# Charge separation in a non-magnetic liquid argon neutrino detector

## 1 Introduction

Neutrinos are fundamental particles that have some weird properties: they are much lighter than all other fundamental particles; and they can spontaneously oscillate between 3 distinct flavours. The probability of oscillation is described by 6 parameters – and measuring these accurately is a major research interest worldwide.

## 2 Neutrino factory

•Currently neutrino beams are seen as an important way to probe the oscillation parameters. Current beams are however fundamentally flawed, they involve decaying $\pi^{\pm}$ (pions) which have two decay modes:

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \qquad \pi^+ \rightarrow e^+ + \nu_e$$

The $\nu_\mu$ channel is dominant, however there is always an intrinsic $\nu_e$ contamination in the beam.

•A neutrino factory is a proposed next generation pure beam. It involves instead decaying $\mu\pm$ (muons) with a single decay mode:

$$\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu_\mu}$$

Therefore the beam produced is of well known flavour – 50% $\nu_e$ and 50% $\overline{\nu_\mu}$.

## 3 Detector signal

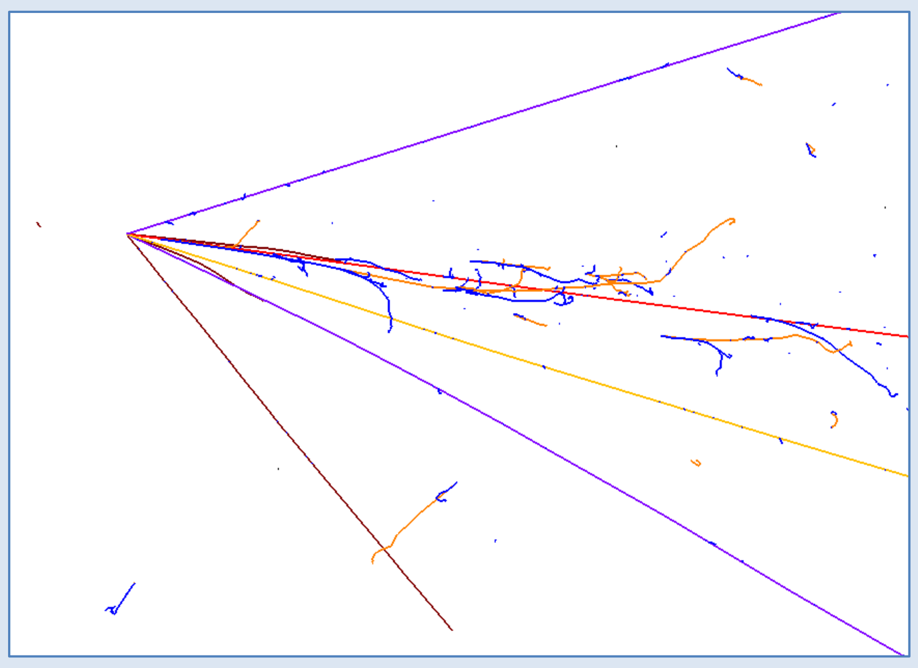
Charged current neutrino reactions in the low energy regime always produce a $\mu$. The main signal from a neutrino factory is a "wrong-sign muon".

$$\overline{\nu_\mu} \rightarrow \overline{\nu_\mu} \rightarrow \mu^+ \qquad \nu_e \rightarrow \nu_\mu \rightarrow \mu^-$$

