrons and random coincidences. An upper limit on the solar (nu) over bar (e) flux, assumed having the B-8 solar neutrino energy spectrum, of 1.1 x 10(5) cm(-2) s(-1) (90 % C.L.) was set with a 7.8 ton x year exposure. This upper limit corresponds to a solar neutrino transition probability, nu(e) -> (nu) over bar (e) of 0.02 (90% C.L.). Predictions for antineutrino detection with Borexino, including geoneutrinos, are discussed on the basis of background measurements performed with the CTF.

Measurement of the Loss and Depolarization Probability of UCN on Beryllium and Diamond Like Carbon Films
Currently several institutes worldwide are working on the development of a new generation of ultracold neutron (UCN) sources. In parallel with source development, new materials for guiding and storage of UCN are developed. Currently the best results have been achieved using Ni-58, Be, solid O-2 and low temperature Fomblin oil (LTF). All of these materials have their shortcomings like cost, toxicity or difficulty of use. A novel very promising material is diamond like carbon (DLC). Several techniques exist to coat surfaces, and industrial applications ( e. g., for extremely hard surfaces) are already wide spread. Preliminary investigations using neutron reflectometry at PSI and Los Alamos yielded a critical velocity for DLC of about 7 m/s thus comparable to Beryllium. A low upper limit of depolarization probability for stored polarized UCN has been measured at the PF2 facility of the Institut Laue-Langevin (ILL) by North Carolina State University (NCSU), Los Alamos National Laboratory (LANL), and Petersburg Nuclear Physics Institute (PNPI), thus making it also a good material for storage and guidance of polarized UCN. Still missing is the loss probability per bounce. We will be able to extract
New Experimental Limits on Violations of the Pauli Exclusion Principle Obtained with the Borexino Counting Test Facility


The Pauli exclusion principle (PEP) has been tested for nucleons (n, p) in C-12 and O-16 nuclei, using the results of background measurements with the prototype of the Borexino detector, the Counting Test Facility (CTF). The approach consisted of a search for gamma, n, p and/or alpha`s emitted in a non-Paulian transition of 1P- shell nucleons to the filled 1S(1/2) shell in nuclei. Similarly, the Pauli-forbidden beta(+/-) decay processes were searched for. Due to the extremely low background and the large mass (4.2 tons) of the CTF detector, the following most stringent up-to-date experimental bounds on PEP violating transitions of nucleons have been established: tau(C-12 --> (12)(C) over tilde + gamma) > 2.1 . 10(27) y, tau(C-12 --> (11)(B) over tilde + p) > 5.0 . 10(26) y, tau(C-12(0-16) --> 11 (C) over tilde((15)(O) over tilde) + n) > 3.7 . 10(26) y, tau(C-12 --> (8)(Be) over tilde+ alpha) > 6.1 . 10(23) y, tau(C-12 --> (12)(N) over tilde + e(-) + (&nu;e) over tilde (e)) > 7.6 . 10(27) y and tau(C-12 --> (12)(B) over tilde + e(+) + nu(e)) > 7.7 . 10(27) y, all at 90% C. L.

Demonstration of a Solid Deuterium Source of Ultra-Cold Neutrons


Ultra-cold neutrons (UCN), neutrons with energies low enough to be confined by the Fermi potential in material bottles, are playing an increasing role in measurements of fundamental properties of the neutron. The ability to manipulate UCN with material guides and bottles, magnetic fields, and gravity can lead to experiments with lower systematic errors than have been obtained in experiments with cold neutron beams. The UCN densities provided by existing reactor sources limit these experiments. The promise of much higher densities from solid deuterium sources has led to proposed facilities coupled to both reactor and spallation neutron sources. In this Letter we report on the performance of a prototype spallation neutron-driven solid deuterium source. This source produced bottled UCN densities of 145 +/- 7 UCN/cm(3), about three times greater than the largest bottled UCN densities previously reported. These results indicate that a production UCN source with substantially higher densities should be possible. (C) 2004 Elsevier B.V. All rights reserved.

