NNN05 highlights

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Abstract

This year, NNN05 gave the opportunity to the organizers to emphasize in this short document the megadetector case for neutrino physics and proton decay. This was done mainly from the speakers contributions and the purpose is to setup a preliminary version of a future – more elaborated – "white book" that should mature in the forthcoming NNN annual meetings and through an inter-regional cooperative project.

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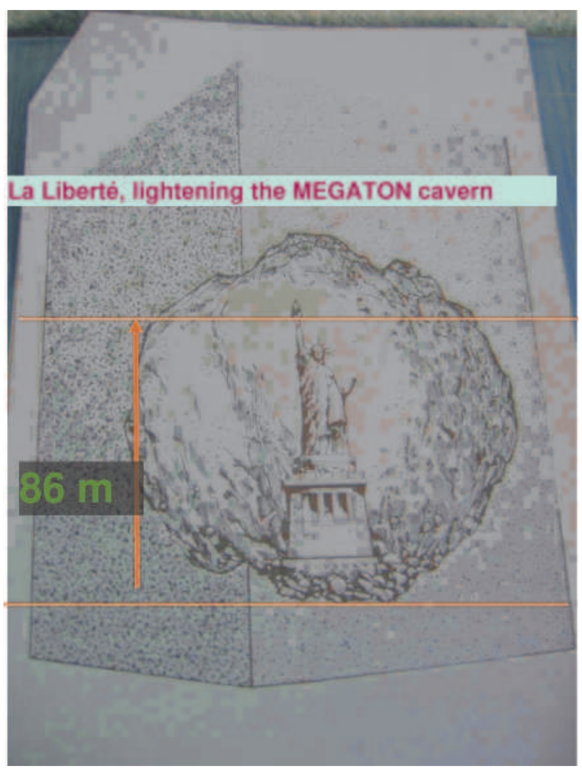

Figure 1: **Drawing for a symbol**

Contents

Chapter 1

Physics Motivation for a Megaton detector

1.1 Introduction

Underground water Cherenkov detectors have found unambiguous evidence for neutino oscillations and therefore beyond-the Standard Model physics. The atmospheric neutrino results of Super- Kamiokande(SK),IMB and FrŐjus, followed by the solar observations of SK, SNO and KamLAND, have confirmed that neutrinos have mass and two large mixing angles. However, there remain many questions about the parameters and properties of leptons, some of which could be addressed by a larger (megatonne) underground neutrino detector. If the location of such a detector was judiciously selected, it could be a suitable distance along the path of a new high intensity ν_μ beam (superbeam), and/or or ν_e beam (β beam).

The observation of neutrinos from SN1987A forshadowed the linked results on astrophysics and neutrino physics that can be obtained from a supernova. Such an exploding star is an extraordinary source, for which it would be reasonable to have a detector. A megatonne detector could perhaps even see relic neutrinos accumulated from past supernovae.

Originally, large underground detectors were built to look for proton decay, a prediction of Grand Unified Theories. Nucleon decay is a "smoking gun" for quark lepton unification, observation of which would confirm many years of theoretical speculation. The current lower bound on the proton lifetime from SK has ruled out the simplest non-supersymmetric GUT, a megaton detector would cover a substantial area of interesting parameter space.

1.2 Bread and Butter: ν Physics

A megatonne detector would have improved sensitivity to currently unknown parameters of neutrino mixing. The neutrinos could be of astrophysical origin— solar, atmospheric or from supernovae— or ν beams of specific flavour and energy could be directed at the detector. A high intensity ν_μ "superbeam", could be produced by increasing the intensity of the proton driver at the source, or a very pure ν_e beam could be produced in the β decay of an ion beam.

1.2.1 status

A review of our current knowledge of neutrino parameters was presented by G. Fogli.

Information [1] on $\sin^2\theta_{23} = 0.45\pm\,^{0.18}_{0.11}$, $\Delta m^2_{23} = 2.4\pm\,^{0.5}_{0.6}\times10^{-3}$ eV^2 and $\sin^2\theta_{13}\leq 0.035$ is obtained from SuperKamiokande, K2K and CHOOZ. The evidence for atmospheric neutrino oscillations with large, or maximal mixing is robust, and confirmed with neutrinos from the K2K beam. SK has found evidence for a decrease in ν_μ flux at the location expected for the first dip in the oscillation probability—this despite the smearing in energy and path length. As discussed by Fogli, the data sets can be combined in various ways to determine the parameters. The results quoted were obtained from the combined data of all three experiments, by using a three-dimensional simulation for the atmospheric neutrino fluxes, by including subleading effects due to Δm^2_{12} and $\sin^2\theta_{12}$, and leaving $\sin^2\theta_{13}$ free. Letting $\sin^2\theta_{13}$ float has little effect because the data prefers it small.

SNO, SK and KamLAND are sensitive to the solar mass difference $\Delta m^2_{12} = 8.0\pm\,^{0.8}_{0.7}\times10^{-5}$ eV^2 and a large but not maximal mixing angle $\sin^2\theta_{23} = 0.31\pm\,^{0.05}_{0.04}$. These data also prefer $\sin^2\theta_{13}\sim 0$ (a non-trivial consistency check with atmospheric and CHOOZ), so the allowed ranges for Δm^2_{12} and $\sin^2\theta_{23}$ are not significantly affected when θ_{13} is allowed to float.

1.2.2 agenda for future experiments

The current bounds on the unknown neutrino parameters, and future prospects for measuring them were discussed by J. Ellis and G. Fogli, and T Schwetz. Some of these unknowns (items 4-7 of the following list) could be determined from more precise oscillation experiments.

1. the number of light neutrinos participating in oscillations is usually taken to be the three active neutrinos expected in the Standard Model. However, the LSND experiment found evidence for $\Delta m^2\sim$ eV^2, which would require one (or more) additional light sterile neutrinos. MiniBoone is searching for oscillations in the LSND window; their results, expected in 2005, will confirm or rule out the LSND claim.

2. The absolute neutrino mass scale is probed in three ways. Firstly, the endpoint spectrum of electrons in nucleon (^3H) β decay is sensitive to the "effective electron neutrino mass"

$$m_e^2 = [c_{13}^2c_{12}^2m_1^2 + c_{13}^2s_{12}^2m_2^2 + s_{13}^2m_3^2]^2 \leq 1.8 \text{ eV} \quad .$$

[1] The numerical values are from the global fit presented by Fogli

Cosmological Large Scale Structure is affected by neutrino masses, because neutrino free-streaming in the early Universe would suppress density fluctuations on small scales. Current cosmological data sets the constraint:

$$m_1 + m_2 + m_3 \leq 0.47 - 1.4\text{eV}$$

The range of the bound is representative of different results in the literature, which are based on inequivalent data sets. The strong bound uses Lyα data to probe small scale structure; this data is sometimes left out because of uncertain systematic errors.

The final observable to which neutrino masses could contribute—if they are majorana— is lepton number violating neutrino-less double β decay ($0\nu2\beta$). The amplitude can be written as a nuclear matrix element, $\times$ the coefficient of a $\Delta L = 2$ non-renormalisable operator. This coefficient can be calculated perturbatively from the new physics that permits this type of decay. When this new physics is majorana neutrino masses, the coefficient is proportional to m_{ee}, where

$$m_{ee} = [c_{13}^2 c_{12}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}]$$

The PMNS matrix has be taken $U = VP$, with V CKM-like with one phase δ ($V_{13} = \sin\theta_{13} e^{-i\delta}$), and $P = diag\{1, e^{\phi_2/2}, e^{i(\phi_3/2+\delta)}\}$ (See talk by G. Fogli.)

There is a controversial claim that $0\nu2\beta$ has been detected in ^{76}Ge, with a rate corresponding to $|m_{ee}| \simeq 0.23 \pm 0.18$ eV. A disagreement with the cosmological bound can be avoided by not using Lyα data.

3. Are neutrinos Majorana or Dirac? Oscillation experiments are sensitive to mass^2 differences, so do not distinguish whether neutrinos are majorana or dirac. The majorana nature of neutrinos, which is "natural" in the popular seesaw mechanism, can be tested in processes that violate lepton number, such as $0\nu2\beta$.

4. Is the mass pattern hierarchical ($\Delta m_{13}^2 > 0$) or inverted ($\Delta m_{13}^2 < 0$)? Oscillation probabililities in matter, for neutrinos and antineutrinos, depend on this sign, because the matter contribution to the mass matrix changes sign between neutrinos and anti-neutrinos. Long baseline neutrino beams and the flux of neutrinos from supernovae are sensitive to this sign.

5. What is the value of θ_{13}? There are only upper bounds on this remaining angle of the PMNS matrix, It can be probed by looking for a ν_e contribution to Δm_{13}^2 oscillations. This angle controls "three flavour" effects, like CP violation.

6. What is the value of δ, the "Dirac phase" of the PMNS matrix, which contributes to CP violation in neutrino oscillations (multiplied by $\sin\theta_{13}$)?

7. is θ_{23} maximal?

The sensitivity of various beam and detector combinations is illustrated in figure 1.1.

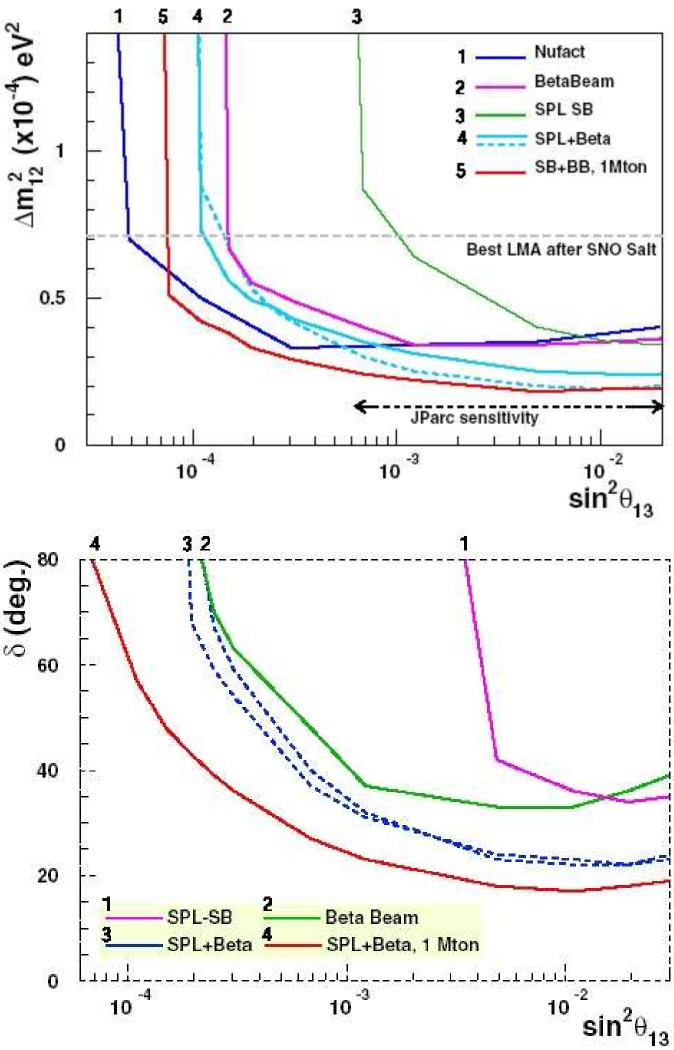

Figure 1.1: plots shown in the presentation of J Ellis, showing the sensitivity to θ_{13}, Δm^2_{12}, and δ of various beams.

1.2.3 θ_{13}, δ and and the sign of Δm^2_{13}

Determining items 4-6 (of the above list) at a future megatonne detector was discussed by T. Schwetz, and J Ellis presented prospects for beams from CERN.

It is known that the 3-flavour oscillation probability has degeneracies, as can be seen from

$$P_{\mu e} \simeq \sin^2 2\theta_{13} \sin^2 \theta_{23} \sin^2 \Delta_{31} + \alpha^2 \sin^2 \theta_{12} \cos^2 \theta_{23} \Delta_{31}^2 + \alpha \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23} \Delta_{31} \sin \Delta_{31} \cos(\Delta_{31} \pm \delta). \quad (1.1)$$

where $\alpha = \Delta_{21}/\Delta_{31}$, and $\Delta_{31} = (m_3^2 - m_1^2)L/4E_\nu$. For instance, a measured $P_{\mu e}$ could corresponds to several solutions in the (δ, θ_{13}) plane. This is refered to as the "intrinsic" degeneracy. There are additional degeneracies associated with the sign of Δm_{13}^2 ("hierarchy" degeneracy), and with the sign of $\pi/4 - \theta_{23}$ ("quadrant" degeneracy), if θ_{23} is not maximal.

The degeneracies can be resolved with spectral information, and by looking at different channels. Having a β-beam and superbeam is helpful in this second respect. Spectral information is available with an off-axis beam, so the (δ, θ_{13}) degeneracy wouuld be absent at T2K-II (T2K to HyperK).

T Schwetz discussed using atmospheric neutrino data to address the degeneracies, by measuring sub-dominant effects due to three-flavour mixing. He showed that there is an enhancement in the ν_e (or $\bar{\nu}_e$) flux, for multi-GeV events, due to θ_{13}. The enhancement is for neutrinos in the normal hierarchy, and anti-neutrinos in the inverted case. Since the ν_e and $\bar{\nu}_e$ detection cross-sections are different, mesuring this enhancement would give information on θ_{13} and the sign of Δm_{13}^2. Sub-GeV events could be sensitive to the octant of θ_{23} via contributions arising due to Δm_{12}^2.

