Physics potentials of large liquid detectors

Liquid Argon (GLACIER), Liquid Scintillator (LENA) and Water Čerenkov(MEMPHYS)

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Abstract

A brief Status Report on the Physics Potential of the projects.

Contribution to the European Funding demand

1 Introduction

The pioneer Water Čerenkovdetectors (IMB, Kamiokande) were built to look for Nucleon Decay, a prediction of Grand Unified Theories. In fact, the Neutrino physics has been the bread and butter since the beginning of operation of such detectors. Just to remind the glorious past: first detection of a Super Novae neutrino burst, Solar and Atmospheric anomalies discovery that was explained as mass & mixing of the neutrinos, the latter being confirmed by the first long base line neutrino beam.

The proposed detectors (GLACIER, LENA, MEMPHYS) using different techniques will push the discovery frontiers on many domains: Proton Decay, Supernova neutrino (burst and diffuse past explosion), Solar and Atmospheric neutrinos, Geo-neutrinos, long baseline neutrinos, indirect dark matter search...

2 Brief detector description

GLACIER (Fig. **??**) [**?**] is the foreseen extrapolation up to 100 kT ($\phi = 70$ m, $Height = 20$ m) of homogeneous Liquid Argon Time Projecting Chamber. To be completed for GLACIER

LENA (Fig. **??**) [**?**] is the foreseen extrapolation up to 50 kT ($\phi = 30$ m, $Leangth = 100$ m) of PXE Liquid Scintillator surrounded by a water active veto shielding. To be completed for LENA

MEMPHYS (Fig. **??**) [**?**] is the foreseen extrapolation up to 730 kT Water Čerenkov. The detector is a collection of up to 5 shafts, and 3 are enough for 500 kt fiducial mass which is used hereafter. Each shaft is 65 m in diameter and 65 m height for the total water container dimensions, and this represent an extrapolation of a factor 4 with respect to the Super-Kamiokande running detector. The PMT surface defined as 2 m inside the water container is covered by about 81,000 12" PMTs to reach a 30% surface coverage equivalent to a 40% coverage with 20" PMTs. The fiducial volume is defined by an additional conservative guard of 2 m. The outer volume between the PMT surface and the water vessel is instrumented with 8" PMTs. If not contrary mentionned, the Super-Kamiokande analysis (efficiency, background reduction) [**?**] is used to compute the physcis potential of such a detector. In the US and in Japan, there are two competitors to MEMPHYS, namely UNO and Hyper-Kamiokande. These projects are similar in many respects and the hereafter presented physics potential may be foreseen also for those detectors. Currently, there is a very interesting R&D activity concerning the possibility to introduce Gadolinium salt ($GdCl_3$) in side the 1 kT Water Čerenkovprototype of the K2K experiment. The physics goal is to decrease the background in many physics channels by tagging the neutron produced in the inverse beta decay interaction of $\bar{\nu}_e$ on free proton. For instance, 100 tons of $GdCl_3$ in SuperKamiokande would yield more then 90% neutron captures on Gd [**?**].

Figure 1: Sketch of the MEMPHYS detector under the Fréjus mountain (Europe).

3 Detector Perfomances

3.1 Supernova neutrinos

Version 0 by JEC 28/2/06: sort of summary of A. Mirizzi talk 16/2/06. Waiting from A. Mirizzi updated version

3.1.1 Core-collapse

The core collapse of a Supernova (SN) occurs during the terminal phase of a massive star $M \gtrsim 8M_\odot$ which becomes instable at the end of its life. It collapses and ejects its outer mantle in a shock wave driven explosion. In more or less 10 sec, 99% of the released energy ($\approx 10^{53}$ erg) is emitted by ν and $\bar{\nu}$ of all flavors. It is expected to see $1-3$ SN per century in our Galaxy ($d \approx O(10\text{ kpc})$).