New Experimental Limits on Heavy Neutrino Mixing in B-8-Decay Obtained with the Borexino Counting Test Facility

If heavy neutrinos with mass $m(\nu_H) \geq 2m(e)$ are emitted in the decays of $B-8$ in the Sun, then $\nu(H) \rightarrow \nu(L) + e^+ + e^-$ decays should be observed. In the present work, the results of background measurements with the Borexino Counting Test Facility have been used to obtain bounds on the number of these decays. As a result, new limits on the coupling $|\mathcal{U}_{eH}(2)|$ of a massive neutrino in the range of 1.1 MeV to 12 MeV have been derived ($|\mathcal{U}_{eH}(2)| \leq 10^{-3} - 10^{-5}$). The obtained limits on the mixing parameter are stronger than obtained in previous experiments using nuclear reactors and accelerators. (C) 2003 MAIK "Nauka/Interperiodica".

New Limits on Nucleon Decays into Invisible Channels with the Borexino Counting Test Facility


The results of background measurements with the second version of the BOREXINO Counting Test Facility (CTF-II), installed in the Gran Sasso Underground Laboratory, were used to obtain limits on the instability of nucleons, bounded in nuclei, for decays into invisible channels (inv): disappearance, decays to neutrinos, etc. The approach consisted of a search for decays of unstable nuclides resulting from N and NN decays of parent C-12, C-13 and O-16 nuclei in the liquid scintillator and the water shield of the CTF. Due to the extremely low background and the large mass (4.2 t) of the CTF detector, the most stringent (or competitive) up-to-date experimental bounds have been established: $\tau(n \rightarrow \text{inv}) > 1.8 \times 10^{25}$ yr, $\tau(p \rightarrow \text{inv}) > 1.1 \times 10^{26}$ yr, $\tau(nn \rightarrow \text{inv}) > 4.9 \times 10^{25}$ yr and $\tau(pp \rightarrow \text{inv}) > 5.0 \times 10^{25}$ yr, all at 90% C.L. (C) 2003 Published by Elsevier Science B.V.

26 citations

Study of Neutrino Electromagnetic Properties with the Prototype of the Borexino Detector


The results of background measurements with the prototype of the Borexino detector (CTF) have been used to obtain an upper bound on the neutrino magnetic moment, $\mu(\nu)$. The new upper limit for $\mu(\nu)$ from pp and Be-7 solar neutrinos is $(5.5 \times 10^{-10})\mu(B)$ (90% c.l.) in the Standard Solar Model scenario. This is the first limit on $\mu(\nu)$ obtained using sub-MeV neutrinos. The sensitivity of the prototype to the neutrino charge radius and the neutrino radiative decay are also presented. (C) 2003 Published by Elsevier Science B.V.

Measurements of Extremely Low Radioactivity Levels in Borexino


The techniques researched, developed and applied towards the measurement of radioisotope concentrations at ultra-low levels in the real-time solar neutrino experiment.
BOREXINO at Gran Sasso are presented and illustrated with specific results of widespread interest. We report the use of low-level germanium gamma spectrometry, low-level miniaturized gas proportional counters and low background scintillation detectors developed in solar neutrino research. Each now sets records in its field. We additionally describe our techniques of radiochemical ultra-pure, few atom manipulations and extractions. Forefront measurements also result from the powerful combination of neutron activation and low-level counting. Finally, with our techniques and commercially available mass spectrometry and atomic absorption spectroscopy, new low-level detection limits for isotopes of interest are obtained. (C) 2002 Elsevier Science B.V. All rights reserved.

72 citations

Search for Electron Decay Mode E -> Gamma + Nu with Prototype of Borexino Detector

The prototype of the Borexino detector Counting Test Facility, located in the Gran-Sasso laboratory, has been used to obtain a bound on the stability of the electron. The new lower limit on the mean lifetime defined on 32.1 days of data set is tau(e(-) --> nu(e) + y) greater than or equal to 4.6 x 10(26) yr (90% c.l.).

25 citations

Science and Technology of Borexino: A Real-Time Detector for Low Energy Solar Neutrinos

Borexino, a real-time device for low energy neutrino spectroscopy is nearing completion of construction in the underground laboratories at Gran Sasso, Italy (LNGS). The experiment's goal is the direct measurement of the flux of Be-7 solar neutrinos of all flavors via neutrino-electron scattering in an ultra-pure scintillation liquid, Seeded by a series of innovations which were brought to fruition by large-scale operation of a 4-ton test detector at LNGS, a new technology has been developed for Borexino. It enables sub-MeV solar neutrino spectroscopy for the first time. This paper describes the design of Borexino, the various facilities essential to its operation, its spectroscopic and background suppression capabilities and a prognosis of the impact of its results towards resolving the solar neutrino problem. Borexino will also address several other frontier questions in particle physics, astrophysics and geophysics. (C) 2002 Elsevier Science B.V. All rights reserved.

