Non-neutrino physics working group summary

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Abstract. This summary covers the physics topics that could benefit from the unprecedented flux of muons produced at the front end of the future neutrino factory. A selection of such opportunities were presented at NuFact02 and their demands on beam properties were evaluated. This summary will survey the rare muon decay experiments and the high precision measurements that could benefit from higher fluxes as well as some of the new programs that could use very large μ^- fluxes. A number of technological developments relevant to the neutrino factories were also discussed.

1. Introduction

The high intensity muon beams which will be developed for the neutrino factory provide unprecedented opportunities in many field of muon research.These fields of science are very active today and are contributing to the ideas behind the development of such high intensity muon sources. As such they represent testing grounds for technologies to be used at the neutrino factories. The physics motivations of these programs are quite enticing today and will provide for the foreseeable future a strong base for muon science. This summary will focus on three main aspects of muon science:

- The rare decay program on lepton flavor violation branches which requires the maximum intensities possible
- the high precision experiments which require a combination of high fluxes but also very specific beam properties.
- novel research presently limited by the low fluxes of specialized low energy negative muons.

A survey of beam properties requirements was made during the meetings of the working group to provide some guidance for the accelerator group designing the front end of the neutrino factory. Some recent developments in muon beam technology were also reported and briefly mentioned at the end of this report.

A survey of several potentially interesting fields of research that could benefit from a super muon source was made last year during a workshop organized by CERN at Trento[1] and whose conclusions were reported at NuFact01 . During the NuFact02 working group 4 sessions ,an attempt was made to update the information gathered in the previous two workshops aiming at providing bench mark requirements for the muon sources to be examined by the accelerator builders at subsequent meetings.

2. Rare decay program

The physics motivation for doing research on rare muon decay processes like $\mu \to e\gamma$, $\mu \to eee$ or μN $\to$ e N conversion has received a considerable boost when it was realized that supersymmetric models naturally induce flavor lepton violation through the slepton sector of the theory. Current experimental upper limits are already placing some constraints on the parameter space of these theories. For a recent review of the field consult the Kuno et al paper..[2] . In a recent turn of events ,it is now possible to induce flavor violation via the Majorana sector of neutrino mass matrix and the prediction for the muon rare decays induced by the coupling to right handed neutrino linked to the observed oscillations in the atmospheric and solar neutrino are within the reach of the current generation of experiments. In Fig 1. predictions for $\mu \to e\gamma$ are given for a range of right handed Majorana neutrino masses needed to get the range of ΔM^2 derived from the solar and atmospheric neutrino oscillation data [3] . However high fluxes of muons are not the only requirements for mounting searches at the level of 10^{-15} or 10^{-17}