The hierarchy and octant degeneracies could be reduced at T2K-II by using the the atmospheric neutrino data of HyperK. This was shown by combining a numerical 3-flavour atmospheric analysis, with long baseline simulation of the beam and detector using with the GloBES software (http://www.ph.tum.de/globes/). An example figure is shown on the right below (figure 1.2). Preliminary results, assuming a superbeam and β-beam from CERN, and including atmospheric data at a 450 kt Cherenkov detector at Frejus, were also shown.

In summary, the combined analysis of atmospheric and long baseline neutrino data at a megaton detector could resolve parameter degeneracies—with the advantage that atmospheric neutrinos arrive "for free".

1.2.4 Theoretical interest

One of the outstanding puzzles for particle theorists is the origin of Yukawa couplings. There are many models, which fit the masses and mixing angles observed in the quark and lepton sector, but none are particularily compelling. Additional hints from the data — symmetries respected by the masses, constraints on the Yukawa parameters— would be particularily welcome. Measuring the third leptonic mixing angle θ_{13}, and determining whether θ_{23} is maximal, are both important in this respect.

A popular mechanism to explain the smallness of neutrino masses is the seesaw, which has 18 parameters in its simplest form (type I) with three ν_R. Twelve of these parameters appear among the light leptons (although not all

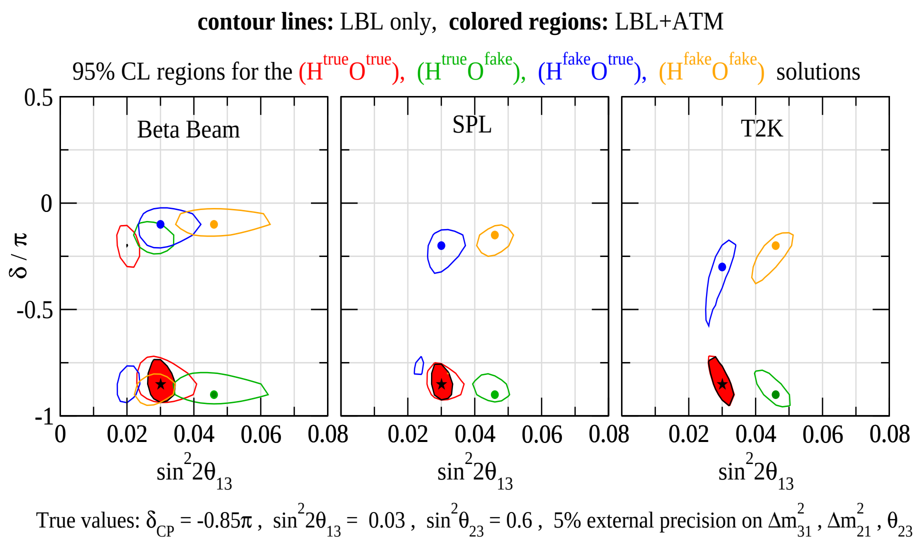

Figure 1.2: Resolving hierarchy(H) and octant (O) degeneracies using atmospheric neutrinos. The figures compare β-beam and SPL from CERN to Fréjus, (details of the experiments can be found in the NuFact05 talks of Mezzetto and Campagne), and T2K to HK The detector in all cases is 450 kt water Cherenkov.

are realistically measurable), and some of the remaining unknowns affect μ and τ decays in SUSY. So measuring many neutrino parameters with good accuracy would reduce the parameter space of seesaw models.

If θ_{13} is found to be large ($\gtrsim .01$, see figure 1.1), the phase δ of the PMNS matrix could be experimentally accessible. Observing CP violation in the leptons, for the first time, would be an exciting phenomenological novelty. It is also tempting to relate δ to the CP violation required in the generation of the matter excess of the Universe (baryo/lepto-genesis). Various leptogenesis mechanisms can be implemented in the seesaw model, and depend on some combination of the seesaw's complex couplings. Observing $\delta \neq 0$ would demonstrate that at least one combination of couplings is complex, thereby suggesting that the phases relevant for leptogenesis might also be present.

1.3 Theoretical expectations : Nucleon Decay

Nucleon decay was the original motivations for large underground detectors, ancestors of the megatonne, and attracted attention from many speakers during the workshop. The theoretical expectations for the proton's lifetime were discussed in some detail in the talks of of J. Ellis and L. Covi.

Our concept of theoretical progress is that we advance by unifying apparently diverse concepts. An example of successful unification is the Standard Model, which united electromagnetism with the weak interactions. Some hints that quarks and leptons might be united in a larger theory are the curious anomaly cancellation among known fermions—where the quarks and leptons cancel each others contributions to dangerous operators which would destroy the consistency (and experimental accuracy) of the SM. Another tantalising hint is that the strong, and electroweak gauge couplings become equal at $\Lambda \sim 10^{16}$ GeV, suggesting a unique gauge interaction at this scale.

Unifying the quarks and leptons into a multiplet means that there are particles in the theory that turn quarks into leptons, so baryons can decay. Observing proton decay would be a smoking gun for such theories, confirming that our theoretical preference for unified theories is reflected in nature—and it could probe higher energy scales, or shorter distances, than any previous observation. It also could give some information on mixing angles in the right-handed quark sector, about which the Standard Model says nothing.

1.3.1 SU(5)

The simplest GUT is SU(5), the lowest rank ("smallest") group capable of accomodating all the SM particles. SO(10) is the one possibility at rank 5, and it has the advantage over SU(5) of accomodating the right-handed neutrino (SM gauge singlet) in its 16-dimensional multiplets. At rank six there is a group E_6, which appears in some string models.

In the minimal SU(5) GUT, the colour-triplet $d^c = \overline{d_R}$ are combined with the lepton SU(2) doublet ℓ_L into a $\bar{5}$, and the e^c shares a 10 with the q_L and u^c. The X and Y gauge bosons, which acquire masses $\sim M_{GUT}$ when SU(5) is broken, have Baryon + Lepton number violating gauge interactions because they mix different multiplet members. They mediate proton decay via dimension six operators such as

$$\frac{g_5^2}{M_X^2}\epsilon_{\alpha\beta\gamma}(\overline{d^c}_{\alpha,k}\overline{u^c}_{\beta,j}q_{\gamma,j}\ell_k - \overline{e^c}_k\overline{u^c}_{\alpha,j}q_{\beta,j}q_{\gamma,k}) \tag{1.2}$$

There are also operators induced by GUT Higgses, with baryon number violating Yukawa-strength couplings.

Proton decay is expected at rates

$$\Gamma_p = C\frac{\alpha_5^2 m_p^5}{M_X^4} \tag{1.3}$$

where C is a constant englobing mixing angles, renormalisation group running, and strong interaction effects. The dominant decay channel in non-supersymmetric SU(5) is $p \to \pi^0 e^+$. The experimental limit $\tau_{p\to\pi e} > 6.9 \times 10^{33}$ years, imposes $M_X \geq 7.3 \times 10^{15}$ GeV, so non-SUSY SU(5) is ruled out because this is above the mass scale where the gauge couplings approximately unify.

Proton decay in supersymmetric SU(5) is different in many respects. The GUT scale (determined from gauge coupling unification) is higher, so decays mediated by X and Y are slower. However, there are new *dimension 5* operators, induced by the coloured triplet Higgsino that shares a 5 with SM-type doublet Higgsinos, and which has Yukawa couplings to SM fields. Schematically these operators can be written

$$\frac{Y_{qq}^{ij} Y_{ql}^{km}}{2M_c} Q_i Q_j Q_k L_m + \frac{Y_{ue}^{ij} Y_{ud}^{km}}{M_c} U_i^c E_j^c U_k^c D_m^c$$

where M_c is the triplet Higgsino mass $\leq M_X$, the capitals are superfields, two of which are scalars and two fermions. Dressing this operator with the exchange of a "-ino" gives a 4-fermion operator $\propto 1/(m_{SUSY} M_c)$. This is enhanced with respect to the X-boson exchange, but suppressed by small Yukawa couplings. In addition, the SM SU(2) and SU(3) contractions are antisymmetric, so the operator is flavour non-diagonal, giving a dominant decay $p \to K^+ \bar{\nu}$.

There are relations among the quark and lepton Yukawa couplings, which depend on the GUT Higgs content of the model. The simplest would be for all the Yukawa matrices to be equal at the GUT scale, but some differences must be included to fit the observed fermion masses. The proton lifetime in SUSY SU(5) depends which Yukawa matrices are equal at the GUT scale: setting $Y_{ql} = Y_{ud}$ equal to the down Yukawa matrix Y_d predicts a a proton lifetime shorter than the current SK limit of $\tau_{p \to K\bar{\nu}} > 1.9 \times 10^{33}$ years. However, setting $Y_{ql} = Y_{ud}$ equal to the charged lepton Yukawa Y_e changes the dependence of τ_p on the fermion mixing angles, so lifetimes in excess of the bound can be found. The proton lifetime in SUSY SU(5) is uncertain due to the non-unification of Yukawa couplings.

A possible string-motivated GUT model, discussed by J Ellis, is flipped SU(5)$\times U(1)$, where the SU(2) doublets of the SM are inverted ($\nu \leftrightarrow e, u \leftrightarrow d$) in the GUT multiplets. This extends the $p \to K^+ \bar{\nu}$ lifetime to $\tau \gtrsim 10^{35} - 10^{36}$ years, potentially testable at a megaton detector.

1.3.2 SO(10) in six space dimensions

In recent years, theorists have constructed models in $d > 4$ dimensional space, with the additional dimensions compactified at some scale $\ll m_{pl}$. These models offer a framework to study new physics possibilities not included in the MSSM. L Covi discussed proton decay in a 6-dimensional SUSY SO(10) model, where the extra 2 dimensions are compactified on a torus (that has additional discrete symmetries). The four fixed points of this torus correspond to 4-dimensional branes, where SM particles can reside. Each SM generation lives at a different fixed point, with a different breaking of SO(10), so the Yukawas in this model are different from 4-dimensional SO(10). The higgsino mixing which allowed the dimension 5 proton decay operators is suppressed, so the dimension 6 X-mediated diagrams dominate in this supersymmetric extra-dimensional model. The proton decay rates are slightly larger than 4-dimensional SU(5) due to the sum over the tower of Kaluza-Klein X modes, but they differ in the flavour structure. This has characteristic signatures, such as suppressing $p \to K^0 \mu^+$. The current bound $\tau_{p \to \pi^0 e^+} \geq 6.9 \times 10^{33}$ years implies in this model $M_X > 9.6 \times 10^{15}$ GeV $\sim M_{GUT}$, suggesting that the proton could be discovered to have a lifetime $\sim 10^{34}$ years.

In summary, proton decay is an unmistakable footprint of Unification, and is just around the corner in many models. Looking to the future, once proton decay is observed, the branching ratios will open a new perspective on the structure and origin of the Yukawa matrices, giving new information on the Yukawa puzzle.

1.4 From the Sky: Supernova Neutrinos

Supernova neutrinos were discussed by A Dighe (galactic supernovae) and S Ando(relic neutrinos), and also by G Fogli. Astrophysical observation of nearby galaxies suggests that 1-4 supernovae should take place in our galaxy per century. Neutrinos carry 99% of the star's binding energy, so these infrequent events could be a fund of information about neutrino parameters and supernova astrophysics.

A real-time SN within 10 kpc may determine whether the hierarchy is normal or inverted, and be sensitive to very small values of $\sin\theta_{13}$. A megatonne detector is probably required to see these effects. The neutrino signal could also trace the outward propagation of the shock which powers the optical explosion.

While waiting for the next galactic supernova, detectors could look for "supernovae relic neutrinos" (SRN), the diffuse background of neutrinos emitted by past supernovae. SK's present limit on this flux is background-limited, and just above predictions. Detecting these neutrinos could give useful information on neutrinos and the history of star formation.

1.4.1 soon in our galaxy?

A star of mass $\gtrsim 8\mathcal{M}_\odot$ becomes unstable at the end of its life. It resembles an onion, with the different layers burning lighter elements into heavier, the end-products of one layer serving as fuel for the one underneath. At the centre develops an iron core, which eventually cannot support the outer layers, and collapses. Most of the binding energy is released as neutrinos.

The SN neutrino flux has various components. The neutronisation burst takes place in the first 10 ms, as the heavy nuclei break up. It consists of ν_e from $p + e \to n + \nu_e$, and is emitted from the "neutrinosphere", that is, the radius from which neutrinos can free-stream outwards. The core density is near nuclear, above the $\sim 10^{10}$ g/cm^3 required to trap a 10 MeV neutrino.

For the following 10 seconds, the core cools by emitting ν and $\bar{\nu}$ of all flavours. 99 % of the SN energy is emitted in these fluxes, refered to as "initial" fluxes F^0, whose characteristics are predicted to be flavour dependent. In particular, the average energies of ν_e, $\bar{\nu}_e$ and ν_x are predicted to differ: $E_0(\nu_e) \sim 10 - 12$ MeV, $E_0(\bar{\nu}_e) \sim 13 - 16$ MeV, and $E_0(\nu_x) \sim 15 - 25$ MeV.

