C. NEUTRINO OSCILLATIONS: HARP/K2K/T2K EXPERIMENTS, NEUTRINO FACTORY R&D (MICE)

1 Research Plan

The field of neutrino physics is certainly one of the most active in particle physics today, and for good reasons. It is by now well established that neutrinos have mass and that the three families mix. In the Standard Model, neutrinos are massless, and there is no question that massive neutrinos require either a new ad-hoc conservation law or new phenomena beyond the present framework, with a possible link to the grand unification scale via the seesaw mechanism.

A deep field of research is thus open, that could last several decades and culminate with the discovery of leptonic CP violation – a key ingredient in the understanding of the baryon-antibaryon asymmetry of the universe. Because observation of CP violation in neutrino oscillations requires appearance experiments, accessible at accelerators only, an important investment in accelerator-based neutrino beams and experiments is called for. The CHIPP Roadmap considers neutrino physics as one of the three pillars of particle physics in Switzerland, and so does the 15 years research plan of the DPNC at University of Geneva.

The neutrino group at DPNC has been actively involved in this quest since the nomination of Prof. A. Blondel in early 2000. The research programme balances participation to a progression of on-going experiments and far-reaching R&D activity, as described in the 3-years report and in the report of October 2006.

We started with an active participation in the HARP experiment at CERN, which took data in 2001-2002 and has now reached the point where experimental results are coming out at a steady rate. HARP took data with a replica of the K2K and mini-BooNE targets. This led us to participate in the K2K experiment in Japan, in which the first observation of neutrino oscillation was achieved with a man-made accelerator neutrino beam, and for which HARP provided important information on the flux calculation. K2K constituted the prototype of neutrino oscillation experiments to come.

The focus, and the main effort of the group, has now shifted to the preparation of the T2K experiment at the new Japanese Proton Accelerator Research Complex J-PARC. A narrow energy $\nu_\mu$ beam with increased intensity, coupled with a new complex of near detectors, should allow a sensitive investigation of the $\nu_\mu \rightarrow \nu_e$ transition, a process which is sensitive to the value of the yet unmeasured angle $\theta_{13}$, and at a later stage perhaps, to CP violation. The group has played a major role in the design and prototyping of the near-detector tracking device, a TPC with micropattern readout, and proposes to contribute substantially
to its construction and exploitation in collaboration with groups in Canada, France and Spain.

Since the T2K beam line, partly because of the very high foreseen intensity, comprises no device suited for absolute flux normalization, we have engaged in the measurement of pion and kaon particle production by 30 GeV protons on carbon (the T2K conditions) using the NA49 apparatus at CERN. This new activity is of crucial importance for some of the measurements to be performed by the T2K experiment and we have had a major role in it. We are requesting a new student for this. It is also the object of a FORCE request.

The need of a high intensity neutrino facility for future neutrino experiments has been recognized by ECFA in 2001, SPSC in 2004, and the CERN Council Strategy for Europe in 2006. The exploratory generation of neutrino experiments will determine the order of magnitude of the mixing angle $\theta_{13}$. A dedicated precision neutrino facility will be needed to discover or study precisely lepton CP violation. University of Geneva has been one of the main players in the definition of this future program, now within a European Network, and an International Scoping Study. The ultimate facility is a neutrino factory based on a muon storage ring; this is a challenging novel accelerator for which a substantial R&D program is needed. We played a leading role in the concept and design of the International Muon Ionization Colling Experiment (MICE). We are now responsible for the data acquisition and trigger of this experiment which starts data taking in August 2007.

The program of activities for 2007-2008 is as follows:

- Termination of the analysis and publication of HARP data. (section 2).
- T2K experiment: construction of the Micromegas-TPC, test of the modules, mechanics of the chambers and software activities; (section 3).
- T2K experiment: measurement of particle production in NA49 at CERN (section 4)
- Continuation of neutrino factory physics and detector studies (section 5)
- MICE experiment, with responsibilities in the data acquisition and trigger (section 6)

The major investments in 2007-2009 concern the T2K experiment which is now approved and funded in Japan with first beam expected in April 2009. The T2K tracker in which we are involved will require a large investment for construction the coming year, tailing off in 2009. The T2K/NA49 has been approved on Feb. 21 2007 and will run in fall 2007, requiring running expenses for this year and some R&D for the upgrade of the TPC electronics. The main investment for the MICE experiment was well advanced in the request of 2006 and will be largely completed with this request. An interesting detector R&D programme is starting for future neutrino detectors.

### 1.1 Participants

The neutrino group at University of Geneva was strengthened considerably in September 2006 by the arrival of Alessandro Bravar, who works on the T2K project. It consists of 9 physicists: one professor, one MER, two post-docs, and five PhD students.

Prof. Alain Blondel (Prof. Ordinaire, Etat)
Dr. Alessandro Bravar (MER, Etat, since September 2006)
Dr. Marie di Marco (MA, FN since April 2006)
Dr. Jean-Sebastien Graulich (MA, Etat, since June 2005)
Rikard Sandström (Assistant FN since August 2003 to second half 2007)
Vassil Vergilov (Assistant FN since June 2006)
Raphael Schroeter (Assistant FN since November 2004)
Nicolas Abgrall (Assistant FN since April 2006)
Melody Ravonel (Masters student, Assistant Fondation Boninchi from spring 2007)
Sebastien Murphy (Masters student from Grenoble, assistant second half of 2007 following Rikard Sandstroem)

Departmental mechanical and electronic engineering support groups: Didier Ferrere, Pierre Bene, Sebastien Pernecker, Eric Perrin, Florian Masciocchi, Yann Meunier.

2 HARP and K2K

The physics objective of the HARP experiment is a systematic study of hadron production for beam momenta between 1.5 and 15 GeV/c on targets ranging from hydrogen to lead. Existing data in this energy range is usually old and spans over limited parts of phase space. The experiment was approved in February 2000 and took data from August 2001 to the end of 2002. A very extensive set of energies and targets was used, including the targets of the K2K and MiniBoone neutrino beams. The low energy region (1.5 to 5 GeV/c) was covered to measure the production of pions of both signs and of kaons, critical ingredients for the design of a future high intensity proton accelerator at CERN. Data taken with HARP are extremely valuable for other fields, including space applications. The first paper was published in October 2005, and several others are in print.

2.1 Large angle cross-sections for neutrino factory particle production

The principle of the neutrino factory muon source is to collect pions from a primary target in the highest density part of phase space i.e. about 500 MeV/c and angles up to around 30°. There are large uncertainties in this region, in particular the incident proton momentum dependence of pion production is poorly known. Crucial information is required for the determination of the energy of a possible high intensity proton source, such as discussed presently in the CERN mandated working groups PAF and POPE. Silvia Borghi completed the first complete analysis of HARP large angle data, using the TPC, and presented the results at the NUFAC'T06 conference and in her PhD thesis. An important consequence is the integral of pion production, essential input to the optimization of the energy of the next high intensity proton accelerator at CERN. The integration over a phase space adequate for a neutrino factory as function of proton kinetic energy is shown in Figure 1. A proton momentum around 4-8 GeV/c is nearly optimal.
Figure 1 Integral of pion production as a function of proton beam momentum normalized to proton kinetic energy. Full symbols show positive pions; empty symbols, negative pions. The circles indicate the integral over HARP acceptance, the squares with a cut on the angular region $0.35 < \theta < 0.95$, the diamonds for momentum between $250 < p_\pi < 500$ MeV/c.

2.2 Further uses of HARP data

Special runs were taken by HARP reproducing the exact K2K conditions, 12.9 GeV/c incident proton beam on a 80 cm long aluminum target. The HARP result on positive pion production in the K2K replica was incorporated in the K2K analysis.

The HARP data taken with a replica of the target of the MINIBOONE experiment are essential for this experiment which operates without a near detector. The beryllium analysis has been submitted for publication, and shown in Figure 2.

Strange particle production in the forward direction is an important piece of the puzzle when trying to determine the $\nu_e$ background in the $\nu_\mu$ beam, since $K^-\pi^+$ decays of $K^0$,$K^0_L$ constitute an irreducible background in the search of the $\nu_\mu \rightarrow \nu_e$ oscillations.

