

Low Energy Solar Neutrino Detection by using Liquid Xenon

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Abstract

Possibility to use ultra pure liquid Xenon as a low energy solar neutrino detector by means of $\nu+e$ scatterings is evaluated. A possible detector with 10 tons of fiducial volume will give ~ 14 events for pp-neutrinos and ~ 6 events for ${}^7\text{Be}$ neutrinos with the energy threshold at 50 keV. The detector can be built with known and established technologies. High density of the liquid- Xe would provide self-shields against the incoming backgrounds originating from the container and outer environments. Internal backgrounds can be reduced by distillation and other techniques. Purification of the liquid Xe can be done continuously throughout the experiment. The spallation backgrounds are estimated to be small though an experimental determination is necessary. The liquid-Xe detector can also provide a significantly better sensitivity for the double beta decay and a dark matter search. However the 2ν double beta decay of ${}^{136}\text{Xe}$ would be most background. It could be overcome if the 2ν lifetime is longer than 10^{22}yr . However, an isotope separation of ${}^{136}\text{Xe}$ is inevitable for a shorter lifetime.

The isotope separations would, introduce a new opportunity to definitively identify dark matter. The interesting feature in addition to the solar neutrino measurements will also be discussed.

I. INTRODUCTION

The long standing solar neutrino problem is now widely thought to be caused by neutrino oscillations, since the discovery of neutrino oscillation in the study of the atmospheric neutrinos in 1998 clearly demonstrated that neutrinos have masses [2]. The on-going real-time solar neutrino experiments, Super-Kamiokande [3], SNO [4] would provide an unique oscillation parameters in near future. However, the ^8B neutrinos where both Super-Kamiokande and SNO detector can detect, are the very fractional tail (0.17%) of the entire solar neutrino spectrum. It is very important and necessary to establish the neutrino oscillation by the low energy solar neutrinos, namely by pp and ^7Be neutrinos.

No experiments have separately measured the pp and ^7Be neutrino flux so far. The gallium(SAGE, GALLEX, GNO) [5]. and chlorine(Homestake) [6]experiments have measured the integrated flux above a certain energy, 235keV for Ga and 817keV for Cl. Borexino [7] in very near future would determine a ^7Be -flux separately by means of neutrino electron scattering. The neutrino electron scattering (neutral current and charged current) and the charged current (absorption) measurements provide complimentary information: the information on charged and neutral current interaction rates can be obtained separately from the two measurements, which is necessary for the complete understanding of neutrino oscillation phenomena including a possible case for the oscillation to sterile neutrinos. LENS [8] that utilizes the neutrino absorption by Yb, aims to provide a charged current information of the ^7Be and pp neutrinos.

A few ambitious proposals, HERON [9], HELLAZ [10], NEON [13] and so on, are under consideration to detect pp-neutrinos by means of the neutrino electron scattering.

We consider here a liquid-Xe detector to measure both pp and ^7Be neutrino spectrum in real time utilizing the neutrino electron elastic scattering of which we know the cross section very well. The characteristics of the liquid-Xenon is very well known and it works as a very good scintillation material.

The $\nu+e$ scattering experiments give relatively higher statistics than the absorption experiments. But no coincidence information is available, and therefore they require ultra-pure materials and environments.

The ultra-low backgrounds have been studied extensively so far, especially by those working for solar neutrino experiments. Borexino group [12] has demonstrated at their CTF facility that the contamination level of a few times 10^{-16}g/g for U/Th and 10^{-18} for the ratio $^{14}\text{C}/^{12}\text{C}$ has possibly been achieved in their liquid scintillator. This is the level required for the ^7Be - neutrino measurement by the $\nu+e$ scattering experiment. Borexino is, however limited by the contamination of ^{14}C to go down to the pp-neutrino region. This is an intrinsic limit of the detector which uses organic scintillators.

The Xe detectors do not contain carbon and therefore have less problem due to ^{14}C . Therefore there is a possibility to go down to the pp-neutrino regions with a similar background level required for Borexino.

II. DETECTION OF SOLAR NEUTRINOS BY MEANS OF LIQUID-XENON

A. Liquid-Xenon Scintillators

Liquid Xenon is a good scintillator. The scintillation mechanism is well known. Xe atoms are either excited or ionized when charged particles have passed through Xe. Both the excitation and the ionization following the recombination produce the excited Xe_2^* states which in turn give ultra-violet photons at 174nm. The de-excitation time is 3ns for the singlet states and 27 ns for the triplet states. The recombination of the ion and electron will take place with a characteristic time determined by the ionization density. If excited by electrons, the recombination time is typically 40nsec and if excited by alphas, then the recombination time is about 3 nsec. This may allow separation of electron from nuclei by the pulse shape discrimination.