The event rate observed by a detector is a convolution of the initial spectrum of a given neutrino flavor $\phi(\nu_\alpha)$, the oscillation probability $P(\nu_\alpha \to \nu_\beta)$, the cross-section $\sigma(\nu_\beta)$ and finally the detector detection efficiency $\epsilon(\nu_\beta)$. The initial flux is the result of the SN explosion simulation (see for instance [**?**]), and the oscillation probability depends from the intrinsic neutrino properties (mixing angles and mass spectrum) as well as the matter density profile which comes from the SN simulation too. The cross section and the detector efficiency are expected to be under control.

The neutrinos are produced in three time scales well separated: first the neutronization burst ≈ 25 ms after the explosion produces ν_e neutrinos with 1% of the total energy, then the thermal burst during the accretion phase (≈ 0.5 s) and the cooling phase (≈ 10 s) produce via Z^0 all the $\nu_x \bar{\nu}_x$ pairs.

The initial neutrino spectra are well described by thermal spectra with an energy hierarchy as: $< E_{\nu_e} > \approx [9-12]$ MeV, $< E_{\bar{\nu}_e} > \approx [14-17]$ MeV and $< E_{\nu_x} > \approx [18-22]$ MeV. As a result, the ν_e spectrum is suppressed at high energy.

To transport the initial spectra from the SN to Earth, one should used the matter density profile inside the SN and the oscillation parameters, in particular: the unknown $\text{sign}(\Delta m^2_{31})$ (>0 means Normal Hierarchy, <0 means Inverted Hierarchy) and θ_{13} mixing angle as well as the solar mixing angle $\sin^2\theta_{12} \cong 0.31$. As a good approximation one uses:

$$\begin{aligned} F_{\nu_e} &= pF^0_{\nu_e} + (1-p)F^0_{\nu_x} \\ F_{\bar{\nu}_e} &= \bar{p}F^0_{\bar{\nu}_e} + (1-\bar{p})F^0_{\nu_x} \\ 4F_{\nu_x} &= (1-p)F^0_{\nu_e} + (1-\bar{p})F^0_{\bar{\nu}_e} + (2+p+\bar{p})F^0_{\nu_x} \end{aligned} \quad (1)$$

with F_i (F^0_i) the Earth (initial SN) flux of the i neutrino flavor, and ν_x stands for neutrino flavor different from ν_e and $\bar{\nu}_e$. The p and $\bar{p}$ parameters (Eqs. **??**) are given in Tab. **??**.

Mass Hierarchy	$\sin^2(\theta_{13})$	p	$\bar{p}$
Normal	$\gtrsim 10^{-3}$	0	$\cos^2(\theta_{12})$
Inverted	$\gtrsim 10^{-3}$	$\sin^2(\theta_{12})$	0
Any	$\lesssim 10^{-5}$	$\sin^2(\theta_{12})$	$\cos^2(\theta_{12})$

Table 1: Values of the p and $\bar{p}$ parameters used in Eqs. **??** in different scenario of Mass Hierarchy and $sin^2(\theta_{13})$.

One of the unsolved problems in astrophysics is the mechanism of supernova core-collapse. Inverse beta decay events from the silicon burning phase preceding the supernova explosion have very low (sub-threshold) positron energies, and could only be detected through neutron capture by adding Gadolinium [**?**], provided that they can be statistically distinguished from background fluctuations. The silicon burning signal should then be seen with a statistical significance of $2 \div 8$ standard deviations at a reference distance of 1 kpc. Unfortunately, at the galactic center (~ 10 kpc) the estimated silicon burning signal would be 100 times smaller and thus unobservable.

More promising are the expected event rates in the three proposed detectors after the SN explosion. The numbers are listed in Tab. **??** and are to be compared with the 19 (11 for Kamiokande and 8 for IMB) events ($\bar{\nu}_e$ IβD) coming from the SN1987A in the Large Magellanic Cloud (50 kpc). One can also appreciate that $\bar{\nu}_e$ detection by Inverse β Decay is the golden channel for MEMPHYS and LENA, while GLACIER has a unique opportunity to see the ν_e flavor by charged current on ^{40}Ar with a very low threshold. The detection complementarity is of great interest and would afford a unique way to probe SN explosion mechanism as well as neutrino intrinsic properties. The huge statistics would allow spectral studies in time and in energy, and using different channels during the three phases: the neutronization burst, the shock wave dynamics, and finally the passing through the Earth matter.