The more weakly interacting neutrinos are more energetic because they escape from closer to the hot centre of the star.

As the neutrinos travel outwards, they pass through ever-decreasing density, so matter effects on the mixing are crucial. Level-crossing occurs when $\Delta m^2 \cos 2\theta = \pm 2\sqrt{2} E_\nu G_F n_e$, where the + (−) refers to (anti) neutrinos. Flavour conversion is possible at two level crossings, corresponding to the solar and atmospheric mass differences, and can appear in the ν or the $\bar{\nu}$ depending on the mass hierarchy. This will mix the initial neutrino fluxes, which were labelled by flavour.

Towards the centre of the star, ν_e is the heaviest neutrino. In the normal mass hierarchy, ν_e has a level crossing at the H resonance, which arises at a matter density $\sim 10^3$ g/cm^3, where ν_3 can transform to ν_2 via the atmospheric mass difference and θ_{13}. The H resonance takes place in the $\bar{\nu}_e$ channel, for the inverted mass hierachy. The L resonance arises at a matter density ~ 10 g/cm^3. It is in the ν channel for both hierarchies, and crosses ν_2 with ν_1 via the solar mass difference and angle. The level crossing probability is adiabatic for the L resonance, and for the H resonance when $\sin^2\theta_{13} \gtrsim 10^{-3}$. It is non-adiabatic at the H resonance if $\sin^2\theta_{13} \lesssim 10^{-3}$. The fluxes arriving at the earth (F) depend on the initial fluxes (F^0) and the oscillation probabilities (p and $\bar{p}$):

$$F_{\nu_e} = pF^0_{\nu_e} + (1-p)F^0_{\nu_x} \quad F_{\bar{\nu}_e} = \bar{p}F^0_{\bar{\nu}_e} + (1-\bar{p})F^0_{\nu_x}$$

(There is a related formula for F_{ν_x}.) There are three interesting cases:

- Case A: normal hierarchy, $\sin^2\theta_{13} \gtrsim 10^{-3}$, ($p = 0$, $\bar{p} = \cos^2\theta_\odot$)
- Case B: inverted hierarchy, $\sin^2\theta_{13} \gtrsim 10^{-3}$ (($p = \sin^2\theta_\odot$, $\bar{p} = 0$)
- Case C: any hierarchy, $\sin^2\theta_{13} \lesssim 10^{-3}$ ($p = \sin^2\theta_\odot$, $\bar{p} = \cos^2\theta_\odot$)

A Dighe discussed whether these cases could be distinguished in the observable signal, given that the initial spectra are poorly known, and only the final spectra for $\bar{\nu}_e$ are cleanly available. It is difficult to find observables that do not depend on assumptions about the initial spectra. A possibility, if the SN neutrino flux crosses the earth, is to look for oscillations in the signal due to matter effects in the earth. This would contribute high frequency wiggles to the spectrum, which could be extracted from the data at a megaton detector. For the normal hierarchy or small θ_{13}, these earth effects would appear in the $\bar{\nu}_e$ channel, so observing such wiggles would eliminate case B.

It could also be possible to identify earth effects if the SN is observed with two detectors, where one is in the earth's shadow and the other not. As A. Dighe discussed, IceCube could be the second detector, which would be complementary to Hyper-K.

Neutrinos have a crucial role in the explosion of supernovae, for instance the energy they deposit in the shock may be the critical contribution that allows the star to explode. The interactions between the shock and the outgoing neutrinos may also provide information on the neutrino parameters. As the shock passes through the H resonance region, it can make adiabatic transitions non-adiabatic, thereby temporarily turning scenarios A and B, into scenario C. One can therefore hope to to track the shock fronts through the star in the time-dependent neutrino signal.

A nearby supernova would illuminate the earth with neutrinos. This flux can be used to simultaneously obtain information about the source, and about neutrino properties. At a megatonne detector, "earth effects" in the neutrino spectra could be observed, which would give SN-model independent information on the hierarchy (inverted vs normal) and whether θ_{13} is large or small. Alternatively, if the SN neutrinos do not cross the earth, information about neutrino parameters could be extracted from shock wave propagation effects in the neutrino spectra.

1.4.2 relics

Most of the energy of a supernova is released as neutrinos. The diffuse background of these neutrinos, today, depends on the neutrino spectrum emitted from each explosion, on the oscillation of those neutrinos in the SN and in the earth, and on the supernova rate over the past history of the Universe.

As discussed in the previous section, the neutrino fluxes emitted from the SN core are expected to be flavour dependent, and to oscillate due to matter effects as they leave the star. For instance, in the normal hierarchy, a $\bar{\nu}_e$ emitted from the core is the lightest $\bar{\nu}$, due to matter effects, so it will exit the star as $\bar{\nu}_1$. The observed $\bar{\nu}_e$ flux will therefore be

$$F_{\bar{\nu}_e} = |U_{ei}|^2 F_{\bar{\nu}_i} = |U_{e1}|^2 F^0_{\bar{\nu}_e} + (1 - |U_{e1}|^2) F^0_{\bar{\nu}_x}$$

so $(1 - |U_{e1}|^2) \sim 30\%$ comes from the harder ν_x spectrum. The oscillations enhance the high-energy tail, but not dramatically in the detectable energy range (<30 MeV).

The SN rate is infered from the star formation rate, which can be extracted from other cosmological observables. Using the recent Galactic Evolution Explorer data, the event rate at SK can be calculated, and is found to be mostly due to SN at $z < 1$. A few $\bar{\nu}_e p \to n e^+$ events per year are predicted in the $E > 18$ MeV window where the flux exceeds the solar and armospheric neutrinos. Unfortunately, in this range there is a background from the decays of slowly moving muons, which are produced by atmospheric ν_μ and are invisible at SK. So SK can set an upper limit on the SRN flux, which can then be inverted into a constraint on the supernova rate. The bound is just above theoretical predictions, so SRN might be seen using 5-10 years of data.

The background could be reduced by adding Gadolinium to a water Cherenkov detector. This would tag the neutrons produced in $\bar{\nu}_e p \to n e^+$, and therefore distinguish the $\bar{\nu}_e$ from other neutrinos. Liquid Argon detectors are sensitive to ν_e, so would be complementary to a water detector.

S. Ando also discussed the possibility of observing, at a megatonne detector, a few neutrinos from SN in nearby galaxies ($\sim$ Mpc away). This would give the time of the collapse, helpful for gravitational wave searches.

In summary, the SK limit on supernovae relic neutrinos is just above the theoretical prediction; a future megatonne detector should therefore have a good chance to see them. At a megatonne Cerenkov detector, a 5 σ detection could be possible with pure water after a few years, ($\sim$ 300 events/yr would be expected with Gd). A 100 kt liquid Argon detector would expect $\sim 57 \pm 12$ events after 5 years.

Chapter 2

Accelerators

In Aussois, the session on "Present and Future Neutrino Beams" reviewed the long baseline experiments that will help to understand the neutrino mixing parameters phenomenology in the coming years. This is a long and step-by-step process. In the first step, the MINOS (see M. Bishai's talk), OPERA and ICARUS (see D. Duchesneau's talk) will confirm and improve the SuperK atmospheric oscillation result. This phase will provide an improvement of the limit on θ_{13} ($\simeq< 0.06$ 90% C.L.) In the second step, T2K (see Kobayashi's talk) and NOνA (see Ray's talk) will focus on measuring θ_{13} ($\simeq< 0.006$ 90% C.L.) . This measurement is a prerequisite before attempting to look for CP violation in the leptonic sector: this will be the task of the third step, and the VLBL (see M. Bishai's talk), the T2K-II (see Kobayashi's talk) and the CERN-Fréjus (see M. Mezzetto's talk) proposals. The ultimate tool in neutrino physics – the neutrino factory – was not discussed in this meeting. The expected sensitivities on θ_{13} of these sets of experiments can be visualized on figure 3.4 (next chapter).

2.1 First step

There are presently four experiments running or planned to confirm the atmospheric neutrino result and improve on the knowledge of the oscillation parameters (Δm^2_{23} , $sin^2 2\theta_{23}$): K2K, MINOS, OPERA and ICARUS. The last 3 will also search for the sub-leading $\nu_\mu \leftrightarrow \nu_e$ oscillations, attempting at a first measurement of the θ_{13} angle. The four experiments rely on very different experimental options (beam and/or detector techniques).

2.1.1 K2K

(http://neutrino.kek.jp/)

The K2K (KEK to Kamioka) long-baseline neutrino oscillation experiment, is the first accelerator-based project to explore neutrino oscillations in the same Δm^2_{23} region as the atmospheric neutrinos. By using a low energy ν_μ beam and a flight distance of 250 km, the oscillation process should manifest itself as a reduction of the ν_μ flux at Kamioka (a disappearance) since the ν_τ produced in the oscillation are below the CC threshold. In addition, the energy spectrum of the observed ν_μ should also be affected by the oscillation.

The K2K neutrino beam is produced by 12 GeV protons from the KEK proton synchrotron. The positively charged secondary particles, mainly pions, are then focused by a horn system. The resulting neutrino beam is 98 % pure ν_μ with a mean energy of 1.3 GeV. It traverses first the near detector (ND) system, located 300 m downstream from the proton target, and then the SuperKamioka detector, 250 km away.

To estimate the ratio of neutrino flux and spectra between Kamioka and KEK (far to near, F/N), a combination of experimental measurements and simulation has to be done. Indeed, due to different geometrical acceptances (the neutrino production place cannot be approximated to a point as seen from the near detector), the neutrino spectra seen by the 2 detectors differ, even with no oscillation.

The beam MC simulation is first tuned on the PIMON measurements (pion monitoring detectors intermitently installed upstream of the decay pipe) and then used to compute the F/N ratio in energy bins. This ratio allows then to extrapolate to SK the integrated flux and energy spectrum as measured in the ND, before neutrino oscillate. This extrapolation is compared to the SuperKamiokande measurements. The latest results from the K2K experiment quotes 151^{+12}_{-10} fully contained events expected in SK and 107 observed.

The main sources of uncertainty in this experiment are the following:

- The Monte Carlo F/N ratio relies on a neutrino interaction model, which includes QE, single meson production via baryon resonance and coherent pion production. The relative importance of these components as a function of energy is poorly known.
- The efficiency of the 1KT Cherenkov detector (affecting the normalization) is dominated by uncertainties in the fiducial volume.
- The energy scale in both Cherenkov detectors

A two flavor neutrino oscillation analysis for ν_μ disappearance is performed by the maximum-likelihood method, using both the number of events and the spectrum shape. The best fit point in the physical region is found at ($sin^2 2\theta_{23}$, Δm^2_{23})=($1.0, 2.8 \times 10^{-3}$ eV^2). This result is consistent with the results from atmospheric neutrinos. The final result of the experiment is expected by the end of 2005.

2.1.2 MINOS

(http://www-numi.fnal.gov/Minos/)

MINOS is a long baseline neutrino oscillation experiment using the NuMI beam at Fermilab. This beam is obtained through an intense (0.25 MW) proton beam hitting a graphite target at 120 GeV/c. The movable 2 horn focussing system allows for selecting different energy spectra: low, medium and high. The experimental setup consists of 2 detectors separated by 730 km and as identical as possible: same transverse and longitudinal granularity, same composition and modularity. The basic components are magnetized iron plates interlayed with scintillator strips (the good timing resolution allows background rejection from atmospheric neutrinos and separation of events piling up in the near detector)

The main aim of the experiment is to probe the region of parameter space indicated by the atmospheric neutrinos, to demonstrate the oscillation behaviour and to make a precise measurement of Δm^2_{23} in a high statistics beam experiment. This will be done through ν_μ disappearance: by plotting, as a function of energy, the ratio of the yield at the far detector to the one expected from near detector measurements. The location and depth of the dip will allow to measure Δm^2_{23} and $sin^2 2\theta_{23}$. The low energy beam spectrum is best suited to match the latest SK results and has been chosen as the present running condition. A measurement at 10% (3 years at upgraded intensity: $25 \times 10^{20} pot$) can be achieved and could then also rule out exotic oscillation models. The limitation in sensitivity comes mainly from statistics and from the uncertainty in the extrapolation process of the neutrino spectrum from the near to the far detector.

A second goal of the experiment is the search for the sub-dominant $\nu_\mu \leftrightarrow \nu_e$ oscillations aiming at a first θ_{13} measurement. In this ν_e appearance search, the background is dominated by NC produced π^0's and some intrinsic ν_e from the beam. But the sensitivity could reach $sin^2 2\theta_{13} < 0.07$ (twice better as the CHOOZ limit).

The detector has been extensively calibrated, both at Cern with a micro-MINOS and with cosmic muons (the shadow of the moon has been observed!). The NuMI beam line has been successfully commissioned and the near and far detectors are presently fully operational with more than 90% live time. They both have observed their first beam neutrinos in March this year.

2.1.3 OPERA

(http://operaweb.web.cern.ch/operaweb/)

The main goal of OPERA is to focus on providing an unambiguous evidence for $\nu_\mu \leftrightarrow \nu_\tau$ oscillations in the region of the oscillation parameters indicated by the atmospheric neutrino results by looking for ν_τ appearance in a ν_μ beam. This implies both a high energy beam (above the τ production threshold) and a very precise tracking detector to observe the τ produced in charged current ν_τ interactions (through the characteristic short kink of the τ decay).

