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Focal plane detector optical readout

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Abstract. A preliminary study of an alternative solution for the optical detection and tracking of the ions in the MAGNEX focal plane detector for the NUMEN project is presented. The tracks of the ions are sampled by means of the light that they produce through a scintillating gas, which is collected by arrays of Silicon Photo Multiplier suitably arranged. A complete Geant4 simulation is under development in order to correlate detector geometry, characteristics of the gas and light collection efficiency. Fast timing performance could be achieved through a completely digital (on-off) read-out system of the light sensors and a position reconstruction algorithm.

1. Introduction

The nature of the neutrino, if it is a Dirac or Majorana particle, is an open question in nuclear and particle physics. The NUMEN project aims to answer this question looking for lepton number violation in double beta decay [1, 2, 3].

The already obtained results indicate that suitable information can be extracted from heavy-ion induced Double Charge Exchange (DCE) reactions [4]. The MAGNEX large acceptance spectrometer [5, 6] of the INFN-Laboratori Nazionali del Sud (LNS) is of fundamental importance for high resolution measurement of reaction channels with very low cross section (in order of few nb). But, in order to explore cases of interest for $\beta\beta$ decay, an upgrade of the LNS Superconducting Cyclotron (CS) is planned to increase beam current about two orders of magnitude [7, 8].

In order to keep track of the foreseen high rate, a major upgrade of the present detection system is also mandatory. The main limitations come from the MAGNEX Focal Plane Detector (FPD) [9], with a sustainable rate of about 5 kHz. The NUMEN project R&D phase sets for the substitution of the present FPD gas tracker with a tracker system based on micro-patterns gas detectors (MPGD).

This paper describes a preliminary exploration of a solution based on purely optical tracking of the ions at focal plane and digital readout of the signals produced in the light sensors, alternative to the MPGD system.

2. The optical readout

2.1. Design of the detectors

The detector is schematically designed as a series of light sensitive rings that surround the gas chamber of the FPD, see figure 1. The chamber is filled with a suitable scintillating gas or gas mixture which produces scintillation light during the passage of charged particles. Each ring is composed of a sequence of four linear arrays of square Silicon Photo Multipliers (SiPMs). In front of each SiPM is placed a collimator in order to reduce its field of view as shown in figure 2. The internal walls of the collimator could be made reflective to improve the photon collection efficiency.

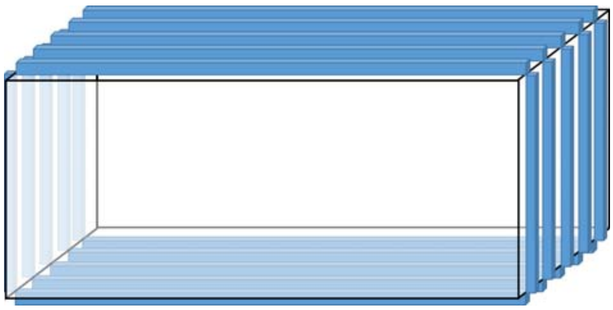


Figure 1. Sketch of the detector. The inner box represents the gas chamber whereas the elements that surround it stand for the light sensors arrays. The dimensions of the gas chamber are $150(\mathrm{l}) \times 20(\mathrm{h}) \times 15(\mathrm{w})\,\mathrm{cm}^3$.

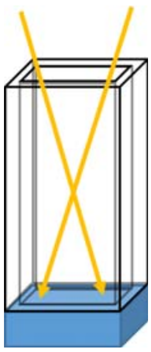


Figure 2. The box on the bottom represents a SiPM coupled with a collimator of which only the edges are drawn to show the light rays that reach the sensitive surface of the sensor.

2.2. The digital readout

The digital readout procedure consists in recording only light sensors which are hit by the scintillation light, without counting how many photons reach each sensors. In practice, it could be considered equivalent to a measure of the width of the light cone over a sensitive array. Starting from this measurement on two facing arrays, a geometric reconstruction algorithm can find the coordinate of the ion on the plane passing through the two arrays.