198 citations

Borexino

In the exciting arena of the solar neutrino research a new actor is expected to come soon in the game: Borexino. This massive, calorimetric, liquid scintillation detector, in advanced phase of installation in the underground Gran Sasso Laboratory, will be
focused towards one of the fundamental issues of this field, i.e. the direct determination of the flux of the neutrinos produced in the 7Be electron capture reaction in the Sun. As a pilot program for the full detector, the Counting Test Facility operated for two years at Gran Sasso, provided the convincing evidence that the fundamental technological challenge of the experiment, the achievement in the scintillator of unprecedented radiopurity levels, can be accomplished successfully, thus opening the way to the realization of the experiment.

42 citations

**Light Propagation in a Large Volume Liquid Scintillator**


The fluorescence light propagation in a large volume detector based on organic liquid scintillators is discussed. In particular, the effects of the fluor radiative transport and solvent Rayleigh scattering are emphasized. These processes have been modelled by a ray-tracing Monte Carlo method and have been experimentally investigated in the Borexino prototype which was a 4.3 ton, 4 pi sensitive detector. The comparison between the model prediction and the experimental data shows a satisfactory agreement indicating that the main aspects of these processes are well understood. Some features of the experimental time response of the detector are still under study.

37 citations

**A Scintillator Purification System for a Large Scale Solar Neutrino Experiment**

Benziger, J. B.; Johnson, M.; Calaprice, F. P.; Chen, M.; Darnton, N.; Loeser, R.; Vogelaar, R. B.


An on-line purification system for a large-scale low-background liquid scintillation detector has been tested with the 5 t liquid scintillation detector, the Counting Test Facility at Gran Sasso. Counter-current water extraction removes polar and charged impurities such as ions and metal salts. Vacuum distillation of the entire scintillator has been applied to remove both radioactive impurities and chemical impurities that affect the optical properties of the scintillator. Filtration with a 0.05 μm particulate filter removed suspended dust particles that may contain U, Th and K. Nitrogen stripping was employed to remove dissolved water and noble gases (e.g. Kr-85) from the scintillator. The system has effectively reduced the internal back in the 5 t liquid scintillation detector from 470 +/- 90 events/d to the detection limit of the detector (+/- 45 events/d) in the energy window 250 < E < 800 keV.

**A Rn-222 Source for Low-Background Liquid Scintillation Detectors**

Johnson, M.; Benziger, J.; Stoia, C.; Calaprice, F.; Chen, M.; Darnton, N.; Loeser, F.; Vogelaar, R. B.


A technique for producing a radioactive source suitable for use in a low-background liquid scintillation detector is described. Rn-222 was concentrated from air to prepare liquid scintillator sources spiked with 10(6) Bq/m(3) of the radioisotope. Air was stripped
of CO, and water vapor, and passed over cooled charcoal which trapped the radon. The accumulated radon was desorbed and transferred into a pseudocumene-based scintillator. These sources have been used for position calibration in the Counting Test Facility (a 5 m(3) spherical liquid scintillation detector) at the Laboratori Nazionali del Gran Sasso.

**Breakout from the Hot Cno Cycle: The F-18(P, Gamma) Vs F-18(P, Alpha) Branching Ratio**
We have studied the properties of low-lying F-18+p resonances as excited states in Ne-19. Three new levels have been found in the range 0 less than or equal to E(c.m.)less than or equal to 1 MeV just above the F-18+p threshold, and partial decay widths and isospin-mirror connections are suggested to known states in F-19 for each of the nine states in this energy range. The properties of these resonances have been used to calculate the reaction rate N-A(sigma v) for the F-18(p,gamma)Ne-19 and F-18(p, alpha)O-15 reactions in the temperature range 10(8)<T<10(9). A comparison of these rates indicates that in this temperature range, the O-14(alpha, gamma)F-17(p,gamma)Ne-18(e(+)nu)F-18(p, gamma)Ne-19 reaction sequence is not as fast as the(15)O(alpha, gamma)Ne-19 reaction. [S0556-2813(98)06305-5].
59 citations