The Xe scintillation produces about 43,000 photons per MeV that is about 70% of NaI. The light attenuation length is not well known and depends upon the level of purity. It is supposed to be longer than 1m for high purity liquid Xenon [14]. The Rayleigh scattering length was measured by a few groups and found to be about 30cm. But this also depends on the purity of the liquid.

The ultra-violet photons can be detected directly by photomultiplier tubes (PMTs). No wave length shifter is needed while a wave length shifter is needed for the liquid-He and liquid-Ne detectors [13] where ~ 80 nm photons are emitted.

The PMTs can be placed either in the liquid or outside of the detector through the windows. One of the photo-tube (for example, R6041Q/HAMAMATSU) can be operated at about -108°C , and has a quartz window of effective diameter of $46\text{mm}\phi$. The wave length of 174nm is just around the edge of cut off wave length of the quartz window. The more the thickness increases, the more you lose the light. The quantum efficiency is $10\sim 15\%$.

The PMTs that are sensitive to ultra-violet photons operated at room temperature are commonly obtained. One of them (for example, EMI9426B) has very high QE of 35% for 174nm photons with MgF_2 2 inch-window. The MgF_2 window with 12mm thickness has a more than 95% transmission for 174nm photons.

Comparisons among noble gas scintillators are listed in table I.

The operating temperature of 165K (-108°C) for liquid Xe is highest among them, which makes the cryogenic very simple and easy. A single layer of vacuum shield is sufficient to keep the detector operated. It requires very low power to keep Xenon in the liquid phase. The 800 liter(2.4ton) detector proposed for the $\mu \rightarrow e + \gamma$ experiment [14] can be kept only by 200W. One of the advantage is that Liquid-Nitrogen can be used to liquefy Xe and this makes the transfer of the Xe through the cryogenic system very easy.

The high density ($\rho=3.06\text{g}/\text{cm}^3$) and high atomic number ($A=131$) would provide a good self-shielding. The radiation length and nuclear collision length is about 2.7cm and 33.6cm, respectively. For example additional thickness of 30cm corresponds to the 4m of the water shields for the electro-magnetic components of backgrounds. Therefore the requirements for the purity of the structure and environmental backgrounds are less serious than those for the other noble gas scintillators.

Electrons and ions are known to drift in the liquid Xenon. The drift velocity of electrons is $\sim 2 \times 10^5 \text{cm}/\text{s}$ when $200/\text{V}/\text{cm}$ of the electric field is applied. In reference [15], an electron drift up to 2m has been observed. Positive ions can also drift. The mobility of the ions are measured to be $3 \times 10^{-4} \text{cm}/\text{V}/\text{s}$. This brings the idea of the 'Ion Sweeper' that will be

discussed later.

Xenon has a very unique feature among other noble gas scintillators. It produces proportional scintillation through a multiplication process in an electric field [16]. In the liquid, the field strength above $5 \times 10^5 \text{V/cm}$ is required in order to produce a proportional light. Very thin wires with a diameter of less than $10 \mu\text{m}$ is necessary for this condition. A few photons per electron are expected to be emitted reduced. The proportional scintillation is much prominent in gas phase even with an electric field about two orders of magnitude smaller than that in the liquid. The wave length of the proportional light is also 175nm .

The particle discrimination between electrons and alphas (or nuclei) is possible by the pulse shape discrimination [18] that is related to the emission mechanism mentioned above. The characteristic time due to the different recombination times is 3 nsec for nuclei and 40 ns for electrons.

The proportional scintillation light would provide another way to discriminate electrons from nuclei. If an electric field applied, those electrons produced through the ionization by electrons/ γ 's, not by nuclei, start to drift before the recombination takes place. Those drifted electrons can be guided into a region with a high electric field, then the proportional scintillation lights can be emitted. Thus the discrimination between electrons and other particles becomes possible. In the liquid, however, the amount of light emitted is a few photons per electron.

If those electrons are guided into the gas phase, then the more intense proportional light can be emitted even in a lower electric field [17]. The potential to pull electrons into gas phase ($\sim 0.7 \text{eV}$) can be obtained by applying the escape field of $2 \sim 3 \text{kV/cm}$. Consequently, one gets large proportional lights in the gas phase and small signal in the liquid Xe for electrons and one gets a signal only in the liquid for alpha or other nuclei.

This method could identify the α background originating from the U/Th decay chain and from possible dark matter interactions in the detector.

The prototype of such a detector—called two phase detector—has been developed for a dark matter search [20].

The liquid Xe has been studied extensively for many years and been widely used for dark matter searches and for studies of double beta decay. Therefore it is a sort of an established and known technology.

In order to detect about $10 \sim 20 \text{ pp-}^7\text{Be}$ neutrinos per day, 10 tons (fiducial volume) of liquid Xenon are needed. This amount is not a big surprise. There is an approved experimental project to use $800 \text{ liter}(2.4 \text{ tons})$ of liquid Xenon for $\mu \rightarrow e + \gamma$ [14] detection.

