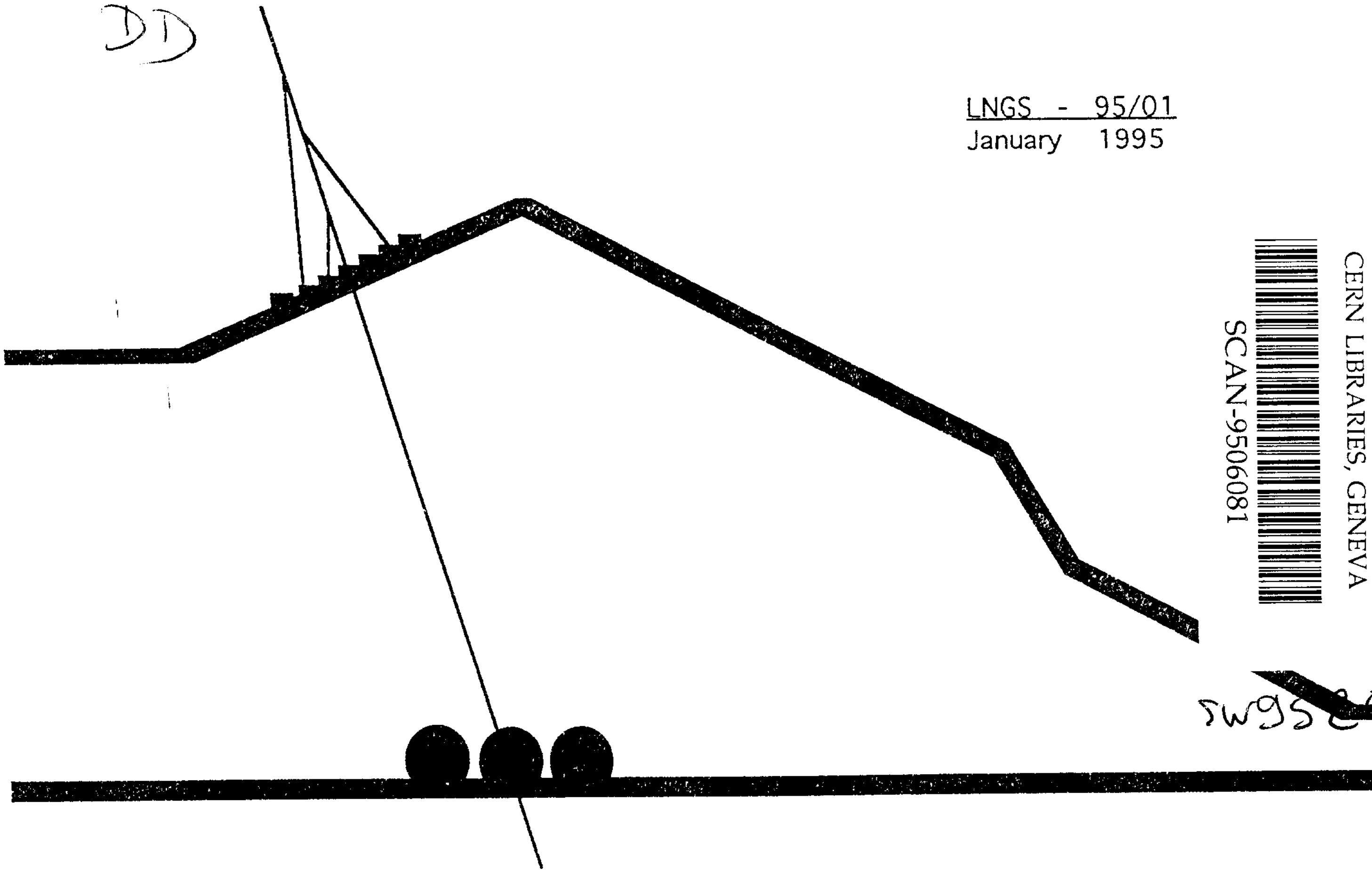
LNGS - 95/01
January 1995



A multiton low activity NaI(Tl) detector for underground physics

R. Bernabei, P. Belli, W. Di Nicolantonio, V. Landoni
Dipartimento di Fisica, II Universita' di Roma and INFN sezione di Roma2, Italy

A. Incicchitti, D. Prosperi
Dipartimento di Fisica, Universita' di Roma and INFN sezione di Roma, Italy.

C. Arpesella
INFN Laboratorio Nazionale del Gran Sasso, Italy.

Dai Chang Jiang, Ding Linkai , Kuang Haohuai
IHEP, Academia Sinica, P.O. Box 918/3, Beijing 100039, China

Submitted to Astroparticle Physics

INFN - Laboratori Nazionali del Gran Sasso

LNGS - 95/01
January 1995

A multiton low activity NaI(Tl) detector for underground physics

R. Bernabei, P. Belli, W. Di Nicolantonio, V. Landoni
Dipartimento di Fisica, II Universita' di Roma and INFN sezione di Roma2, Italy

A. Incicchitti, D. Prosperi
Dipartimento di Fisica, Universita' di Roma and INFN sezione di Roma, Italy.

C. Arpesella
INFN Laboratorio Nazionale del Gran Sasso, Italy.

Dai Chang Jiang, Ding Linkai , Kuang Haohuai
IHEP, Academia Sinica, P.O. Box 918/3, Beijing 100039, China

ABSTRACT

This paper presents the main physical goals reacheable with a large mass and extremely low activity NaI(Tl) apparatus such as the detection of very low interacting rate Dark Matter candidates and of solar neutrinos.

1. Introduction

A big challenge is in progress to develop ultimate radiopurity detectors for underground experiments, in particular for Dark Matter search (1) and solar neutrinos (2). It is clear the interest to concentrate the efforts on a detector that can be suitable for more than a single physical goal.

In the last years research programs to develop very low activity NaI(Tl) detectors have been carried out by different groups (3); relevant improvements have been reached and the work is still in progress.

In this paper we will describe some of the physical goals that can be reached with a multiton NaI(Tl) set-up of suitable radiopurity level.

2. Dark Matter search

The existence of Dark Matter in the Universe is supported both by experimental and theoretical arguments (4) and it has been demonstrated (5) - to account for the galaxies formation - that a part has to be constituted by relic particles - non relativistic at temperatures greater than 10^4 K - with masses from few GeV to 10^{19} GeV generated in the primordial Universe [1)].