**A Large-Scale Low-Background Liquid Scintillation Detector: The Counting Test Facility at Gran Sasso**
A 4.8 m(3) unsegmented liquid scintillation detector at the underground Laboratori Nazionali del Gran Sasso has shown the feasibility of multi-ton low-background detectors operating to energies as low as 250 keV. Detector construction and the handling of large volumes of liquid scintillator to minimize the background are described. The scintillator, 1.5 g PPO/L-pseudocumene, is held in a flexible nylon vessel shielded by 1000 t of purified water. The active detector volume is viewed by 100 photomultipliers, which measure time and charge for each event, from which energy, position and pulse shape are deduced. On-line purification of the scintillator by water extraction, vacuum distillation and nitrogen stripping removed radioactive impurities. Upper limits were established of < 10(-7) Bq/kg-scintillator for events with energies 250 keV < E < 800 keV, and < 10(-9) Bq/g-scintillator due to the decay products of uranium and thorium. The isotopic abundance of C-14/C-12 in the scintillator was shown to be approximately 10(-18) by extending the energy window of the detector to 25-250 keV. The C-14 abundance and uranium and thorium levels in the CTF are compatible with the Borexino Solar Neutrino Experiment. (C) 1998 Elsevier Science B.V. All rights reserved. 97 citations

**Measurement of the C-14 Abundance in a Low-Background Liquid Scintillator**
Alimonti, G.; Angloher, G.; Arpesella, C.; Balata, M.; Bellini, G.; Benziger, J.; Bonetti, S.; Cadonati, L.; Calaprice, F. P.; Cecchet, G.; Chen, M.; Darnton, N.; De Bari, A.; Deutsch,
The C-14/C-12 ratio in 4.8 m(3) of high-purity liquid scintillator was measured at (1.94 +/- 0.09) x 10(-18), the lowest C-14 abundance ever measured. At this level the spectroscopy of low-energy solar neutrinos, in particular a measurement of the Be-7 neutrino flux, will not be obstructed by the C-14 beta decay intrinsic to a liquid scintillator detector. A comprehensive study of the deviation of the shape of the C-14 beta spectrum from the allowed statistical shape reveals consistent results with recent observations and calculations. Possible origins of the C-14 in the liquid scintillator are discussed. (C) 1998 Elsevier Science B.V.

Ultra-Low Background Measurements in a Large Volume Underground Detector

A large volume (4.8 m(3)) liquid scintillator detector has been running in Hall C of the Gran Sasso Underground Laboratory since February 1995. This detector is called the "Counting Test Facility" (CTF). The main goal of the detector facility is the measurement of ultralow background levels in scintillators and the development of processes able to purify them at this level. The detector has been designed to have exceptional sensitivity using a variety of methods to identify backgrounds. With the CTF, records were achieved in the domain of low background large volume detectors. Limits of 3.5 +/- 1.3 x 10(-16) g/g and 4.41(-1.2)(+1.5) x 10(-16) g/g for the U-238 and Th-232 daughters, respectively, and 1.85 +/- 0.13 +/- 0.01 x 10(-18) for the isotopic abundance of C-14 relative to C-12 were obtained. These results are very encouraging and point towards the feasibility of low energy, real time scintillation detectors for solar neutrinos, such as Borexino. (C) 1998 Elsevier Science B.V.

Al-26(N,P(1)) and (N,Alpha(0)) Cross Sections from Thermal Energy to 70 Kev and the Nucleosynthesis of Al-26

We have measured the Al-26(n,alpha(0))Mg-23 and Al-26(n,p(t))Mg-26* cross sections from thermal energy to approximately 10 keV and 70 keV, respectively. These reactions are thought to be the major mechanisms for the destruction of Al-26 in many nucleosynthesis environments; hence, an accurate determination of their rates is important for understanding the observations of gamma rays from "live" Al-26 in our galaxy and of "extinct" Al-26 in meteorites. The astrophysical rate for the Al-26(n,alpha(0))Mg-23 reaction determined from our measurements is in good agreement with the rate determined via inverse measurements. On the other hand, the rate we determined for the Al-26(n,p(t))Mg-26* reaction is significantly larger than previously reported. In addition, we were able to determine this rate in the temperature range below 0.2 GK which was not covered by previous measurements. This lower temperature range may be important for understanding the production of Al-26 in Red Giant stars. Both of our rates are significantly different than the rates used in most nucleosynthesis
calculations, We discuss the impact of our measurements on the nucleosynthesis of Al-26.