The HARP data will also be useful for the determination of the quality of the possible low energy conventional neutrino beam such as the CERN SPL. The measurement of charged Kaon production is the analysis work of the PhD thesis of Raphaël Schroeter. The charged kaon production double differential cross-sections are computed using HARP’s time of flight (TOF) counters. TOF data are used to identify hadrons species (Figure 2) and to obtain their respective yields. The main difficulty of this analysis is to separate kaons and pions at higher energies where the two peaks overlap. The analysis of HARP will be finished by end 2007, the requested contribution only addresses travel to conferences and publications.
Figure 2 Measurement of the double-differential production cross-section of positive pions, $d^2\sigma/dp d\Omega$, from 8.9 GeV/c protons on beryllium as a function of pion momentum, $p$, in bins of pion angle, $\theta$, in the laboratory frame. The error bars shown include statistical errors and all (diagonal) systematic errors. The dotted histograms show the Sanford-Wang parametrization that best fits the HARP data.

Figure 3 Particle velocity as measured in the HARP forward Time-of-Flight (K2K replica data, 12.9 GeV/c proton beam) in 0.5 GeV momentum bins ($1<p<4$ GeV). The sensitive region is ($p>2.5$ GeV) where the kaon and proton peaks overlap is clearly visible. The fit (blue line) to the TOF data (black dots) is shown. (R. Schroeter’s thesis, in preparation).
### 3. The T2K experiment

#### 3.1 The case for the $\nu_\mu \rightarrow \nu_e$ oscillation search\textsuperscript{18,27}

The present experimental observations on neutrino oscillations, (with the exception of the possible effect seen by the LSND experiment, which is to be tested by the MiniBoone experiment) are consistently described by three family oscillations, with mass eigenstates \{\nu_1, \nu_2, \nu_3\} related to the flavour eigenstates \{\nu_e, \nu_\mu, \nu_\tau\} by a set of Euler angles $\theta_{12}$, $\theta_{13}$, $\theta_{23}$ as depicted in Figure 4, with two independent mass splittings. The present values of oscillation parameters are summarized in Figure 4\textsuperscript{18}, Figure 5 and Figure 6. Matter effects in the sun on the well defined solar $\nu_e$ allow the sign of the mass splitting $\Delta m^2_{12}$ to be determined, but the fact that atmospheric neutrino oscillations take place mostly between $\nu_\mu$ and $\nu_\tau$ prevent the sign of $\Delta m^2_{23}$ to be determined.

Neutrinos being massive definitely requires physics beyond the standard model. Furthermore, it opens the very attractive possibility that leptonic number is not conserved, and that neutrinos are their own anti-particles. This, coupled with the ‘natural’ appearance of CP violation in the three family oscillations would provide a natural solution to the baryon asymmetry of the Universe, through the mechanism known as Leptogenesis\textsuperscript{19}, in which the matter-antimatter asymmetry of the universe is explained by lepton number violation in the decay of heavy neutrino states ($\nu_R$ and $\nu_L$), generated by the so-called seesaw mechanism, and their decays. The generation of baryon asymmetry via leptogenesis from such Majorana Neutrinos would work provided that $m_\nu < 0.1\,\text{eV}$, for all species of neutrinos.

Two low energy observations will be necessary to support this attractive construction. The first one would be the observation of neutrinoless double-beta decay ($\beta \beta 0\nu$) in suitable isotopes. The second would be the discovery of leptonic CP violation in neutrino oscillations, and requires accelerator neutrino experiments.

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**Figure 4**: Present knowledge of the neutrino mixing matrix. The best values are, for the angles, $\theta_{12} = 32^\circ$, $\theta_{23} = 45^\circ$, $\theta_{13} < 15^\circ$, and for the masses $\Delta m^2_{12} = +\,8 \times 10^{-5}\,\text{eV}^2$, $\Delta m^2_{23} = \pm\,2.5\,\text{eV}^2$. The unknown phase $\delta$ would, if non-vanishing, generate CP and T violation in neutrino oscillations.
Figure 5 Present knowledge of solar oscillation parameters in the plane $\Delta m^2_{12}, \theta_{12}$.

Figure 6 Left: left, atmospheric parameters; right, present situation for the yet unknown mixing angle $\theta_{13}$. The expected precision from T2K phase I is shown on both graphs. The improvement from NA49/T2K is mostly visible on the atmospheric parameters.

With three families and a favorable set of parameters, it will be possible to observe violation of CP or T symmetries in neutrino oscillations$^{10}$. The phenomenon of CP (or T) violation in neutrino oscillations manifests itself by a difference in the oscillation probabilities of say,
$P(\nu_\mu \rightarrow \nu_e)$ vs $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ (CP violation), or $P(\nu_\mu \rightarrow \nu_e)$ vs $P(\nu_e \rightarrow \nu_\mu)$ (T violation).

Observation of this important phenomenon requires appearance experiments, feasible only with accelerator neutrino beams. The $\nu_\mu \rightarrow \nu_e$ transition probability can be seen as a superimposition of solar and atmospheric oscillations as shown in Figure 7.

![Figure 7](image)

Figure 7 neutrino oscillations for 1 GeV neutrinos as function of distance to the source. The oscillation parameters are: $\sin^2 2\theta_{13} = 0.01$, $\delta = 0$, on the left, $\delta = -\pi/2$ on the right.

Of experimental interest is the CP-violating asymmetry $A_{CP}$:

$$A_{CP} = \frac{P(\nu_e \rightarrow \nu_\mu) - P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu)}{P(\nu_e \rightarrow \nu_\mu) + P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu)} = \frac{\sin \delta \sin \theta_{13} \sin (\Delta m^2_{13} L/4E) \sin \theta_{12}}{\sin^2 \theta_{13} + \text{solar term}}$$

or the equivalent time reversal asymmetry $A_T$ which is displayed on Figure 8. The size of the asymmetry is sensitive to the value of the yet unknown mixing angle $\theta_{13}$. In order to design optimally a CP asymmetry experiment, it is essential to measure $\theta_{13}$, or at least to establish its order of magnitude. This will be one of the main goals of the T2K experiment.

![Figure 8](image)

Figure 8. Left: Magnitude of the time reversal asymmetry at the first oscillation maximum, for $\delta=1$ as a function of the mixing angle $\sin^2 2\theta_{13}$. The curve marked ‘error’ indicates the $\theta_{13}$ dependence of the statistical
error on such a measurement for a given flux and detector mass. Right: sensitivity to \( \sin^2 2\theta_{13} \) as function of year taking into account presently approved projects. (From Mezzetto\(^2\))

In Figure 8 (right), the evolution of the world combined sensitivity to \( \theta_{13} \) is shown as a function of the year. The T2K experiment will be improving the sensitivity to \( \theta_{13} \) by more than a factor 20 with respect to the present limits, and by more than a factor 5 with respect to the sensitivity at the time of its starting date.

### 3.2 The T2K experiment

The Tokai to Kamioka (T2K) neutrino experiment, sketched on Figure 9, will use a newly constructed neutrino beam line at the high intensity Japanese Proton Accelerator Research Complex (J-PARC) pointing to the famous SuperKamiokaNDE detector. The secondary pion beam points at an angle of 2.5 degrees, allowing the neutrino beam energy (600 MeV) to match the distance (295 km) in exact proportion to the value of \( \Delta m^2_{23} \sim 500 \text{ km/GeV} \). The new 30-50 GeV Proton Synchrotron is expected to reach after a few years a beam power of 0.75 MW, making it the highest intensity high energy (\( \gg 1 \text{ GeV} \)) proton beam in the world. The accelerator is now under construction and the proposed neutrino beam is planned to operate starting in 2009. A near detector complex ensures the proper alignment of the beam line, measurement and analysis of neutrino interactions and a measurement of flux times cross-sections for the various flavor (\( \nu_\mu, \nu_e \) and antineutrinos) components of the beam.

![T2K setup](image)

*Figure 9: Overview of the Tokai to SuperKamiokande (T2K) experiment.*
The main design features of the T2K experiment lie in its beam line:

1. The neutrino beam is produced by pion decay from a horn focused beam, with a system of three horns and reflectors. The decay tunnel length (110 m long) is optimized for the decay of 2-8 GeV pions and short to minimize the occurrence of muon decays.