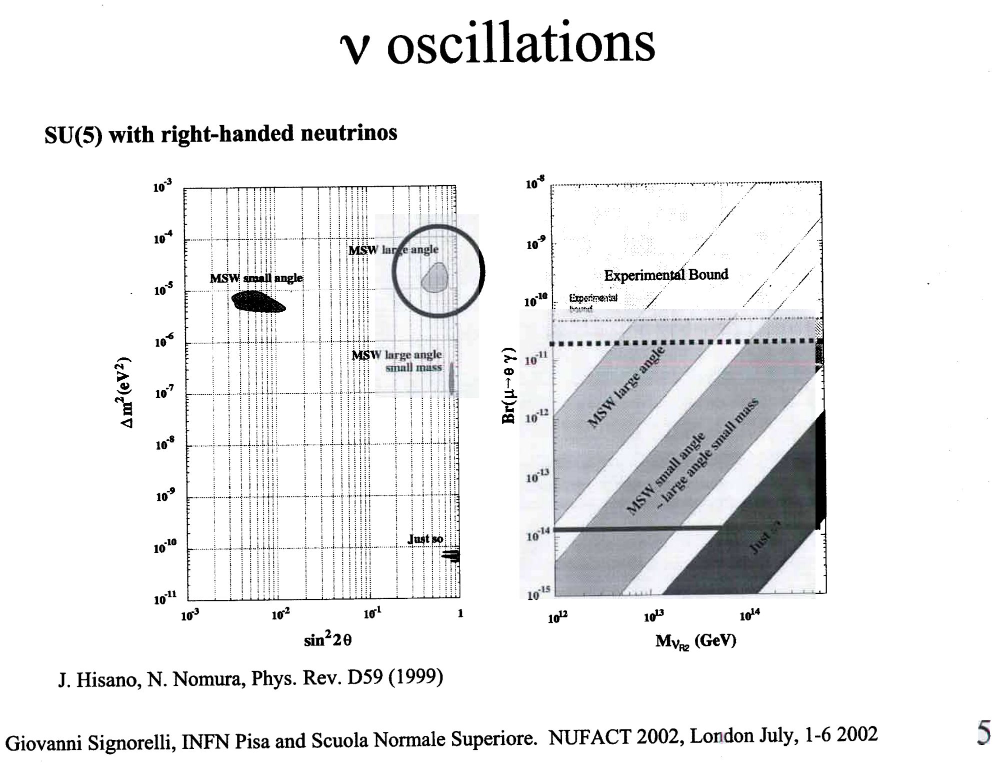

Fig. 1 Theoretical prediction for the $\mu \to e\gamma$ branching ratio for plausible value of righthanded Majorana neutrino mass

branching ratios. To exploit these very large fluxes considerable sophistication must go into the triggering scheme and detector performance both in term of resolution to reduce the background and in terms of data acquisition capabilities. Unlike the situation with neutrino experiments,rare decay searches rely on identifying few events in a large background of events which pass the trigger requirements. Recent ideas about photon detection for example were described during the workshop which are to be incorporated in the PSI search for $\mu \to$ e γ . Photon detection in a liquid Xenon detector promises to give high efficiency,good energy resolution at 50 MeV and tracking capabilities. [4]. The ideas for detecting 105 MeV electrons from μ N $\to$ e N experiments within a narrow energy window are being simulated and will be incorporated in the Brookhaven effort for the MECO experiment[5].

In general, another requirement for these experiments is to have a time structure for the muons arriving at the experiment which matches the muon lifetime (1 to 10 microsec between bursts) allowing for the observation of the decays while proton beam induced background is minimized. Consequently, rare decay searches require intensities in the range of 10^{12} muons/sec, a few percent energy spread to stop the muons in thin targets, and repetition rates in the MHz range.

3. High precision experiments

In a second series of talks, the status of current experiments on precision measurements of muon decay were reviewed: there are two efforts to improve the precision of the lifetime of positive muons,one a RAL and one at PSI. The interest here is to provide parts per million accuracy for the determination of the Fermi coupling constant, G_f. Two complementary determinations of the Michel parameters describing the decaying positron energy and angular distribution on one hand (TWIST experiment at TRIUMF) and its polarization vector components (PSI) on the other hand are starting to produce results. In these efforts, high intensity accelerators are used to provide specialized muon beams with properties tailored to the specific measurements: (beam emittance,beam absolute polarization, time structure to minimize pile-up of muons in the target ,etc..).

The current measurements of the muon lifetime are aimed at reducing the error on τ_μ to 2 picosec which translate on a 1 ppm error in G_f. Two experiments were discussed; the RAL/RIKEN effort at ISIS [6] and the FAST collaborative effort at PSI [8] . A third program is also approved at PSI,the μLAN experiment

These experiments require large data samples (10^{12} events) over 10 muon lifetimes with careful considerations for multiple decays,residual polarization asymmetries and magnetic field induced spin rotations. Tracking and detector segmentations are used to fight the pile up of simultaneous muon decays. Stopped pions as a muon source or careful selection of depolarising target material are used to provide unpolarised muon samples.

The RIKEN/RAL collaboration presented a preliminary evaluation of their data corresponding to a 14 ppm measurement of τ_μ and described the improvements being implemented to reach the 1 ppm goal. The FAST collaboration reported on their plans and described the detector under construction which allows for independent tracking of each muon event.

These measurements rely on very high counting rates and would benefit from a time structure providing sharp beam bunches at a 1 to 100 kHz rate.