[1)] WIMPs (Weakly Interacting Massive Particles): cosmions, heavy neutrinos and SUSY particles.

The interest in using low activity NaI(Tl) as target-material for a direct search of particle dark matter has been already pointed out and the experimental feasibility has been demonstrated [3]. An experiment with ~90 kg of target-detector to search for WIMPs by direct detection of WIMP-nucleus elastic scattering is already in installation at Gran Sasso.

Although even exotic (not yet provided by theories) candidates for WIMPs can be considered, the more attractive one is at present the lightest supersymmetric particle, named neutralino: χ. In the Minimal Supersymmetric Standard Model (MSSM) the R-parity is conserved and this implies that heavier SUSY particles decay in lighter ones: therefore, χ must be stable. Furthermore, the neutralinos cannot interact neither by electromagnetic nor by strong interactions, otherwise they would condensate and be detected in the galactic halo with ordinary matter. The upper limit for the expected rate [6] in the MSSM has been already discussed, but the lower limit is not clear and could be evaluated as well reduced constraining the models in various ways [7]. Therefore, a negative result at present limit of detector sensitivity and mass will support the effort both to further reduce the intrinsic radioactivity and to increase the mass to obtain a suitable statistics.

The lowest counting rate for a low activity NaI(Tl) is at present ~ 1 cpd/kg/keV at 4 keV electron equivalent with ~ 2ppt U/Th and less than 50 ppb ^{nat}K in the crystal [8]. Furthermore, as pointed out by the BPRS collaboration a pulse shape analysis is feasible even at very low energy [8]: the use of this technique will allow to reject large part of residual electromagnetic background. The actual generation experiments have as goal to get a sensitivity of 1 - 0.1 cpd/kg with ~ 100 kg detector; a negative result in those searches will require a new step toward 0.1-0.01 cpd/kg with ~ 1 ton detector.

3. Solar neutrino detection

The solar neutrino flux from the Sun has been studied since twenty years [2,9,10] and recently the results of the Gallex experiment [10] pointed out that the problem could be constrained at the level of the ^{7}Be or ^{8}B neutrino flux. Furthermore, it has been suggested that the comparison of the experimental results from Chlorine, Kamiokande and Gallex/Sage experiments indicates that an astrophysical solution of the solar neutrino problem could fail and that the solution could be a large suppression of the ^{7}Be neutrinos [11].

A low activity large mass NaI(Tl) detector will be - in principle - well suitable to study almost the whole neutrino energy spectrum and shape. It will allow to realize a real time experiment in which the time occurrence of each event and its energy can be provided with a good energy resolution. Large mass detectors need a particular care to optimize the light collection in a very low activity environment. Typical energy resolutions are quoted in ref.[3]. In addition, the identification of the involved reaction could also offer a significant signature. Although large efforts are still needed in order to reduce the background contaminants of the crystals and of the apparatus (see par. 5), we stress that the very low activity scintillators have been developed only recently. A detailed description of selection and purification procedures with the relative radiopurity levels can be found in ref.[3].

In table 1 we summarize the ν_e-Na, ν_e-I (1 to 5 charged current reactions; 6 to 9 neutral current reactions) and ν_e-e^- scattering (10) reactions of interest for solar neutrino detection, while in fig.1 a) and b) we show the schemas of the excited levels for Na and I [12]. Notice that in this figure only the levels considered in the following calculations are shown.

The reaction 1) could allow to detect ^8B neutrinos by studying the time correlation between prompt electrons and β^+ signals. In case the experimental set-up would have a suitable granularity the annihilation gammas from the positron could be separately identified and, in addition, a 440 keV photon will further enhance the reliability of the signature in the 8.6% of the times .

The reaction 3) is sensitive to the 861 keV ^7Be neutrino line and to higher energy neutrinos. In principle, a signature could be provided by the subsequent X-rays produced in the electron shell rearrangement following a ^{127}Xe electron capture; however, the long decay time of ^{127}Xe ($T_{1/2}$=36.4 d) would make the proper data handling difficult. The ^{127}Xe can be produced also in the reaction 4) following the ^{127m}Xe decay; this reaction (sensitive essentially to ^8B neutrinos) could be distinguished by time correlation analysis between the prompt electron and the photons at 124.6 keV and 172.5 keV. However, both reactions 3) and 4) are forbidden by selection rules (having ^{127}I spin $5/2^+$, ^{127}Xe spin $1/2^+$ and ^{127m}Xe spin $9/2^-$) and are not considered in the present calculations.

The reactions 2) and 5) will allow to detect the coincidence of prompt electrons and gammas coming from the disexcitation of $^{23}Mg^*$ and $^{127}Xe^*$ respectively. The 2) in addition has the significant signature of a delayed $^{23}Mg \rightarrow \beta^+ \, ^{23}Na$ decay; here considerations similar to the case of reaction 1) can be done. The reaction 5) is sensitive to the 861 keV ^7Be neutrino line and to higher energy neutrinos, while reaction 2) is sensitive only to ^8B neutrinos with energy greater than 4.51 MeV.

Neutrino interactions 6) and 7) produce only recoil nuclei as in the case of Dark Matter detection. At the low energies relevant for solar neutrinos, the nucleus can be treated as pointlike and the whole nucleus responds coherently; however, although the total expected rates for these reactions are of order of some thousands events/y/tons, even the lowest reacheable experimental threshold (2 keV electron equivalent) does not allow a significant detection of such events.

The reactions 8) and 9) need an extreme radiopure detector to point out the corresponding γ line contributions that will be the main signatures for these reactions. In case of 100 tons detector these could be the most interesting reactions, but the background rate in the energy region of the emitted photons should be of the order of the expected ν_e-e^- rate.

Finally, the whole solar neutrino energy spectrum can be detected by the reaction 10); the main limitation could be the increasing of the background when decreasing the energy threshold on the accepted events. In any case, the 100% alpha rejection by pulse shape analysis (8), anticoincidence and other conventional background rejection techniques can be combined to offer an almost zero background real time experiment for ^8B neutrino over 3 MeV.