2. The neutrino beam is set at an angle of 2.5±0.5 degrees from the direction of the super-Kamiokande detector.

3. The beam line is equipped with a set of dedicated on-axis and off-axis detectors at two different distances, 280 meters, and, at a later stage, 2 km. see Figure 10.

The main goals of the experiment are as follows:

1. The highest priority of the experiment is the appearance search for the yet unobserved neutrino oscillation $\nu_\mu \leftrightarrow \nu_e$ with the same frequency as the atmospheric oscillation (which is known to be mostly due to $\nu_\mu \leftrightarrow \nu_\tau$). This will manifest itself by appearance of events with an electron in the final state. This reaction is driven by the yet unknown mixing angle $\theta_{13}$, which also drives the CP violation asymmetry which could be observed in the same channel by comparing neutrino oscillations to antineutrino oscillations. The main challenge is the understanding of the backgrounds that produce or mimic an electromagnetic shower: beam $\nu_e$ from K and muon decay; $\pi^0$ production by neutral current and charged current events. The solution is to measure precisely in the near detector the beam composition and the rate and topology of backgrounds, so as to be able to perform a good simulation of the far detector. Since nuclear effects are rather important (pion absorption in particular), the material should be as near as possible to the water of Super-Kamiokande. A magnetic, fine grain detector situated in the 280m near detector station, where the rate is higher, will be dedicated to these studies. The 280m detector is part of the approved T2K project.
2. Disappearance measurements, where the number and rate of $\nu_\mu \rightarrow \nu_\mu$ events is studied, will improve the measurement of $\Delta m^2_{13}$ (after MINOS, CNGS) down to a precision of 0.0003 (stat) or so (the present preferred value is $0.0024\pm0.0003$ eV$^2$). The exact measurement of the maximum disappearance constitutes a precise measurement of $\sin^22\theta_{23}$. These precision measurements of already known quantities require good knowledge of flux shape, absolute energy scale, experimental energy resolution and of the cross-section as a function of energy. It is absolutely necessary here to have a near detector station with material and acceptance as similar as possible to those of the far detector. This issue can be solved by building detectors, in particular a Water Cherenkov, at a 2km near detector station where the flux is much more similar to the SK flux than at 280 m; on a shorter time scale, the precise measurement of the properties of the beam as can be obtained by measuring particle production in the NA49 detector at CERN can allow a substantial reduction of extrapolation uncertainties.

T2K$^{22}$, was approved in December 2003, including the 280 meter near detector. The contribution of the European groups will be in the 280m near detector station. The Swiss groups (UNIGE, UNIBE, ETHZ) will contribute to i) the provision of the magnet, ii) an important contribution to the ND280 tracker (more specific to UNIGE), iii) the measurement of secondary particle production with the NA49 experiment, iv) R&D for the 2km detector. A detailed description of the ND280m project can be found in the attached TDR$^{23}$ and a sketch in Figure 11.

![Figure 11 Cut-away view of the ND280 magnetic detector](image)
3.3 Magnet
The detector will be embedded inside the UA1/NOMAD magnet. A magnetic field of 0.2 T will be delivered to all parts of the detector, and in particular to the tracker. The availability of a magnetic field allows the direct measurement of the momentum and precise direction of the leptons as well as of the secondary pions produced by neutrino interactions. It is to be emphasized that even in T2K phase 2 if the 2 km near detector station will be installed, the role of the ND280 magnetic detector will remain unique by the ability to perform the charge assignment of all particles. This will be precious to establish the beam composition and backgrounds for neutrinos vs antineutrinos for the CP violation measurement.

This important contribution is the gift by CERN to the project, and was approved by the CERN council in December 2004. The installation of the magnet on site at Tokai is foreseen in the fourth quarter of 2008, thus the magnet refurbishment and shipping must be executed in 2007 and first half of 2008. The magnet, its installation and commissioning are a European contribution to the experiment, which will be financed by the groups from France, Germany, Spain, Switzerland and UK. The preliminary cost estimate\textsuperscript{24} is as follows:

<table>
<thead>
<tr>
<th>PRELIMINARY COST of UA1 magnet refurbishing, shipping and reassembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply</td>
</tr>
<tr>
<td>Shipping</td>
</tr>
<tr>
<td>Refurbishing, movement, slow control</td>
</tr>
<tr>
<td>Basket, support, rails</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

This amount will be shared between the European groups of T2K, following the different responsibilities in the project and the size of the groups. A total of 50k€ (75kCHF) is at the charge of University of Geneva. This expense will be spread over two funding years corresponding to the funding requests of 2006-2007, and 2007-2008 in two slices of 35kCHF and 40 kCHF. Given the uncertainty in the estimate, it cannot be ruled out that a further contribution will be requested at a later stage.

![Figure 12 Refurbishment of the NOMAD/UA1 magnet at CERN: recovery of the coils (background on the left)](image-url)
3.4 The ND280 Tracker

The Geneva group is involved in the tracker of the 280m near detector: building on our experience with TPCs with GEM readout that was developed for the light material option of the MICE tracker\textsuperscript{25,26}, we propose an important contribution to the tracking system. The 280m detector station is described in detail in the T2K ND280 Conceptual Design Report\textsuperscript{27}. A sketch is shown in Figure 13. Following a \(\pi^0\) detector, a tracking system will measure the momentum of the charged particles produced by neutrino interactions. The tracker is constituted of fine grained massive detectors interspaced between several TPC volumes; it will allow a selection of the quasi elastic events in which the secondary proton is detected.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure13.png}
\caption{Top: Sketch of the detectors laid inside the ND280 magnet. The neutrino beam enters from the left, and encounters first the P0D, pi-zero detector. This is followed by the tracking device, constituted of three TPCs interspaced with two active scintillator target. The first target has a high water content to reproduce the SuperKamiokande chemical composition.}
\end{figure}

\textbf{C.3.4.1 TPC design considerations}

In its first phase, T2K will measure \(\nu_e\) disappearance to measure \(\Delta m^2_{34}\) and sin\(^2\)2\(\theta_{23}\), with high precision. The role of the near detector is to detect the \(\nu_\mu\) charged current events and to measure the spectrum and rates as if they were detected in SuperKamiokande NDE. To reach this goal, the momentum resolution needs to be better than 10% at 1 GeV, which is about the effect of Fermi motion of the target nuclei. In addition one of the larger sources of systematic errors is the ratio of quasi-elastic events to elastic events, in the selected single ring muon sample in SK, an issue that can be studied with the near detector by identifying events with one or several additional neutral or charged pion. The segmentation of the FGD and TPC, added to the particle identification capability with dE/dx, will allow a comprehension of the nature of events that would be recorded as single ring muons or electrons in SK.

Another task of the near detector is the measurement of the rate and properties of charged current \(\nu_e\) events. The TPC can distinguish electrons from muons at 3 \(\sigma\), a resolution of 10\% on dE/dx at that energy is a reasonable performance requirement. Because of the moderate magnetic field of 0.2T provided by the UA1 magnet, the curvature of the tracks is also moderate, and needs to be compensated by an optimal space point resolution. For that, a high segmentation of the readout becomes necessary, and because of the space constraints
imposed by the fact that the tracker has to sit within the UA1 magnet, the readout has to be compact. In the ND280 configuration, the tracks are perpendicular to the drift field (see fig.16), therefore strips cannot be used, and the readout has to be made out of pads.

Figure 14 Layout of one of the TPCs. Assembly of the field cage, readout chambers and electronics.

A sketch of one of the TPCs to be designed an built is shown in Figure 14. The electric field is parallel to the magnetic field provided by the dipole, and provided by a copper-claded rohacell field cage with double walls. The drifted ionization electrons will be collected after a drift distance of 1.25 m on each side of the TPC, and amplified by micropattern detectors. Micromegas have been chosen for this purpose.