For the SN explosion mechanism topic, an examples is given in [**?**] in the context of shock-wave effects, based on the comparison of arrival times in different energy bins. And by using LENA elastic scattering on proton events at low threshold would provide an unique way to separate the non-electron-like neutrino contribution to the binding energy from the electron-like neutrino contribution.

MEMPHYS		LENA		GLACIER	
Interaction	Rates	Interaction	Rates	Interaction	Rates
$\bar{\nu}_e$ IβD	2 10^5	$\bar{\nu}_e$ IβD	9 10^3	$\nu_e^{CC}(^{40}Ar, ^{40}K^*)$	2.5 10^4
$\overset{(-)}{\nu}_e^{CC}(^{16}O, X)$	10^4	ν_x pES	7 10^3	$\nu_x^{NC}(^{40}Ar^*)$	3.0 10^4
ν_x eES	10^3	$\nu_x^{NC}(^{12}C^*)$	3 10^3	ν_x eES	10^3
		ν_x eES	600	$\bar{\nu}_e^{CC}(^{40}Ar, ^{40}Cl^*)$	540
		$\bar{\nu}_e^{CC}(^{12}C, ^{12}B^{\beta^+})$	500		
		$\nu_e^{CC}(^{12}C, ^{12}N^{\beta^-})$	85		
Neutronization Burst rates					
MEMPHYS	15	ν_e eES			
LENA	10 ???	$\nu_e^{CC}(^{12}C, ^{12}N^{\beta^-})$			
GLACIER	380	$\nu_x^{NC}(^{40}Ar^*)$			

Table 2: Summary of the expected neutrino interaction rates in the different detectors for a $8M_\odot$ SN located at 10 kpc (Galactic center). The following notations have been used: IβD, eES and pES stands for Inverse β Decay, electron and proton Elastic Scattering, respectively. The final state nuclei are generally unstable and decay either radiatively (notattion *), or by β^-/β^+ weak interaction (notation $^{\beta^{-,+}}$). The event rates during the neutronization phase (see text) has been emphasized as if detected it will constitute a discovery compared to the historical SN1987A explosion detection by Kamioka and IMB.

Concerning the spectral properties which depend on neutrino oscillation parameters, it has been shown in [**?**] that a detector like MEMPHYS, considering the Inverse β Decay channel alone with the current best values of solar neutrino oscillation parameters, would allow the determination of the parameter τ_E, defined as the ratio of the average energy of time-integrated neutrino spectra $\tau_E = \langle E_{\bar{\nu}_\mu}\rangle / \langle E_{\bar{\nu}_e}\rangle$, with a precision at the level of few percent, to be compared with a ~20% error possible at Super-Kamiokande. This would make it possible to distinguish normal from inverted mass hierarchy, if $\sin^2\theta_{13} > 10^{-3}$ [**?**]. In the region $\sin^2\theta_{13} \sim (3\times10^{-6} - 3\times10^{-4})$, measurements of $\sin^2\theta_{13}$ are possible with a sensitivity at least an order of magnitude better than planned terrestrial experiments [**?**]. However, using the unique GLACIER features to look at ν_e CC it is possible to probe oscillation physics during the early stage of the SN explosion, and also using the NC it is possible to decouple the SN mechanism from the oscillation physics. The Earth matter effects can be revealed by wiggles in energy spectra and LENA benefit from a better energy resolution than MEMPHYS in this respect which may be partially compensated by 10 times more statistics. A qualitative summary of what can be done to probe neutrino properties is shown in Tab. **??**