To evaluate the practical feasibility of such an experiment we estimate the expected rates for the considered reactions calculated from the SSM fluxes (13). The main uncertainties in our calculations are due to the Gamow-Teller strenghts. In the following we recall the used formulas [2)].

The charged current cross sections on nuclei can be written as:

$$\sigma_{CC} = (G_F^2/\pi)\, \lambda_{CC}\, P_{CC},$$

where G_F is the Fermi coupling constant, P_{CC} is the phase space factor and λ_{CC} is the charged current strength: $\lambda_{CC} = B(F)+(g_a/g_v)^2\, B(GT)$, with B(F) and B(GT) Fermi and Gamow-Teller strengths respectively, and $g_a/g_v = 1.26$. The phase space factor P_{CC} is:

$$P_{CC} = \int p_e w_e\, F(Z,w_e)\, \Phi(E_\nu) dw_e;$$

p_e and w_e are the electron momentum and energy respectively, $F(Z,w_e)$ is the Fermi function and $\Phi(E_\nu)$ is the normalized solar neutrino flux distribution as a function of $E_\nu = w_e - m_e + E_{th}$, with m_e electron mass and E_{th} experimental energy threshold.

For the neutral current cross sections on nuclei we can write:

$$\sigma_{NC} = (G_F^2/\pi)\, \lambda_{NC}\, P_{NC}$$

with $\lambda_{NC} = B(F)+(g_a/g_v)^2\, B(GT)$ and $P_{NC} = \int (E_\nu - E_{th})^2 \Phi(E_\nu) dw_e$.

The neutrino electron scattering as a function of the electron kinetic energy, T, is described by:

$$d\sigma_{\nu\text{-}e}/dT = \int_{E_{\nu min}}^{E_{\nu max}} (d\sigma(E_\nu)/dT)\ \Phi(E_\nu) dE_\nu$$

where $0 \leq T \leq T_{max} = 2E^2_{\nu max} / (m_e + 2E_{\nu\,max})$ and $E_{\nu min} = 1/2\, [T + \sqrt{(T(T+2m_e))}]$. $E_{\nu max}$ is the maximum neutrino energy for the considered neutrino spectrum. The differential cross section at fixed neutrino energy is given by

---

2) Here $h/2\pi = c = 1$.

$$d\sigma(E_\nu)/dT = (\sigma_e/m_e)[g_L^2 + g_R^2(1-T/E_\nu)^2 - g_L g_R m_e T/E_\nu^2]$$

with $\sigma_e = 0.881 \times 10^{-44}$ cm^2, $g_L=1/2+\sin^2\theta_W$ and $g_R=\sin^2\theta_W$.

The following assumptions have been considered in the calculation: i) the intensities and the shapes of each solar neutrino spectrum are taken from the SSM (13); ii) $\lambda_{CC} = \lambda_{NC} = 0$, for forbidden transitions; iii) in case of ^{127}Xe excited states we consider that only the lowest $3/2^+$ state could give allowed transitions with B(F)=0 and B(GT)=0.04 (14) (reaction 5); iv) being log(ft)=3.7 for the ^{23}Mg β^+ decay, we derive λ_{CC} = 6165s/5012s = 1.23 for the ground state transition ^{23}Na-^{23}Mg (reaction 1). Then, B(GT)= 0.145 knowing B(F)=2T=1; v) B(F)=0 and B(GT)=0.20 for the ^{23}Mg excited states (reaction 2); vi) having an isodoublet mirror pair (T=1/2) such as ^{23}Na-^{23}Mg, it results $4\lambda_{NC} = \lambda_{CC}$, so we assume λ_{NC} =0.08 for the ^{23}Na excited states (reaction 8); vii) λ_{NC}=0.2 for the ^{127}I excited states (reaction 9).

As it is clear from table 2, in case of a multiton (≥100) detector a signature could be obtained in case of reaction 1) in particular if using a suitable set up granularity (see above), while reaction 10) above 3 MeV could offer the lowest background region.

In fig. 2 it is shown the differential counting rate from the pp, ^{7}Be, pep and ^{8}B solar neutrinos as a function of the total energy detected in NaI(Tl); the spectrum was broadened by typical NaI(Tl) resolution considering full calorimetry. In particular, we concentrate our attention on the ^{7}Be and ^{8}B neutrino signatures. As shown in fig.3, the ^{7}Be neutrinos can be identified f.i. by observing the two peaks at 58 and 200 keV[3] collecting events for at least 2 years with a 100 tons detector to clearly state their presence - within 4σ - over the almost flat (in this region) energy distribution due to neutrino scattering. Furthermore, from fig. 4 it is clear that the whole expected spectrum between 0.24 and 0.64 MeV is essentially due to ^{7}Be neutrinos (in that case the main problem could be the intrinsic radioactive background of the experimental set up).

The real time measurement of the ^{8}B neutrinos would be performed with ~ 3 MeV energy threshold (see above), which is reasonable with suitable reduced background. The total rate for ^{8}B neutrinos above this threshold is expected to be: ~250 events/y/100tons. Furthermore, the peaks induced in NaI(Tl) by the ^{8}B neutrinos (see fig. 5) could be an additional tool for the data analysis. The sensitivity of these signatures depends on the level of background reduction.

We finally notice also that the quoted rates could allow also the study of an eventual night/day effect or solar flares correlation.

---

[3] centroid of the two peaks at 197 keV - from ^{7}Be neutrinos inducing CC on Iodine - and 203 keV - from ^{7}Be neutrinos inducing NC on Iodine; the 65 % of the events in the peak is expected from ^{7}Be neutrinos.

4. Long baseline neutrino oscillation

It has been suggested the possibility to produce high flux long baseline neutrino beams from CERN to Gran Sasso to extend the investigation of the plane (Δm^2-$\sin^2 2\theta$) looking for neutrino oscillation (15).

Several detectors have been proposed that will offer powerfull tools for neutrino flavour changing identification (15); however, considering the beam size at Gran Sasso location more than one detector can be foreseen and a multiton low activity NaI(Tl) set-up deep underground in the Gran Sasso Laboratory could even contribute to a similar investigation. In fact considering a SPS proton beam of energy 450 GeV with a mean expected flux ~ 10^{19} protons/year on target, we can estimate - if no flavour oscillation occurs - ~ 3×10^7 ν_μ/y/cm^2 with $<E_\nu^{-2}>^{-1/2}$ = 14.6 GeV in case of perfect focusing [4] and, therefore, the expected rate in the detector can be evaluated as ~ 50 events/y/100tons.