In 2005 an intense campaign of R&D and prototyping was undertaken, with the main aim of measuring the resolution and establishing the operability of the two techniques, GEMs and Micromegas. The work done since the last grant request was reported in Innovative Particle and Radiation Detectors conference\textsuperscript{28} and at the IEEE Conference\textsuperscript{29}; resolutions of typically 450 µm per point were reported in the scientific report of 2006 and in a report submitted for publication\textsuperscript{30}. At the end, the Micromegas technology was chosen to equip the T2K ND280 TPCs. The $1 \times 2.5 \times 2.5$ m$^3$ TPC’s will measure the 3-momentum of the charged particles, readout by 12 Micromegas each (see Figure 15). With the resolution that has been achieved, a TPCs with an active volume composed of 2 vertical columns of Micromegas chambers of 35 cm lateral size separated by 5 cm for services. With pad sizes of 9x7mm, a typical resolution of $\Delta p/p = 0.07 p_t$ should be achieved.
The detection principle of the Micromegas\textsuperscript{31} is sketched in Figure 16. An avalanche is produced between the micromesh, supported 70 \(\mu\)m above the anode by short cylindrical pillars, and the anode. In the case of the T2K ND280 TPC, the baseline for the drift field is 200 V/cm, and the Micromegas amplification gap will be set to a value of the order of -360 V over 128 \(\mu\)m. Each T2K Micromegas module, is glued on a mechanical support frame (the stiffener) which assures the rigidity of the structure.
C.3.4.2 Need of pad-per-pad characterization and the test-bench

Several causes degrade the space resolution in a TPC: i) noisy or dead pads, ii) cross-talk iii) non-uniformity of the electron amplification across the pad-plane. The latest Micromegas prototype built for T2K in the fall of 2006 presented no faulty pad at the end of the fabrication process. The two other issues will be address with a systematic campaign of measurements on a test bench.

The T2K ND280 TPC calibration program is divided following the 3 main steps of the detection process: the electron transportation in the gas, their detection by the Micromegas, and finally the digitization of the signal. The last two points are addressed by the test-bench, which is responsible for providing the complete mapping of the pad response over each board. To this effect, each Micromegas chamber will be placed a gas box reproducing the conditions of the TPC, and exposed to a $^{55}$Fe X-ray source placed on a x-y scanning table. The following measurements will be performed:
- A scan is performed across all pads of the chamber at a rate of about one pad per minute, allowing a complete~1% pad-to-pad calibration of a module in about one day.
- The stability of the system is monitored by four sources placed on the edges of the chamber and recorded continuously during the process.
- The ‘pad response function’ (local charge distribution) is measured by scanning across pad boundaries or borders, with a source collimated so as to produce a spot much smaller than the pad size.

The test-bench has been entirely conceived and constructed at the Université de Genève. As a first step, the characterization of a 3 GEM tower is presently being performed. Two other boxes will be built and installed at CERN to be part of the Micromegas production chain. Figure 17 shows a general view of the setup. The module is held vertically inside a 61.6×44.4×7.5 cm$^3$ (20.5L) G-10 gas box, which is operated as a small drift chamber. It is closed by the padplane on one side, and by the cathode (an aluminized mylar sheet) supported by a protection grid on the other. It is mounted on a rail which allows to move it
to the desired distance from the collimation tube holding the $^{55}$Fe source, fixed on a set of two mechanical arms (X-Y stages), which move the source for the scanning of the pads. The readout cards are connected vertically on the pad-plane for a better ventilation. The gas box is also used for transporting the module from the assembly point to the test bench. It is operated with premix Ar:CO$_2$ (90:10) for the Gem, Ar:CF$_4$:C$_4$H$_{10}$ (95:3:2) for the T2K Micromegas modules (CF$_4$ might be replaced by CO$_2$ in the final design). Geneva is responsible for the design, construction and operation of the calibration test bench that will characterize each of the 72 Micromegas modules before their shipment to Canada for assembly in the TPC. Details and history of the mounting of the test bench are shown in Figure 18, Figure 19, and Figure 20.

![Figure 17 3D view of the test-bench (left), side-view and view from the back with opened gas box (left).](image17)

![Figure 18 Left: test-bench viewed from the padplane. Right fully operational with electronics and gas system.](image18)
Figure 19 Micromegas and GEM calibration test bench. left: overview of the system: the Micromegas module with its mechanics, pad board and electronics is placed inside a test box and exposed to collimated $^{55}$Fe sources: a powerful mobile one which will measure in detail the gain for each pad and pad response function, and two weaker ones to ensure the gain stability of the system. Right: the $^{55}$Fe excitation peak with a resolution of 10%.

Figure 20 Caption: 3D mock-up of the Micromegas calibration test bench seen from the $^{55}$Fe source (left), used to scan the module pad per pad, and from the backplane side (right) where the readout electronics is to be plugged in.
3.5 Constructions, planning and cost at University of Geneva

The responsibilities in the TPC construction are shared as follows:
-- field cage construction and design: Canada (UBC, U.Victoria, TRIUMF)
-- gas system: Canada
-- front end electronics: Saclay
-- back-end electronics: IN2P3
-- Micromégas production; CERN, Saclay
-- mechanical assembly and chamber frames: Geneva, Saclay
-- chamber tests and characterization: Geneva
-- calibration: all groups, under the supervision of Valencia (A. Cervera)
-- software: Barcelona, Saclay, Geneva

The DPNC ensures the coordination mechanics of the Micromegas modules and their integration on the TPCs.

These activities require a considerable effort from Geneva that will be focused on the:

- Construction and production of precision components for the Micromegas module integration
- Construction of the calibration test bench
- Participation to the installation of the production laboratory at CERN

Concerning the first point, Geneva is responsible for the production of mechanical pieces that will allow the integration of the modules on the TPC endplates. These components are called “stiffeners” in the mechanical design, and will be machined out of G10. Four prototypes have already been produced and assembled and are used to improve the design, machining and gluing techniques. Figure 21 shows a technical 3D mock-up of the final pieces.

![Figure 21 3D mock-up of the stiffener final design for production. The bare stiffener before the assembling of the Micromegas module (left), mounted with the readout electronics (center); right: a first attempt at the design of a full module including cooling system, handles and controls.](image-url)
The production of the stiffeners is critical in the sense that these components of the modules have to be machined and assembled with very low planarity tolerances so that the alignment of the modules on the readout plane can be done with a precision of 100 microns, which is a real challenge from the mechanical point of view.

The price per stiffener is estimated to around 500 CHF, so that the full production of 84 pieces (12 per endplate for each endplate of 3 TPC’s, plus a full endplate of spares) would require about 50 kCHF including a few prototypes and spare parts. Apart from the stiffeners, the production of secondary components such as cooling plates for the electronics and guiding tools for the insertion of the electronic cards on the modules, handles, locks etc… is also partly under the responsibility of Geneva (shared with Saclay). This will require about 30 kCHF. To perform the whole production, dedicated tooling will be necessary (e.g. marble bench for precise reference surface during gluing operations) and represents a rough cost of 10 kCHF. Finally, during the production period, a large amount of consumables (e.g. raw material, glue, O-rings etc) will be required and a safe margin of 5 kCHF is estimated accordingly.

The overall production and calibration chain of the modules has now been clearly established between Saclay and Geneva. To perform this task in the most efficient way it appears that the test bench (only the box on which the modules are mounted) is to be duplicated in order to minimize the loss of time between two calibrations.

Finally, the last point is dealing with the installation of a common production/calibration laboratory at CERN in dedicated premises. Geneva is responsible for different work spaces such as the integration of the modules in the test box under laminar flow, the test bench and the respective monitoring and gas stations, and the storage of the modules in transport boxes in the clean room. The implantation of the test bench in operation mode is estimated at about 26’500.- (3000.-for the clean air system; 13’500.- for the premix gas, and 10’000.- for a number of various clean room consumables and other small mechanical assemblies).

The general time schedule of the T2K experiment is of course leading the order of priority of these activities at Geneva. The next corner stone of this schedule is the first test of the mechanical integration of the modules on the TPC module 0 at the end of July 2007. For this, four complete Micromegas modules have to be produced and shipped to Canada. These four modules will follow the normal production chain at CERN including full characterization in the test bench. Soon after these first prototypes, the production/calibration should start in September 2007 and is expected to last one year. Starting in spring 2008, substantial travel to TRIUMF will be required in order to assemble the Micromegas modules in the TPC field cage and endplate built in Canada. Then in fall 2008-winter 2009 the TPC will be shipped and installed in the ND280 pit at Tokai.