The determination of the MICHEL parameters provide a window of opportunity to explore physics beyond the V-A structure of the weak interaction. In the most general derivative free, Lorentz invariant lagrangian formulation,these parameters can be expressed by linear combinations of all coupling constants square which include both righhanded and lefthanded fermions and scalar, vector or tensor interactions. The current knowledge of the Michel parameters and the inverse neutrino electron charge current reaction cannot place severe constraints on the non V-A part of the interaction. This was reviewed by W.Fetscher[7] in the plenary part of the proceedings. The new TWIST experiment at TRIUMF is aimed at providing a 10^{-4} precision determination of the four parameters describing polarized muon decay angular and momentum distribution. This could be used to limit for

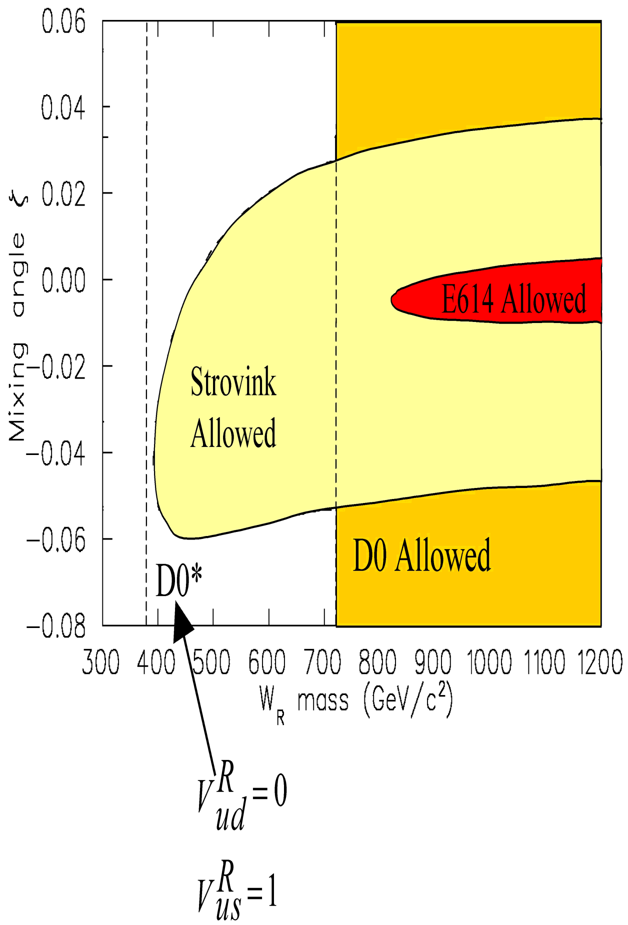

Fig. 2 Limits on right handed W mass and mixing from the TWIST experiment at TRIUMF

example the mass and mixing of the possible right handed sector in left right symmetric model in a complementary way to the direct searches for right handed W at the hadron colliders (CDF,D0) see Fig 2. .

In a join session with the working group on neutrino oscillation theories, Dr. Babu presented a model of anomalous muon decay which could explain the LSND anomaly by allowing a branch to decay to two antineutrino [9]. The model is build to avoid lepton flavor violating decays. A possible signature of such a muon decay branch would be a reduction of the ρ Michel parameter from its V-A value of .75 to .7418 which should be seen in the TWIST experiment.

The TWIST experiment currently taking data at TRIUMF relies on specially prepared muon beam with high polarization, obtained by selecting muon originating from pion decaying on the surface of the production target . The high polarization is maintained during the transport of the muon to a stopping target located in center of a 2T solenoid which contains a set of 52 low mass wire chambers to track the decaying positrons. A 10^{-4} determination of the $P_\mu\xi$ parameter would constraint a righhanded W mass to $\geq$ 700GeV with very small mixing to its lefthanded partner.

The PSI effort focused on the determination of the polarization vector components of the positron, In a recent series of measurement tight constraints have been obtained on P_L the longitudinal component which is 1 in the standard model,P_{T_1} and P_{T_2} which are the transverse components respectively 10^{-3} and 0 in the standard model . P_{T_2} is time reversal violating and a limit was obtained of $1.2 * 10^{-3}$, a unique test of TRI in a purely leptonic system. P_{T_1} can be related to the other parameter η in the positron energy distribution and a new value compatible with zero was obtained: $\eta = 0.0013 \pm 0.0008$

This experiment relied on a high polarization, a short beam burst which was synchronized to the cyclotron frequency and to the larmor rotation of the polarization vector to produce an ensemble of decaying muons in phase with each other.

In these programs of precision measurements of the MICHEL parameters, it is not obvious how the larger intensity of neutrino factories can be use to an advantage.

4. Negative muon program

During the proceedings of the working group, a number of possible programs making use of large fluxes of negative muons were examined. Amongst them muon catalyzed fusion is a field that could be substantially enhanced by the availability of huge fluxes. Muon catalyzed fusion proceeds through the capture of a muon into a molecule with the subsequent fusion of the nuclei involved while the muon is released and can proceed to trigger further fusions during its lifetime. The efficacy of the process depends crucially on the capture probability, the fusion probability of the muonic molecule formed and the release of the muon after fusion.