The CNGS ν_μ beam will have an average energy of about 17 GeV, a ν_e and $\overline{\nu}_e$ contamination of 0.87% and a negligible prompt ν_τ contamination. This high energy choice means that, given the 730 km distance between the neutrino source (at CERN) and the OPERA detector, the experiment will be running off the oscillation peak (as expected from the atmospheric neutrino results) and thus will not be sensitive to the oscillation pattern.

The τ detection relies on the photographic emulsion technique. 200000 bricks (emulsion and lead sanwiches) amounting to 1.8 kt will be complemented by electronic trackers and a muon spectrometer.. Although the expected signal is very low (115 ν_τ CC interactions in the detector and 13 identified by the selection procedure) the expected background will stay around 1 event: the evidence for $\nu_\mu \leftrightarrow \nu_\tau$ should then be very clear.

Besides the technical difficulties and complexity of constructing the apparatus, the challenges in this experiment mainly concern efficiencies: tracking, matching between tracker and emulsions, scanning and selection.

Given the good electron identification capabilities in the emulsion bricks, OPERA can look as well for $\nu_\mu \leftrightarrow \nu_e$ oscillations. The main backgrounds to the $\nu_\mu \leftrightarrow \nu_e$ oscillations search are the π^0 identified as electrons in ν_μ neutral current events, the intrinsic ν_e beam contamination and the electrons coming from τ decays in $\nu_\mu \leftrightarrow \nu_\tau$ oscillations. The signal to background ratio can however be enhanced by performing a simultaneous fit to the distribution of the visible energy, electron energy and missing transverse momentum. This yields a 5 year sensitivity corresponding to an upper limit on $sin^2(2\theta_{13})$ of 0.06 for the nominal beam, similar to the MINOS sensitivity.

2.1.4 ICARUS

(http://www.aquila.infn.it/icarus/)

Located in the Gran Sasso Laboratory in the same CNGS beam as OPERA, the ICARUS experiment is a liquid Argon TPC with imaging capabilities, able to produce high granularity 3D reconstruction of recorded events. The operating principle of the LAr TPC is based on the fact that in highly purified LAr ionization tracks can indeed be transported undistorted by a uniform electric field over distances of the order of meters.

The detector is not only a tracking device with a precise event topology reconstruction but it can also estimate momentum via multiple scattering, measure local energy deposition (dE/dx, providing e/π^0 separation and particle identification via range versus dE/dx measurement) and reconstruct the total energy of the event from charge integration providing excellent accuracy for contained events.

A 600 ton prototype has been extensively tested at surface during the summer 2001, demonstrating that the LAr TPC technique can be operated at the *kton* scale with a drift length up to 1.5 m. Installation at the Gran Sasso Underground Laboratory is currently on-going. Cloning the T600 module will permit to gradually increase the mass and reach a sensitive mass of 2.35ktons. In the present sensitivity estimates only 3 such modules are used since this is the actual guaranteed funding level.

Given the good detector performance and the beam conditions (energy and flux), ICARUS will also have as a first goal to prove the $\nu_\mu \leftrightarrow \nu_\tau$ oscillation. The analysis will rely on the golden channel: $\tau \to e\nu_e\nu_\tau$. The suppression of the background, dominated by ν_e CC interactions from the beam contamination, will be done through a kinematical analysis, using a 3-dimensional likelihood, including visible energy and missing transverse momentum. With a T1800 detector and 5 years data taking (2.25 10^{20} pot) 6.2 signal events at $2.5 \times 10^{-3} eV^2$ ($\epsilon.BR = 6\%$) for 0.3 background event are expected.

The excellent capability of identifying electrons by the ICARUS detector obviously allows to also search for ν_e appearance. This $\nu_\mu \leftrightarrow \nu_e$ oscillation component would appear as a distorsion in the energy spectrum of the ν_e CC interaction sample. The sensitivity to an expected E_{vis} distorsion at low energy has been evaluated to $sin^2 2\theta_{13} < 0.07$ at 90% CL (for $\Delta m^2_{23} = 2.5 \times 10^{-3} eV^2$ and full mixing).

2.2 Second step

MW-class proton accelerators are being constructed for several physics needs. High intensity conventional horn-focused neutrino beams, "super beams", will then provide a new opportunity to further develop neutrino physics: several super beam LBL experiments are proposed as next generation (~10 years) high sensitivity, high precision experiments before the neutrino-factory era. Their most important goal is discovery of the $\nu_\mu \to \nu_e$ oscillation but one should not neglect other interests such as detailed study of the neutrino interactions or spin structure of nucleons.

In all the future super beam experiments (T2K-I and NOνA), "off-axis (OA)" beam plays a key role to achieve high sensitivity: the proton beam line is shooting a few degrees away from the direction to a far detector. In this way, a high intensity low energy narrow band neutrino beam can be obtained and its energy can be adjusted close to the L/E oscillation maximum. Moreover this "trick" effectively reduces 2 important background sources: the high energy NC production of π^0's and the intrinsic contamination of the beam by ν_e.

2.2.1 T2K-I

(http://neutrino.kek.jp/jhfnu/)

The Tokai-to-Kamioka (T2K) experiment is the next generation LBL experiment in Japan. The ν_μ beam is produced using a 50-GeV proton synchrotron from the Japan Proton Accelerator Research Complex (J-PARC). The peak position of its energy spectrum is tunable from 500 MeV to 900 MeV by changing the OA angle from 2 to 3 degrees. The narrow band is important because it increases the fux at the oscillation maximum, maximizing the appearance signal. The far detector is located at Kamioka, 295 km from J-PARC.

In the first phase of T2K (T2K-I), the design beam power of the 50-GeV PS is 0.75 MW (more than 100 time as powerful as the K2K beam) and the far detector is Super-Kamiokande (SK) of 22.5-kt fiducial mass. The main purpose of T2K-I is a measurement of θ_{13} with more than one order of magnitude sensitivity better than any existing experiment ($\simeq <$ 0.006 90% C.L.). The second goal would be a determination of the "atmospheric" parameters, θ_{23} to an accuracy of 0.01 and Δm^2_{23} to 10^{-4} eV^2. $sin^2 2\theta_{23}$ is presently known to be at least 0.95. Maximal mixing could lead to an underlying new symmetry and thus being able to measure θ_{23} to high enough precision to distinguish maximal and nearly maximal mixing is very important.

With an OA beam at 2.5^o the expected statistics at SK would be 1600 ν_μ CC events per year. The intrinsic beam contamination by ν_e is 0.4%. The appearance signal events in SK are interactions with a single showering Cherenkov ring. The neutrino energy is reconstructed assuming quasi-elastic two-body kinematics. An excess of events over the expected background is the signal for ν_e appearance. Since the signal and background events have different energy spectra, it is essential to control both the flux and the shape of the input spectrum. This is why the experiment will rely on 2 near detectors: at 280m the first near detector will be magnetized (contained in the UA1/NOMAD magnet) and permit detailed studies of the flux and spectra of the different beam components (ν_μ, ν_e, $\overline{\nu}_\mu$ and $\overline{\nu}_e$). This knowledge is important in the extrapolation to SK procedure. The second near detector will be located at 2km, where the energy spectra of the neutrinos crossing a 1kT water Cherenkov and those crossing SK are identical. The uncertainty sources listed above for the K2K experiment should then be drastically reduced.

The neutrino beam line construction has started, together with an intensive R&D and design work on each of its components. The tecnical design report of the 280m detector is expected this summer, while the 2km detector is not yet approved. The first neutrinos in T2K should be delivered in spring 2009 for 5 years.

2.2.2 NOνA

(http://www-nova.fnal.gov/)

With the same physics goal as T2K, the NOνA proposal is in addition raising the neutrino mass ordering question: the mass ordering can be resolved only by matter effects in the earth over long baselines. At 810 km - the NOνA chosen baseline - matter effects should be about 30% for a NuMI off-axis beam and only 10% for T2K.

NOνA is proposed to be a 30 kT totally active low-Z calorimeter (15m x 15m x 130m) placed 15 mrad off the NuMI beam axis. The far detector will consist of 1984 planes of liquid scintillator strips contained in extruded rigid PVC and readout by APD's through wls fibers. Water cherenkov has been discarded because it does not provide sufficient NC rejection at NuMI energy (2 GeV) while a 0.15 X_0 sampling calorimeter provides good π^0-electron discrimination. The fast timing of the scintillator allows to install the detector at ground level: this will mean less than 10 cosmic rays in the 10 μs beam spill. The near detector, very similar to the far detector but complemented with a veto and a muon catcher, can fit in several existing locations in the

NuMI access tunnel. No single location optimizes all parameters, and the collaboration is considering making it movable or building 2 detectors.

NOνA has been granted stage-I approval by Fermilab in april 2005 and benefits a strong support as being the only approved US experiment in the post 2010 era. The expected beam intensity could reach 6.5x10^{20} pot/yr, i.e. 0.65 MW after the collider stops operating in 2009. The construction could start in FY2006, have the first kT operational in 2009 and the full detector operational in 2011. With this optimistic schedule, the experiment is expected to reach an order of magnitude better sensitivity in θ_{13} even faster than T2K.

2.3 Third step

T2K and NOνA will have very limited sensitivity to the CP phase δ_{CP} even if complemented by high sensitivity reactor experiments. A third generation of LBL neutrino experiments will then be required to start a sensitive search for leptonic CP violation. These future experiments will push conventional neutrino beams to their ultimate performances (neutrino SuperBeams), or will require new concepts in the production of neutrino beams.

2.3.1 VLBL-Brookhaven

The BNL proposal of a Very Long BaseLine conceptual design is advocating the use of a broad band low energy (1-6 GeV) on axis beam heading on a megaton class detector to be sensitive both to δ_{CP} and to the sign of Δm^2_{23} .

The CP contribution is dependent on both atmospheric and solar Δm^2 and is affecting the ν_e appearance spectrum (and ν_μ disappearance) in the 1-3 GeV range. On the other hand, the matter effect causes the $\nu_\mu \leftrightarrow \nu_e$ conversion probability to rise with energy and is mostly confined to energies > 3 GeV. this energy dependence can be used to measure the value of δ_{CP} and $\sin^2 2\theta_{13}$. The detector requirements for such an experiment – both in size and performance – are well-matched to other important goals in particle physics, such as detection of proton decay and astrophysical neutrinos.

In the present design the neutrino beam is produced by the 28 GeV proton beam from AGS (Brookhaven) and is detected by a Mton UNO type water Cherenkov detector in Homestake mine at 2540 km from BNL or in Henderson mine (2700 km). The AGS beam power is supposed to be upgraded to 1 MW from present 0.1 MW by introducing a 1.2 GeV superconducting LINAC for direct injection and increasing repetition rate. The beam is a horn-focused on-axis wide band beam with the spectrum ranging up to about 6 GeV and the peak at around 2 GeV. The expected number of ν_μ CC interactions without oscillation is $\sim$13,000/500kt/year. Running with anti-neutrinos could improve further a δ_{CP} measurement.

2.3.2 T2K-II

A future extension of T2K is already envisaged with an upgrading of the proton synchrotron to 4 MW and the construction of a 1-Mt "Hyper-Kamiokande". With ~5 times higher intensity and about 25 times larger fiducial mass, statistics at HK will be 2 orders of magnitude higher than at T2K-I. The expected number of ν_μ CC interactions is $\sim 360,000$/year with a 2° off-axis beam. The goals of T2K-II are the discovery of CP violation and the precise measurement of ν_e appearance.

Preliminary studies on a possible upgrade of the 50-GeV PS to 4 MW have been made by the J-PARC accelerator group. A first gain (by a factor ~2.5) can be obtained by increasing the repetition rate (doubling the number of RF cavities) and by eliminating some idle time in the acceleration cycle. Second, another factor ~2 could be gained by doubling the number of circulating protons when adopting the "barrier bucket" method.

The design of the neutrino beam line presently under construction at JPARC includes the property of being off-axis (tunable between 2° and 3°) both for T2K-I and T2K-II: the HK site would be in the Tochibora mine, ~8 kilometers away from the SK location at 500 m depth (1400 mwe). Two 250m long parallel tunnels would host huge water Cherenkov detectors similar in principle to SK, amounting to 0.54 Mt fiducial mass.

The expected sensitivity on CP violation in T2K-II, based on a full detector simulation (SK scaled to HK), very much depends on the size of the systematic errors. If 2% error is achieved, then the CP violating phase δ_{CP} can be explored down to $\sim 20°$ for $\sin^2 2\theta_{13}$ greater than 0.01.

2.3.3 CERN-Fréjus SPL

This new proposal has been stimulated by 2 converging "opportunities". First CERN is considering the construction of a new proton driver, a Superconducting Proton Linac of low energy (2-3 GeV/c kinetic energy) but very high intensity (4 MW, i.e. 10^{23} protons/yr!). Second the drilling machines of the new safety tunnel in Fréjus should meet at the center around 2009, giving the opportunity to dig a new cavity that could be ready by 2012 and host a Megaton class detector at about 1750m depth i.e 4800 mwe .