Regarding the $\nu_\mu \to \nu_e$ oscillation, we can consider that the $\nu_\mu\, n \to \mu^-\, p$ reaction could be identified detecting the proton energy in the NaI(Tl) and the μ^- appearance - from inside the detector - in a muon detector surrounding it and giving time of flight information [5] in order to strongly reduce the atmospheric neutrino induced background, dominant at these energies. After 4 years running time with 100 tons detector the reachable sensitivity, obtained considering full μ identification, will be $\sin^2 2\theta$ ~ 0.07 and Δm^2 ~ 4×10^{-3} eV^2.

For $\nu_\mu \to \nu_\tau$ oscillation, we have to consider that a significant fraction of candidates ν_μ from the μ^- appearance in the muon detector (see before) will belong to the eventually flavor flipped ν_τ; in fact, τ^- from ν_τ interaction decays through several channels producing μ^-. Therefore, the reacheable sensitivity with 100 tons detector after 4 years running time for $\nu_\mu \to \nu_\tau$ oscillations would be only $\sin^2 2\theta$ ~ 0.28 and Δm^2 ~ 8.3×10^{-3} eV^2.

5. Backgrounds in NaI(Tl) detectors

The main problem - when developing detectors devoted to underground physics - is to get the needed extreme background reduction. In fact, it is necessary to discriminate few events per month starting from the residual cosmic ray background, the environmental activity, the residual contaminations inside the detector itself and the shield and from the electronic noise.

Low activity scintillators have been developed only recently, therefore large efforts are still needed to find the most effective methods for the internal background extreme reduction. At present, the BPRS collaboration has developed NaI(Tl) crystals with ~ 2×10^{-12} g/g in $^{238}U+^{232}Th$ and $^{40}K < 5 \times 10^{-12}$ g/g (2σ

---

[4] In the original beam the contamination of different neutrino flavours would be a few percent.
[5] Similar performances can be obtained f.i. with RPC detectors (16).

C.L.) (8) and new 3" photomultipliers giving less than 1 cpm over 30 keV if directly coupled to the scintillator (~ 30 times better than previously available).

If we consider the more stringent requirements coming from the possible use of low activity NaI(Tl) detectors for solar neutrino experiments, we can easily deduce that for an almost zero background experiment the U/Th contents has to be reduced toward 10^{-16} g/g. This is a goal similar to the one needed for most of the detectors proposed up to now for solar neutrino experiments such as Borex which has a liquid scintillator as target-detector. However, we have to notice that the possibility to clearly identify the U/Th and K contaminations inside the crystal together with the possibility of a proper evaluation of the associated gamma and beta spectrum and the 100% alpha rejection by PSD could allow to manage even situation in which the background would be several times higher than the expected events. A discussion on possible strategies for data analysis in a scintillation detector for solar neutrinos can be found in ref. (17). Furthermore, the comparison of different possible signatures for the various channels can also offer - in our case - further tools for reliable data analysis.

In any case, improvements to increase the detector radiopurity can be done by requiring a more stringent selection of the powders by using atomic absorption and mass spectrometer and, for first time, also purification procedures. Furthermore, the underground growth with the more suitable growing method (which acts also as a purification procedure) and multiple growths procedures can allow to further increase the intrinsic radiopurity of the crystals. However, the most relevant point will be the overcoming of the constraints set by the "normal" industrial procedure for growing and handling the detectors which forbidden up to now e.g. both the possibility to use suitable cleaning room for the installation of the growing furnace and detector assembling system and suitable selection and purification of the gases used in the growing which can add dangerous contaminants such as krypton, tritium and radon or even particles present in the distribution line. Obviously all the materials used in the detector assembling such as glues and optical greases have to be selected at same level or even better than the powder itself.

New efforts can be also foreseen to build new photomultipliers with higher radiopurity, although in case of a solar neutrino search long UV low activity quartz light guides can be used because the energy threshold can be much higher than in case of neutralino search.

The environmental radioactivity can be reduced by low activity passive shields around the detector: presently we use 15 cm of very low activity lead and 10 cm of OFHC freshly electrolysed copper. Further, it will be essential to shield the detector from the neutrons present in the environment (due to the rock contaminants and/or muon spallation in the rock) with some tens cm of polyethylen and a thin cadmium foil outside the Pb/Cu shield. Finally, the radon concentration depends on local situations and on the presence and efficiency of a ventilation system (a typical value ~ 30 Bq/m^3); it can be reduced to << 1 Bq/m^3

nearby the detector sealing and even cancelled maintaining inside a nitrogen flux typically at about 10 mbar differential pressure.

6. Conclusions

This brief presentation shows how stimulating is the challenge to develop high purity detectors to identify low interacting rate particles. A 1 ton experimental set up can be realized in a single sealed passive shield by e.g. 10 kg detectors with >10 cm long pure special low activity quartz, seen by two low activity photomultipliers in coincidence. Larger mass set-ups can be realized in a modular way by repeating the first apparatus. Therefore, the development of an extreme low activity 1 tons NaI(Tl) set-up would have as aim e.g. both a real detector for neutralino search and a suitable R&D step toward the feseability of a solar neutrino experiment. The present performances of such detectors could be already suitable for a long baseline experiment.

Large efforts are needed, in any case, to get the ultimate low rate for NaI(Tl) detectors and to obtain a suitable multiton apparata.

7. Acknowledgements

It is a pleasure to thanks Proff. E. Bellotti, V. Berezinsky and S. d'Angelo for many helpfull discussions and the other members of the Beijing-Paris-Roma-Saclay collaboration.

Table 1

ν_e-Na, ν_e-I and ν_e-e^- reactions of interest for solar neutrino detection.