A summary of the funding requests is shown in Table 1. This table still includes a number of costs which are quite uncertain in particular the stiffeners and the module mechanics which is under design.
These contributions represent:

- **magnet**: 5% of the cost of refurbishing, shipping and installing the UA1 magnet in Japan. This is the agreed Geneva contribution. Other Swiss groups (ETHZ and Bern) are responsible for the refurbishment of the magnet. In case of cost over-run a further request could be made a year from now.

- **Common project**: this is an agreed contribution to the T2K common project of 5000.- USD per PhD physicist (there are three in the Geneva group).

- **Micromegas frames**: this represents the cost of fabrication of 84 Micromegas frames.

- **Micromegas other mechanics**: this represents the cost of other components of the Micromegas module mechanics, such as handles, alignment targets, cooling components.

- **Tooling**: this is the tooling required for the production and assembly of the Micromegas frames

- **The x-y table** has now been purchased

- **Test bench assembly and gas system**: this involves the construction of three test boxes and of the gas system, as well as maintenance. In addition a full maintenance of the clean air system (flux laminaire) will be needed at the end of the testing period.

- **Electronics**: this represents the cost of equipping completely with presently available electronics the readout pads corresponding to two Micromegas modules, in order to proceed with the testing and characterization of all chambers. For the second and third year a contribution to the electronics and data acquisition system is foreseen. For the third and following years a contribution to computing and data storage is foreseen.

- **Travel**: In addition of the normal spending (three or four persons attending three collaboration meetings a year at a cost of 3000.- per meeting, equiv. to 27’000.- per year). In 2008 a extended stay (3-6 months total ~12000.-) in Vancouver will be necessary. It is assumed that one person will be staying for 6 months in Japan in each of 2009-2010-2011 in addition to the normal visits for shifts etc… It is likely that a more extended presence will be necessary, but we plan to request fellowships from KEK in Japan or from other sources.

### Table 1 Funding profile for the T2K-Geneva project

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3.6 T2K ND280 production Data Base

While this year the construction of the ND280 detector starts, a large volume of information will be produced and dispatched among all collaborative institutes during the construction and installation phase. At the end of 2006, University of Geneva proposed to implement and host a production Data Base (DB) allowing storing all the relevant information for the construction of this detector. This type of DB has been developed and proved to be very useful and efficient on ATLAS SCT\(^2\) and Pixel while retrieving and analysing data all along the project phases. For the ND280, TPC, FGD and ECAL detectors agreed so far to use this DB.

The collaboration between the DPNC and the DINF (Departement d'Informatique) in Geneva University is essential to achieve this project and support. The University of Geneva (DINF) hosts an Oracle 9i DB with an Oracle Application Server (OAS 10g) which is installed on SUN machines. The main features of such DB are:

- Storage in a single and central place information on items, assemblies, tests and calibration data
- The data integrity and in a secure place
- Management of a large volume of data with appropriate time response on queries
- Secure accesses from anywhere in the world
- Open ability of DB for any report utilities
- Scalability of the data structure and therefore adequate when new test data storage is requested

![Figure 22: Data Base structure and line borders for users and developers](image)

Given the numerous activities and the wide possibility of data storage, an organisational structure has been proposed into the collaboration to allow an efficient scalability of the future needs in term of test and calibration data.

As originally scheduled, the first user DB accesses to a core data structure were delivered to the collaboration at the end of January 2007 with 2 types of tools.
- web access modules to visualize, insert, update the records
- java upload application for massive data insertion of items

The accesses are so far restricted to items and people information, but implementation of future access tools are either in progress or on schedule.

The serial number is the key identifier which also defines the uniqueness of an item. This identifier is used as a primary key in the structure of the DB and is related to the item, the assembly, the test and the shipment information. This serial number will follow a semantic rule where the last 7 digits numbers are free for each registered institute. For batch item like screws or SMD components which are not defined as unique, a global serial number will be used. Bar code printings are proposed with DMILL code 128 and, allow identifying each item either on its body, or on its packaging.

4 T2K experiment: measurement of particle production in the NA49 apparatus at CERN

Since the T2K beam line, partly because of the very high foreseen intensity, comprises no device suited for absolute flux normalization, a measurement of pion and kaon particle production by 30 GeV protons on Carbon (the T2K conditions) would be highly beneficial to the experiment. This can be done using the NA49 apparatus at CERN. A proposal\(^{13}\) to this effect was submitted in November 2006, and discussed at the SPSC on the 6\(^{th}\) of February 2007. The Swiss groups, and University of Geneva in particular, have played a leading role in the promotion and writing of the neutrino-related part of the proposal. These measurements are of crucial importance for some of the measurements to be performed by the T2K experiment already in the first few years, and a first proton run capable of providing a first set of data for T2K was recommended to take place already in fall 2007 and approved at the CERN research board on the 21\(^{st}\) of February 2007. A full description of the research plan for NA49 T2K and a description of the benefit to T2K of the measurement, can be found in the associated FORCE request.

A FORCE request of 125 kCHF in collaboration with the Bern and ETHZ groups addresses only the Swiss groups contribution to the 2007 run of NA49 future, for which resources are needed in september 2007. We plan to submit another common FORCE request in september 2007 addressing extensively the other contributions.

TPC readout upgrade

A significant task is the design and construction of prototype electronics for the upgrade of the NA49 TPC readout. The Swiss groups are collaborating with the KFKI Research Institute for Particle and Nuclear Physics in Budapest in the design and production of prototype electronics for the upgrade of the TPC readout system.

The TPC readout system comprises a total of 182,000 pads. The TPC readout electronics was developed about 15 years ago and is based on relatively old technology. The maximum
readout speed is around 10 events / second. In order to achieve the event rates and statistics required for the physics program outlined in the NA49-future proposal we have to increase the TPC readout speed by a factor of 10 at least.

In the meantime the technology has progressed offering significantly larger bandwidths. Two scenarios are presently under study:

1. replacement of all the digital data handling part downstream of the front end electronics (Figure 23);
2. replacement of all TPCs electronics (including the front end).

In the present configuration, 24 front end cards are read out serially, one after the other. Each front end card has 32 channels and is directly connected to the pads of the TPCs readout chambers. The FE cards comprise a charge amplifier, a shaping amplifier, a capacitor storage array, and an ADC for each channel. These FE cards could be readout in parallel increasing significantly the readout speed. In this scheme, existing front end cards are used and the properties of the chamber readout are preserved, using the same sampling and digitization clock frequency. A newly designed mother board (MB) with one or more FPGAs on board will organize the readout of 24 FE cards in parallel and build the data structure. Pedestal subtraction and zero suppression will be performed by this board. Several MBs will be connected to a data collector board (CB), which will provide the interface to the detector data link system (DDL) developed for the ALICE experiment at CERN. With this upgrade we can achieve a readout rate in excess of 50 Hz. An additional factor of 2 will be gained by reducing the sampling frequency of drift electrons from 100 ns to 200 ns. A total of 200 MB and 8 CD is foreseen. The total cost of the upgrade is around 500.000 CHF. Additional details, including the cost estimates, are given in the proposal, pages 49 to 52.

![Figure 23: Logic scheme of the proposed readout – scenario 1. FE: Front-end electronics card, MB: mother board, CB: data collector board, DDL: detector data link.](image)

In the second scenario, all the TPC electronics could be replaced by the ALICE TPC readout electronics based on the ALTRO chip and the DDL system. Some minor modifications of the ALICE system, however, are required, in particular the ALTRO FE card has to fit to the NA49 geometry. With this upgrade a readout rate in excess of several kHz could be
achieved. To cope with these rates, however, the readout of all NA49 components need to be upgraded. To implement this scheme, a total of 1400 ALTRO cards are required. Their readout will be organized by 48 readout control units and 48 DDL links. A first estimate of this upgrade, based on existing electronics, places it between twice and thrice more expensive than the first scenario, however it is clear that further study could potentially reduce it substantially.

During the 2007 run both options will be tested. Two sectors of a MTPC will be equipped with prototype electronics, the first one with the upgrade NA49 electronics (scheme 1), the second one with the ALTRO electronics (scheme 2). That will allow us to extensively test both systems during the 2007 run. A final decision will be made in the fall of 2007. In the first scenarios all the electronics could be ready and installed for the 2008 run, in the second case in 2009.