Up to now, we have investigated SN in our Galaxy, but the calculated rate of

Mass Hierarchy	$\sin^2\theta_{13}$	ν_e neutronization peak	Shock wave	Earth effect
Normal	$\gtrsim 10^{-3}$	Absent	ν_e	$\bar{\nu}_e$ ν_e (delayed)
Inverted	$\gtrsim 10^{-3}$	Present	$\bar{\nu}_e$	ν_e $\bar{\nu}_e$ (delayed)
Any	$\lesssim 10^{-5}$	Present	-	both $\bar{\nu}_e$ ν_e

Table 3: Summary of the neutrino properties effect on ν_e and $\bar{\nu}_e$ signals.

supernova explosions within a distance of 10 Mpc is about 1 per year. Although the number of events from a single explosion at such large distances would be small, the signal could be separated from the background with the request to observe at least two events within a time window comparable to the neutrino emission time-scale (~ 10 sec), together with the full energy and time distribution of the events [?]. In a MEMPHYS-type detector, with at least two neutrinos observed, a supernova could be identified without optical confirmation, so that the start of the light curve could be forecasted by a few hours, along with a short list of probable host galaxies. This would also allow the detection of supernovae which are either heavily obscured by dust or are optically dark due to prompt black hole formation.

Finally, one may note that electron elastic scattering events would provide in MEMPHYS and GLACIER a pointing accuracy of the SN explosion of about 1°, while in LENA the proton elastic scatering events would provide a 9° pointing resolution.

3.1.2 Diffuse Supernova neutrinos

An upper limit on the flux of neutrinos coming from all past core-collapse supernovae (the Diffuse Supernova Neutrinos[1], DSN) has been set by the Super-Kamiokande experiment [?]

$$\phi_{\bar{\nu}_e}^{DSN} < 1.2\ cm^{-2}\ s^{-1} \qquad\qquad (E_\nu > 19.3 \text{ MeV}) \tag{2}$$

However, most of the estimates are below this limit and therefore DSN detection appears to be feasible only with the large detector foreseen, through $\bar{\nu}_e$ Inverse β Decay in MEMPHYS and LENA detectors and through $\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$ (and the associated gamma cascade) in GLACIER.

[1]We prefer the "Diffuse" rather the "Relic" word to not confuse with the primordial neutrinos produced one second after the Big Bang.

Figure 2: *The number of events in a 400 kt water Čerenkov detector (left scale) and in SK (right scale) in all channels and in the individual detection channels as a function of distance for a supernova explosion [**?**].*

Typical estimates for DSN fluxes (see for example [?]) predict an event rate of the order of $(0.1 \div 0.5) cm^{-2}\ s^{-1}\text{MeV}^{-1}$ for energies above 20 MeV.

The DSN signal energy window is constrained from above by the atmospheric neutrinos and from below by either the nuclear reactor $\bar{\nu}_e$ (I), the spallation production unstable radionuclei by cosmic ray muons (II), the decay of "invisible" muon into electron (III), and solar ν_e neutrinos (IV).

The three detectors are affected differently by the above backgrounds. Namely, MEMPHYS filled with pure water is mainly affected by type III due to the fact that the muons may have not enough energy to produce Čerenkov light; while LENA takes benefit from the delayed neutron capture in $\bar{\nu}_e + p \to n + e^+$, so it is mainly affected by type I which impose to choose an underground site far from nuclear plants; and GLACIER looking at ν_e is mainly affected by type IV. As pointed out in [?], with addition of Gadolinium [?] the detection of the captured neutron, releasing 8 MeV gamma after of the order of 20 μs (10 times faster than in pure water), would give the possibility to reject neutrinos other than $\bar{\nu}_e$ that is to say not only the "invisible" muon (type III) but also the spallation background (type II).