Reaction	ν_e energy threshold (MeV)	Remarks
1) $\nu_e\ ^{23}Na \to e^-\ ^{23}Mg$	4.06	$^{23}Mg \to \beta^+\ ^{23}Na$; T1/2= 11.3 s, 440 keV γ(8.6%)
2) $\nu_e\ ^{23}Na \to e^-\ ^{23}Mg^*$	4.51	$^{23}Mg^* \to \gamma\ ^{23}Mg$ γ's: 450.7, 2051,2359 keV etc from higher energy levels + decay $^{23}Mg \to \beta^+\ ^{23}Na$
3) $\nu_e\ ^{127}I \to e^-\ ^{127}Xe$	0.664	$^{127}Xe \to\ ^{127}I$ (EC); T1/2=36.4 d, X rays and γ's: 57.6, 145,172,202.8,375.0 keV.
4) $\nu_e\ ^{127}I \to e^-\ ^{127m}Xe$	0.961	$^{127m}Xe \to\ ^{127}Xe$ (IT); T1/2= 69.2 s, γ's: 124.6 keV (68%), 172.5 keV 37.4%) + decay of ^{127}Xe(EC)
5) $\nu_e\ ^{127}I \to e^-\ ^{127}Xe^*$	0.789	$^{127}Xe^* \to \gamma\ ^{127}Xe$ γ's:124.7,172.5,174.9,196.2, 286.6, 321.3, 411.1 keV etc from higher energy levels + decay ^{127}Xe(EC) OR $^{127}Xe^* \to \gamma\ ^{127m}Xe$ γ's: 483,519, 577, 684 keV etc from higher energy levels+ decay ^{127m}Xe(IT) and ^{127}Xe(EC)
6) $\nu_e\ ^{23}Na \to \nu_e\ ^{23}Na$	0.	nucleus recoil energy detection (similar to WIMP case)
7) $\nu_e\ ^{127}I \to \nu_e\ ^{127}I$	0.	nucleus recoil energy detection (similar to WIMP case)
8) $\nu_e\ ^{23}Na \to \nu_e\ ^{23}Na^*$	0.440	$^{23}Na^* \to \gamma\ ^{23}Na$; γs: 440 , 2076, 2391, 2640, 2704 keV, etc from higher energy levels
9) $\nu_e\ ^{127}I \to \nu_e\ ^{127}I^*$	0.058	$^{127}I^* \to \gamma\ ^{127}I$; γs: 57.6, 145.22, 202.84, 215.1, 360.3, 417.9, 618.6, 628.6 keV etc from higher energy levels
10) $\nu_e\ e^- \to \nu_e\ e^-$	0.	e^- recoil energy detection

Table 2

Expected rates at zero energy threshold for the reactions of table 1 using the SSM fluxes [13]. The not allowed reactions are assumed to give zero rates.

Reaction	Signature	pp ν_e rate (ev/y/100ton)	^{7}Be ν_e rate (ev/y/100ton)	pep ν_e rate (ev/y/100ton)	^{8}B ν_e rate (ev/y/100ton)	TOTAL ν_e rate (ev/y/100ton)
1)	$e^- + \beta^+$ decay (11.3 s): $E_{thr\,\nu}$ =4.06MeV	-	-	-	29	29
2)	$e^- + \gamma + \beta^+$ decay (11.3 s): $E_{thr\,\nu}$ =4.51 MeV	-	-	-	12	12
3)	e^- : $E_{thr\,\nu}$=0.664 MeV	-	-	-	-	-
4)	e^- + disexcitation ^{127m}Xe (69 s): $E_{thr\,\nu}$=0.961 MeV	-	-	-	-	-
5)	$e^- + \gamma$ + decay ^{127}Xe ($E_{thr\,\nu}$ =0.789 MeV) & ^{127m}Xe ($E_{thr\,\nu}$ =1.444 MeV)	-	11	4	6	21
6)	nucleus recoil	under exp. threshold	under exp. threshold	under exp. threshold	under exp. threshold	under exp threshold
7)	nucleus recoil	under exp. threshold	under exp. threshold	under exp. threshold	under exp. threshold	under exp threshold
8)	γ rays: $E_{thr\,\nu}$ =0.440 MeV	-	13	3	20	36
9)	γ rays: $E_{thr\,\nu}$=0.058MeV	154 (E_γ=0.058, 0.203 MeV)	255 (E_γ=0.058, 0.203, 0.418 MeV)	37	136	582
10)	e^-	56250	20930	1260	310	78750

Figure Captions

Fig. 1: Schemas of the excited levels for ^{23}Na-^{23}Mg system (a) and ^{127}I-^{127}Xe system (b). Only the levels considered in the present calculations are shown.

Fig. 2: Differential counting rate from the pp, ^{7}Be, pep and ^{8}B solar neutrino components as a function of the total energy detected in NaI(Tl); the main contribution for each energy region is indicated. The spectrum was broadened by typical NaI(Tl) resolution considering full calorimetry. The energy bin is 10 keV.

Fig. 3: The 58 keV and 200 keV peaks - induced by ^{7}Be neutrinos - over the ν_e-e^- scattering events calculated as in fig. 2. The energy bin is 10 keV.

Fig. 4: Ratio of the events from ^{7}Be neutrinos over total as a function of the energy. It is evident that the whole expected spectrum between 0.24 MeV and 0.64 MeV is essentially due to ^{7}Be ν_e.

Fig. 5: Energy distribution induced by the ^{8}B neutrinos in NaI(Tl) calculated as in fig. 2. The energy bin is 10 keV.

References

1) R. Bernabei, C. Tao eds, "The Dark side of the Universe: experimental efforts and theoretical framework", World Sc. Pub. (1994); L. Mosca, "Review of particle Dark Matter experiments", DAPNIA/SPP 94-12 to appear on the Proceed. of the Rencontres de Moriond, jan 1994; R. Bernabei, "Particle dark matter direct search in underground laboratories", ROM2F/94/33 to appear in the Proceed. of "Fundamental Physics, the Standard Model and Beyond", Jaca 1994.

2) J. Bahcall, "Neutrino astrophysics", Cambridge Univ. Press. 1989; O. Cremonesi, Riv. Nuovo Cim. Vol. 16 n. 12 (1993), 1 and references quoted therein.

