THE COHERENT MUON TO ELECTRON TRANSITION (COMET) EXPERIMENT. *

A. Kurup, Imperial College London, UK

Abstract

The COherent Muon to Electron Transition (COMET) experiment aims to measure muon to electron conversion with an unprecedented sensitivity of less than 1 in 10 million billion. The COMET experiment was given stage 1 approval by the J-PARC Program Advisory Committee in July 2009 and work is currently underway towards preparing a technical design report for the whole experiment. The need for this sensitivity places several stringent requirements on the beamline, such as, a pulsed proton beam with an extinction level between pulses of 9 orders of magnitude; a 5T superconducting solenoid operating near a high radiation environment; precise momentum selection of a large emittance muon beam and momentum selection and collimation of a large emittance electron beam. This paper will present the current status of the various components of the COMET beamline.

INTRODUCTION

The COherent Muon to Electron Transition (COMET) experiment [2] aims to measure the conversion of muons to electrons in the presence of a nucleus. This process is forbidden by the Standard Model (SM) of particle physics. However, models that go beyond the SM such as supersymmetric theories predict this process to exist with a branching ratio that may be in the range 10^{-13}–10^{-15} [1]. COMET aims to achieve a sensitivity of 10^{-16} and thus will be able to observe conversions at this level.

It is vital that the beamline and detector components are carefully designed since achieving such a high sensitivity requires stringent rejection of background events. In addition, the beamline and detector components are intimately connected, unlike traditional particle physics experiments, and so an integrated approach needs to be taken when simulating the experiment. Figure 1 shows the layout of the COMET experiment. A proton beam is used to produce pions, which are then captured and transported by a series of superconducting solenoids. The pions decay into muons as they travel along the muon transport channel. The toroidal field of the muon transport channel selects muons with negative charge and momentum less than 75 MeV/c. The muon stopping target slows the muons down until they are captured in nuclear orbit by a nucleus in the target. A muon could then convert into an electron, with a momentum of around 105 MeV/c, or it could decay normally producing an electron with lower momentum. The electron spectrometer selects electrons of interest, collimating off electrons not of interest at the exit of the spectrometer. The momentum and energy of the electron is then measured by the tracker and calorimeter, respectively.

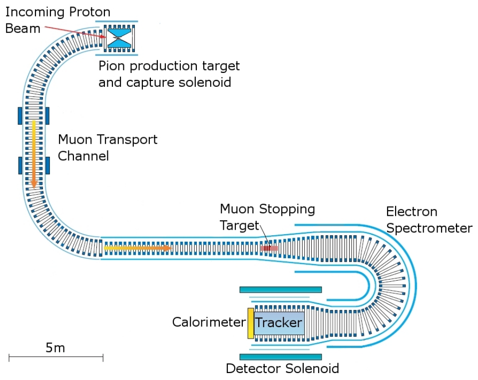

Figure 1: Schematic layout of the COMET experiment.

A conceptual design report (CDR) was submitted to the J-PARC Phyics Advisory Council and was given stage-1 approval in July 2009. Work is currently underway towards producing a technical design report (TDR) and the aim is to complete this by the end of 2010. This paper summarises the design presented in the CDR and progress made towards finalising the design for the TDR.

PROTON BEAM

COMET plans to use an 8 GeV, 7 μA, slow-extracted proton beam from the J-PARC main ring (MR). A method for producing the required time structure of the proton beam was presented at EPAC'08 [3]. Currently, there are two bunching configuration options for the operation of the RCS and the MR, see Figure 2. The figure on the left shows the RCS in h=2 with one bucket filled, and the MR in h=8 with four buckets filled. The figure on the right illustrates operation of the RCS in h=1 and the MR in h=4 with all buckets filled. The latter option is expected to give a better performance as there are no empty buckets for protons to leak into. However, this option requires significant changes to the RF system and so might not be realistic if beam is shared with other experiments.

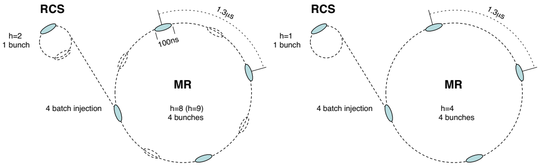

Figure 2: Bunching configuration with RCS h=2 and MR h=8 on the left and RCS h=1 and MR h=4 on the right.