The optical readout solution is under investigation because it could give some advantages, compared with standard solutions for ions tracking like drift chambers, such as:

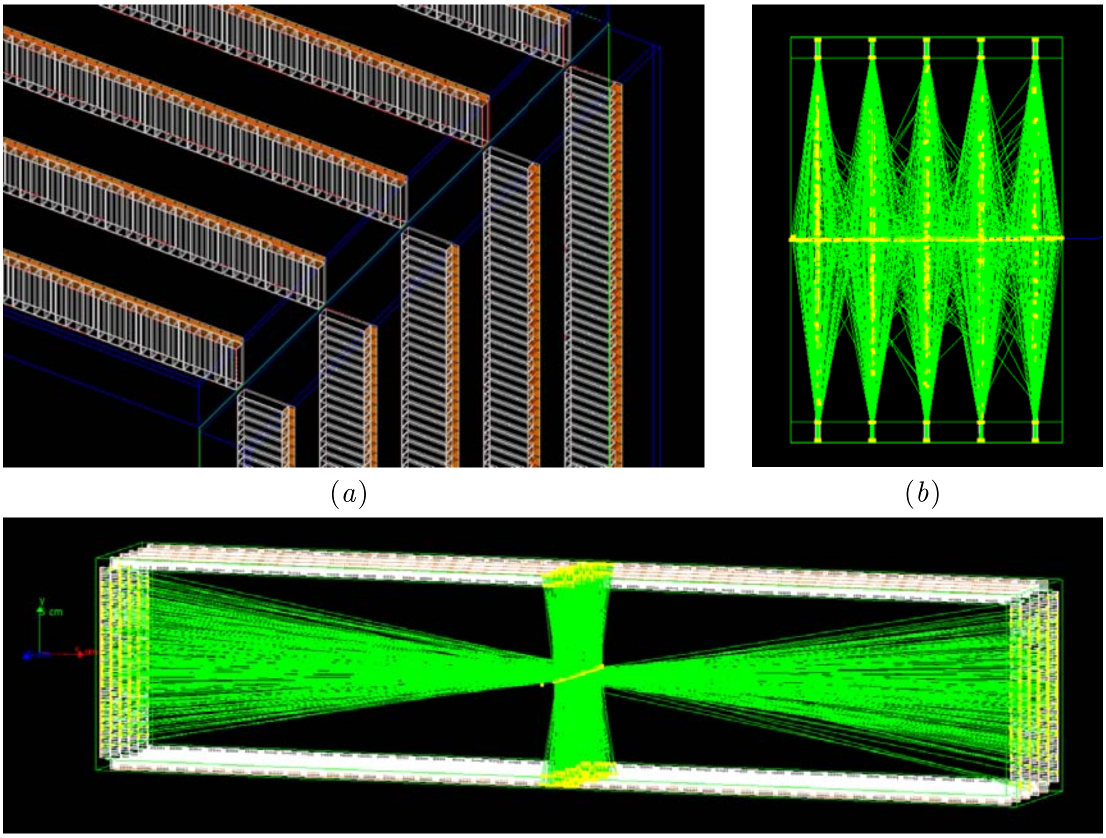
- low operating voltages limited to SiPMs bias;
- high uniformity due to no electric field distortion;
- high spatial resolution of a few hundreds microns;
- high counting rate up to a few hundreds of MHz;
- reduced data stream.

These last two features will be achieved only if the information needed to accurately reconstruct the position of the ions can be obtained by a fully digital readout of the SiPMs.

3. Geant4 simulation

To verify the feasibility of an optical tracker with these characteristics and to study its performance, a detailed Monte Carlo simulation is under development by means of the Geant4 toolkit [10, 11]. Figure 3 shows some screenshots acquired during the debugging phase.

The parameters of the simulation are: (i) type and pressure of scintillating gas; (ii) number, size and position of the SiPMs; (iii) collimator size and its optical properties. These parameters determine the luminescence spectrum and the photon yield of the gas, the energy loss and angular straggling of the ions and the geometric photon collection efficiency at the light sensitive surfaces.



(a) (b)

(c)

Figure 3. Figure a shows the arrangement of light sensors (orange) and collimators (white frame) on a corner of the gas box that represents the FPD volume. Figures b and c show the scintillation photons produced by an α particle of 5 MeV traversing the FPD filled with CH_4 at 25 torr. Photons are radiated isotropically, but it is possible to display only that ones which hit any of the SiPM.