3) C. Bacci et al., Phys. Lett. B293 (1992) 460; K. Fushimi et al., Phys. Rev. C47 (1993) R425; M.L. Sarsa et al., Nucl. Phys. B35 (1994) 154;T.J. Sumner et al., to appear in Proc. of Renc. de Moriond, march 1994; K. Fushimi et al., Nucl. Phys. B35 (1994) 400; C. Bacci et al., preprint LNGS-94/94 to appear in Proc. of Renc. de Moriond, march 1994; J.J. Quenby et al., pre-print 001 Astrophys. group-Imp. College (1994).

4) V. Trimble, Contemp. Phys. 19 (1988), 373; F. Zwicky, Helv. Phys. Acta 6 (1933), 110; J. Einasto et al., Nature 250 (1974), 309; J. P. Ostriker, P.J.E. Peebles and A. Yahil, Ap. J. Lett. 193 (1974), L1; M. Strauss and M. Davis, Proceed.IAU Proc. no. 130; M. Davis and P.J.E. Peebles, Ann. Rev. Astr. 21 (1983), 109; M. Fich and S. Tremaine, Ann. Rev. Astron. Astrop. 29 (1991), 409; V. Trimble, Ann. Rev. Astron. Astrop. 25 (1987), 425; Bird et al., Ap. J. 404 (1993), 81; Wright E. et al., Ap. J. 396 (1992), L13; Smooth G. et al., Ap. J. 396 (1992), L1; Dekel A. et al., Ap. J. 405 (1993), 437; Olive K. and Schramm D. W., Nature 360 (1992),434.

5) Taylor A. N. and Rowan-Robinson M., Nature 359 (1992), 396.

6) A. Bottino et al., Phys. Lett. B295 (1992), 330; A. Bottino et al., pre-print DFTT 38/93 pub. on Astrop. Phys.

7) F. M. Borzumati et al., KEK-Th-400; R. Arnowitt et al., CERN-TH.7362/94.

8) C. Bacci et al., pre-print LNGS-108/94 to appear in Proc. of Vulcano workshop, may 1994.

9) Davis et al., Proc. 25th Int. Conf. on high energy physics, World Sc. (1991) 667; Y. Suzuki, Nucl. Phys. B35 (1994) 407; V.N. Gavrin et al, Nucl. Phys. B35 (1994) 412.

10) P. Anselmann et al, Phys. Lett. B285 (1992), 376 and Phys. Lett. B314 (1993), 445 and Phys. Lett. B327 (1994), 377 and pre-print GX 65-1994 to appear on Phys. Lett.

11) G. Fiorentini et al., Phys. Rev. D49 (1994), 6298.

12)TABLE OF ISOTOPES (Seventh Edition), Edited by: C. Michael Lederer and Virginia S. Shirley, John Wiley & sons, New York.

13) J. Bahcall and Pinsonneault, Rev. Mod. Phys. 64 (1992) 885.

14) F. Dellagiacoma and F. Iachello, Phys. Lett. B218 (1989), 399; J. Engel et al., Phys. Rev. Lett. 67 (1991), 426; J. Engel et al., Phys. Rev. C50 (1994), 1702.

15) for instance in the "MEETING ON LONG BASELINE EXPERIMENTS AT GRAN SASSO", Gran Sasso december 1994.

16) R. Cardarelli et al., Nucl.Instr & Meth. A263 (1988) 20; M. Abbrescia et al., Nucl.Instr & Meth. A336 (1993) 322; T. Moers et al., Nucl.Instr & Meth. A345 (1994) 474.
17)Borexino Coll., "Proposal of Borexino", first edition, vol. I , august 1991, pg.29-43.