Although no definite decision on the SPL construction will be taken by CERN before 2009, intense R&D is already going on for a liquid mercury target station able to cope with the 4 MW beam and for the neutrino beam optics, capable to stand heat, radiation and mercury. Recently an optimization of the SPL neutrino superbeam has been made and found that, given the 130 km baseline (from CERN to the Fréjus tunnel), a 3.5 GeV proton beam plus a 40 m long and 2 m diameter decay tunnel would greatly improve the performances over the 2.2 GeV initial option: the ν_μ CC interaction rate at 130 km would rise from 42 to 122 events/kton/year in case of no oscillation.

In these running conditions, both the NC π^0 background and the intrinsic

ν_e beam contamination are expected to be low and the sensitivity to θ_{13} an order of magnitude better than in T2K-I for a 5 years run of with ν_μ beam (using a 2% systematic error both on the background normalization and on the signal efficiency). The discovery potential (at 3σ) to δ_{CP} could reach 45° if $sin^2 2\theta_{23} = 0.001$ by running 2 years with ν_μ and 8 years with $\overline{\nu}_\mu$.

Conventional neutrino beams are going to hit their ultimate limitations, specifically in the search for CP violation. But when combined with BetaBeams they can improve the CP sensitivity and allow for T and CPT searches in the appearance mode.

2.3.4 CERN-Fréjus Beta-beam

The recently proposed beta-beam idea is taking advantage of the possibility of accelerating and storing radioactive ions within their lifetime, thus producing just one flavor neutrino beam (ν_e or $\overline{\nu}_e$). Its energy spectrum is precisely defined by the end point energy of the beta decay and by the γ of the parent ion. The flux normalization is given by the number of ions circulating in the storage ring and the beam divergence is determined by the γ: the beam control is then virtually systematics free.

Beta-beam studies are essentially done in Europe presently and synergies with nuclear physics are emphasized. A EURISOL-like complex fed by the SPL could produce 6×10^{18} ^{6}He ions ($\overline{\nu}_e$) and 2.5×10^{18} ^{18}Ne (ν_e) ions per year boosted with a $\gamma = 100$.

The superbeam and beta-beam have the advantage of having similar energies which allows usage of the same far detector and explore CP violation in two different channels with different backgrounds and systematics. The disadvantages however are the low cross section at these energies, wich implies very massive detectors, and the limitation in the energy resolution due to Fermi motion. A 10 year experiment, combining a superbeam (running 2 years with ν_μ and 8 years with $\overline{\nu}_\mu$) and a beta-beam (running 5 years with ν_e and 5 years with $\overline{\nu}_e$) would give a discovery potential (at 3σ) to δ_{CP} of 30° if $sin^2 2\theta_{23} = 0.001$.

Ideas about storing radioactive ions that can only decay by electron capture have been recently proposed: this could lead to monochromatic ν_e beams and should be studied further.

2.3.5 Neutrino factory

This subject was not discussed in the meeting but could be viewed as the ultimate step for a full understanding of the neutrino mixing and neutrino phenomenology.

Chapter 3

Detectors

The session was organized around : Water Cerenkov detectors in the three regions of the world - USA-Asia-Europa. Other detectors in the same regions.

3.1 Megaton class Water Cerenkov detectors

There are three projects in the world with the same goals but with different schedules and political priority. So the situation for each " region " has been shown.

3.1.1 Japan with Hyper-Kamiokande (Nakamura)

Japan has a wide experience in using water Cerenkov detector since the experiments done with Kamiokande and Superkamiokande and it is not very surprising that the concept of a Megaton water Cherenkov detector dates back to 1992 in this country.

On table 3.1 a comparison is done between old and future water Cerenkov in Japan.

The next detector HyperKamiokande (fig. 3.1) will have characteristics such as : Water depth < 50m (If the present 20-inch PMT are used), and linear dimensions for light path has to be less than 100m. According to optimization

	Kamiokande	Super Kamiokande	Hyper Kamiokande
Mass	3,000 t (+1,500 t)	50,000 t	1,000,000 t
PM's Coverage	20%	40% (SK-I and SK-III) 20% (SK-II)	?
Observation Started	1983	1996	2023?
Cost (Oku-Yen)[1]	5	100	500? [2]

Table 3.1: Comparison is done between old and future water Cerenkov in Japan

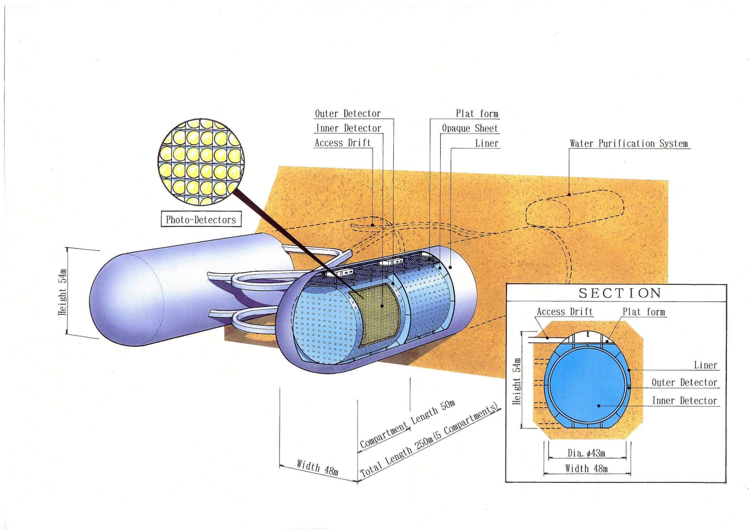

Figure 3.1: *Artistic view of a possible scenario for the futur Hyper-Kamiokande detector*

of Fid/total, rock stability, no sharp edges the best compromise looks to be two twin cavities - tunnel shaped - and two twin cylindrical - detectors.

-Two detectors are independent. One detector is alive when the other is calibrated or maintained.

-Both cavities should be excavated at the same time. But staging scenario is possible for the later phase of the detector construction.

Precise measurements of ^8B solar neutrino spectrum and day/night asymmetry by Mega-ton detectors are still important for further study of solar neutrino oscillation. Quite high statistics of supernova events is expected for galactic supernova (fig 3.2). It enables us to measure:

- Precise antiν_e spectrum and time variation
- ν_e and ν_x spectrum measurement by ν_e scattering

Expected number of supernova relic neutrino (SRN) event is 250/5yr/Megaton (fig. 3.3). Delayed coincidence method to tag ne bar is important to discover SRN neutrinos but it needs to fill the water tank with Gd (see Gadzooks) Hyper-K could be installed in Tochibora Mine (close to kamioka). Some years after start-up of T2K- the construction could last for 10 years, hopefully from 2013 - 2022. And followed by a T2-HK experiment.

3.1.2 DUSEL and UNO- in USA (B.Sadoulet)

The DUSEL (Deep Underground Science and Engineering Laboratory) process is in three parts :

- Solicitation 1 Community wide study of

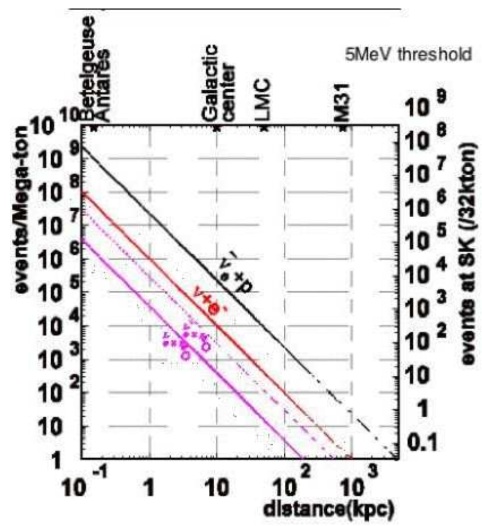

Figure 3.2: *Supernovae events from galaxies*

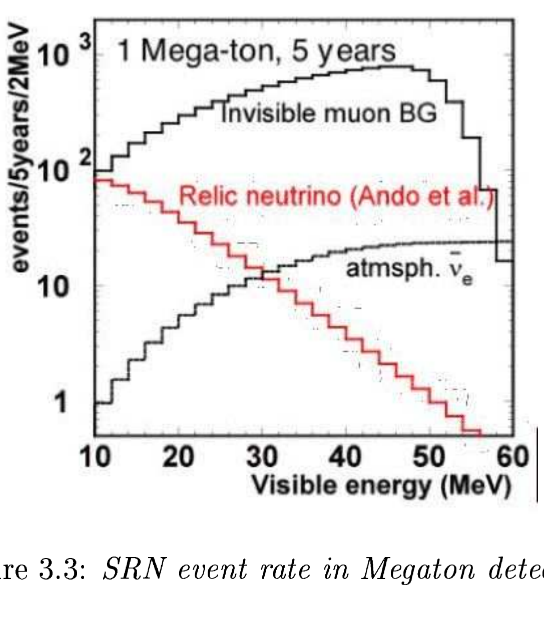

Figure 3.3: *SRN event rate in Megaton detector*

- Scientific roadmap : from Nuclear/Particle/Astro-Physics to Geo Physics/Chemistry/Microbiology/Engineering
- Generic infrastructure requirements
- Proposal supported by all 8 sites Approved by NSF (January 05) PI's went to Washington 28 February to 2 March to clarify goals and time scale

- Solicitation 2 Preselection of 3 sites Þ Solicitation 3 Þ Selection of initial site(s) Þ MRE and Presidential Budget (09) -> 2012-2015

  The main requirements for a good site are :

  Multidisciplinary from the start Not only physics. astrophysics but also Earth sciences, biology, engineering Internal strategy inside NSF : interest many directorates ->MRE line NSF=lead agency but involvement of other agencies: DOE (HEP/Nuclear, Basic Sciences) , NASA (Astrobiology), NIH, USGS + industry Flexibility This is an experimental science facility, not an observatory Specifically adaptive strategy to take into account :

  - The evolution of science
  - International environment (available facilities -e.g. SNOLAB, Mega-Science coord.)
  - Budgetary realities

  Excavate as we go ? LN Gran Sasso Potentially multi-sites Although some advantages of a single site in terms of technical infrastructure and visibility not necessary provide we have a common management (multi-campus concept) variety of rock type and geological history closer to various universities (important for student involvement

- DUSEL aims at a selection of major questions in physics , astrophysics, biology:

  1. What are the properties of the neutrinos? Are neutrinos their own antiparticle? 3rd generation of neutrinoless double beta decay. (1 ton) key ingredient in the formulation of a new "Standard Model", and can only be obtained by the study of : What is the remaining, and presently unknown, parameters of the neutrino mass matrix? θ_{13} What is the hierarchy of masses? Is there significant violation of the CP symmetry among the neutrinos?
  2. Do protons decay? The lifetime for proton decay is a hallmark of theories beyond the Standard Model. Strong dependence on theory may allow a spectacular discovery!

     These questions relate immediately to :

     - the completion of our understanding of particle and nuclear physics
     - the mystery of matter-antimatter asymmetry

3. What is the nature of the dark matter in the universe? Is it comprised of weakly interacting massive particles (WIMPs) of a type not presently known, but predicted by theories such as Supersymmetry?
4. What is the low-energy spectrum of neutrinos from the sun? Solar neutrinos have been important in providing new information not only about the sun but also about the fundamental properties of neutrinos.
5. Important by-products - Neutrinos from Supernovae: Long term enterprise for galactic SN! - Underground accelerator (cf. Luna) - Nuclear cross sections important for astrophysics and cosmology
6. What can we learn on evolution and genomics? Isolated from the surface gene pool for very long periods of time. Does the deep subsurface harbor primitive life processes today? How different are they from microbes on the surface? A reservoir for unexpected and biotechnologically useful enzymes? Potential biotechnology and pharmaceutical applications! How do these microbes evolve with very low population density, extremely low metabolism rate and high longevity, no predators? Phage? The role of the underground in the life cycle Did life on the earth's surface come from underground? Can has the subsurface acted as refuge during extinctions. What signs of subsurface life should we search for on Mars? Is there dark life as we don't know it? Does unique biochemistry, e.g. non-nucleic acid based, and molecular signatures exist in isolated subsurface niches? Same requirements as geomicrobiology + sequencing and DNA/protein synthetic facilities

Since august 2005 the National Science Foundation (NSF) selected two sites for its "Deep Underground Science and Engineering Laboratory (DUSEL) Site and Conceptual Design." *Homestake (South Dakota) and Henderson (Colorado)* **will receive 0.5M$ to produce a conceptual design for a possible DUSEL. The awards result from the 2nd stage of a 3-stage process that is providing input for NSF's future decision on DUSEL.**

UNO R&D Proposal (C.K Jung)

UNO has been proposed in September 99 at the conference NNN99 first one of the series. Since there a lot of questions arose :

-Is it feasible to excavate a UNO size cavern?

- Can it be stable for more than 30 years?

- Can it be done economically?

Can the water containment be done using liners?

Can the PMT mounting system be built economically?

Can the photo-detection be done more economically?

Cheaper PMTs? Or New photo-detectors?