The expected rates of signal and background are presented in Tab. ??. As an

Interaction	Exposure	Energy Window	Signal/Bkgd
	MEMPHYS + 0.2% Gd (at Kamioka)		
$\bar{\nu}_e + p \to n + e^+$ $n + Gd \to \gamma$ (8 MeV, 20 μs)	1 Mt.y 2 yrs	$[15-30]$ MeV	(60-150)/65
	LENA at Pyhäsalmi		
$\bar{\nu}_e + p \to n + e^+$ $n + p \to d + \gamma$ (2 MeV, 200 μs)	0.4 Mt.y 10 yrs	$[9.5-30]$ MeV	(40-260)/20
	GLACIER		
$\nu_e + {}^{40}Ar \to e^- + {}^{40}K^*$	0.5 Mt.y 5 yrs	$[16-40]$ MeV	(?-60)/30

Table 4: DSN expected rates. The larger numbers are computed with the present limit on the flux by SuperKamiokande collaboration. The lower numbers are computed for typical models. The background coming from reator plants have been computed for specific locations for MEMPHYS and LENA. For MEMPHYS one has been using the SuperKamiokande background scaled by the exposure. More studies are needed to estimate the background at the new Fréjus laboratory.

example of energy spectra, for the MEMPHYS detector, the results are shown in Fig. ??: the signal could be observed with a statistical significance of about 2 standard deviations after 10 years. The spectra of the two backgrounds were taken from the Super-Kamiokande estimates and rescaled to a fiducial mass of 440 kton of water, while the expected signal was computed according to the model called LL in [?].

Figure 3: *Supernova relic neutrino signal and backgrounds (left) and subtracted signal with statistical errors (right) in a 440 kt water cherenkov detector with a 10 years exposure. The selection efficiencies of SK were assumed; the efficiency change at 34 MeV is due to the spallation cut.*

References

[1] K. Nakamura, "Hyper-Kamiokande: A Next Generation Water Cherenkov Detector", Int. J. Mod. Phys. A18 (2003) 4053-4063
Y. Itow et al., "The JHF-Kamioka Neutrino Project"' (arXiv:hep-ex/0106019)

[2] M. Ishitsuka, T. Kajita, H. Minakata, and H. Nunokawa, Phys. Rev. D72, 033003 (2005), (arXiv:hep-ph/0504026)

[3] C. K. Jung, Feasibility a Next Generation Underground Water Cherenkov Detector: UNO, Preprint (arXiv:hep-ex/0005046) from the NNN99 Proceedings

[4] A. de Bellefon et al., MEMPHYS: A large scale water Čerenkov detector at Fréjus, Contribution to the CERN strategic committee

[5] To be defined

[6] P. Nath and P. Fileviez Pérez, “Proton stability in grand unified theories, in strings, and in branes,” arXiv:hep-ph/0601023. Submitted to Physics Reports.

[7] I. Dorsner and P. Fileviez Pérez, “How long could we live?,” Phys. Lett. B **625** (2005) 88 [arXiv:hep-ph/0410198].

[8] H. Georgi and S. L. Glashow, “Unity Of All Elementary Particle Forces,” Phys. Rev. Lett. **32** (1974) 438.

[9] I. Dorsner and P. Fileviez Pérez, "Unification without supersymmetry: Neutrino mass, proton decay and light leptoquarks," Nucl. Phys. B **723** (2005) 53 [arXiv:hep-ph/0504276]; I. Dorsner, P. Fileviez Pérez and R. Gonzalez Felipe, "Phenomenological and cosmological aspects of a minimal GUT scenario," arXiv:hep-ph/0512068.

[10] D. G. Lee, R. N. Mohapatra, M. K. Parida and M. Rani, "Predictions for proton lifetime in minimal nonsupersymmetric SO(10) models: An update," Phys. Rev. D **51** (1995) 229 [arXiv:hep-ph/9404238].

[11] H. Murayama and A. Pierce, "Not even decoupling can save minimal supersymmetric SU(5)," Phys. Rev. D **65** (2002) 055009 [arXiv:hep-ph/0108104].
B. Bajc, P. Fileviez Pérez and G. Senjanovic, "Proton decay in minimal supersymmetric SU(5)," Phys. Rev. D **66** (2002) 075005 [arXiv:hep-ph/0204311].
B. Bajc, P. Fileviez Pérez and G. Senjanovic, "Minimal supersymmetric SU(5) theory and proton decay: Where do we stand?," arXiv:hep-ph/0210374.
D. Emmanuel-Costa and S. Wiesenfeldt, "Proton decay in a consistent supersymmetric SU(5) GUT model," Nucl. Phys. B **661** (2003) 62 [arXiv:hep-ph/0302272].

