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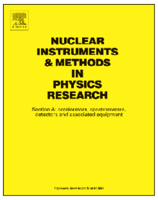

Development of an extremely thin-wall straw tracker operational in vacuum – The COMET straw tracker system

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ABSTRACT

The COMET experiment at J-PARC aims to search for a lepton-flavour violating process of muon to electron conversion in a muonic atom, μ-e conversion, with a branching-ratio sensitivity of better than 10^{-16}, 4 orders of magnitude better than the present limit, in order to explore the parameter region predicted by most of well-motivated theoretical models beyond the Standard Model. The need for this sensitivity places several stringent requirements on the detector development. The experiment requires to detect the monochromatic electron of 105 MeV, the momentum resolution is primarily limited by the multiple scattering effect for this momentum region. Thus we need the very light material detector in order to achieve an excellent momentum resolution, better than 2%, for 100 MeV region. In order to fulfil such a requirement, the thin-wall straw-tube planar tracker has been developed by an *extremely light* material which is operational in *vacuum*. The COMET straw tracker consists of 9.8 mm diameter straw tube, longer than 1 m length, with 20-μm-thick Mylar foil and 70-nm-thick aluminium deposition. Currently even thinner and smaller, 12 μm thick and 5 mm diameter, straw is under development by the ultrasonic welding technique.

1. Introduction

A *Lepton Flavour Violation* (*LFV*) among charged leptons, e.g. $\mu^+ \to e^+\gamma$, $\mu^- N \to e^- N$ processes etc., which has never been observed while the quark mixing and the neutrino oscillations have been experimentally confirmed, is attracting a great deal of attention, since its observation is highly expected by most of well-motivated theories beyond the Standard Model [1]. It is predicted that $\mu^- N \to e^- N$ is naturally causable with a branching ratio just below the current upper limit, $10^{-13} \sim 10^{-16}$, by leading theories for physics beyond the standard model. (see Ref., e.g. [2,3], for a review). The ambitious goal of the *COMET* experiment (*CO*herent *M*uon to *E*lectron *T*ransition) [4] is searching for a $\mu^- N \to e^- N$ process with an improved sensitivity by at least four orders of magnitude over the present best upper limit on a $\mu^- N \to e^- N$ branching ratio of 7×10^{-13} reported by the SINDRUM-II collaboration [5].

The event signature of μ-e conversion in a muonic atom is a monochromatic single electron emitted from the conversion with an energy of $E_{\mu e} = m_\mu - B_\mu - E_{\mathrm{recoil}}$, where m_μ is the muon rest mass, B_μ is the binding energy of the 1*s* muonic atom, and E_{recoil} is the nuclear recoil energy which is extremely small and thus negligible. Since B_μ depends on nuclei $E_{\mu e}$ varies, e.g. $E_{\mu e}$ is 105.1 MeV for Al.

The most of electron backgrounds coming from muon-stopping target is the Decay In Orbit (DIO) electron, $\mu^- \to e^- \nu_\mu \bar{\nu}_e$. The energy spectrum of electrons from muon decay has a sharp falling edge at the kinematical end-point, namely 52.8 MeV which is a half the muon rest mass. However the electron from muon DIO can have a higher energy than this end-point up to ~105 MeV as a long tail due to the recoil effect of the nuclear field [6]. In order to suppress this background, an excellent momentum resolution, i.e. better than 200 keV/c at least, is required. For this momentum region, the momentum resolution is primarily limited by the multiple scattering effect, and hence the suppression of material amount of the detector component is essential. In order to fulfil this requirement, *the extremely thin-wall straw chamber which is operational in vacuum* is employed, i.e. ultimately low material tracker is realized.

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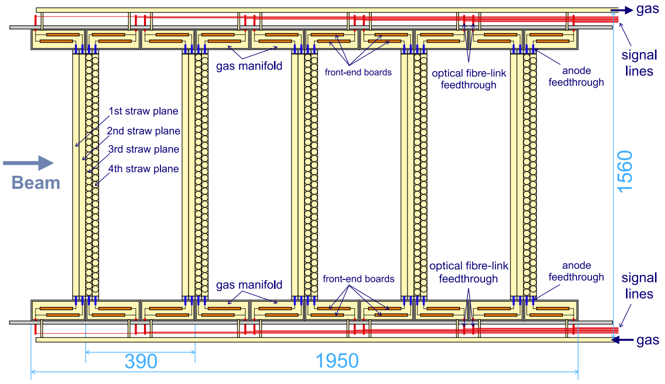

Fig. 1. Schematic view of the straw tracker.