Among the recommandations from US comittees at the APS meeting:
- The Henderson mine is the UNO preferred site

- Owned by Climax Molybdenum Company, a subsidiary of Phelps Dodge Corporation
- Established in 1970's -Henderson is a modern mine developed under strict environmental regulation and self imposed high standards
- One of the 10 largest underground hard rock mines operating in the world w/ a vast infrastructure
- Mine Product: Molybdenum (Moly) ore
- Mining Method: Panel Caving (Block Caving)
- Mining Capacity: 40,000 - 50,000 ton/day - Actual operation: 20,000 - 30,000 ton/day ? under-utilized infrastructure
- Expected Mine Life: another 20 years

On the physics motivations :

- Promote the science case of proton decay research further
- Proton decay: a Giant Orphan of Particle Physics
- Need serious assistance of theoretical community e.g. writing letters to funding agencies
- Do rigorous R&D
- Establish feasibility and reduce detector cost
- Engage private industry
- Develop full simulation/analysis software

3.1.3 The CERN-Frejus Project

Historically the idea of using a Superbeam (proton beam on a target with a magnetic horn to focus a neutrino beam) on a large water cerenkov detector was first developed in Japan with K2K and T2K, and now the T2HK project, and in the US with the UNO project. In the nineties some people begin to think in a competitive European project of megaton water cerenkov class detector for proton decay, neutrino oscillation and astroparticle physics. CERN is the most potential neutrino beam site in Europe. The idea to go cheap and fast lead tp think of reused the superconducting LEP cavities to boost a 4MW proton beam at 2.2GeV, giving a ν_μ beam of 270MeV as mean energy. The ideal baseline for a far detector is then around 135km. By case the Frejus underground laboratory is located at this exact distance and because of the Mont-Blanc tragedy it was planned to drill a new safety gallery before the end of 2010. The convergence of this two facts leads naturally people to propose the CERN-Frejus project, also known as the MEMPHYS project. Since this time two main things have changed in this basic proposition.
The first one is due to the fact that the use of LEP cavities is not foreseen anymore. It let the opportunity of optimising the superbeam scenario in energy and intensity. This work, done by J.E.Campagne and A.Cazes [2] shows that a 3.5GeV proton energy improve greatly the physics sensitivity with a superbeam at 130km from its detector. The second point is the new idea developed by P.Zucchelli [1] to use a beta beam, produced by radioactive ios stored in a decay ring, to produce ν_e and antiν_e beams of very high purity with a perfectly known spectrum and intensity. The required in energy is achievable with the SPS at CERN, increasing greatly the synergy between CERN and Frejus laboratory. Beta beams profits also from a strong synergy with nuclear physicists using radioactive ions produced from the ISOL technique : the neutrino beta beams is now a part of the design study funded by Europe of the future EURISOL facility. After some iterations it seems that the best scenario for a CERN beta beam is to run with He^6 (for anti-ν_e production) and Ne^{18} (for ν_e production), both with a gamma factor of 100. Physics case for the CERN-Frejus project will be developed in this paper in session 2, but as a preliminary result figure 3.4 show the θ_{13} limits of sensitivity for different future experiments as a function of the year including some realistic schedules and figure 3.5 show the θ_{13} sensitivity in function of the CP phase for different experiments, scenarios and combinations of super and beta beams.

Super and beta beams can be ready before 2020 but the physics case of a large Water Cerenkov in the Frejus site includes a large part of non accelerator physics : proton decay and super nova observation are at least as reach as the neutrino beam physics. This leads people to prefer to build a cavity and a detector taking benefit of the safety gallery, start non accelerator physics right away and design neutrino oscillation study as soon as beams are available. A prestudy of the feasibility of the cavity has been launched and funding for a more detailed study will be requested to UE in 2007. A collaboration with

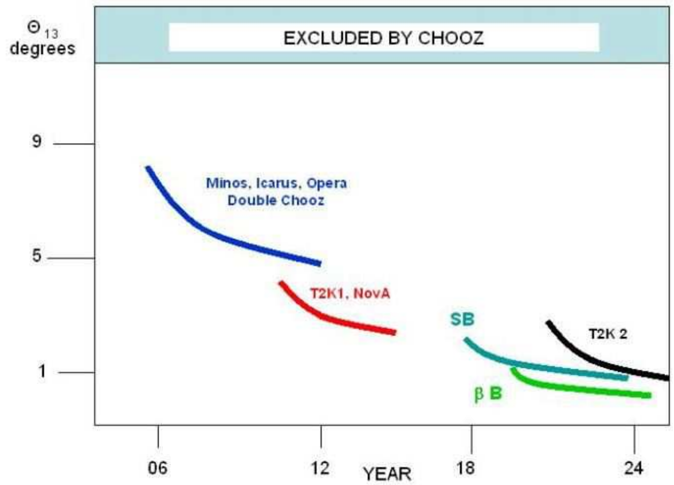

Figure 3.4: *A possible schedule baseline of the θ_{13} sensitivity for the future detectors*

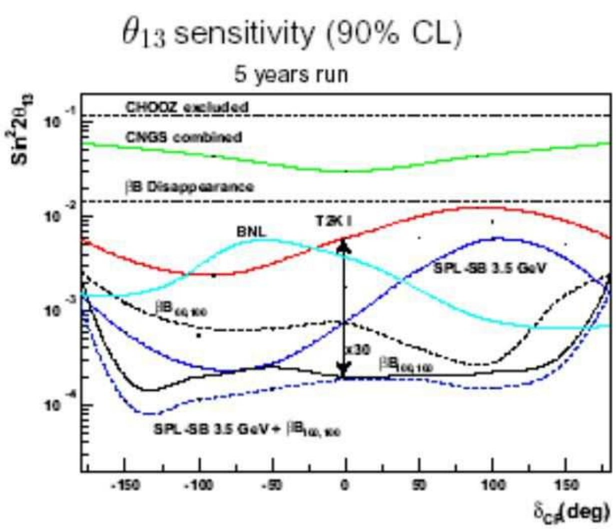

Figure 3.5: *θ_{13} sensitivity in fonction of the CP violation phase for different scenarios*

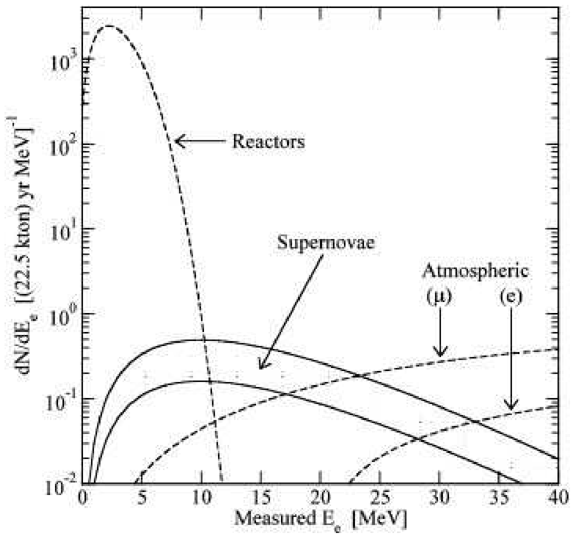

Figure 3.6: *The expected coincident signals in Super-K with 100 tons of $GdCl_3$. Detector energy resolution is properly taken in account. The upper supernova curve is the current SK relic limit, while the lower curve is the thoretical lower bound.*

Photonis has started around a R&D on photodetection. Finally a closer inter-regional (North-America, Japan, Europe) cooperation around this project is wished.

3.1.4 GADZOOKS!

One can imagine how powerful would be a large water cerenkov able to differenciate the anti-neutrino spectroscopy with the specific $\overline{\nu}_e p \rightarrow e + n$ reaction through n tagging. This is the proposition of GADZOOKS! (Gadolinium Antineutrino Detector Zealously Outperforming Old Kamiokande, Super!)[3]. Beyond the kT scale one can forget to use liquid scintillator, ^3He counters or NaCl. In this last case for example, only 50% of n capture on Cl is possible with 6% of NaCl by mass water, which means 60 kilotons of salt in a megaton detector! The solution is perhaps contained in gadolinium trichloride, GdCl3, which is highly soluble, newly inexpensive and transparent in solution.

Neutrons in water quickly lose energy by collisions with free protons (and oxygen nuclei); once thermal energies are reached, the neutron continues to undergo collisions, changing its direction, but on average not its energy, until it is captured. The cross section for thermal neutron capture on natural Gd is 49000 barns, compared to 0.3 barns on free protons. With the proposed 0.2% admixture by mass of GdCl3 in water, 90% of neutron captures are on Gd (8 MeV gamma cascade), 0.2% on Cl (8.6 MeV gamma cascade), and the rest on H (2.2 MeV gamma, not detectable in SK). After thermalization, capture occurs in about 20 ţs (about 10 times faster than in pure water) and about

4 cm; both are slightly increased by the pre-thermalization phase. Compared to typical time and distance separations between events in SK, as well as the position resolution, these are exceedingly small. For 1% of the total cost of a Mton detector assuming 40% PM coverage, this kind of new detector is achievable. In such a detector backgrounds have to be studied in details. The goal is to not compromise an antineutrino single signal by making background neutron capture visible. Neutron from cosmic ray muon spallation in the detector walls, the U/Th/Rn decay chains, or also the ^{152}Gd which alpha decay can produce 17O(a,n) or 18O(a,n) reactions, are backgrounds which have to be deeply studied.
Under this background conditions many goals of physics are achievable. Detection of Diffuse Supernova Neutrino Background (noted DSNB later) would be the first detection of neutrinos from significant redshifts. Rate and shape of DSNB spectrum (see fig. 1) are important inputs for cosmology. Of course a galactic supernovae would be more than easily visible in a GdCl3 megaton class detector producing almost 300000 events ! Speacking of reactor neutrinos, a megaton detector with GdCl3 to maintain a threshold as low as 3 MeV would collect six Kamland years of data in one day. The spread on Dm212 value fron 10% to 1% with three monthes of data. For accelerator neutrinos, neutrino-neutron elastic scattering will be a significant neutral current channel. For proton decay, neutron detection may reduce atmospheric backgrounds.
This summer the near detector of K2K experiment will be used as a large R&D to improve some hardware aspects as Gd filtering, light attenuation and material effects. If this one year R&D is positive a possible improvement of super-K with GdCl3 is in 2006.

3.2 Other type of detectors projects

3.2.1 LNGS

The present satus of the LNGS has been shown (A.Ianni) and the future beyond 2012 has been envisaged also.

- present status up to 2010 The status is summarized on fig. (3.7). The recent works were mainly focussed on the updating and upgrading of the security in the lab.

- after 2010 No Megaton detector will be installed in Gran-Sasso but after 2013 some space will be free and new ideas are welcome for neutrino-beams and low energy solar neutrinos detectors.

3.2.2 Very Large Liquid Argon TPC detector

The LAr TPC technology could have a great potential for future experiments on neutrino oscillations and astroparticle physics. The principle of a LAr TPC

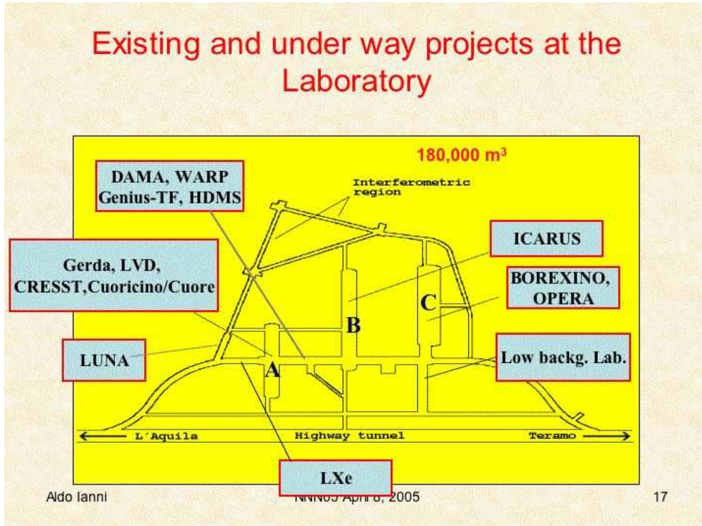

Figure 3.7: *status of the experiments up to 2010 in LNGS.*

is based on the fact that in pure liquid argon charges, due to particle ionisation along their tracks, can be drifted over long distances in a uniform electric field and then readout on a two dimensions plane by different techniques. The long ICARUS R&D program has demonstrated the feasibility of this technology. The first ICARUS module of 600 tons recorded about 30000 cosmic-rays during its full test and is now in process of installation in Gran Sasso Underground Laboratory. The event reconstruction provides simultaneously a three dimensions tracking reconstruction and a full sampling calorimetry permitting a good particle identification. Implementations at different mass scales are now foreseen.
In the T2K long baseline program it is proposed to add an intermediate station at two kilometres with a detector technology based on LAr TPC in order to achieve the challenging goals of the experiment. With a 100 tons LAr TPC as a 2 km near station it would be possible to measure in principle : the ν_μ CC events, the nu NV events, the intrinsic ν_e CC events. Another extrapolation proposed with the same technology is a 10 to 100 kton Lar TPC as a potential concurrent of the megaton water cerenkov class projects (fig.(3.8))