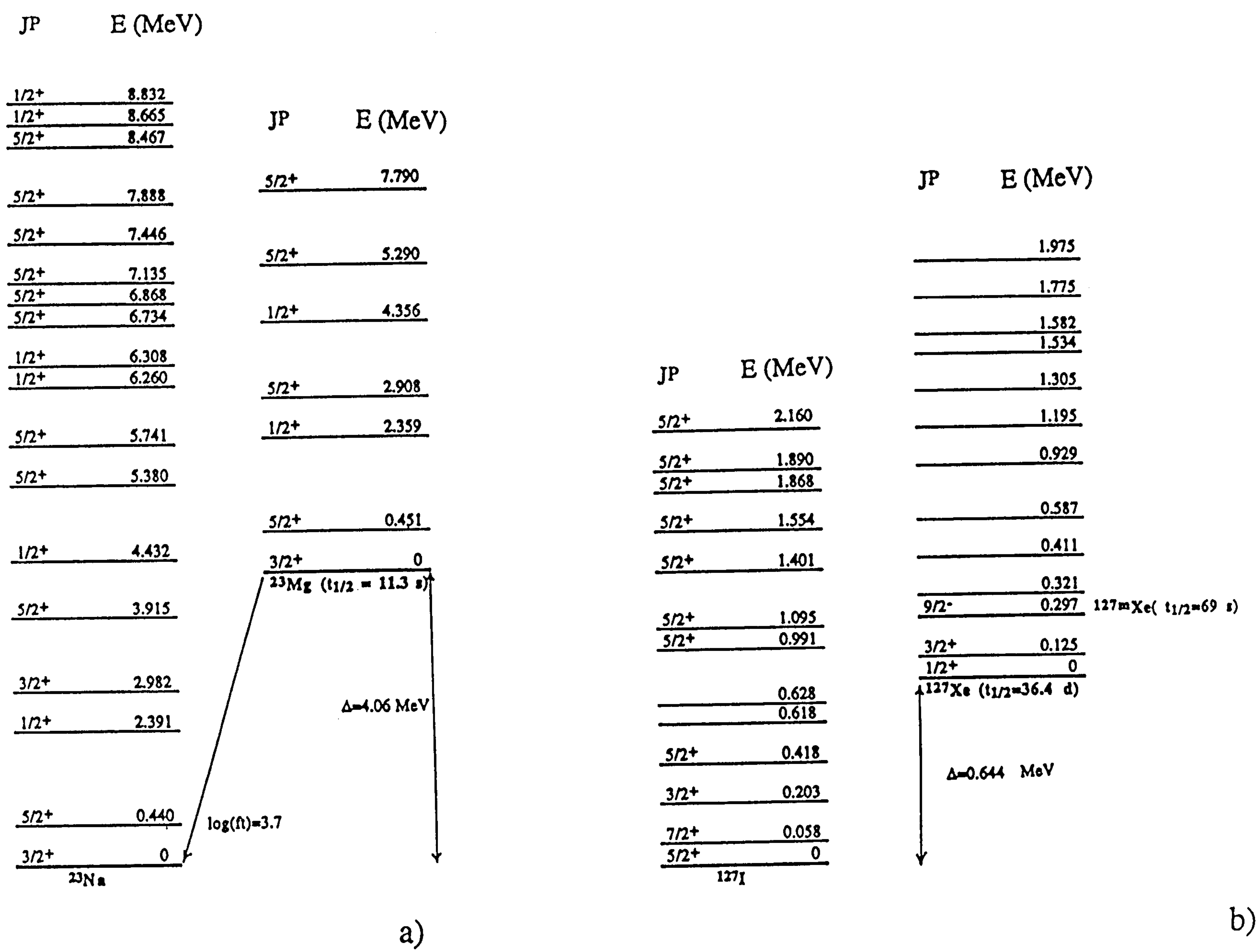

JP
E (MeV)
1/2+ 8.832
1/2+ 8.665
5/2+ 8.467
5/2+ 7.888
5/2+ 7.446
5/2+ 7.135
5/2+ 6.868
5/2+ 6.734
1/2+ 6.308
1/2+ 6.260
5/2+ 5.741
5/2+ 5.380
1/2+ 4.432
5/2+ 3.915
3/2+ 2.982
1/2+ 2.391
5/2+ 0.440
3/2+ 0
23Na
log(ft)=3.7
JP
E (MeV)
5/2+ 7.790
5/2+ 5.290
1/2+ 4.356
5/2+ 2.908
1/2+ 2.359
5/2+ 0.451
3/2+ 0
23Mg (t1/2 = 11.3 s)
Δ=4.06 MeV
a)
JP
E (MeV)
5/2+ 2.160
5/2+ 1.890
5/2+ 1.868
5/2+ 1.554
5/2+ 1.401
5/2+ 1.095
5/2+ 0.991
0.628
0.618
5/2+ 0.418
3/2+ 0.203
7/2+ 0.058
5/2+ 0
127I
JP
E (MeV)
1.975
1.775
1.582
1.534
1.305
1.195
0.929
0.587
0.411
0.321
9/2- 0.297
127mXe(t1/2=69 s)
3/2+ 0.125
1/2+ 0
127Xe (t1/2=36.4 d)
Δ=0.644 MeV
b)