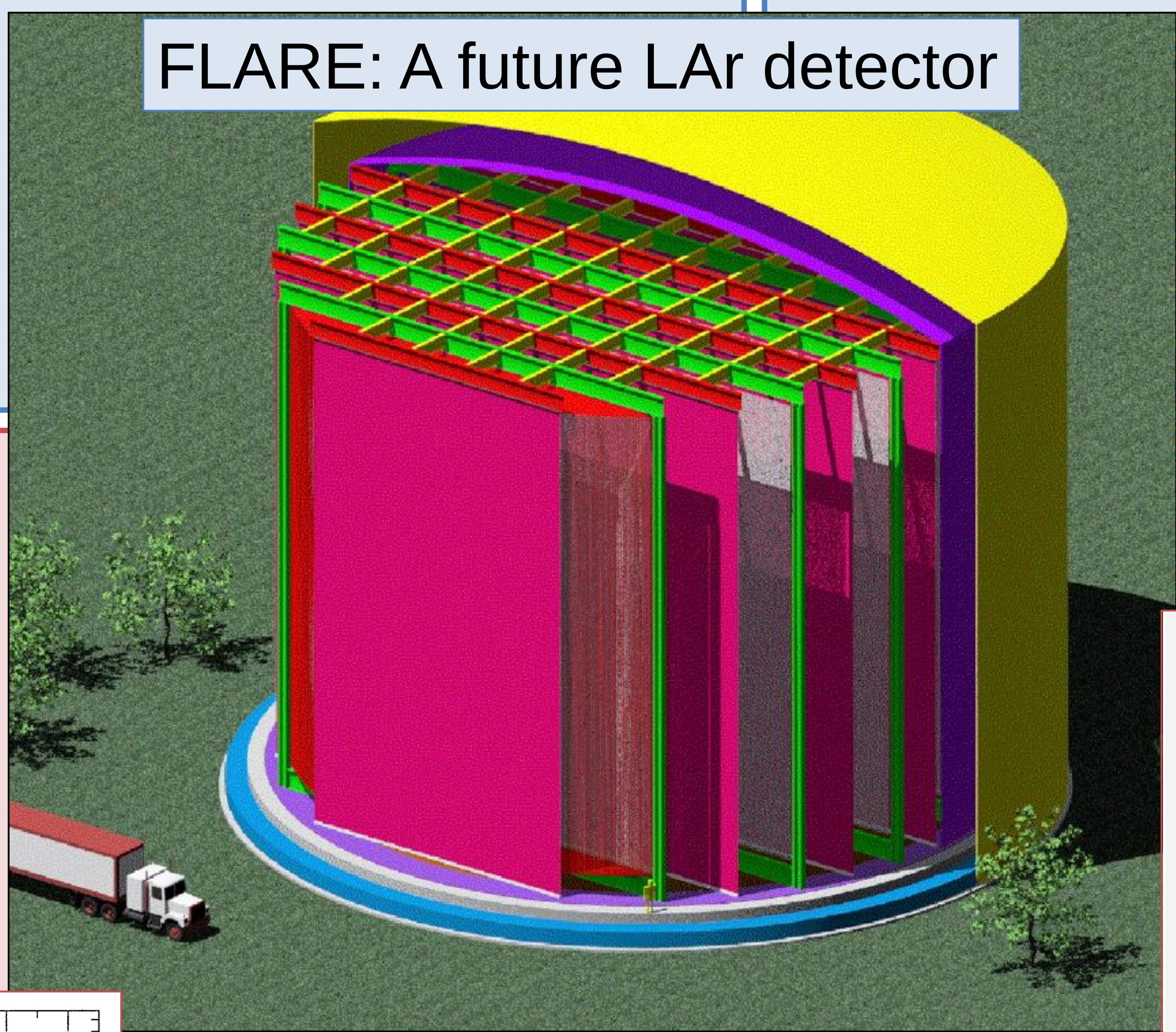
i.e. the electron neutrino oscillates into a muon neutrino while propagating. The muon antineutrino not oscillating over propagation produces "right-sign muons".

## 4 Neutrino detectors

Liquid argon (LAr) is seen as the best detector for low energy (≈1GeV) neutrino factories due to bubble chamber-like properties – particles are tracked along their entire path in 3D. Therefore we get a lot of information about the reaction – path length, direction, energy loss, and particle type.