The cryogenic features of the proposed design are based on the use of industrial large volume cryogenic tankers developed by the petro-chemical industry. The detector is characterized by the large fiducial volume of LAr included in a large tanker, with external dimensions of approximately 40 m in height and 70 m in diameter. A cathode located at the bottom of the inner tanker volume creates a drift electric field of the order of 1 kV/cm over a distance of about 20 m. The tanker contains both liquid and gas Argon phases at equilibrium. In order to amplify the extracted charge at the level of the anode, one can consider various options as MWPC, GEM or LEM. In addition to the readout, one can also envision to locate PMTs around the inner surface of the tanker. Scintillation and Cerenkov light can be readout essentially independently be-

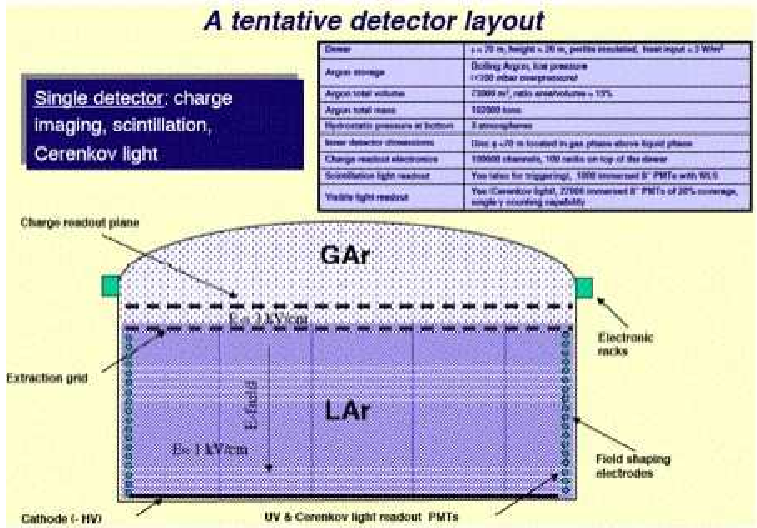

Figure 3.8: *Scaling of the Liquid Argon TPC project to the 100kT scale*

cause the photon number and the light spectrum are quiet different. In order to demonstrate the feasibility of a so huge and complicated detector an R&D program is planned by the GLACIER working group and is already started. It includes studies on the readout plane (charge extraction, amplification and collection), long drift distances, LAr TPC with magnetic field, industrial design of large underground tanks.

3.2.3 Next liquid scintillator generation detector (LENA) - Lothar Oberauer

The detector which is proposed consist of a 50kt liquid scintillator within a cylinder 30m diameter and 90m length with 30

Scientific goals are :

1. Galactic Supernova neutrino detection :

   Which could be done by means of the following reactions :

   In total 13000 events can be recorded such as:

   7800 events ($\overline{\nu}_e p \rightarrow e + n$, $\overline{\nu}_e{}^{12}C -> e +^{12} B$)

   65 events ($\nu_e{}^{12}C \rightarrow e^{12}N$) ,

   4000 events ($\nu_x^{12}C \rightarrow \nu_x^{12}C^*$) ,

   65 events ($\nu_x e \rightarrow \nu_x e$) ,

   2200 events ($\nu_x p \rightarrow \nu_x p$),

2. Supernova relic neutrinos :

   The $\overline{\nu}_e$ p -> e+n and if neutron is detected the background will be strongly reduced in order to reach about 10 MeV threshold

3. Proton decay The decay mode $p- > K + \nu$ favored by SUSY is visible with a high efficiency in a large scintillation detector as LENA.

4. Solar neutrinos They also could be detected at low energies below 1 MeV.

3.2.4 India Neutrino Observatory (Mondal from Mumbai)

- Atmospheric Neutrino Physics are now entering a new era.

  - From observation of oscillation to precision measurement of parameters. A large mass detector with a magnetic field is essential to achieve many of the physics goals.

  - Reconfirmation of atmospheric neutrino oscillation through explicit observation of first oscillation swing as a fn. of L/E

  - Improved measurement of the oscillation parameters

  - Search for potential matter effect and sign of Δm^2_{23}

  - Discrimination between ν_μ ν_τ vs ν_μ ν_s

  - CP violation in neutrino sector

  - Probing CPT violation

  - Constraining long range leptonic forces

- A large magnetised detector of 50-100 Kton is needed to achieve some of the very exciting physics goals using neutrinos.

- A case for such a detector was highlighted earlier by the Monolith Collaboration.

- Physics case for such a detector is strong as evident from recent publications.

  – It will complement the existing and planned water cherenkov detectors.

  – Can be used as a far detector during neutrino factory era.

  – We have started a very active R & D work towards building such a detector.

To end up they are looking for participation from international neutrino community

Chapter 4

Background studies and Photodetection

4.1 Monte Carlo Generators

Accurate measurements of neutrino oscillation parameters by future experiments could be significantly hampered by the large uncertainties in neutrino cross-section in the sub-GeV range. Neutrino interactions with nucleon in nuclei are not well understood from a theoretical point of view, especially at low energies, and experimental data are sparse. Futhermore, most of available data come from Bubble chamber experiments made in the late 70s and have large systematic errors induced by the determination of the neutrino flux. Calulations for charged current ν_μ are shown in Fig 4.1.

New generation of high intensity and well controlled neutrino beams allow to collect much precised data that will attend to futher understand interactions and better constrain models.

Many Monte-carlo generator codes exist but are optimised for a dedicated experiment, *e.g.* tuned for specific target materials. The GENIE collaboration[1] [4] gathers experimentalists from major neutrino experiments as well as theorits and proposes a Universal neutrino generator that will work for all nuclear targets in all energies. The code of the framework is developped in Object-Oriented language to ease the interface with standard libraries like the CERNLIB or CLHEP packages, with other existing simulation softwares (Geant4, Pythia7, ...) and with standard analysis tools such as ROOT.
An additional feature that is included in the GENIE framework is an interface with a database containing the world's neutrino data [5] for model validation.

[1]http://hepunx.rl.ac.uk/ candreop/generators/GENIE/

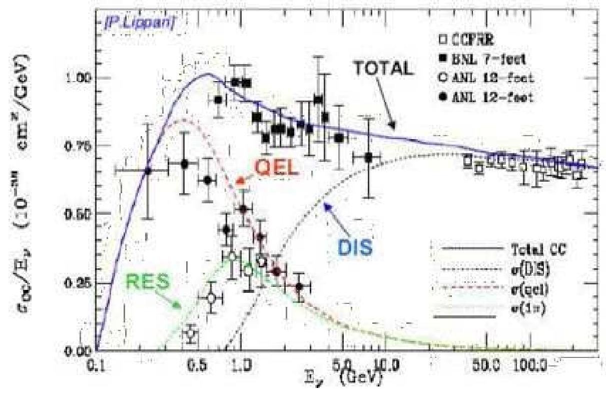

Figure 4.1: ν_μ charged current cross-section calculations compared with experimental data

4.2 Background rejection in large water Cerenkov

Large underground water Cherenkov detectors can measure ν_e appearance as well as ν_μ disappearance. Projects have different configurations in neutrino flux and energy spectrum, although with a similar overall shape with a the dip from oscillation minimum in the oscillated ν_μ distribution.

For a ν_μ disapearance experiment, the signal is muons from charged current quasi elestic interactions, $\nu_\mu + n \rightarrow p + \mu^-$.

For a ν_e appearance experiment, the signal comes from oscillated ν_e neutrinos, $\nu_\mu \rightarrow \nu_e$, $\nu_e + n \rightarrow p + e^-$ and is detected as a fully contained single electron-ring event.

Realistic monte-carlo studies for background rejection in ν_e appearance experiments are the essential groundwork for the quest for the last unknown mixing angle of the mixing matrix and precise measurement of θ_{13}. Main background sources are the ν_e contamination in the beam and neutral current events with one pion decaying into two photons, $\nu + N \rightarrow N' + \nu + \pi^0(\gamma\gamma)$. The latter can be reduced by the reconstruction of the second fainter photon-ring. Indeed, it is likely that one of the photon will carry away most of the energy, and when the energy fraction of one photon is very small, the event closely resembles electron signal. Algorthims for π^0 identification have thus been developped both at T2K [7] and at a megaton class detector on a Very Long Base Line neutrino beam [8]. Background can be subtracted for values of θ_{13} at the CHOOZ limit, understanding of systematic uncertainties becomes yet crucial as θ_{13} gets smaller.

Estimated performances can be further improved with a better energy reconstruction for all charged current events.

4.3 Photodetection

The remarkable successes of SuperK, Kamland, and SNO experiments have triggered future extrapolated projects aiming the improvement on the accuracy of the actual neutrinos family parameters, the exploration of the other ones as well as the search for proton lifetime; sensitive volumes should reach the megaton scale, which is an extrapolation by a factor 10-20 of the SK size. In the same inflatory direction, the detection of very high energy cosmic neutrinos in ice or water Cerenkov-based detectors will also lead to large numbers of photomultipliers. It exists then a strong motivation for R&D trying to decrease the price of photo-sensitive cm^2, which is a major component of projects budgets. Note that for the calculation of these "surface unit prices", HV, front-end electronics and cables have of course to be included.

In another hand, the use of Cerenkov light requires conflicting qualities concerning the single photoelectron sensitivity, the fast time response needed for a good vertex determination, the best photodetection efficiency for setting lower energy thresholds and a robust water pressure resistant envelop able to work at 10 atmospheres pressure without fatal implosion. The process of fabrication should also take account of the time needed to built large quantities (scale: 100000 u). Clearly common R&D with industry are needed.

Price lowering can follow one or several recepices:

- Remove the glass blowing ([9])

  This leads to a very elegant development using sealed glass planes ([9])

- Simplify the electron multiplicative element ([9],[10],[12])

  The basic idea is to accelerate photoelectrons from photocathode with a large potential (10-20 KV); for shaped field, it exists a small surface of convergence where can be placed either scintillator+small pm ([12]), or an APD ([10]). The total gain is then the product of the acceleration gain ($\sim$ 4500) followed by the detecting device gain ($\sim$ 30 or more for an APD). Such system disposes of a fast time response even for large size photocathods and of an impressive single p.e performance. The main drawbacks are the problems brought with the isolation of the very high voltage and a frontend fast amplification needed for the APD case.

- Optimize the unit size ([12])

  For classical big pmts, there is a not obvious relation between size, price/cm^2 ,time performance, total efficiency and investments for production tools. Photonis ([12]) evaluated this and found as the best candidate a 12 inches tube, compared to bigger ones.

- Increase the photocathode efficiencies ([9],[12])

  The use of $\sim$ 20 KV hv permits an excellent collection efficiency. Improvement of photocathode QE efficiency can be found in the use of reflective photo-cathod (30-44 % instead of $\sim$ 20%)

Chapter 5

Large cavities

5.1 Large Cavities and Vessels

5.1.1 introduction

(L. Mosca)

1. remind the list of the present candidate sites for future projects of Very Large ("Megaton scale") Laboratories :

   Japan : HYperKamioka site

   North America : Cascades-Icicle Creek, WA/USA (Greenfield escarpment site & nearby railroad tunnel) Henderson Mine, Empire, CO/USA (Operating molybdenum mine since mid 1970s) Homestake Mine, Lead, SD/USA (Former operating gold mine) Kimballton Mine, Giles Co., VA/USA (Limestone mine & adjacent subsurface) San Jacinto, CA/USA (Greenfield escarpment site) Soudan Mine, Soudan, MN/USA (Operating lab at former iron mine, expansion into adjacent Subsurface) SNOLAB, Sudbury, Ontario/CANADA (Operating lab in operating nickel mine) WIPP, Carlsbad, NM/USA (Operating lab in operating low-level waste facility)

   Europe : Fréjus road tunnel (connecting France with Italy) Poland site

2. shows the Volume (m3) vs Depth (mwe) distribution for some of these candidate sites compared to the already existing laboratories.

3. Emphasizes that the challenge is now to find out the best site(s) with : - relatively large depth - very large volume (megaton scale) - well adapted access configurations and infrastructures - favourable environmental conditions (geographic, scientific, logistic, etc.) - convenient position (long baseline) with respect to accelerator(s)

   and, last not least, to be able to excavate and stabilize such cavities of unprecedented size

5.1.2 Large cavities in USA,Japan and Europe

The laboratoire souterrain de modane has been presented by its director (G.Gerbier) as an introduction also in view of the visit of this deep underground laboratory planned in the afternoon.

The three following talks concerned the projects of large cavities excavations respectively in North-America, in Japan and in Europe.

