The COMET Muon-to-Electron Conversion Search Experiment

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Background

COMET (Coherent Muon to Electron Transition) is an experiment undergoing development that will seek to discover **charged lepton flavour violation (CLFV)** by looking for a neutrinoless decay of a muon in orbit of an aluminium atom into an electron. Any decays would result in a electron of a constant energy value of 104.8 MeV, and a detector will be set up to look for electrons of this exact energy.

Experimental Phases

The COMET experiment is planned to take place in multiple phases, ending with Phase-II. Prior to this a much simplified Phase-I that will only cover up to the end of the first 90° bend will take place, this will start taking data looking for muon to electron decays as well as providing data necessary for the design on Phase-II. Prior to Phase-I an even more simplified phase-α will take place.

Phase-α

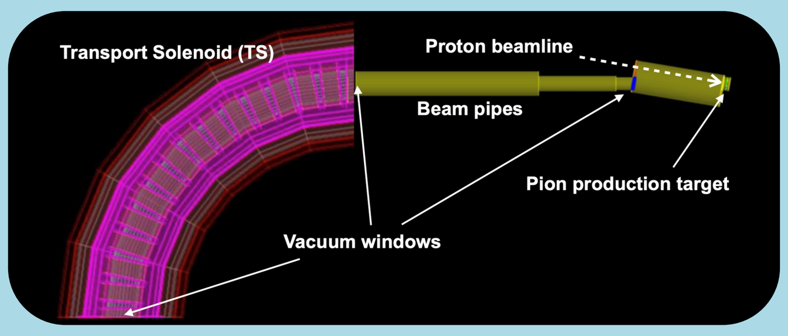


Figure 1: Pion production and transport sections of Phase-Alpha [1]

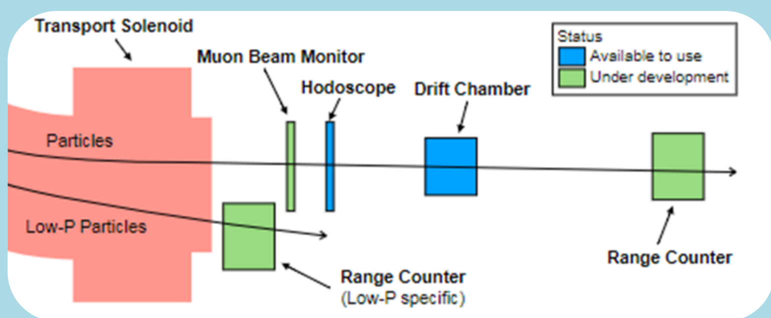


Figure 2: Layout of the detector setup that follows from Figure 1 [2]

Phase-α has the main goal of testing the pion production and transportation equipment as seen in Figure 1. To analyse the particles produced and their location, there will be 4 detectors in the main beam line: a Muon Beam Monitor, Hodoscope, Cylindrical Drift Chamber, and a Range Counter as shown in Figure 2. From these it will be possible to obtain information about the particles in the beam line, but only for particles that pass through and are recorded by all detectors will this be complete.

Aims

This project aims to optimize the detectors' positions so that as much useful data as possible can be gathered whilst phase-α runs. To this end we aim to:

- Determine a good 'Figure of Merit', F, a measure of how good a detector position is
- Create an analyser that calculates F when provided with simulated data for a given detector position
- Computationally determine F for a large variety of detector positions and analyse this data to find its maximum and thus the optimal experimental setup

Figure of Merit

To quantitatively compare detector positions, we need to evaluate what aspects make a good/bad detector position and scale them appropriately. This can change between detectors, with variables changed, included or removed, but the general formula is:

$$F = \frac{m^{\lambda_1} + p^{\lambda_2}}{n^{\lambda_3}}$$

m and **p** are the numbers of 'useful' muons and pions that hit the detector respectively. To be considered 'useful', a muon or pion must be detectable, and hit all detectors.

n is the number of 'noise' particles that hit the detector, particles that aren't muons or pions, and may interfere with the detector's readings.

The $\boldsymbol{\lambda_i}$ are used to scale these values, and F is the value produced

Methods

1. Multiple simulations of the Muon Beam Monitor (MBM) were done, each spaced by the monitor width and the data was collated to give us a view of the total muon distribution as seen in Figure 3
2. Run an analyser that predicts the values of F for MBM positions across the detector's Y/Z plane, according to the step 1's dataset.
3. From this data, find the best 20x20mm region and run a series of intensive (every 1mm grid point) simulations over this area to find the optimum position for the Muon Beam Monitor.
4. Update the simulation file with this new detector position and proceed to move on to the following detector, repeating the previous steps.

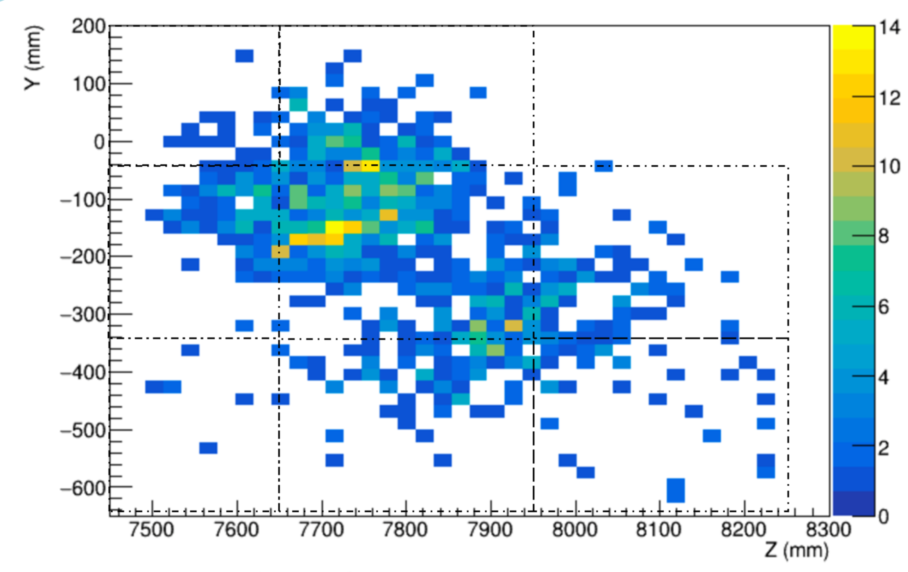


Figure 3: Number of muon hits at the MBM region. Grid lines mark individually simulated MBMs