A most problem we have to carefully address is backgrounds, which will be discussed in later sections.

B. Solar Neutrino signal

The cross section of the $\nu + e \rightarrow \nu + e$ scatterings is very well known. Therefore we do not need a calibration for the absorption (interaction) cross sections. The flux averaged cross sections for pp- and ^7Be neutrinos are $1.2 \times 10^{-45} \text{cm}^2$ and $61 \times 10^{-45} \text{cm}^2$, respectively. The Compton like maximum energy of pp-neutrinos is 260keV . The energy spectrum expected for no oscillations is shown in Fig. 1 without energy resolution smearing. The event rate

expected as a function of the threshold energy is shown in Fig 2. We expect ~ 14 pp-neutrino events/day and ~ 6 ${}^7\text{Be}$ neutrinos/day for 10 tons of liquid Xe.

Liquid Xenon are considered also as a solar neutrino detector by means of the neutrino absorption process of ${}^{131}\text{Xe}$ with the threshold energy of 352keV that is mostly sensitive to the ${}^7\text{Be}$ neutrinos [21]. However the event rate is about 1500 events/yr/kton. For 10 ton detector, the events from this reaction is negligible.

C. detector

Two types of the detector can be considered—single phase (liquid) Xenon detector and double phase (liquid+gas) detector.

a. single phase detector A schematic view of the single phase detector is shown in Fig. 3. It is a spherical counter and contains 23.27 tons of liquid Xe in the inner container with a radius of 1.22m. The radius for the 10 tons fiducial volume is 0.92m and an additional 30cm layer act as self-shielding against the backgrounds entering into the inner container. This provide the shield of 11 radiation length, which is equivalent to the 4m of the water shield for γ 's and electrons.

Phototubes can be placed either in the liquid or out side of the liquid through quartz or MgF_2 windows. If you place the PMTs in the liquid Xe, you need additional insensitive layer filled with liquid Xe. For this schematic design, we have placed all the photo-tube outside of the inner container. The inner container can be made either by stainless steel, oxygen free copper, or other materials, depending on the contamination level of U/Th. The windows may be made by MgF_2 , quartz or other suitable materials.

For the heat insulation purpose, there is a gap between windows and the PMT surface. The layers having an array of PMTs act also as a vacuum insulator.

Suppose we cover 40% of the surface with PMTs at the distance of 1.22m from the center, we need either 1640 inch diameter PMTs or 3690 PMTs with 2 inch diameter.

Outside of the PMT layers, the water layer of 2 m thickness to provide the shields against backgrounds from environments is placed. If necessary, the thickness of this water shield can be increased. This layer can be made as an active veto like Super-Kamiokande anti-counters.

For the small scale test experiment [14] with 2.3 ℓ of active volume of which $\sim 40\%$ of the surface are covered by PMTs, the energy resolutions of 9.4% and 7%, for 320 and 662 keV γ - rays were obtained [14]. The extrapolated resolute at 100keV is 17.5%. They claim that they could improve the collection factor about 2 in future. The event vertex can be reconstructed by the pulse height distributions and the timing distributions. For the small size test experiment, they obtained 7mm for 320 keV [14]. Pulse shape discrimination of electrons and alphas (nuclei) may be possible in the single phase detector. However, detailed study for this possibility is necessary.

b. two phase detector Another interesting configuration is that we use both liquid and gas phases. This kind of arrangement has been proposed and studied extensively [19,20] for the dark matter experiments in order to obtain better discrimination of electrons from nuclear recoils. A few hundred V/cm of the electric field makes electrons produced by the ionization to drift towards the anode at the surface of the liquid, while the electrons produced by the ionization of alpha particles to recombine. Therefore we expect larger

prompt scintillation lights for the alpha particles and a small signal for the electron events in the liquid.

If the field of about 2 to 3 kV is applied to overcome the potential difference between liquid and gas phases, then those drifted electrons evaporate from the liquid to the gas. Those electrons are further accelerated in the gas with an applied field of about 10^3V/cm , then electron multiplication takes place and emits proportional lights. The electron events can be identified with the delayed coincidence signal from the gas phase.

Both singles from the liquid and from the gas can be measured by photo-multiplier tubes.

In this configuration, an idea of the 'Ion Sweep' that will be discussed later can also be possible.

III. BACKGROUNDS

The backgrounds should be removed as much as possible and the remaining backgrounds should be well understood since there is no coincidence information available for the neutrino electron scattering experiments. The backgrounds come from the impurity of the target material(Xe), the material surrounding the detector, muon induced radioactive products and so on. The 2ν double beta decay of ^{136}Xe is the most serious backgrounds for this experiment.