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* Presented on behalf of the COMET collaboration.

Recent work has focussed on the development of the proton extinction device used to reduce the fraction of protons outside of the pulse to 10^{-9}. The intrinsic extinction of the J-PARC MR is 10^{-7}, which means an additional device is needed to reduce this further by a factor of 10^{-2}. The design described in the CDR consists of two AC dipole magnets with a collimator between them. The magnets have a peak field of 600 G and oscillate at a frequency of 385 MHz. The development of this AC dipole extinction device was done in collaboration with the Mu2e experiment.

PION PRODUCTION

The CDR design for the pion production target utilises a heavy metal target to maximise the pion yield for 8 GeV protons. Three materials are being considered, gold, platinum and tungsten. Simulations of pion production were done using a gold target. Figure 3 shows the momentum distribution of forward–going and backward–going pions. Since the backward–going pions are less contaminated by high–momentum pions it was decided to only collect pions going in the backward direction. A 5 T superconducting solenoid is used to collect the backward–going pions. This solenoid has to operate in a high radiation environment so tungsten shielding fills most of the inner bore to protect the superconducting coils of the magnet. The inner bore of the magnet design in the CDR was 1.0 m. However, radiation damage simulations done since then have lead to the inner diameter of the bore to be increased to 1.3 m. Work on the development of the capture solenoid is presented here [4].

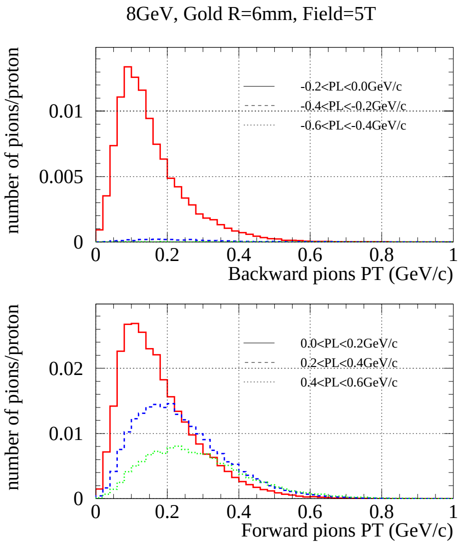

Figure 3: Transverse momentum distribution for backward–going and forward–going pions.

MUON TRANSPORT CHANNEL

The muon transport channel is needed to provide a channel long enough to allow pions to decay into muons and to provide charge and momentum selection. A C–shaped bent solenoid transport channel (see Figure 1) is used composed of two 90 ° bends joined by a straight solenoid. The dispersive drift of the bent solenoid allows charge and momentum selection. In order to keep particles with the reference momentum in the centre of the transport channel an additional vertical dipole field is required. This can be done in a cost–effective way by tilting the solenoid coils. However, post–manufacturing tuning of the dipole field is restricted with this method. An investigation into how this limitation may be overcome was presented at LINAC08 [5]. An alternative technology choice for producing the dipole field is to use an additional winding on top of the solenoid windings that has a current distribution that follows $cos(\theta)$. A prototype of this design has been constructed for the MUSIC project at Osaka University.

The design presented in the CDR uses 2 T superconducting solenoids for the muon transport channel. However, this leads to a rise in the magnetic field just before the stopping target. The current design uses a field of 3 T, which eliminates this bump and increases the number of stopped muons. The results of this study is presented here [6].

MUON STOPPING TARGET

The muon stopping target is designed to slow down muons and eventually stop them in the target material. The muons can then undergo nuclear capture and conversion into an electron, via interactions with the nucleus, could occur. The choice of material for the stopping target defines the lifetime of muonic atoms. For COMET the target material is chosen to be aluminium. The stopping target is composed of 17 Al disks, 100 mm in radius and 0.2 mm thick. The magnetic field varies from 3 T at the end of the muon transport channel to 1 T at the entrance of the electron spectrometer, see Figure 4. This field gradient improves the acceptance of conversion electrons in the detector. Simulations studies are underway to optimise the geometry of the stopping target.

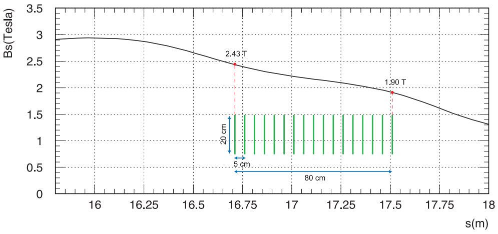

Figure 4: CDR configuration for the stopping target showing the graded magnetic field over the region.