20 Citations

Constraining Al-26+P Resonances Using Al-26(He-3,D)Si-27
Vogelaar, R. B.; Mitchell, L. W.; Kavanagh, R. W.; Champagne, A. E.; Magnus, P. V.; Smith, M. S.; Howard, A. J.; Parker, P. D.; O'Brien, H. A.

The Al-26(He-3,d)Si-27 reaction was measured from 0 degrees less than or equal to theta(c.m.)less than or equal to 35 degrees at E(He-3)=20 MeV using a quadrupole-dipole-dipole-dipole magnetic spectrometer. States in Si-27 were observed above the background at 7652 and 7741 keV and upper limits were set for the state at 7592 keV. Implications for the Al-26(p, gamma)Si-27 Stellar reaction rate are discussed.

24 Citations

Structure of Ne-18 and the Breakout from the Hot CNO Cycle

We used the O-16(He-3,n)Ne-18, C-12(C-12,He-6)Ne-18, and Ne-20(p,t)Ne-18 reactions to study Ne-18 states up to an excitation energy of 10 MeV, with emphasis on levels corresponding to O-14(alpha,p)F-17 and F-17(p, gamma)Ne-18 resonances that could strongly affect these reaction rates in hot stellar environments. Excitation energies, widths, absolute cross sections, and angular distributions were measured. We found previously unidentified states at E(x) = 6.15 +/- 0.01 MeV, 7.12 +/- 0.02 MeV, 7.35 +/- 0.02 MeV, 7.62 +/- 0.02 MeV, 8.30 +/- 0.02 MeV, (8.45 +/- 0.03 MeV), 8.55 +/- 0.03 MeV, 8.94 +/- 0.02 MeV, and 9.58 +/- 0.02 MeV. We combined level width, cross section, and angular distribution data to infer J(pi) values for a number of the new levels as well as for the previously known 5.1-MeV doublet. Using information from our experiments, we recalculated the O-14(alpha,p) F-17 reaction rate, which constitutes a possible path out of the hot CNO cycle into the rp process and could play an important role in transforming nuclei involved in the hot CNO cycle into heavier nuclei with Z greater than or equal to 10.

97 citations

Removal of Cosmogenic Be-7 from Scintillators
Vogelaar, R. B.; Benziger, J.; Calaprice, F. P.; Darnton, N.

Cosmogenic Be can provide a substantial background to low threshold and low counting rate scintillation detectors such as the Borexino solar neutrino detector. The efficacy of various Be-7 removal techniques is examined. Distillation appears to be the best with a reduction factor of at least 1000 per stage.

Indirect Study of Low-Energy Resonances in (31)P(Alpha)Si-28 and Cl-35(Alpha)S-32

The reaction sequences governing the reaction flow in the rp process are important for
the understanding of the energy generation and nucleosynthesis of heavy elements in hot and explosive stellar hydrogen burning. Of considerable interest are (p,alpha) reactions along the process path which lead to the formation of reaction cycles rather than to chains of proton capture processes and beta decays. Previous direct attempts to measure the low-energy reaction cross sections for P-31(p,alpha)Si-28 and Cl-35(p,alpha)S-32 resulted only in upper limits for the strengths of possible low-energy resonances which may dominate the reaction rates. In this paper an indirect experimental approach is presented to study the structure of the low-energy unbound states in the compound nuclei S-32 and Ar-36. Th, results allow a more accurate determination of the contributions of these low-energy levels in the (p,alpha) reaction channel.