A. Internal backgrounds

1. Cosmogenic

Fortunately Xe does not have an isotope with a lifetime longer than a couple of months. The longest isotope is ^{127}Xe with the half-life of 36.4 days, which decay through electron capture with the Q-value of 0.664MeV. The second longest isotope is $^{131}\text{Xe}^m$ with the lifetime of 11.8days. Therefore the cosmogenic production of the Xe isotopes is not a serious problem.

2. ^{85}Kr , ^{42}Ar

Krypton and Argon may remain in the Xenon, since their boiling temperatures are lower than Xenon. In the nuclear reactors and from other sources, the radioisotopes, ^{85}Kr , ^{42}Ar and ^{39}Ar are produced. The half life of the ^{85}Kr is 10.7 years. The end point energy of the beta decay is 687keV. The current abundance, $^{85}\text{Kr}/\text{Kr}$, is reported to be $\sim 2 \times 10^{-11}$. This number is also confirmed by the direct beta decay measurement of ^{85}Kr in liquid Kr [22]. This abundant Krypton gives about 1 Bq/m³ in air ($\text{Kr}/\text{Air}=1.1 \times 10^{-4}\text{Vol}\%$). The standard Xe gas for an industrial production contains about 10ppm of Kr which gives about 10Hz of ^{85}Kr decays for 1 litter of liquid Xe. Suppose we allow 1 ^{85}Kr decay per day in 10 ton Xe detector, then we need to reduce the Kr in Xe down to $4 \times 10^{-15}\text{g/g}$.

The ^{42}Ar ($\tau_{1/2}=33\text{y}$) concentration is evaluated to be $^{42}\text{Ar}/\text{Ar} = 7 \times 10^{-15}$ [23–25] and gives about 1 Bq/m³ in air. Suppose we require that the backgrounds from this source is less than 1 event per day, then the Ar/Xe ratio should be less than $1.7 \times 10^{-11}\text{g/g}$, a level easier than the ^{85}Kr case.

Since Xe can be handled in three phases, gas, liquid and solid, there are variety of methods to purify Xenon. Bubbling can be used particularly to remove Kr and Ar and may be Rn. Helium and nitrogen are the best suited for the bubbling gases. Distillation can also applied to separate Kr and Ar.

There is a development of the absorption column [26]. They have demonstrated that 10ppm Kr contamination in Xe-gas reduced down to 1ppb by passing through this column. We expect to reduce further by applying this column repeatedly.

We should note that Xe can be circulated through the purification system and improvements of purification systems are possible even during the experiment.

3. 3H

The end point energy of 18keV is sufficiently small for the solar neutrino measurements, although 3H can be removed effectively by chemical processes.

4. ^{40}K

^{40}K ($\tau_{1/2}=1.28\times 10^9y$) decay through β^- (89.3%) with end point energy of 1.31MeV and through EC(10.7%)with the Q-value of 1.51MeV. The K contamination in Xe should be less than $3.9\times 10^{-14}g/g$ if the ^{40}K decay is allowed to be less than 1/day.

5. *U/Th contamination*

The radioactive decay of the U/Th chain is a large source of backgrounds although the solid U/Th can be removed relatively easily in the Xenon gas. If we allow one ^{238}U decay per day, which produces 8 α 's and 6 β 's assuming in equilibrium, the corresponding contamination level is $9.3\times 10^{-17}g/g$ for 10 tons of liquid Xenon. Similar level is required for Th-chain. Borexino group has achieved the U/Th contamination level of $\sim 4\times 10^{-16}g/g$ in their liquid scintillator.

Alpha decay can be identified by the pulse shape discrimination or in the two phase detector as described before. Positive quantitative identification of U/Th contamination is possible by detecting Bi-Po delayed coincidence, which enable us to evaluate the total backgrounds coming from the U/Th contamination and to make a statistical subtraction of the remaining backgrounds.

In addition to that, the idea of Ion Sweeper, which is described in the following paragraph, may improve the situation significantly.

6. *Positive Ion Sweeper*

Suppose the daughter nuclei of the decay products are ionized, those ions may be swepted away by applying the suitable electric fields in liquid Xenon detectors. Once this ion sweeper works, all the daughter nuclides newly produced are swepted away.

For a first few months after the electric field turned on we still get β 's and γ 's from the short lived nuclides in the U/Th chain, but after a few months of the sweeping time, in the liquid-Xe, all the short lived nuclides are decayed out and only the long lived nuclei remain as background sources.

For the U/Th chain, the long life nuclei (>30 days), ^{232}Th , ^{238}U , ^{234}U , ^{230}Th , ^{226}Ra , do alpha decay. The alpha decay can be identified in the liquid Xenon detector by the pulse shape discrimination. The ^{228}Ra (5.75yr) and ^{210}Pb (22.3yr) are the only long life nuclei, which decay through $\beta/(\gamma)$. However the Q-value is small, 45keV for ^{228}Ra and 63keV for ^{210}Pb . Those backgrounds may determine the energy threshold of the experiment.