2. Straw tracker

The tracker consists of five tracker super-layer, so-called “station”. Each tracker station consists of four straw-tube planes; x_1 and x_2 for measuring the x-coordinate and y_1 and y_2 for measuring the y-coordinate, respectively. Each pair of planes are staggered by half a straw diameter to allow local resolution of left-right ambiguities. The total thickness of tracker is less than $0.004X_0$ since the straw-wall thickness is extremely thin, 200 μm, and the gap between each stations is vacuum. The design of straw tracker is schematically shown in Fig. 1. Each station is constructed as a stand-alone unit and mounted on the detector frame which is inserted and removed from the solenoid on rails. Anode wires, made of gold coated tungsten, are extracted via a feedthrough into the gas manifold as shown in Fig. 1. A gas manifold is implemented in the outer border of straw-tube volume which is just inside the detector solenoid. For the COMET straw tracker, the gas manifold does not only provide the gas supply but it also makes the tracker to be operational in a vacuum, since the gas manifold contains the front-end electronics and the high voltage (HV) supply lines so that the electronics parts are put in the chamber active gas to avoid any discharge probability and rising temperature in a vacuum. A default gas mixture of 50%-Ar and 50%-C_2H_6 is provided from this gas manifold to the straw tube. An alternative gas mixture is under investigation using the prototype detector.

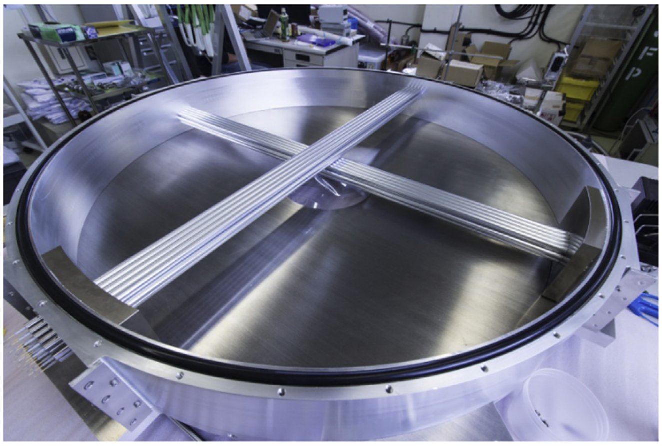

Fig. 4. Picture of full scale prototype.

3. Straw tube

There are mainly two methods to provide thin wall straw for a particle detector, namely “doubly wound” and “straight adhesion”. The doubly-wound type of straw is composed by a double layer of spirally over-woven straws of metalised polyimide film, e.g.

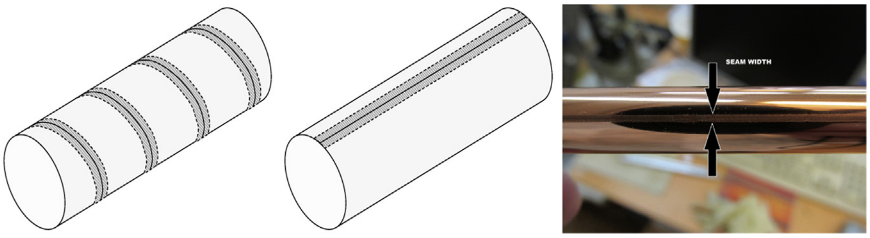

Fig. 2. Different adhesion styles of straw construction; (Left) the original doubly-wound style, (Centre) the new straight-adhesion style, (Right) the welding seam of a completed straw.

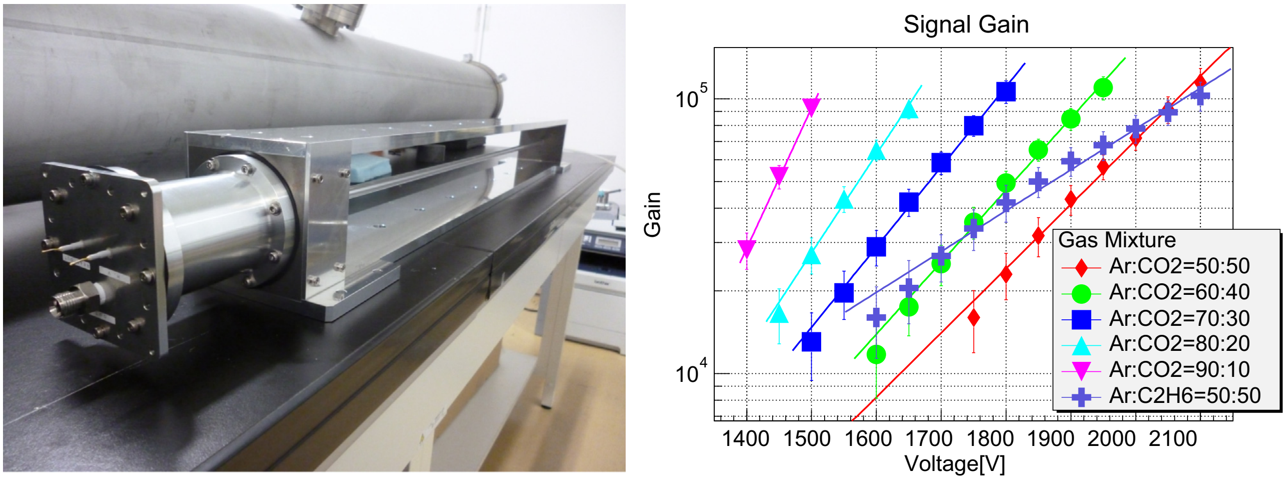

Fig. 3. One straw Prototype; (Left) Photo, (Right) Obtained gas amplifications with different gas mixtures as a function of applied HV.

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