3.1. Preliminary results

Once the number of rings has been chosen, the first step of the simulation is to calculate the angular straggling and the energy lost by the ions. Figure 4 shows an example for 1000 α particles of 5 MeV passing through 150 mm of CH_4 at a pressure of 25 torr.

4. Conclusions and outlooks

The idea of a new detector with optical readout is described as alternative for the FPD of the NUMEN experiment and preliminary results of the simulations are reported. The next

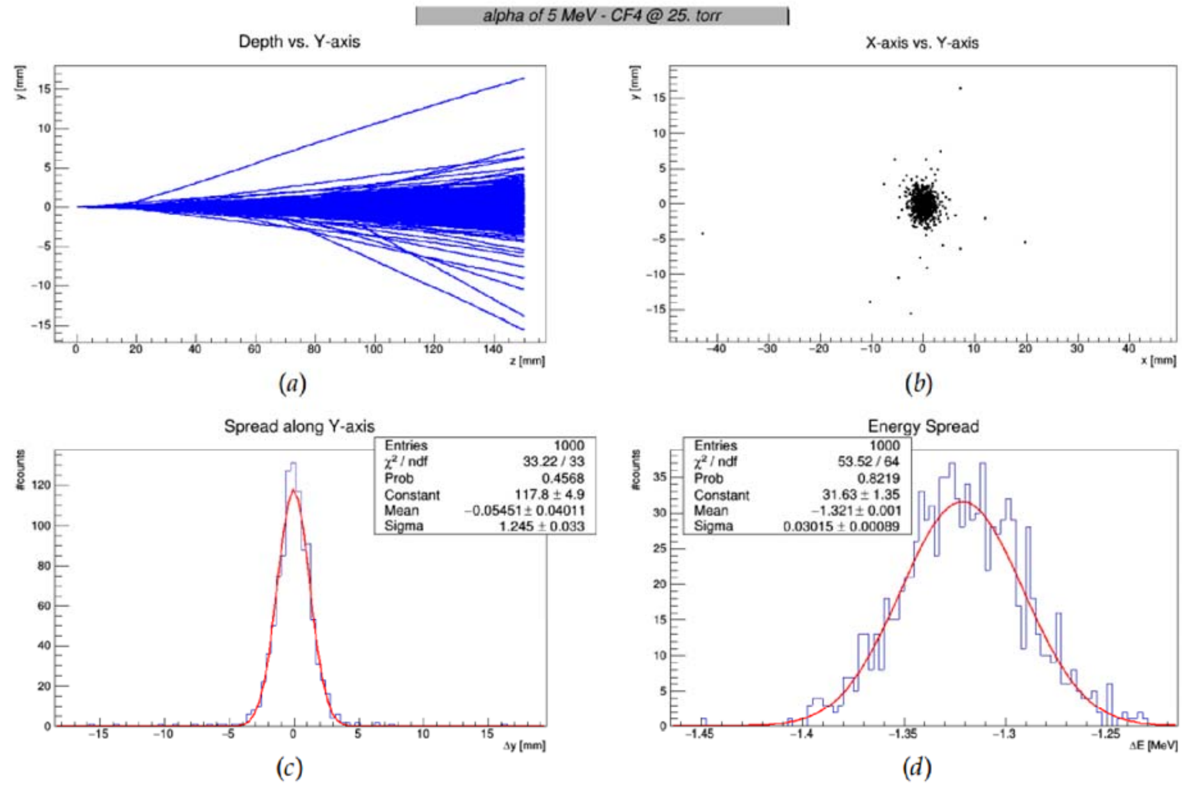


Figure 4. The upper part of the figure shows as the beam spread traversing the gas along z direction: (a) is a side projection showing the spread along vertical direction y; (b) is a plot of the beam spot on a plane at z $= 150$ mm perpendicular to the propagation direction of the ions. The bottom part of the figure shows an histogram of the beam spread along y direction at the exit of the beam (c) and an histogram of the energy loss after traversing the gas chamber (d).

steps of this work include the study of detector performance with ions involved in the reaction channels of interest for the NUMEN project, such as double β decay, finding the best parameters to maximize the number of photons collected, and the implementation of the algorithm to reconstruct the position of the ions through the detector. This simulation platform will help to design other detectors with similar requirements which could be of interest in many field of particle identification. If the first promising results of the simulations are confirmed, a prototype will be built to confirm performance.

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