If the ion sweep is demonstrated to work, the U/Th contamination would not be a big problem. And it is probably not necessary to achieve $10^{-16}(\text{U/Th})\text{g/g}$ level.

However, by a general argument, those U/Th contamination should be as small as possible anyway, which makes the energy threshold hopefully lower.

Anyway the two crucial issues on the “positive ion sweeper” that; 1) if the daughter nuclides are ionized and 2) if the positive ions have long enough life to drift out the chamber, must be proved.

The ionization potential of Xe(12.13eV) is the deepest compare to the products of U/Th-decay chain—U(6.19eV), Pa(5.89eV), Th(6.31eV), Ac(5.17eV), Ra(5.28eV), Rn(10.75eV), At(?), Po(8.41eV), Bi(7.29eV), Pb(7.42eV) and Tl(6.11eV). Therefore the probability for the daughter nuclides to exchange charge with Xe is negligible during the drift. The ion mobility in liquid Xenon has actually measured by [27,28]. An idea of collecting Ba ions through electric fields was discussed in [28] for the $\beta\beta$ decay identification. The drift velocity of Ba ions is estimated to be $3\times 10^{-4}\text{cm}^2/\text{V/s}$.

We could test the this idea probably by using a small test set up.

B. muogenic/spallation

It is difficult to estimate the backgrounds produced in the liquid Xe by penetrating muons at underground. The muon rate at Kamioka site for the 10 ton liquid Xe detector (1.8m in diameter) is ~ 250 muons/day.

Obviously, those muons and the prompt interactions can be removed very easily. Short live backgrounds can be removed by so called spallation cuts, à la Super-Kamiokande.

Problem comes from long-lived products. The muogenic cross section for some heavy elements like Gd, Yb, were measured by the accelerator experiment [30]. We would use their results to estimate the cross sections on Xe. The most cross sections for 100 GeV muons are 9.3 ± 1.0 mb for Gd case in ($^{160}\text{Gd}\rightarrow^{159}\text{Gd}$) and 27.7 ± 3.9 mb for Yb case in the reaction ($^{176}\text{Yb}\rightarrow^{175}\text{Yb}$). The most cross sections come from the (γ, n) reactions and the $(\gamma, 2n)$ reactions, which produce $(Z, A-1)$ and $(Z, A-2)$ nuclides. For Xenon case, the candidate transitions are $^{136}\text{Xe}(8.87\%)\rightarrow^{135}\text{Xe}$, $^{134}\text{Xe}(10.44\%)\rightarrow^{133}\text{Xe}$, $^{128}\text{Xe}(1.919\%)\rightarrow^{127}\text{Xe}$, $^{126}\text{Xe}(0.089\%)\rightarrow^{125}\text{Xe}$, $^{124}\text{Xe}(0.096\%)\rightarrow^{123}\text{Xe}$, and $^{129}\text{Xe}(26.4\%)\rightarrow^{127}\text{Xe}$, where, in the parenthesis, the natural abundance ratio is shown. We may ignore of the transition of $^{124,126,128}\text{Xe}$ due to the small abundance. ^{127}Xe decays through electron capture with 664keV, which could be identified. ^{135}Xe decays for 96% of the time with β and γ (249keV). For the most of the case, the total amount of the energy released is above the pp-neutrinos (260keV),

but it still be a problem. ^{133}Xe also decays through β and γ , with 81 keV γ energy, and the time difference is 6ns, which may be identified by the delayed coincidence.

As a crude guide line, suppose the muon cross section on ^{136}Xe and ^{134}Xe is $\sim 10\text{mb}$, the rate of the production of ^{135}Xe and ^{133}Xe is 1.9 events/day altogether. We have used the fact that the energy dependence of the spallation cross section, roughly proportional to $E_\mu^{0.75}$ [30–33], give roughly factor of two increase of the spallation cross section to $E_\mu \sim 285\text{GeV}$ for Kamioka site.

Here we have not considered other channels to produce neighbouring element like I, Cs and so on. Which may have a contribution of the similar order. The background situation of muogenics is probably marginal.

If we go about 100m deeper than the Super-Kamiokande level, then the muon rate reduces by 1order of magnitude therefore the problem would disappear. Since the size of the cavity required for the experiment is small, therefore there is no trouble to find and go deeper places.

Further reduction of the spallation backgrounds would also be achieved:

- If the ion sweep, which is described in III A 6 as a method to sweep the decay products of U/Th-chains, is demonstrated to work, then those spallation products are also swept out, since the spallation products are supposed to be ionized.
- If we adopt the isotope separation of ^{136}Xe (removing), to be discribed later the most spallation problem ($^{136}\text{Xe} \rightarrow ^{135}\text{Xe}$) disappears.