ELECTRON SPECTROMETER

The electron spectrometer is designed to transport electrons from muon conversion or normal decay. The main source of background electrons is from muons that decay after nuclear capture, which are called decay in orbit

(DIO) electrons. Electrons from muon conversion have a momentum around 104.7 MeV/c whereas DIO electrons have a broader range of energies, see Figure 5. The tail of the DIO spectrum extends up to the kinematic endpoint of 104.97 MeV/c, but the number of DIO electrons with a momentum > 104 MeV/c is negligible.

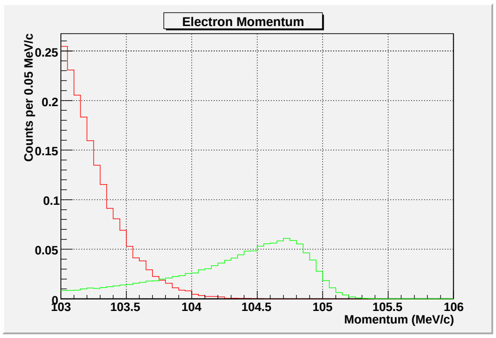

Figure 5: Electron momentum spectrum for electrons from muon conversion and decay in orbit electrons. Both spectra correspond to 10^{20} stopped muons, which is 100 times more that the expected muon yield. The branching ratio for muon to electron conversion used was 10^{-16}.

The vertical dispersion of the toroidal field of the electron spectrometer allows lower momentum DIO electrons to be removed by placing an aluminium collimator at the end of the channel. Figure 6 shows the vertical position of electrons from muon conversion and DIO electrons after passing through the electron spectrometer. By placing a collimator that extends from 20 cm below the median plane it is possible to remove electrons that have a momentum < 60 MeV/c, thus reducing the rate in the detector systems.

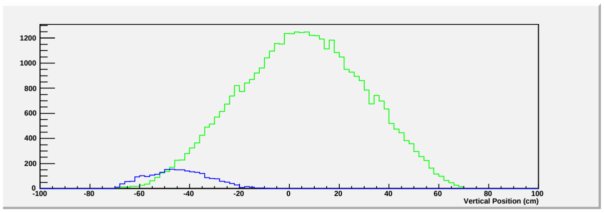

Figure 6: Vertical position of electrons from muon conversion and DIO electrons after passing through the electron spectrometer.

DETECTOR

Tracker

The purpose of the tracker is to measure the momentum of electrons with high precision, in order to distinguish those that come from conversion and those that come from a background process, e.g. DIO. These are relatively low momentum particles and are easily scattered so the amount of material the electrons see has to be as low as possible. The tracker also needs to withstand a charged particle rate of 800 kHz and a photon rate of 8 MHz. In order to meet these requirements, a straw–tube tracker was proposed in the CDR. This consists of five transverse straw planes 48 cm apart, operating in a 1 T solenoid field. Each plane has two (x, y) arrays of straws, rotated by 45 °, to provide a redundant measurement.

Calorimeter

The calorimeter is required to measure the energy of the electrons and provide a timing signal to trigger events of interest. It should also provide additional position information which can be correlated with the track measured in the tracker. These requirements lead to the need for a highly-segmented calorimeter with a fast response time. A number of inorganic scintillator crystals were considered in the CDR, with Gd_2SiO_5 (GSO) being the favoured choice. For GSO, the calorimeter will be segmented into 3x3x15 cm^3 crystals (about 11 radiation lengths long) covering an area 55 cm in radius, which requires 1056 crystals. Recent studies have looked at using Cerium-doped Lutetium Yttrium Orthoscilicate (LYSO) instead of GSO. The readout of the calorimeter also needs to operate in a 1 T magnetic field, which excludes the use of low-noise, high-gain phototubes. Multi–pixel photon counters are best suited for this application as they offer the benefits of high gains and fast response times and can operate in magnetic fields.

SUMMARY

In order to achieve the unprecedented sensitivity of 10^{-16} all aspects of the experiment needs to be carefully simulated; combining both beamline simulations and detector simulations. Several design options for the different components were presented in the CDR. Since then a number of changes have been made and work towards finalising the design is underway with the aim of producing a TDR by the end of 2010.

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