22 Citations

Laser Oriented K-36 for Time-Reversal Symmetry Measurements

We have produced very large nuclear alignments in radioactive K-36 (half-life 0.34 sec) through laser optical pumping techniques. The K-36 was created through (p,n) reactions using a 50 nA, 22 MeV proton beam, and a 3.3 atmosphere Ar-36 target. Measurements were made with the target cell at room temperature, when direct optical pumping produces nuclear orientation in the K-36, and at elevated temperatures 160 degrees C and 180 degrees C) where the K-36 is oriented through a combination of direct optical pumping and spin exchange. The fraction of the maximal nuclear alignment for the 180 degrees C data was determined to be 0.46+/-0.07 stat+/-0.05 syst through measurements of the gamma-ray anisotropy following positron decay. Roughly 10(5) or more decays of oriented K-36 occurred each second. The application of the superallowed decay of K-36 to measurements of time-reversal symmetry in beta decay is discussed.

Investigating the Astrophysically Important E(X)=2.646 Mev State in Na-20
Hofstee, M. A.; Blackmon, J. C.; Champagne, A. E.; Bateman, N. P. T.; Parker, P. D.; Yildiz, K.; Young, B. M.; Vogelaar, R. B.; Smith, M. S.

Observations of neon lines in the spectra of energetic novae have prompted a renewed look at explosive hydrogen burning. The Ne-19(p, gamma)Na-20 reaction is expected to play a major role in the breakout of the hot CNO cycle to the rp-process, which can process CNO nuclei to heavier elements. The reaction rate is dominated by the lowest resonance in the Ne-19 + p system, corresponding to the E(x) = 2.646 MeV state in Na-20. A large variety of nuclear experimental techniques have been used to study this state; e.g. charge exchange reactions, beta-delayed proton decay and radioactive beams. Their results have lead to a J(pi) = 3(+) assignment for this state [B. Brown et al., Phys. Rev. C 48 (1993) 1456], allowing an estimate of the proton width (Gamma(p)). This leaves the gamma width (Gamma(gamma)) to be determined. We have performed Ne-20(He-3, t gamma) experiments to measure the branching ratio (Gamma(gamma)/Gamma) of the E(x) = 2.646 MeV excited state in Na-20.

Undergraduate Laboratory - Principles of Gel-Electrophoresis
Erramilli, S.; Osterberg, F.; Vogelaar, B.
States in B-12 and Primordial Nucleosynthesis .1. Spectroscopic Measurements
Mao, Z. Q.; Vogelaar, R. B.; Champagne, A. E.
*Nuclear Physics A 567 1 (1994) pp 111-124*
The Be-9(alpha, p)B-12 and B-11(d, p)B-12 reactions have been used to determine excitation energies, total widths and spin-parities for states which could correspond to astrophysically significant resonances in the Li-8(alpha, n)B-11 reaction. Six such states are observed at E(x) = 10.199, 10.417, 10.564, 10.880, 11.328 and 11.571 MeV. None of these states corresponds to the broad resonance observed in the B-11(n, alpha)Li-8 reaction. However, we find no evidence that such a resonance exists.

States in B-12 and Primordial Nucleosynthesis .2. Resonance Properties and Astrophysical Aspects
Mao, Z. Q.; Vogelaar, R. B.; Champagne, A. E.; Blackmon, J. C.; Das, R. K.; Hahn, K. I.; Yuan, J.
*Nuclear Physics A 567 1 (1994) pp 125-145*
The Be-9(alpha, p)B-12 has been used to populate states which could correspond to astrophysically significant resonances in the Li-8(alpha, n)B-11 reaction. The branching ratios for neutron decays have been measured and the neutron angular distributions have been used to determine J(pi) for these states. This information, combined with previous measurements of excitation energies and total widths, allows us to extract the resonance strengths for these states. The astrophysical significance of these results is discussed.

The Princeton Separator, Past and Future
Naumann, R. A.; Loeser, F. W.; Vogelaar, R. B.
*Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions with Materials and Atoms 70 1-4 (1992) pp 80-88*
Some past research applications of the Princeton separator are reviewed. The future program envisaged includes fundamental beta-decay studies, low temperature nuclear orientation and nuclear astrophysics.

