MuScat Report - the Muon scattering experiment.

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Abstract. The MuScat experiment for measuring the multiple scattering of muons in low Z materials at momenta relevant to the cooling channel of a muon accelerator is described.

An engineering run in Triumf in 2000 suffered from problems with the delay line chambers, and a new tracking detector, a 3 layer scintillating fibre detector which can be seen as a parent of one of the MICE tracker options, has been constructed. First performance indications are given.

1. Introduction

The Muscat experiment (E875) at Triumf is designed to measure the multiple scattering of muons of momenta up to 200MeV/c. This process has never been measured, and it is very important for the optimal design of a cooling channel for a neutrino factory or muon collider. The motivation is discussed in section 2.

The history, status and prospects are also described herein.

The project is a collaboration involving people from CERN, UCLA, Birmingham, RAL, Oxford and Imperial College, London.

2. Motivation

The preparation of a beam of muons for a neutrino factory or collider is likely to rely upon ionization cooling[1] to prepare the muons for acceleration. This entails passing the muons through matter to reduce their p_T and p_L through de/dx losses, and then subsequent re-acceleration, restoring only the p_L. This cooling process is counteracted by multiple scattering, which warms the beam by adding random components to the p_T. It is probably best performed at momenta around 200 to 300 MeV/c.

The design of the cooling channel is a complicated affair, with a choice to be made between liquid hydrogen, which provides the best cooling but requires containment and safety windows, and possibly a heavier element which might require less additional material. This compromise, and the details of the layout, require an accurate knowledge of the cooling and warming effects of the different materials if it is to be made optimally.

There is no relevant data on the scattering of muons. Figure 1 shows the scattering of electrons in low-Z materials, with the prediction of Moliere theory overlayed. The

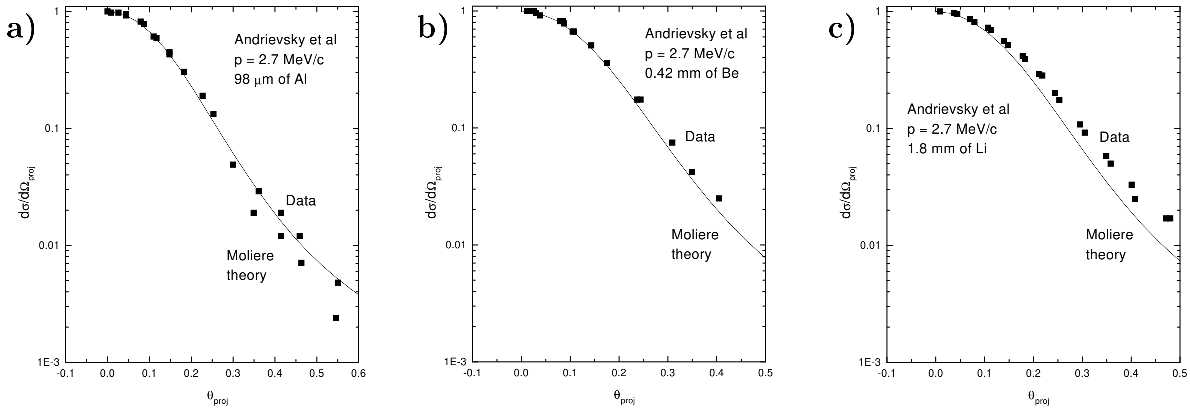

Figure 1. Measurements of the scattering distribution for electrons, from 1942.

agreement is not overwhelming, especially for Lithium, and it can be argued that the disagreement is growing as the Z of the target material drops, which motivates checking this.

Multiple scattering is, of course, calculable. The calculations are not completely trivial, because the screening of the nuclear charge by the electron cloud requires an accurate knowledge of the wave-function for H_2, or whichever molecule is used, and in a liquid this is not the same as the wave-function in vacuum.