Anyway it is important and necessary to measure the spallation cross sections by muon beam produced by high energy accelerators.

C. External backgrounds

The γ -rays and neutrinos from the materials surrounding the liquid Xenon—container, PMTs, cables, structures and rocks—would be backgrounds. The shell structure, which provide a graded shielding against those radio-activites, would reduce the backgrounds.

The inner structures would require more purity than those situated outer side of the detector.

The high density and high Z of Xenon would provide very good self-shield against those background. The 30cm self-shield is equivalent to the 4m of water shield for the electromagnetic component. The detailed study and simulations for background should be done.

D. Backgrounds from double beta decay

Xenon contains two double beta-decay and two double beta-plus decay isotopes. Among them the ^{136}Xe 2ν -double beta decay is a potential problem, since the Q-value(2.48MeV) is highest and the natural abundance(8.9%) is high. The expected event rate assuming the $8 \times 10^{21}\text{yr}$ for 2ν double beta decay is about 1,000 events per day as shown in Fig. 4. The energy spectrum extends up to 2.48 MeV. We expect 10 to 20pp- solar neutrino interactions below 300 keV where about 10% of the double beta signals, about 100 events, overlaps.

If the lifetime of the double beta decay is longer (say 100 times of 8×10^{21} yr), then the solar neutrino signal may be extracted and the double beta decay would not be a problem. It is necessary to determine the lifetime of the $2\nu \beta\beta$ -decay. The current experimental lower limit is 0.5×10^{21} yr. Of course the 10 ton Xenon (0.87 tons of ^{136}Xe) has a potential sensitivity for 0ν double beta decay. If the lifetime of the double beta decay is shorter, then the isotope separation of ^{136}Xe is inevitable. The isotope separation will be essential and improve the situation significantly, which will be discussed in the next section IV.

IV. ISOTOPE SEPARATION AND DETECTION OF SOLAR NEUTRINOS, DOUBLE BETA DECAY AND DARK MATTER.

The isotope separation (enrichment or depletion) would be essential for this experiment, since it is very difficult to anticipate the lifetime of the 2ν double beta decay to be 100 times longer than the current theoretical estimate of $2 \sim 8 \times 10^{21}$ yr.

But, once we accept the necessity of the isotope separation, then we will obtain other possible and interesting applications than the solar neutrino detection: One should note that it will open up a new possibility of a positive identification of the dark matter detection. The isotope distribution of Xenon is, ^{124}Xe (0.096%), ^{126}Xe (0.089%), ^{128}Xe (1.919%), ^{129}Xe (26.4%), ^{130}Xe (4.07%), ^{131}Xe (21.18%), ^{132}Xe (26.89%), ^{134}Xe (10.44%), ^{136}Xe (8.87%). If we are able to split between 131 and 132, we can separate Xe into two sub-sets which consist of mostly odd nucleus (129 (26.4%) and 131 (21.2%)) and mostly even nucleus (132 (26.9%), 134 (10.44%) and 136 (8.87%)). Of course it is not possible to make a clear separation, but anyway we are able to measure the dark matter interaction separately with the mostly-odd nuclei and with the mostly-even nuclei to extract the information of spin independent and spin dependent interactions. Furthermore, for example, by exchanging the detector containers of two sub-sets, we can set the background environment to be common for the two sub samples which is very important.

Therefore the experiment can be configured dynamically: the solar neutrinos detection can be done by odd enriched sample and the double beta decay experiment can be done by even enriched sample and dark matter can be measured in both samples. The isotope separation really gives a new experimental approach and opportunities for a variety of physics.

In addition to the increased physics opportunities, the purity of liquid Xenon can be significantly improved by the isotope separation.

V. CONCLUSIONS

The 10ton liquid Xenon solar neutrino detector by which we expect to detect ~ 14 pp and ~ 6 ^7Be neutrinos per day can be built by known technologies. The impurity level of the liquid Xe should be reduced down to 10^{-16} g/g, 10^{-15} g/g and 10^{-11} g/g for U/Th, ^{85}Kr and ^{42}Ar , respectively. Alpha decay may further be identified and be separated from the electron events. The required purity level can be accomplished by bubbling, distillation, filtering, and so on. The detector is shielded by the outer 30cm layer of Xe against the incoming

backgrounds. Spallation products are estimated to be about 2 events per day. The ion sweeper, if possible, improves the situation.

Most serious background comes from the 2ν double beta decay of ^{136}Xe . The lifetime of the 2ν double beta decay should be determined before the final design of the experiment, which infers the required level of the isotope separation.

The isotope separation is inevitable if the 2ν lifetime is shorter than $100 \times 8 \times 10^{21}\text{yr}$.