We plan to actively work on the prototyping of the TPC electronics. For the first solution, it should be foreseen to prototype a few (4) backend cards of the new type, for an estimated amount of 2500.- each. We will equip one sector of a MTPC with 16 ALTRO cards. In order to carry on these R&D projects we consider that an amount of 40,000 CHF will be necessary. This includes purchase of a set of ALTRO front end cards (16 at 800.- CHF each for 12800.-CHF) and the corresponding front end connection card, bus and back end cards and DAQ system (11600.- including some CPUs). We are well equipped to test these electronics first on the EM test bench and then on the NA49 TPC.

5 Future neutrino beams

In spite of the spectacular success of the neutrino physics program in Japan, it is essential to pursue the successful undertakings in accelerator and detector R&D in Europe towards Neutrino Facilities. A. Blondel, M. Campanelli and A. Cervera have been involved with the studies of various options leading to several publications34, 35, 36, in the framework of the ECFA working groups for future neutrino facilities (chaired by A. Blondel) or of the network BENE (Beams for European Neutrino Experiments)

Two main possibilities (Figure 24) have been identified: one is the low energy option with a superbeam+betabeam coupled to a very large detector such as a water Cherenkov or a Large Liquid Argon detector; the second being a neutrino factory based on a muon decay ring, coupled with a large magnetic detector.
The low energy (around 300 MeV) conventional neutrino beam could be produced from a high power, low momentum proton driver, such as the Superconducting proton linac under consideration at CERN, pointing to e.g. the large underground Fréjus laboratory, where the possible excavation of a large cavern (capable of hosting a 1 Megaton detector) is being studied jointly by France and Italy.\textsuperscript{37}

The next step, that could aim at the same detector, could be a ‘beta-beam’ in which radioactive nuclei such as $^6\text{He} \rightarrow ^7\text{Li} \, e^- \bar{\nu}_e$ and $^{18}\text{Ne} \rightarrow ^{19}\text{F} \, e^+ \nu_e$ could be stored and produce low energy beams of pure electron neutrinos or anti-neutrinos.

Finally the SPL would also be an adequate (but not unique) solution for a proton driver for a muon based Neutrino Factory, which is recognized as the ultimate tool for the study of neutrino oscillations as well as a first stepping-stone towards muon colliders. University of Geneva has largely contributed to the definition of this future neutrino program by the original calculations of the superbeam neutrino flux,\textsuperscript{38} of the performance of a large water Cherenkov detector in this beam and in the beta-beam,\textsuperscript{39} as well as for the evaluation of the capabilities of neutrino factories,\textsuperscript{40} in particular for what concerns the precision in the determination of the neutrino flux or the possibility to use both signs of muons.\textsuperscript{41} This has led to many invited conferences.\textsuperscript{43}

Following an encouraging prospective study in 1998, a Neutrino Factory Working Group was created in 1999 by the CERN management. The neutrino factory was stated as one of the possible options for the future of CERN and the R&D for high intensity proton sources and neutrino factories explicitly described in the medium term plan of May 2001.\textsuperscript{45} This program made significant contributions leading to a CERN-baseline design for a Neutrino Factory.\textsuperscript{46}

In 2003, ECFA recommended the creation of a European network of Accelerator R&D, which was approved under the FP6 program Integrated Infrastructures under the acronym of CARE. (Coordinated Accelerator Research in Europe). University of Geneva is the university node for Switzerland, which also encompasses University of Bern, Neuchatel, and...
Zurich. The main activity in which we are involved is the definition of future neutrino beams and experiments for Europe, (BENE\textsuperscript{47}).

Under sponsorship of ECFA and BENE we organized a workshop on the possible use of a Multi Megawatt proton driver at CERN 25-27 May 2004, the proceedings of which we edited\textsuperscript{48} and submitted to the CERN SPS committee, for his meeting of 22-28 September in Villars, where in particular the physics case for the Neutrino Factory was presented\textsuperscript{49}. The committee stated that “Future neutrino facilities offer great promise for fundamental discoveries (such as CP violation) in neutrino physics, and a post-LHC construction window may exist for one such facility to be sited at CERN” and recommended that ‘CERN should support the European Neutrino Factory initiative in its conceptual design’; this statement was endorsed by the CERN Scientific Policy Committee.

Following these encouragements, it is now important to prepare a powerful bid for a Design Study proposal under the European Commission’s Framework Plan 7 (FP7). This preparation is the main aim of the International Scoping Study for a future precision neutrino facility, (ISS)\textsuperscript{50}. The study was launched at the occasion of the NUFAC'T05\textsuperscript{51} workshop, in which A. Blondel gave the physics summary talk\textsuperscript{52}. A. Blondel is responsible for the study of detectors for future precision neutrino oscillation experiments. We organized a successful workshop at CERN 22-24 September 2005. The ISS will be concluded on a meeting at CERN March 29-31 2007. The report is in preparation\textsuperscript{53}, and will be issued at this occasion. Some important results have been obtained:

1. the preliminary study of the feasibility of a megaton water Cherenkov detector has been presented. It appears that such a detector would be feasible, by combining 5 200 kton caverns. The cost for 3 such caverns has is been evaluated to about 500M€.

2. It appears that a much improved detector design for the neutrino factory could be feasible using the NOvA liquid scintillator approach interspaced with magnetized iron plates, leading to a good acceptance down to a muon momentum of 2-3 GeV/c instead of the previously achieved 5 GeV/c. This improves considerably the expected performance of a neutrino factory.

3. Matter effect uncertainties have been demonstrated to cause limited uncertainties at the level of 2% systematics.

4. Low energy cross-section effects, and in particular the effect of the final state lepton ass have been investigated. The nuclear effects, (Fermi motion and binding energy) cause changes with respect to the free nucleus calculation of as much as 12% -- a number on which a systematic error still needs to be calculated.

5. near detectors and beam instrumentation: the measurement of the beam divergence has been identified as a clear issue and a beam Cherenkov with very low material budget has to be designed. In addition the design of the near detector station and the associated shielding needs to be investigated with appropriate simulation.

The participation of UNIGE in these studies is an integral part of the neutrino programme supported by the Swiss National Foundation and by OFES in its support of the network BENE. The synergy of these studies with the possible luminosity upgrades of LHC was emphasized in the recent work of the CERN-mandated POFPA group\textsuperscript{54} and confirmed by the statement of the CERN direction concerning the LHC luminosity upgrade: “the proposed strategy is to replace the old PS by a new one […] capable of 50 GeV, and to replace the
present linac 2 and the booster by a new injector linac4 and probably a superconducting proton linac (SPL) capable of about 5 GeV and of a large current, [...] appropriate for a neutrino production facility”.

Discussions are ongoing at present to understand how University of Geneva can best contribute to the design study, probably by a study of the beam instrumentation in close contact with CERN. Meanwhile we are contributing in an important way in the study of muon cooling with MICE.
6 International Muon Ionization cooling experiment (MICE)

Cooling is an important component of a Neutrino Factory, both in performance and cost. The group is participant in the International Muon Cooling Experiment, the success of which is a crucial milestone in the demonstration of feasibility of a neutrino factory and of Muon Colliders. Alain Blondel initiated the concept of the experiment\cite{55} and was elected in March 2004 spokesperson of the collaboration. As can be seen in Figure 25, MICE consists of a section of cooling channel providing about 15\% reduction of the beam emittance. Since such a small change of emittance is not measurable with standard accelerator diagnostics, we have designed two spectrometers which measure the beam particle by particle during a 1ms long spill. The full description of the experiment can be found in the MICE proposal\cite{56}, Technical Reference Document\cite{57} and web site\cite{58}. A total 40 institutes, including several teams from large laboratories around the world (Fermilab, CERN, Brookhaven, Berkeley and RAL) are participating in this effort.

![Figure 25: layout of MICE, the International muon ionization cooling experiment.](image)
6.1 Status of the experiment

The status of the experiment was recently reviewed in a collaboration meeting organized at CERN by University of Geneva\textsuperscript{59}. The spokesperson’s report gives a summary of the situation\textsuperscript{60}. MICE phase I is now a fully approved and funded project. The collaboration is focused on getting the first beam successfully in summer 2007, and first measurements of emittance in the first half of 2008. Progress can be read from the MICE collaboration meetings, available from the MICE web site. The specific responsibilities of UNIGE are the Trigger System and the Data Acquisition. However our group is also active in the development of the Simulation and Analysis software.