1. **"Large excavations in the USA"** prepared by Lee Petersen (Minneapolis), was in fact presented by Chang Kee Jung (Stony Brook), due to the impossibility for Lee Petersen to attend this conference. This talk starts with a brief review of the North-American sites presently submitted to the DUSEL (Deep Underground Science and Engineering Laboratory) for selection (see the list above), then the site characteristics important for large excavations are discussed, with the following considerations and consequences. The rock "material" can be strong, stiff

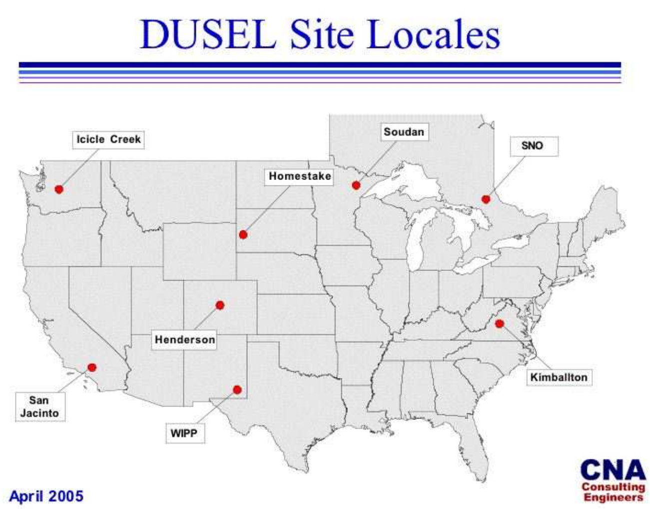

Figure 5.1: DUSEL candidats sites

or brittle and the rock "mass" behavior is controlled by discontinuities. As a consequence the rock mass strength can range from 1/2 to 1/10 of rock material strength. Discontinuities give rock masses scale effects depending if the rock is "massive" (excavation dimensions smaller than discontinuity spacing), or "jointed" or "blocky" (excavation dimensions larger than discontinuity spacing), or even heavily jointed (excavation dimensions much larger than discontinuity spacing).The rock Engineering is concerned with the "rock stresses" in situ, where the "vertical stress" is essentially controlled by the weight of overlying rock, while the "horizontal stress" is controlled by tectonic forces (builds stresses) and creep (relaxes stresses). At depth, ?vert. Å ?horiz. unless there are active tectonic forces. On the basis of all these elements, the following consequences have been derived, concerning: - the depth (shielding capacity) : all sites appear adequate - the rock type (rock chemistry) : all sites appear adequate, but salt at WIPP may be problematic (due to creep & solubility) - the rock quality (in situ stress) : all sites are potentially suitable, but none are guaranteed feasible - the access (rock removal) : all sites are potentially suitable, but horizontal access is beneficial and emphasis has been put on the most important of these characteristics : the rock type for which creep and solubility are the principal issues; the rock quality which commonly influences costs by a factor of 2 to 4, and which could make a site unfeasible, and finally the access, especially for rock removal, which can influence costs significantly, and which is very site dependent. Then the requirements of rock engineering for large cavern construction have been stressed : a) find a site with excellent rock type and quality b) characterize the rock mass : this is the "job one" c) avoid tectonic zones and characterize the in situ stresses d) select size, shape and orientation of the cavity, in order to minimize the rock support, the stress concentrations, etc.

Finally, the following remarks concluded the talk : Is a megadetector feasible? If qualified, yes What are the qualifications? - the rock conditions and depth : the best location at the best site, and not too deep - enlightened funding agencies : to understand and manage the risks and the cost uncertainties - the site factors : the rock removal, which needs competing demands for resources - the contractor : to be chosen on cost and qualifications criteria

2. **"Study on the Excavation of the Hyper-KAMIOKANDE Cavern at Kamioka Mine (Mitsui Mining & Smelting Co., Ltd. (MITSUI KINZOKU)) in Japan"** by Tetsuo NAKAGAWA (Tokyo).

   The summary on this "Ongoing Investigation and Feasibility Study" at the end of the talk looks very well adapted to fit in this "white-paper", so it is inserted here (nearly) as it is :

   *Site Selection : TOCHIBORA Mine, at a depth (overburn) of about 500m (cavern in between 480m and 550m) is the most appropriate location with very competent rock condition.

   Cavern Design: Two 250m Long Parallel Tunnels with Modified Egg Shaped Section of 2,076m2 are capable of being safely excavated and stabilized. Stress Concentration at the Cavern Ends should be relieved by Rounding the Edge to form "Slanted Ellipsoid" (for example Protruded Length of 9.04m) *Cavern Layout : Two Parallel Tunnels as above should be Located properly with 80m Đ100m Spacing and 50m-100m Offset to avoid the Deteriorated Zone of Surrounding Faults such as "Namari", "Anko", "240?-ME" Faults. In Determining the Direction of the Tunnel-Axis (for example 42 ?N from E), Asymmetry of

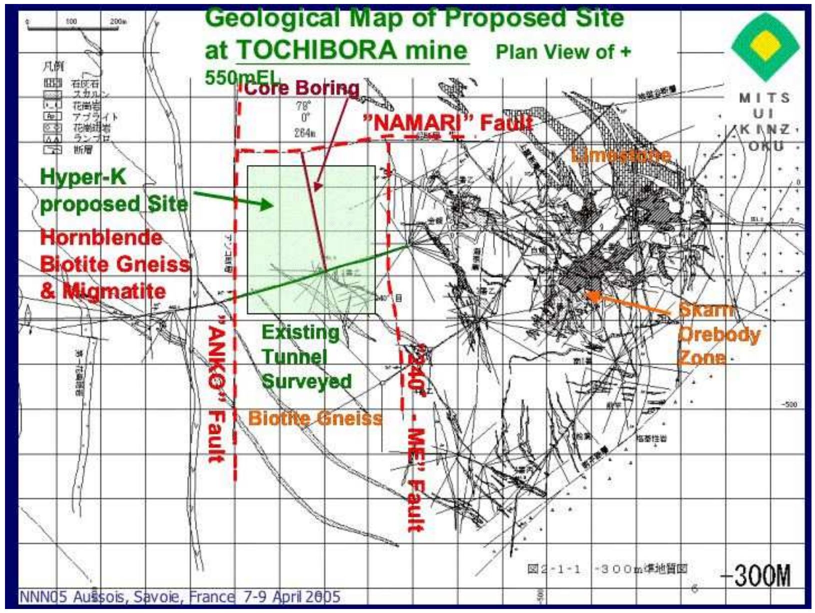

Figure 5.2: site proposed for HyperK

the Real In-Situ Initial Stress Conditions must be seriously considered. Further Investigations and Rock Engineering Studies are needed, and especially Measurements of In-Situ Initial Rock Stresses are indispensable, including Direct Exploration Drilling & Geo-survey Tunneling at the TOCHIBORA MineÕs Candidate Site.

Themes of our Major Concerns : On Further Engineering Study of Rock-Mechanics & Construction

*Excavation Method Ð Bench Stoping or Modified Sublevel Stoping Method

*Effective Rock Support System and Monitored, Informed Excavation System should be Designed and Harmonized with Construction Design & Procedures in Well Organized Manners.

*Main Haulage Tunnel Design Speedy & Convenient Routes should be Proposed.

*Treatment method of the Excavated Waste Rock should be considered. - Disposal in the existing Waste Tailing Dam, we think negotiation with the Authorities of Mine Safety Laws is necessary. - Reuse as Construction Materials, Crushed Gravel Rocks, Sands, Mixing Material in Concrete Products etc. could be possible.

*Clean Water Resource & Supply at TOCHIBORA Mine should be precisely Planned and Estimated

*The Hyper-K Cavern Construction Scheduling & Precise Cost Estimation need to be pushed forward.

3. **"Large excavations in Europe".**(M.Lévy)

   He considered as candidate site the Fréjus mountain crossed by a road-tunnel connecting France (Modane) to Italy (Bardonecchia). He stressed the fact that the quality (parameters) of the rock is well known there due to the systematic investigations (measurements) that have been performed during the excavation of the road tunnel. He reminded that a second tunnel (called "safety Tunnel"), close and parallel to the present road tunnel, should be realized in the next few years, while the final value of its diameter (about 6m or about 9m) is still a matter of discussion between the French and the Italian side.

   The above-mentioned measurements allow to select three regions where the rock is of good quality (essentially where the "convergence" parameter is minimal) : the best of these regions is in the middle of the Tunnel, with an overburn of about 1750 m of rock, and the other two are at about 3km respectively from each entrance (France and Italy), with an overburn of about 1750 m of rock. A preliminary study of feasibility is just started for an excavation of a total volume of about one million cubic meters, in two different positions : in the mentioned central region (near to the present LSM Laboratory), and in one of the other two pre-selected regions (the one on the French side). This preliminary study is considering two different geometries : the "tunnel shape" and the "shaft shape" and is supposed to give, in addition to the feasibility characteristics and conditions, also an indication of the possible method(s) of excavation with a row estimate of cost and time of realisation. The most sensitive dimension being the width (the so-called "span" by the specialists) of the cavities, this preliminary study will a priori investigate width values up to 60m in the case of the "tunnel shape" and of 75m in the case of the "shaft shape".

4. Finally Pierre Duffaut, engineer of the "école des mines" and expert in geology (ancient President of the CFMR "Comité Français de Mécanique des Roches") gave the last talk of this session on a subject "transversal" with respect to the various possible sites, with the title : **"Engineering of large and deep rock caverns for physics research"**

   He started by giving several exemples of large caverns, both natural and man-made, in France and worldwide and discussing the shape of their section and practice of their support. Then he presented a recent French textbook on Rock Mechanics, "Manuel de mécanique des roches " in two volumes : vol. 1 : Fundamentals (2000) and vol. 2 : Applications (2004), a collective work of the French Committee on Rock Mechanics, coordinated by himself. The section 3 of the 2nd volume : "Mechanics of underground works" and especially the chapter 20 therein : " Caverns " is particularly relevant to the main purpose of this session. In this context he insisted on the importance of geology in geotechnique : "

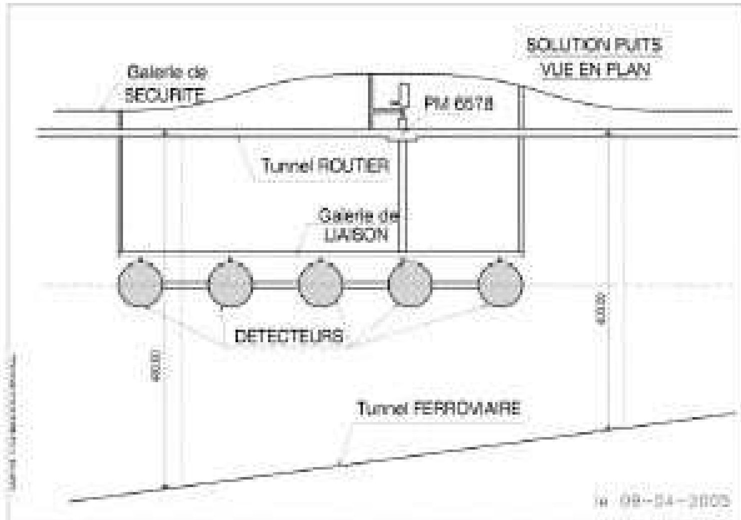

Figure 5.3: possible scenario for the installation of a Megaton detector in the Fréjus Tunnel

all underground works are embedded in geology. Inside the ground, we are like surgeons in a man body, where the anatomy correspond to the materials and structures inside the ground, and the physiology to all what is moving, water, heat, stress, surface and where morphology may give useful clues ". "We have to accept the ground as it comes; it is the same with weather, along the Norwegian proverb :"no bad weather, only poor clothes", which gives in our case : "no bad ground, only poor engineering".

Then Pierre Duffaut remind us with the "theory of the hole and the stress control" fig. 5.5 and in this context he develops its main message, concerning a method to significantly reduce the constaints in the rock, as explained in the following few transparencies :

And finally **"Some conclusions for a billion litres (megaton) chamber"**

- - multiple caverns would call for very wide spacing
- - horizontal caverns are very sensitive to rock & stress anisotropy (one direction only permitted)
- - many experts suppose that granite-like rocks are the best ones . but deformation of schistose rocks, such as Fréjus rocks, could assist destressing before excavation a megaton cavern at Fréjus is an impressive challenge and I would like to help you to master it.

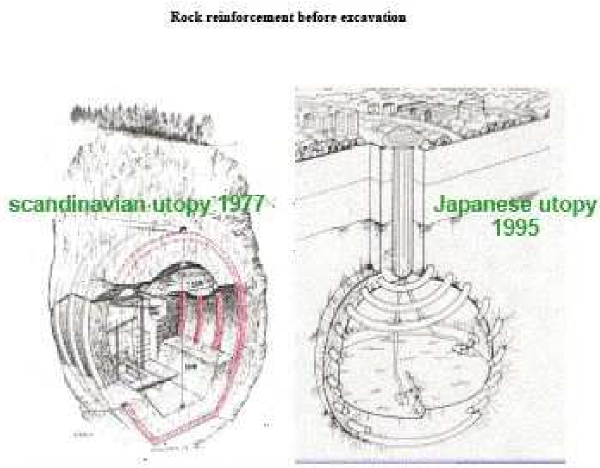

Figure 5.4: Reinforcement before excavation

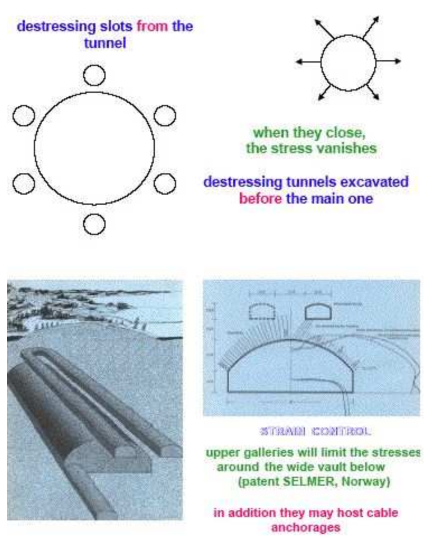

Figure 5.5: The theory of the hole inside a highly stressed medium & stress control

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[14] Burle Indistries: Recent photomultiplier and device developments
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