The isotope separation, however, improves the situation in many aspects, not only for the backgrounds from the double beta decay, but also for the internal background.

Xe could be divided into odd enriched and even enriched samples by the isotope separation. Two detectors can be prepared for the two samples, and the odd enriched sample, which does not contain the large amount of ^{136}Xe can be used for the solar neutrino detection and the even enriched sample can be used for the double beta decay study. An occasional exchange of the containers would provide the way to evaluate the background in each sub sample and provide a new way to identify the dark matter signal by the evaluation of the spin independent and dependent interactions through the separately measured interactions with odd and even nuclei.

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TABLES

	He	Ne	Ar	Kr	Xe
atomic number	2	10	18	36	54
atomic mass	4.00260	20.1797	39.948	83.80	131.29
Ionization Potential(eV)	24.587	21.564	15.759	13.999	12.13
operating temperature(boiling point)(k)	4.215	27.096	87.28	119.8	165.03
wave length of scintillation light	73nm	80nm	128nm	147nm	174nm
number of photons(/MeV)			40,000		43,000
Long life Isotopes(>a months)	—	—	³⁹ Ar, ⁴² Ar	⁸⁵ Kr	—
density in liquid phase(g/cm ³)	0.125	1.20	1.40	2.6	3.06
radiation length(cm)	756	24	14		2.4
Volume fraction in air (in %)	0.0005	0.0018	0.9325	0.0001	0.0000009

TABLE I. Comparison between noble gas scintillators. Source Particle data book and others

FIGURES

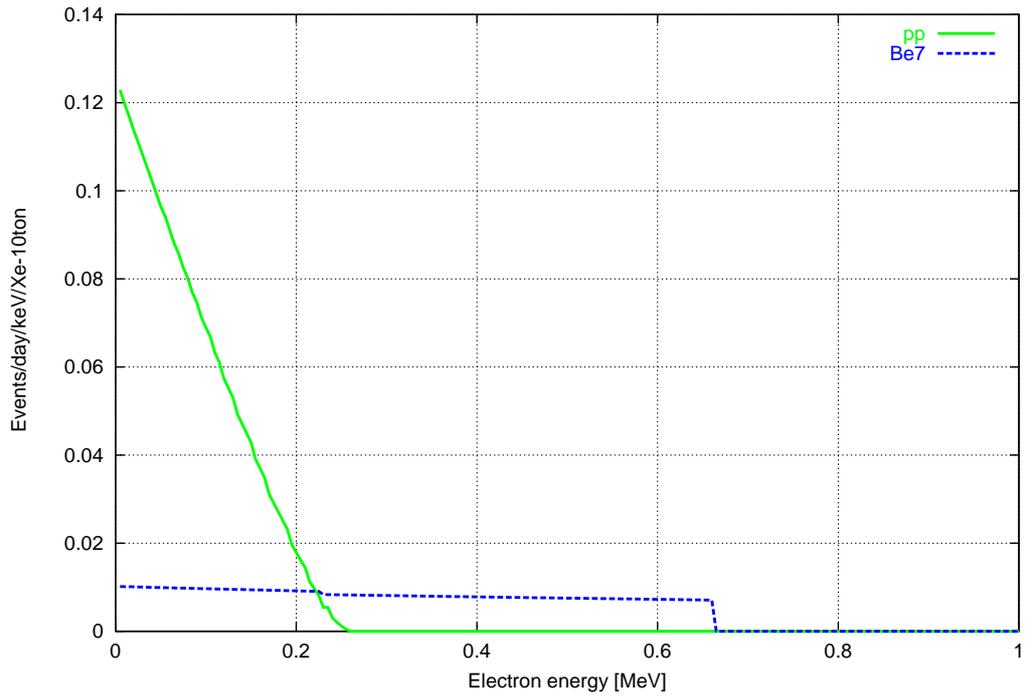


FIG. 1. The recoil electron energy spectrum.