B-11+Alpha Reaction-Rates and Primordial Nucleosynthesis
Wang, T. R.; Vogelaar, R. B.; Kavanagh, R. W.
Total cross sections and resonance yields have been measured for the B-11(alpha,n)N-14 reaction for E-alpha = 350-2400 keV, and for the C-14(p,n)N-14 reaction for E(p) = 1000-1550 keV, using 4-pi neutron detectors. Differential cross sections for the B-11(a,p)C-14 reaction were measured for E-alpha =600-1820 keV. A strong and narrow (GAMMA = 2.2 eV) new resonance was found at E-alpha = 606 keV, with J-pi = 7/2 - established by (alpha,gamma) and (alpha, p) angular distributions. This resonance dominates the thermonuclear (alpha,n) and (alpha,p) reaction rates for tau approximately 0.5 x 10(9) K. The B-11(alpha,n), (alpha,p), and (alpha,gamma) reaction rates versus temperature are presented and compared with B-11(n,gamma) rates.
20 Citations

Low-Energy Reaction Yields for O-18(P,Gamma) and O-18(Alpha,Gamma)
Vogelaar, R. B.; Wang, T. R.; Kellogg, S. E.; Kavanagh, R. W.
*Physical Review C 42 2 (1990) pp 753-757*
Resonance yields, y-ray branching, and low-energy limits have been measured for 18O(p,γ) and 18O(α,γ), for Ep<0.22 MeV and Eα<0.78 MeV, using a 4π array of NaI
detectors. The results confirm previous resonance strengths, and set additional constraints on possible low-energy contributions to stellar reaction rates.

**Searches for Low-Temperature Nuclear-Fusion of Deuterium in Palladium**


A series of experiments has been performed to determine whether nuclear fusion processes occur in palladium rods that have been electrochemically charged with deuterium. With a variety of metalurgical pretreatment procedures and different electrolytes, no evidence has been obtained for any excess enthalpy, neutron, gamma ray, tritium or helium production during electrolysis of D20 with palladium cathodes.

67 citations

**Search for Resonances in the Na-22(P, Gamma)Mg-23 Reaction**


The reaction 22Na(p,γ)23Mg has been investigated in the energy range Ep=0.4–1.27 MeV using a radioactive 22Na target. Upper limits for the γ yield have been determined for transitions to states in 23Mg up to Ex=4.4 MeV. The upper limits for the expected resonances in this energy range are more than an order of magnitude weaker than previously predicted. These upper limits are compared with shell model calculations.

**The 26Al(p,gamma)27Si reaction: stellar origins of galactic 26Al.**

Vogelaar, R. B.


To explain the Mg-26 isotopic anomaly seen in meteorites (Al-26 daughter) as well as the observation of 1809-keV gamma rays in the interstellar medium (live decay of Al-26) one must know, among other things the destruction rate of Al-26. Properties of states in Si-27 just above the Al-27 + p mass were investigated to determine the destruction rate of Al-26 via the Al-26(rho, gamma)Si-27 reaction at astrophysical temperatures. Twenty micrograms of Al-26 were used to produce two types of Al2O3 targets by evaporation of the oxide. One was onto a thick platinum backing suitable for (rho, gamma) work, and the other onto a thin carbon foil for the (He-3, d) reaction. The Al-26(rho, gamma)Si-27 excitation function, obtained using a germanium detector and voltage-ramped target, confirmed known resonances and revealed new ones at 770, 847, 876, 917, and 928 keV. Possible resonances below the lowest observed on at E(sub p) = 286 keV were investigated using the Al-26(He-3, d)Si-27 proton-transfer reaction. States in Si-27 corresponding to 196 and 286 keV proton resonances were observed. A possible resonance at 130 keV (postulated in prior work) was shown to have a strength of omega gamma is less than 0.02 microe V. By arranging four large NaI detector as a 4 pi calorimeter, the 196-keV proton resonance, and one at 247 keV, were observed directly, having omega gamma = 55 + or - 9 and 10 + or - 5 microe V respectively. Large uncertainties in the reaction rate have been reduced. At novae temperatures, the rate is about 100 times faster than that used in recent model calculations, casting some doubt on novae production of galactic Al-26. (Dissert. Abstr.)

27 citations

**The Fabrication and Properties of a Na-22 Target**

Wiescher, M.; Gorres, J.; Kratz, K. L.; Leist, B.; Chang, K. H.; Filippone, B. W.; Mitchell,
A 60 μCi radioactive 22Na target has been produced to study the reaction $^{22}\text{Na}(p, \gamma)^{23}\text{Mg}$. The diffusion of NaCl-target material into various backings has been studied via the $^{23}\text{Na}(p, \gamma)^{24}\text{Mg}$ reaction. The stability, homogeneity and impurities of the target were studied. The results of these studies are discussed.