[12] K. S. Babu and R. N. Mohapatra, "Predictive neutrino spectrum in minimal SO(10) grand unification," Phys. Rev. Lett. **70** (1993) 2845 [arXiv:hep-ph/9209215].
C. S. Aulakh, B. Bajc, A. Melfo, G. Senjanovic and F. Vissani, "The minimal supersymmetric grand unified theory," Phys. Lett. B **588** (2004) 196 [arXiv:hep-ph/0306242].
T. Fukuyama, A. Ilakovac, T. Kikuchi, S. Meljanac and N. Okada, "Detailed analysis of proton decay rate in the minimal supersymmetric SO(10) model," JHEP **0409** (2004) 052 [arXiv:hep-ph/0406068].
H. S. Goh, R. N. Mohapatra, S. Nasri and S. P. Ng, "Proton decay in a minimal SUSY SO(10) model for neutrino mixings," Phys. Lett. B **587** (2004) 105 [arXiv:hep-ph/0311330].

[13] T. Friedmann and E. Witten, "Unification scale, proton decay, and manifolds of G(2) holonomy," Adv. Theor. Math. Phys. **7** (2003) 577 [arXiv:hep-th/0211269].

[14] T. Totani, K.Sato, H.E. Dalhed, and J.R. Wilson, Astrophys. J. 496, 216 (1998)

[15] Beacom, J. F. and Vagins, M. R., *Phys. Rev. Lett.* 93 (2004) 171101, arXiv:hep-ph/0309300

[16] Fogli, G. L. and Lisi, E. and Mirizzi, A. and Montanino, D., JCAP 0504 (2005) 002, arXiv:hep-ph/0412046

[17] Minakata, H. and Nunokawa, H. and Tomas, R. and Valle, J. W. F., *Phys. Lett.* B542 (2002) 239-244, arXiv:hep-ph/0112160

[18] Lunardini, C. and Smirnov, A. Yu., JCAP 0306 (2003) 009, arXiv:hep-ph/0302033

[19] Ando, S. and Beacom, J. F. and Yuksel, H., *Phys. Rev. Lett.* 95 (2005) 171101, arXiv:astro-ph/0503321

[20] Malek, M. et al. [Super-Kamiokande Collaboration], *Phys. Rev. Lett.* 90 (2003) 061101, arXiv:hep-ex/0209028

[21] Ando, S., Astrophys. J. 607 (2004) 20-31, arXiv:astro-ph/0401531

[22] Smy, M. B. [Super-Kamiokande Collaboration], Nucl. Phys. Proc. Suppl. 118 (2003) 25-32, arXiv:hep-ex/0208004

[23] A. Ianni, D. Montanino and F. L. Villante, *Phys. Lett.* B 627 (2005) 38, arXiv:physics/0506171

[24] G. Alimonti et al. [Borexino Collaboration], Astrop. Phys. 8, 141 (1998); ibid., *Nucl. Instrum. Methods* A406, 411 (1998)

[25] P. Arneodo et al. [ICARUS], LNGS-P28/2001, LNGS-EXP 13/89 add. 1/01, ICARUS-TM/2001-03

[26] B. Aharmim *et al.* [SNO Collaboration], *Phys. Rev.* C 72 (2005) 055502, arXiv:nucl-ex/0502021

[27] T. Araki et al. [KamLAND], Nature 436 (2005) 499-503

[28] S. Fukuda et al. [SuperKamiokande], *Nucl. Instrum. Methods* A501 (2003) 418-462

[29] K. Eguchi et al. [KamLAND], *Phys. Rev. Lett.* 90 (2003) 021802; T. Araki et al. , arXiv:hep-ex/0406035