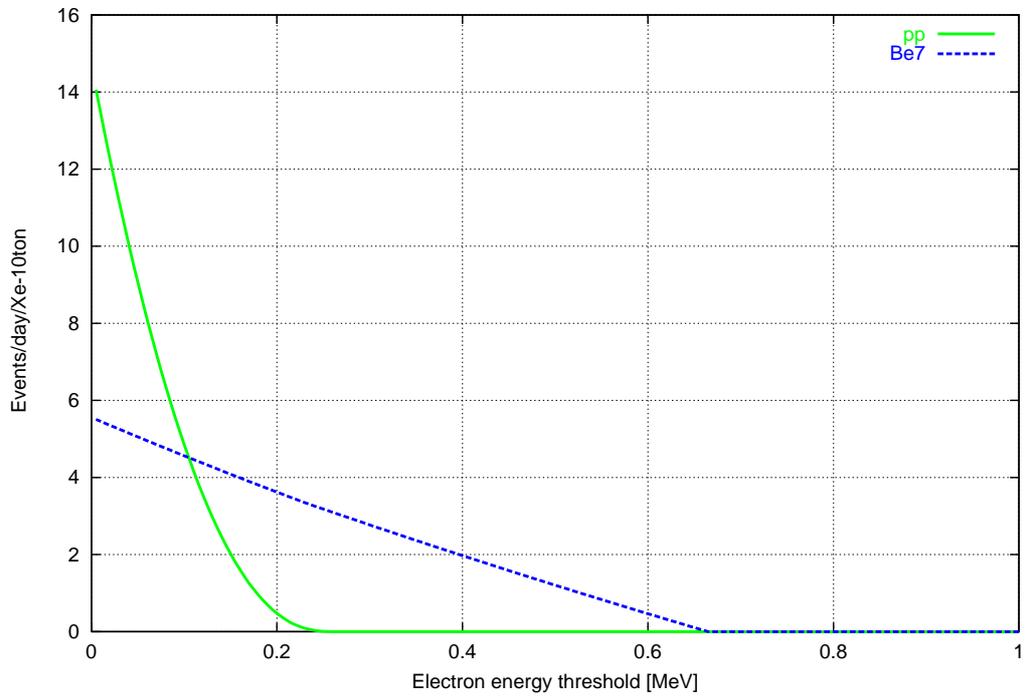


FIG. 2. The expected event rate as a function of the threshold energy.

Detector

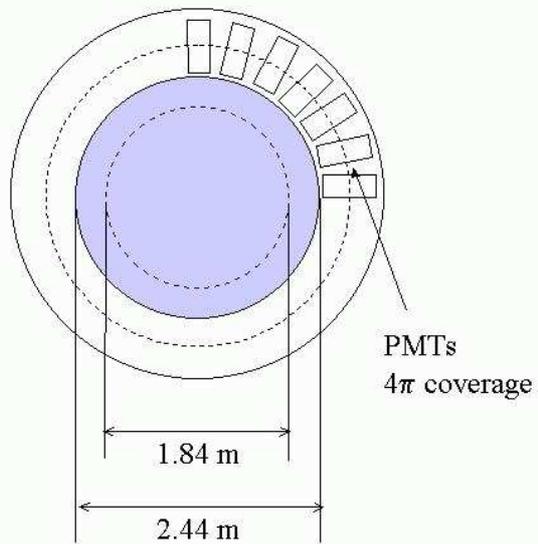


FIG. 3. Single phase detector.

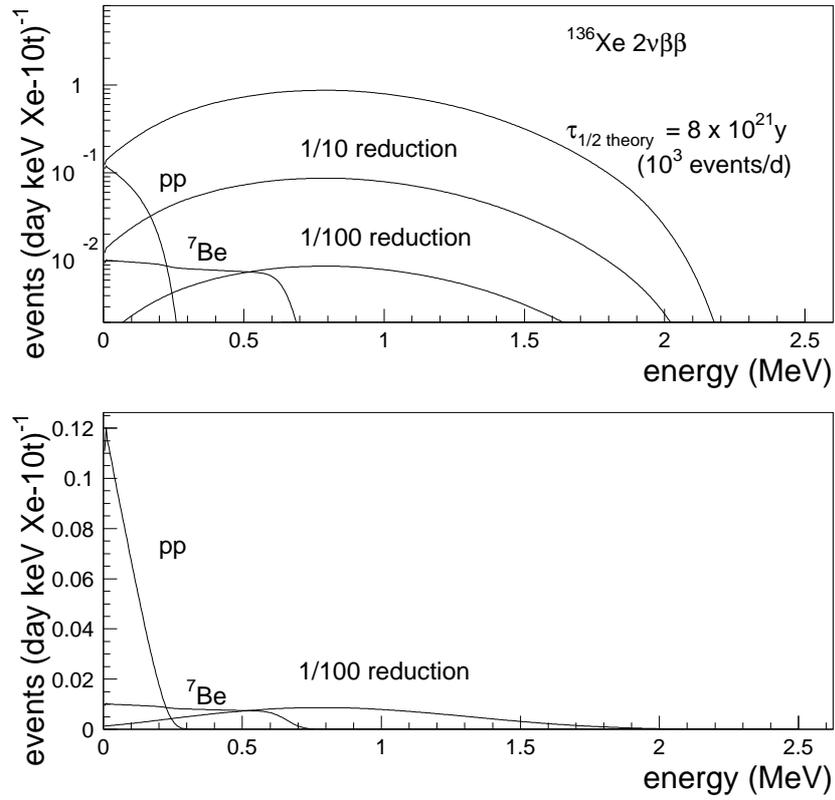


FIG. 4. Background from 2ν -double β decay of ^{136}Xe .