6.2 Optimization of Detector Design

In order to reduce the systematical error on the emittance measurement originating from mis identification of particles it was estimated that only two per mille electron contamination can be accepted while the efficiency for the signal detection should be kept as high as 99.9\% to avoid large bias on the measured sample. The intrinsic impurity of good events is estimated at around five per mille, depending on the central momentum of the beam. Therefore, more than 50\% of the background must be rejected by analysis in order to meet the required purity. However, a higher background rate is expected when the experiment is running in non-flipped magnetic field mode and it has been decided to add a safety factor of 3 on the background content. This translates into a rejection power of at least
85%. Since the beam impurity depends on the momentum, the required rejection power is higher for lower momentum.

Simulation studies performed in 2005 and 2006 at University of Geneva concluded that this performance could not be obtained with the original configuration of particle identification detectors. Due to the high economical cost per performance of CKOV2 and lack of dedicated funding it was scrapped in 2006 and a new, cheaper, calorimeter design with better performance emerged.

The new calorimeter design ( ) consists of one active pre-shower layer, made of scintillating fibers interleaved with lead foils, followed by ten layers of plastic scintillator. The pre-shower layer is identical to the layers used in the original design, the KLOE-Light (KL). Its high density is used to induce electromagnetic showers for electrons and positrons while still sampling the energy in the fibers. The following layers are fully active which allows more precise energy and range measurement.

Due to the relatively low muon momentum in MICE (~200 MeV/c), calorimetric technique alone cannot reach the required electron rejection power. Instead multidimensional fits (neural network) are performed which gives probability density functions shown on Figure

Figure 27 MICE downstream PID showing the tracker followed by the (shielded) time of flight, a lead-scintillator pre-shower detector and a pure scintillator detector. Left: cut-away view; right: side view. (pictures from Rikard Sandstrom using G4MICE.)
The performance of the calorimeter and the associated analysis is between 4.1 and 100 safety factors, depending on momentum, when the calorimeter is used in conjunction with the two trackers and the time of flight counters. It is 2.0 safety factors or better when the calorimeter is used alone. As a conclusion, the performance of the new calorimeter design ranges between good to excellent, for a fraction of the cost of the original design. This work has been summarized in MICE notes\textsuperscript{61} and will constitute the thesis subject of Rikard Sandstroem.

\begin{figure}[h]
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\caption{Left: Probability density functions for muons (signal) and electrons (background) as a function of the normalized neural network output (or “muonness”) with the new design of the Electron-Muon Calorimeter at 200 MeV/c. The two peaks are extremely well separated: 99.9 \% of the muons have muonness larger than 0.70 for only 0.06 \% of the electrons. Right: Probability of having a muonness larger than the abscissa value for electrons (blue) and muons (red).}
\end{figure}

6.3 Trigger and Data Acquisition

There is no need to emphasize the importance of the Trigger and Data Acquisition systems for the experiment. They have to be ready from the very beginning of the experiment. In MICE, the trigger counters (TOF0, TOF1 and TOF2) also provide the precise timing which is an integral part of the (longitudinal) emittance measurement and an ingredient to the particle identification system. They will be built by our Italian colleagues from INFN Milano.

C.6.3.1 Front-End Electronics

The requirements on the DAQ system have been presented in our previous request. The main requirement is to acquire all the information for the ~600 muons traversing the cooling channel in the 1 ms beam spill. The resulting DAQ strategy is to use front-end electronics able to digitize the analog signal in less than 500 ns and to store the digitized data in local buffer memory until the end of the spill, when there is ~1 s to read it out before the next spill\textsuperscript{62}. This led us to choose the CAEN TDC V1290 for the time measurement in the TOF counters. The V1290 has a Least Significant Bit resolution of 25 ps, complying with the required 60 ps resolution on the time of flight measurement. In our previous request we exposed the problem of the charge measurement for which no commercial module complying with MICE requirements was available on the market.

After several tests with cosmic muons and a test with an electron beam at the BTF facility in Frascati, Italy, in July 2006, we have adopted the following solution for the charge
measurement in the TOF and EMCal counters: The analog signal from the photomultipliers will be send to a RC shaper-amplifier which is producing an analog signal considerably stretched in time. This signal will be send to the CAEN flash ADC V1724. The V1724 has a sampling period of 100 MHz and a charge resolution of 14 bits. A typical cosmic muon signal recorded in the V1724 after a home made, two stages, prototype RC-shaper is shown on Figure 29 (Left). We have found a very good correlation between the charge measured in a conventional gated QDC and the charge estimated by the maximum amplitude of the shaped signal. Moreover, we have observed no significant difference in energy resolution between the two methods.

An additional advantage of this technique is that it gives also information on the time of arrival of the signal. The resolution on this time measurement has been estimated by looking at the time difference between the signals collected at the two ends of a scintillator slab compared with the same information measured with a conventional TDC. The correlation between the two measurements is shown on Figure 29 (Right). A time resolution of about 600 ps has been obtained with the flash ADC. For the EMCal detector, this resolution is good enough and there is no need for additional TDCs.

Following this decision, we have to equip all the 110 channels of the TOF and the 240 channels of the EMCal with shapers and flash ADC. This represents an additional cost for the TOF counters for which we originally planned to use Constant Fraction Discriminators to correct for the time walk. Our tests in Frascati have demonstrated that this approach doesn’t meet our resolution requirement. The shaper PCB boards are currently being designed by our Bulgarian colleagues. Their production cost also adds to what we had foreseen last year.

In parallel, we are still investigating the possibility of using a custom made discriminator based on the NINO\textsuperscript{63} ASIC developed at CERN, allowing charge estimation from the time-over-threshold of the photomultiplier output signal. This would allow large savings for the TOF counters since they would not require additional charge measurement with the expensive flash ADC.

The Table 2 summarizes our request for the MICE Front End Electronics.

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</tr>
<tr>
<td>80</td>
<td>9000</td>
</tr>
<tr>
<td>100</td>
<td>9200</td>
</tr>
</tbody>
</table>

Time Difference in TDC (ns)

<table>
<thead>
<tr>
<th>Time Difference in TDC (ns)</th>
<th>Time Difference in ADC (sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>0.10</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Figure 29: Left: Typical cosmic muon signal recorded in the V1724 after a home made prototype RC shaper. The bold curve is obtained by fitting the theoretical shape to the data with 5 free parameters being the baseline, the overall normalization, the time of arrival and the two characteristic times of the RC shaper. Right: Correlation between the differences in time of arrival at the two ends of a scintillator slab measured with a conventional TDC and with the flash ADC.
Table 2: Request for the MICE Front End

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost (kCHF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaper boards Production</td>
<td>250 ch</td>
<td>16</td>
</tr>
<tr>
<td>CAEN V1724 flash ADC</td>
<td>112 ch (14 boards)</td>
<td>67</td>
</tr>
<tr>
<td>NINO board R&amp;D</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>TOTAL FEE</td>
<td></td>
<td>90</td>
</tr>
</tbody>
</table>

C.6.3.2 Detector DAQ

The architecture of the Detector DAQ system is reminded on Figure 30. The front end electronics modules reside in VME crates. Each crate is connected through an optical link interface to a PC running Linux, which is collecting the data locally and then sending it to the event builder. The event builder puts together the event fragments collected in the different crates and store the complete events locally. The data is transferred to the remote mass storage unit off-line. An on-line cluster allows monitoring of the data quality and simple analysis on the fly. The DAQ software will be based on the software framework DATE developed for the CERN-ALICE experiment.