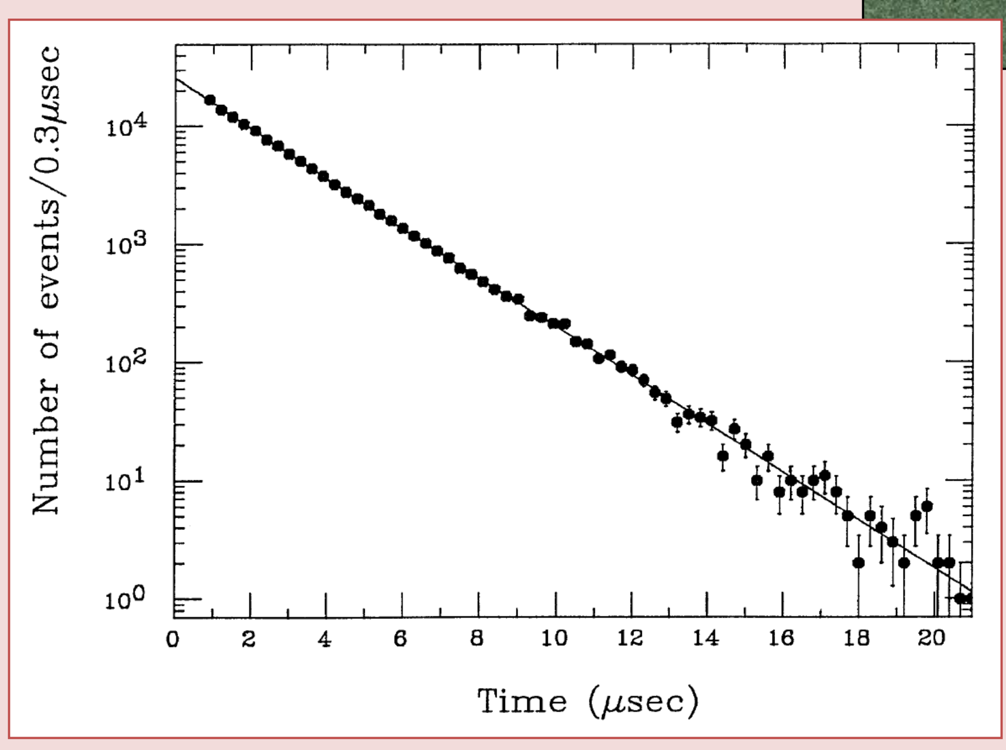


There are however some areas of R&D required. Currently analysis is not computerised; data needs to be looked at by eye. Also momentum and charge separation are usually done using a magnetic field. A big volume of LAr is hard to magnetise, therefore other techniques are required.

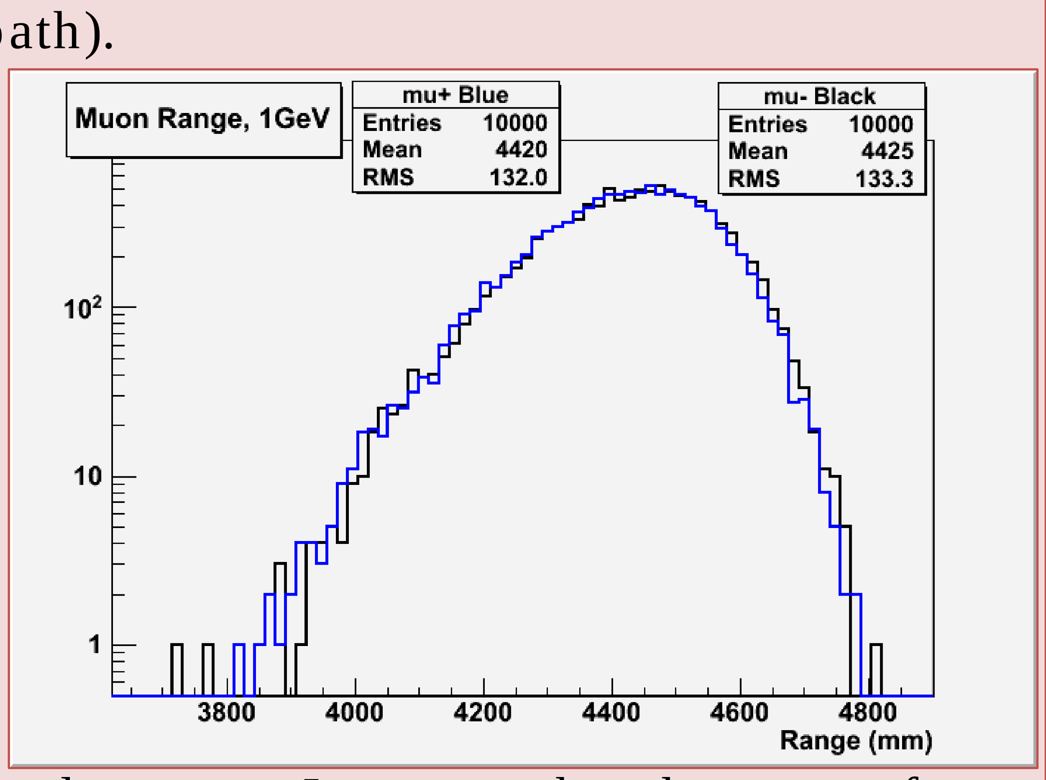



## 5 Muon lifetime

$\mu^+$ and $\mu^-$ behave differently in matter. $\mu^+$ are created in the detector and slow down through collisions, eventually decaying with mean lifetime $\tau_+$. $\mu^-$ also slow down and decay, but some can be captured by the nucleus. Absorbed muons cannot decay. This absorption reduces the apparent lifetime to $\tau_-$. Measuring mean lifetimes produces a sum of two exponential decay curves [1], from which a charge ratio is easily extractable.