During the last two decades considerable progress has been made in understanding the basic molecular dynamics involved and resonances have been identified both theoretically and experimentally for example in the D-T system. To go beyond this basic research and identify the optimal conditions which could lead to practical applications will require higher intensities and higher energy muons than are available at the present meson facilities. Dr. K.Nagamine[10] described the concept of fusion reactor vessels which could be used with high pressure mixtures of D-T. To increase the probability of fusions high temperatures and high pressure will most likely be required. Considerable studies of the optimal conditions will have to be done before a break even situation can be envisaged. This was reported by Dr.K.Ishida [11]

Radioactive muonic ions could also be produced and the standard technique of determining the charge radii of nuclei could be available for very exotic nuclei that can be produced at the new radioactive beam facilities. A concept project is under way at ISIS by the RIKEN collaboration using long lived ions that can be delivered to a target in which large fluxes of negative muons can be stopped. By relying on the fast and effective transfer of the captured muons from a light target material to higher Z nuclei, the group is able to observe muonic X-rays of the unstable nuclei [12]. For very short lived nuclei, very intense muon beams will be required.

Muonic atom X-rays are very characteristic of the Z value of the nucleus. The capture probability is itself Z-dependent. This can be use to do non destructive elemental analysis as was demonstrated in a pilot experiment by the RIKEN group at TRIUMF. By combining stopping distribution information from a tracking detector , and high energy X-rays analysis, one can conceive of powerful elemental analysis tool for application in medicine or other field of science.

5. Other applications and new technologies

A further application of the high flux of muons available at the front end of a neutrino factory would be the development of very low energy muon beams which are of considerable interest for the condensed matter programs using the Muon spin rotation (μSR) technique. Currently low energy muons are produced by ionizing a muonium atom either thermally or via laser ionization. Such an intense low energy muon source could also be use at the front end of an accelerator system which would make use of the very small phase space of the source. Considerable improvements are needed to produce intense ultra low energy muons. The current source at PSI is limited to a few hundred muon per seconds[13]. Recent progress has been made toward the development of high acceptance muon channels. The DAI-OMEGA project [14] at the KEK booster delivered its first beam since the last NuFact01 meeting. It is a superconducting axial focusing channel with 1sr solid angle. Several of the ideas considered for the front end of a neutrino factory are embedded in this channel. In particular the operation of a superconducting capture solenoid around a proton target is relevant to the neutrino factory muon source

6. Conclusions

The muon beam requirements of the programs reviewed during the workshop have been summarized in table 1.

It is clear that although fluxes are an important ingredient , the time structure of the beam is often a key parameter to optimize the conditions of the experiments. Those requirements should be considered in the design of the neutrino factory front end and its proton driver accelerator as it could had considerable attraction to users of such muon sources.

Table 1. Muon beam requirements.

process	Q	Inten. $\int_0^{10^7 s}$	pulse width (nsec)	pulse interval ((μsec)	Energy (MeV)	Mom. spread (%)	purity	size	Pol
μN→eN'	-	10^{21}	10-100	1-1000	≤ 20	≤ 10			n/a
μN→eN'	-	10^{20}	10-100	1-1000	≤ 20	3	$10^{-15}(\pi)$	cm	n/a
$\mu \to e\gamma$	+	10^{17}	DC	≤ 1	1	≤ 10	10^{-2}(e)	cm	n/a
τ_μ	+	10^{14}	~ 100	30-100	4	1-10			depol
$\tau_\mu(\pi)$	+	10^{14}	~ 100	30-100	4	1-10			π beam
Michel para.	+	10^{16}	≤ 0.5	$\geq .02$	30-40	1-3			100%
Pol. para.	+	10^{16}	≤ 0.5	$\geq .02$	30-40	1-3			~ 100 %
g-2	+/-	10^{15}	≤ 50	≥ 1000	3100	10^{-2}			pol
edm	+/-	10^{16}	≤ 50	≥ 1000	≥ 1000	10^{-3}			pol
μ-atoms	-	10^{16}	≤ 100	100-1000	1-4	1 to 5	10^{-2} (e)	cm	n a
Life Science	-	10^{15}	1	100-1000	1-4	1 to 5		mm	n a
μCF	-	10^{19}	1	≥ 1000	≥ 100				n a.

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