![Figure 30: Architecture for the MICE detector data acquisition system.](image)

Last year our request covered the purchase of the VME crates, VME-PCI interface, CPUs, disk space and Ethernet switches required for the implementation of this scheme. Even though the allocated funding was not sufficient to complete the picture we will be able to use other sources of funding to buy the minimum equipment needed to start the experiment in October 2007. This year, we shall request only for the spare parts and the shipment of the DAQ hardware equipment to RAL, including the VME crates and racks, to RAL following the staged installation plan. The Table 3 presents our request for the DAQ system.
Table 3: Request for the MICE Detector DAQ system

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost (kCHF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6U VME crates + power supply</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>VME-PCI interface</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Data Collector PC</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Backbone Gbit switch</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Event Builders</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Shipment</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTAL DAQ</strong></td>
<td><strong>33</strong></td>
<td></td>
</tr>
</tbody>
</table>

C.6.3.3 Trigger System

The trigger system in MICE is extremely simple compared to larger scale experiments. Only one level of trigger has to be implemented since we aim at collecting all the information for all the muons. However, it is important to distinguish between the Particle Trigger which is triggering the digitization in the FEE modules and the DAQ Trigger which is triggering the readout of the buffer memory and the event building. One DAQ Event should contain all the data of one entire spill. The DAQ Trigger should arrive at the end of the spill and is generated by the signal synchronizing the beam with the target and the MICE RF system. It has to be sent to all the VME crates in an Input Register called Trigger Receiver.

The Particle Trigger has to be produced by the passage of a particle through the cooling channel. Four Particle Trigger conditions are envisaged:

- **Burst (Burst Gate)**
- **Beam (Burst@TOF0)**
- **Upstream Particle (Beam@TOF1)**
- **Traversing Particle (Upstream@TOF2)**

The Burst Gate is a logic signal in time with the arrival of a muon bucket coming from the crossing of a proton bunch with the MICE target inside the ISIS synchrotron. The burst gate is about 100 ns wide and is repeating every 324 ns. The TOF$_n$ ($n = 0, 1, 2$) signal is derived from the TOF counters of the $n^{th}$ station. Each station is divided in two crossed planes of 10 (7 for TOF0) scintillator slabs equipped with one photomultiplier at both ends. The TOF$_n$ signal is the logic OR over all the first plane’s slabs of the coincidence of the two photomultiplier of the slab. The selection of the trigger condition will be done by software at the start of run via a VME Output Register.

We plan to reuse CAMAC logic modules available at the University but it requires the production of several signal splitter boards and cable dispatch boxes in order to interface them with the Coax cables from the photomultipliers. Additionally, a VME Scaler unit is required to monitor the ratio between the different conditions independently from the selected one.

The Table 4 presents our request for the trigger system. The Input/Output registers have been already ordered in 2006.

Table 4: Request for the MICE Trigger System

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost (kCHF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VME Scaler</td>
<td>1 + 1 spare</td>
<td>7</td>
</tr>
<tr>
<td>Signal Splitters and Cable Dispatch boxes</td>
<td>110 channels</td>
<td>10</td>
</tr>
<tr>
<td><strong>TOTAL TRIGGER</strong></td>
<td><strong>17</strong></td>
<td></td>
</tr>
</tbody>
</table>
BIBLIOGRAPHY


5 B. Autin, A. Blondel and J. Ellis, Prospective study of muon storage rings at CERN, CERN 99-02 (1999)


CERN-SPSC/2003.027 SPSC-P-325 August 2003
CERN-SPSC/2005-023 SPSC-M-737 June 2005


S. Borghi et al., "Clustering algorithm", HARP-memo 2003-012
A. Cervera-Villanueva et al., *NDC reconstruction & matching with other subdetectors*. HARP Memo 2003-14
http://harp.web.cern.ch/harp/Classified/Private/Memoranda/memo/memo03/memo03-014.pdf

S. Borghi, *Study of Delta p_t in the HARP TPC*, HARP memo 2003-16
http://harp.web.cern.ch/harp/Classified/Private/Memoranda/memo/memo03/memo03-016.pdf


M.G. Catanese et al, (HARP collaboration), *Measurement of the production of charged pions by protons on a tantalum target*, submitted for publication in NIM A

S. Borghi, PhD Thesis


15 See for a recent review, the presentations at NUFAC06 UC Irvine.
S. Borghi, Measurement of the Production of Charged Pions by Low-Energy Protons, D. Schmitz Hadron Production Experiments,
P. Soler Comparison of GEANT4 and Mars Pion Cross Sections with HARP Data,
M. Sorel Neutrino Flux Uncertainties with New HARP Data


21 M. Mezzetto, contribution to NUFAC0T5, hep-ex/0511005.


24 P. Loverre, private communication

TPG Test Results, P. Chimenti et al., IEEE, Nuclear Science Symposium and Medical Imaging Conference, Rome (Italy) October 2004.

27 A. Blondel, P. Béné, A. Cervera, D. Ferrere, F. Masciocchi, E. Perrin, R. Schroeter, T2K ND280 Conceptual Design Report, T2K internal document (attached to this report)


30 J. Bouchez et al, Bulk Micromegas detectors for large TPC applications, Dapnia-07-02, to appear in NIM A. (attached)


33 Study of Hadron production in Hadron-Nucleus and Nucleus-Nucleus production at the CERN SPS, The NA49 Future Collaboration CERN-SPSC-2006-034 SPSC-P-339 (Nov. 3 2006); Addendum (30 January 2007) attached documents.


36 The BENE mid-term report, CERN Yellow report 2006-005

37 A large scale water Cerenkov detector at Frejus, J.-E. Campagne et al.,

38 Study of neutrino oscillations with a low energy conventional neutrino superbeam
M. Donegà, Tesi di Laurea, Università degli studi di Milano, March 2001, matr. 508510

Study of (Anti-)Neutrino Fluxes from a Horn Neutrino Beam Using 2.2 GeV Protons


Why we think we can measure the flux to $10^{-3}$ at the neutrino factory. A. Blondel, NuFact03 (Columbia, June 2003) http://www.cap.bnl.gov/nufact03/WG1/7june/blondel.ppt


A. Blondel, Precision physics at neutrino factories, invited presentation at PAVI04 on Parity Violation and Hadronic Structure, Grenoble 2004, The European Physical Journal A - Hadrons and Nuclei Publisher: Springer-Verlag GmbH Volume 24, Supplement 2 Date: February 2005 Pages: 183 - 186


Invited member of round table panel discussions in NOVE03, HIF04 Elba, NUFAct04, Osaka, Nobel Symposium 2004, BENE04

44 B. Autin, A. Blondel and J. Ellis, *Prospective study of muon storage rings at CERN*, CERN 99-02 (1999)


*Introduction to the Neutrino Factory*, S. Gilardoni ECFA Beam Dynamics Newsletter, No. 29,


47 BENE: Beams for European Neutrino Experiments; [http://cern.ch/BENE](http://cern.ch/BENE)

A. Blondel, *Neutrino Factory: the physics case*, presentation at the SPSC Villars Workshop Sept. 23 2004  
http://agenda.cern.ch/askArchive.php?base=agenda&categ=a043551&id=a043551s911/transparencies

Main ISS web page [http://hep.ph.ic.ac.uk/iss/](http://hep.ph.ic.ac.uk/iss/)


A. Blondel: future neutrino facilities, physics studies and open questions.  
http://www.lnf.infn.it/conference/nufact05/talks/Plenary/Blondel_Plenary.ppt  
Extended version published as hep-ph/0601158.

The ISS detector Working group report (draft) [http://www.cern.ch/accelera/iss_report](http://www.cern.ch/accelera/iss_report)

J. Ellis et al, *Physics Opportunities of Future Proton Accelerators*,  

An International Muon Ionization Cooling Experiment, Goals and preliminary design, A. Blondel, [http://hep04.phys.iit.edu/cooldemo/intcoolex.pdf](http://hep04.phys.iit.edu/cooldemo/intcoolex.pdf)


The MICE Technical Reference Document  
[http://www.isis.rl.ac.uk/accelerator/MICE/TR/MICE_Tech_ref.html](http://www.isis.rl.ac.uk/accelerator/MICE/TR/MICE_Tech_ref.html)

MICE, the International Ionization Cooling Experiment, [http://hep04.phys.iit.edu/cooldemo/](http://hep04.phys.iit.edu/cooldemo/)

A. Blondel ‘State of the experiment and goals of the meeting’  
[http://indico.cern.ch/materialDisplay.py?contribId=4&amp;sessionId=14&amp;materialId=slides&amp;confId=7432](http://indico.cern.ch/materialDisplay.py?contribId=4&amp;sessionId=14&amp;materialId=slides&amp;confId=7432)

Rikard Sandström, *downstream PID analysis MICE* note 164  
Rikard Sandström, *Comparison of two calorimeter designs*, Mice note 146  