LAr detectors have higher spacial resolution than time resolution, and so it was proposed that a plot of muon range would produce the same exponential decay (due to constant energy loss along the majority of the path).

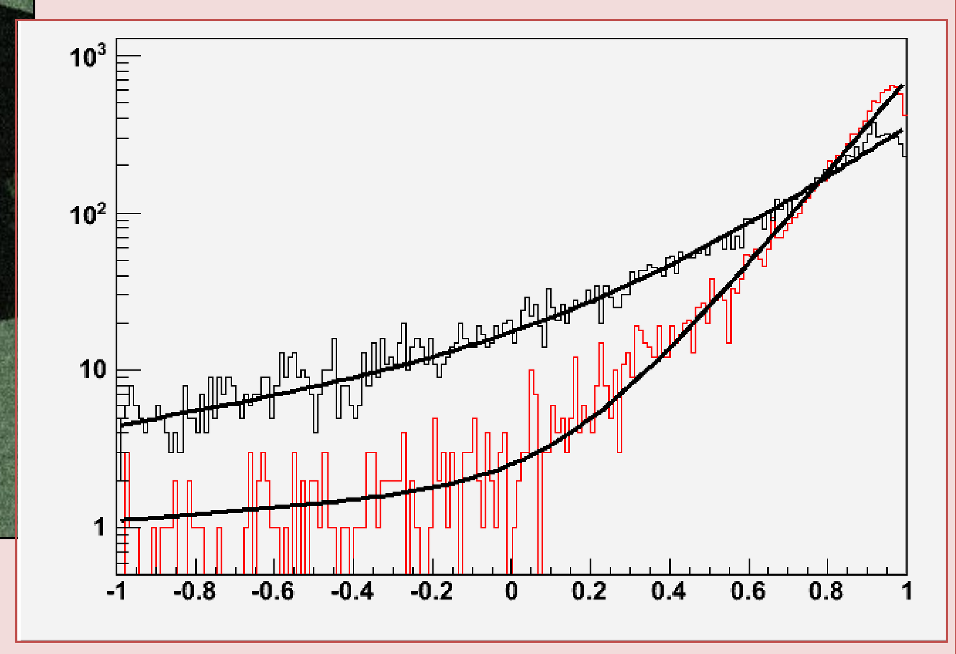



These results from a GEANT Monte Carlo simulation show that muon range is not a possible way to produce charge separation in LAr detectors. I propose that the reason for this is that LAr is an excellent muon stopper, and so all muons have negligible energy before they either decay or are captured.

## 6 Angular distributions of muons

Charged current quasi-elastic (CCQE) scattering is an important process at 1GeV energies and below:

$$\nu_\mu + n \rightarrow \mu^- + p$$
$$\overline{\nu_\mu} + p \rightarrow \mu^+ + n$$



The $\mu^+$ from $\overline{\nu_\mu}$ is produced almost exclusively in the forward direction (cosθ>0). The results are from the GENIE Monte Carlo simulation. The histograms have been shown to be statistically inconsistent across the whole angular range, meaning charge separation will be possible

## 7 Other possible methods

These have been used in the past for other detectors, but not yet simulated in LAr.

•**Nucleon tagging.** CCQE events usually emit the reacted nucleon (n or p) from the nucleus. If this nucleon is detected, we know about the parent neutrino. No data available for intranuclear effects in LAr. For example, elastic scattering of the nucleon in the nucleus, causing the wrong nucleon to be emitted.

•**Charged pion lifetime in matter.** Similar to muon lifetime, $\pi^+$ decay always, while $\pi^-$ can be captured by the nucleus, reducing their apparent lifetime. No LAr data available for $\pi^-$ absorption.

•**Angular distribution of neutral pions.** Similar to CCQE muon distribution. $\pi^0$ are produced in two types of process, coherent (nucleus left in ground state) and resonant (nucleus left in excited state). The angular distribution of $\pi^0$ for these two process is different, and so they should be able to be separated.

## 8 Conclusions

Charge separation in a non-magnetic LAr detector is possible to some degree. Further work is required to see which methods (and combinations of methods) will give the best results for the ratio of wrong-sign to right-sign muon. The work shows muon lifetime differences do not translate into the spacial domain in LAr. Also, the angular distribution of muons in CCQE events is promising.


**References**

[1] M. Yamada *et al.*, *Phys. Rev. D* ***44****, 617 (1991).*

[2] L. Bartoszek *et al.*, FLARE letter of intent, arXiv:hep-ex/ 0408121v1.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