[30] S. Choubey and S.T. Petcov, *Phys. Lett.* B594 (2004) 333-346

[31] Autin, B. et al. , CERN-2000-012

[32] Gomez-Cadenas J. J. et al. , CERN working group on Super Beams (2001), arXiv:hep-ph/0105297

[33] Blondel A. et al. , *Nucl. Instrum. Methods* A503 (2001) 173-178

[34] Mezzetto M., J. Phys. G29 (2003)1781-1784, arXiv:hep-ex/0302005

[35] Apollonio M. et al. , arXiv:hep-ph/0210192

[36] Mosca L., Nucl. Phys. Proc. Suppl. 138 (2005) 203-205

[37] Campagne J.-E. and Cazes A., arXiv:hep-ex/0411062, to appear in Eur. Phys. J. C 2005

[38] Garoby R., AIP Conf. Proc. 773 (2005) 239-243

[39] Gilardoni S. et al. , AIP Conf. Proc. 721 (2004) 334-337

[40] Blondel A. and Donega M. and Gilardoni S., CERN-NUFACT-NOTE-078

[41] Catanesi M.G. et al. [HARP Collaboration], CERN-SPSC/2001-017 SPSC/P322 May 2001

[42] Mezzetto M., Nucl. Phys. Proc. Suppl. 149 (2005) 179-181

[43] Campagne J.-E., arXiv:hep-ex/0510029

[44] Huber P. and Lindner M. and Winter W., Comput. Phys. Commun. 167 (2005)195, arXiv:hep-ph/0407333

[45] Zucchelli P., Phys. Lett. B532 (2002) 166-172

[46] Sortais P., presentations at the Moriond workshop on radioactive beams Les Arcs (France) 2003 ECR technology `http://moriond.in2p3.fr/radio`

[47] `http://www.ganil.fr/eurisol/`

[48] Huber P. and Lindner M. and Winter W., Nucl. Phys. B645 (2002)3-48, arXiv:hep-ph/0204352

[49] Mezzetto M., J. Phys. G29 (2003) 1771-1776, arXiv:hep-ex/0302007

[50] Bouchez J. and Lindroos M. and Mezzetto M., AIP Conf. Proc. 721 (2004) 37-47, arXiv:hep-ex/0310059

[51] Mezzetto M., Nucl. Phys. Proc. Suppl. 143 (2005) 309-316, arXiv:hep-ex/0410083

[52] Donini A. and Fernandez-Martinez E. and Migliozzi P. and Rigolin S. and Scotto Lavina L., Nucl. Phys. B710 (2005) 402-424, arXiv:hep-ph/0406132

[53] Bernabeu J. and Burguet-Castell J. and Espinoza C. and Lindroos M., arXiv:hep-ph/0505054

[54] Sato J., Phys. Rev. Lett. 95 (2005) 131804, arXiv:hep-ph/0503144

[55] Huber P. and Maltoni M. and Schwetz Th., Phys. Rev. D71 (2005) 053006, arXiv:hep-ph/0501037

[56] Burguet-Castell J. and Casper D. and Couce E. and Gomez-Cadenas J. J. and Hernandez P., Nucl. Phys. B725 (2005) 306-326, arXiv:hep-ph/0503021

[57] Burguet-Castell J. and Casper D. and Gomez-Cadenas J. J. and Hernandez P. and Sanchez F., Nucl. Phys. B695 (2004) 217-240, arXiv:hep-ph/0312068

[58] Terranova F. and Marotta A. and Migliozzi P. and Spinetti M., Eur. Phys. J. C38 (2004) 69-77, arXiv:hep-ph/0405081

[59] Huber P. and Lindner M. and Rolinec M. and Winter W., arXiv:hep-ph/0506237

[60] Bruning O. et al. , CERN-LHC-PROJECT-REPORT-626

[61] Donini A. et al. , arXiv:hep-ph/0511134

[62] Lindroos M., EURISOL DS/TASK12/TN-05-02 to be published in Nucl. Phys. Proc. Suppl. (2006)