Preliminary Results

Figure 4: Frequency of useful muons in detector at centre points of MBM

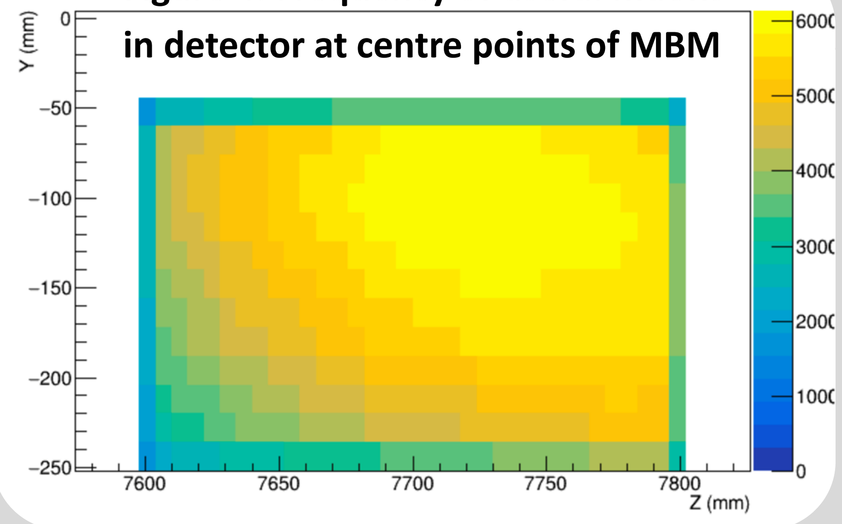
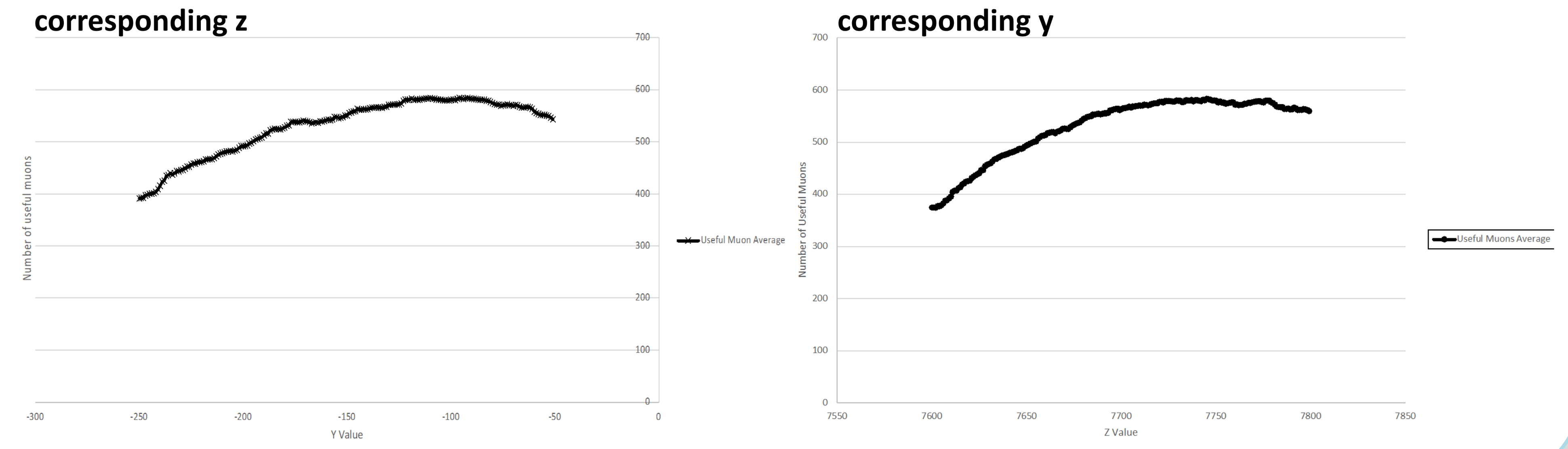


Figure 4 above shows the number of useful muons (m) that hit the detector as a function of the position of the centre of the Muon Beam Monitor. The joint peak has a value of 642 at −112mm(y) , 7724/7725mm(z), pion value of (p) 145/144 and number of noisy particles (n) 8999/8970 respectively.

Figure 5: Useful muons vs y averaged across corresponding z

Figure 6: Useful muons vs z averaged across corresponding y



Due to the broad peaks in Figures 5 and 6 we can conclude that a search as precise as done for the Muon Beam Monitor is unnecessary for the required accuracy with regard to the optimisation of the positions of the rest of the detectors. This was corroborated upon discussion with the head of the phase-α team.

References:

1. COMET collaboration, Status of COMET Phase-α Study, January 2021
2. COMET collaboration, Status of COMET Phase-α Study, January 2022