Fig. 1

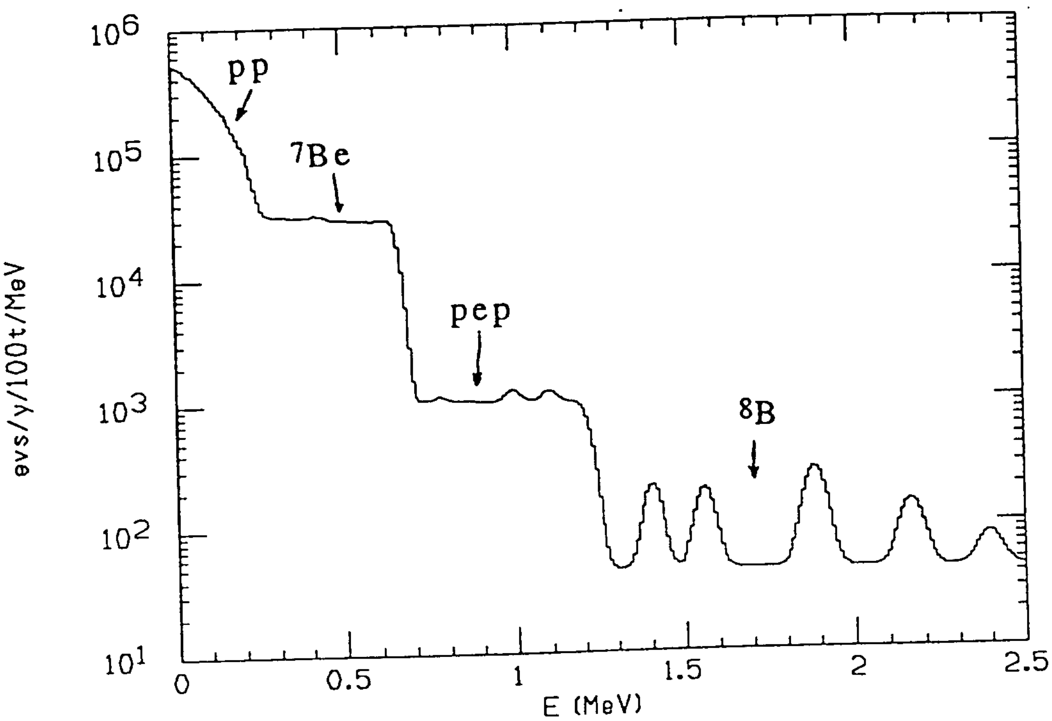


Fig. 2

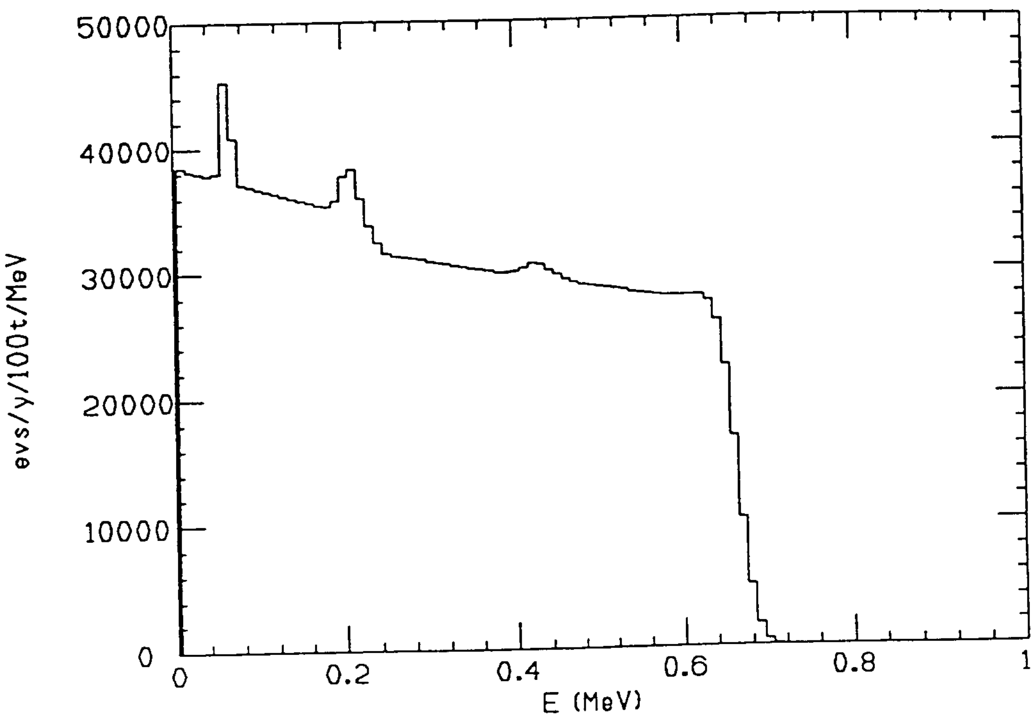

50000
40000
30000
20000
10000
0
evs/y/100t/MeV
0
0.2
0.4
0.6
0.8
1
E (MeV)

Fig. 3

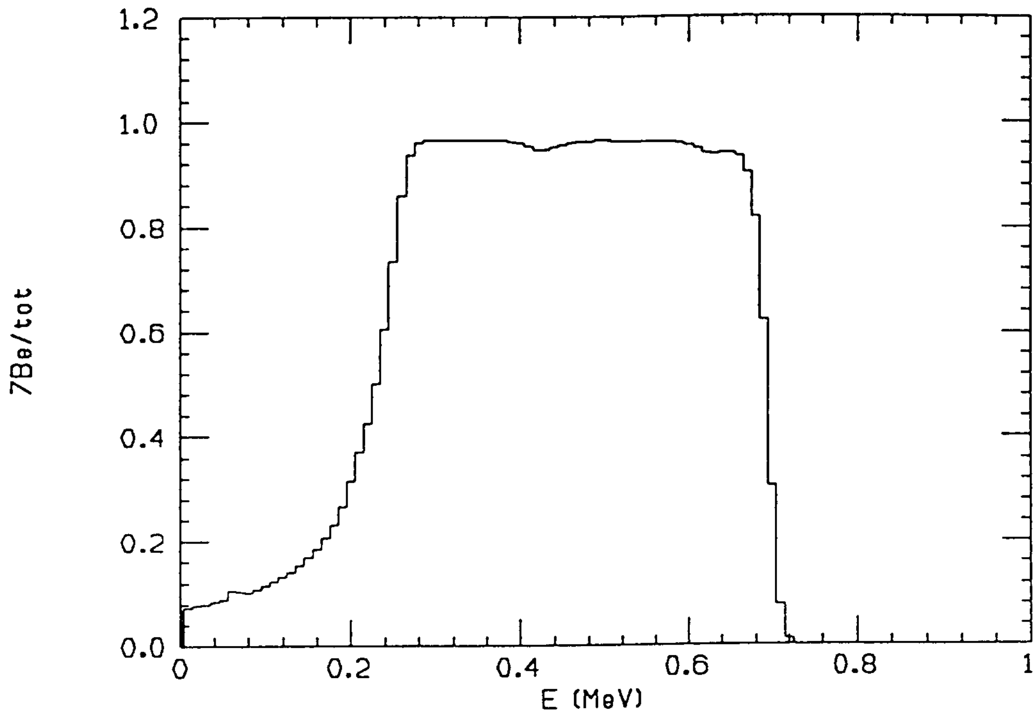


Fig. 4

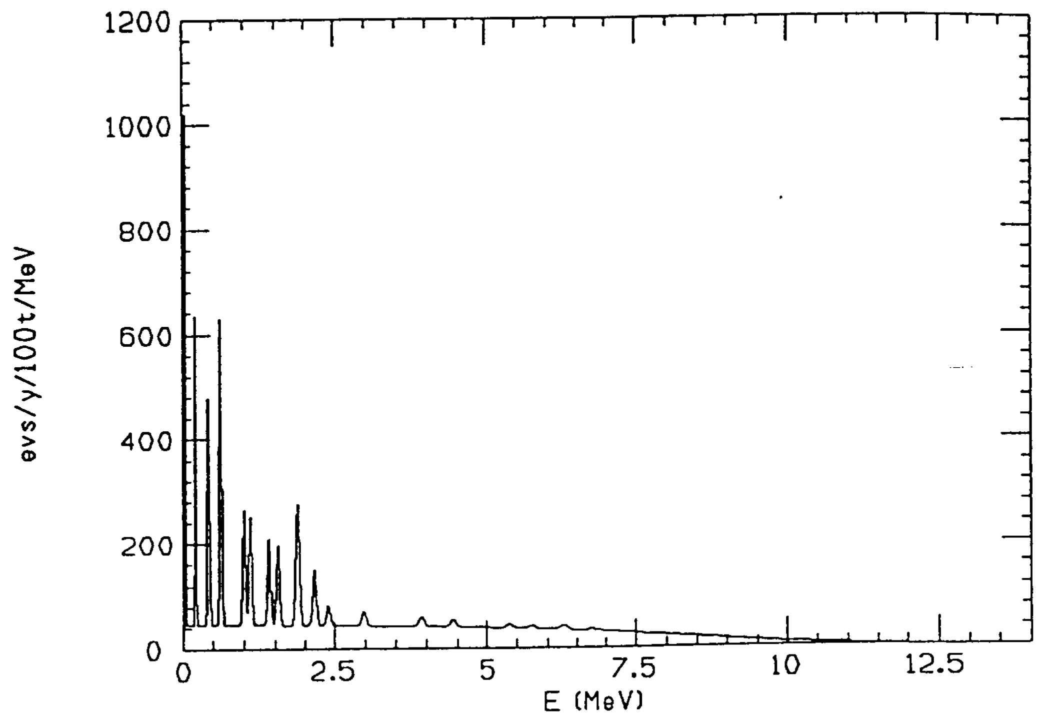


Fig. 5