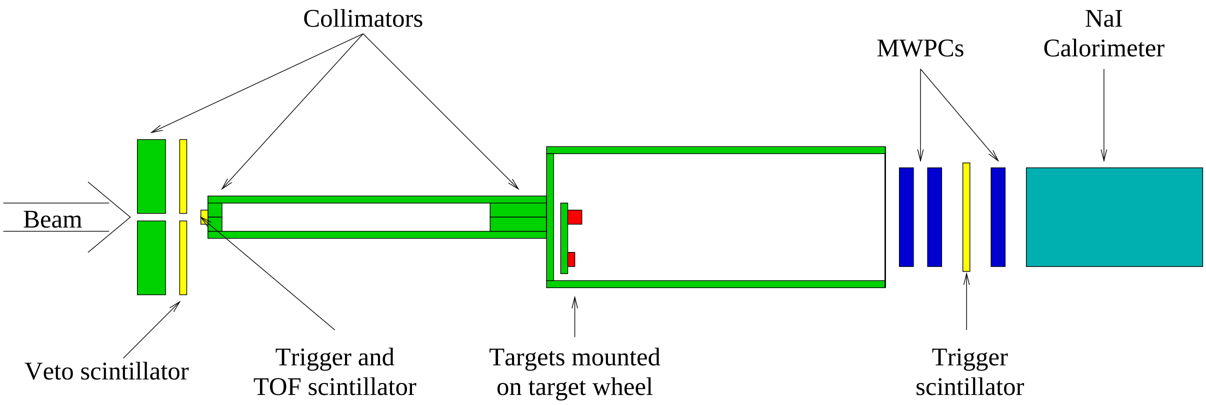

Figure 2. The MuScat apparatus, as run in 2000. The MWPC's have been replaced by a scintillating fibre tracker.

A cartoon of the apparatus to measure the multiple scattering is shown in figure 2. There are two defining collimator slits, each of 2 mm in height, separated by 1 m. An assortment of targets can be rotated into the beam at this point, and then s further metre is allowed for the beam to diverge, allowing a single measurement of position to yield a deflection angle. The NaI calorimeter, Mina, is a facility of the Triumf laboratory, used by the experiment while data-taking.

3. History

The initial intention for the experiment was to check the multiple scattering of muons using the beams available at Rutherford Appleton Laboratory, which have a momentum up to about 100 MeV/c. At these low momenta, the scattering in whatever measurement system was used to characterise the beam is significant, and it was decided to use a collimation approach instead.

However, the pulsed muons source at RAL is not particularly suitable for this experiment, where single muons are analysed individually, and the beams were heavily used, so we applied for beam-time at Triumf, which has a DC source. This has the added advantage that the beam momentum can be raised to nearly 200 MeV/c, which is much closer to the momenta favoured for a cooling channel.

An engineering run was made in Triumf in summer 2000, using solid targets such as aluminium, lithium and beryllium, which was generally successful. The collimation system worked exactly as planned and the time-of-flight system was able to separate pions, muons and electrons in the beam. Unfortunately, the delay line chambers which were used to reconstruct the outgoing particle were designed to work with CFC's as a damping agent, and this is now forbidden. A gas mixture was improvised using methylal, but unfortunately too much was used, and the chambers were damaged. The efficiency was thus not uniform, and even worse, time dependent. Furthermore, there were some details of the performance of the chambers which were never properly understood. The decision was made to build a new tracking system for the main physics run.

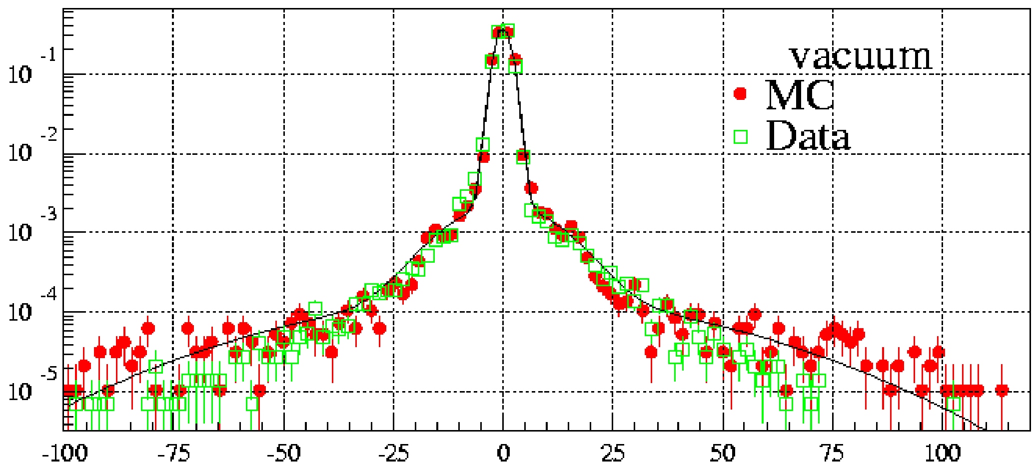

Figure 3. The distribution measured during the engineering run with no target, i.e. the collimators only. The data is in green, and a G4 simulation in red. Shoulders due to particles partially penetrating the collimator jaws can be seen at ±15 cm.

Figure 3 shows the measured outgoing particle distribution during the engineering run with no target present, compared with the simulation, and a simple fit to guide the eye. The data is well described by the Geant 4 simulation, including both the level of the tails, and the presence and level of a shoulder at ±15cm.

4. Scintillating Fibre Tracker

The new tracker has three double planes of scintillating fibres, each with 512 fibres in both x and y. The fibres are double clad Bicron scintillating fibre with an external diameter of 1 mm, and are spaced at intervals of just under 0.6 mm, so as to cover a 30 cm squared area with good efficiency. This is a total of 3096 fibres, which were tensioned in a Delrin frame and then potted into a plane of resin. A black resin is used to reduce the effect of cross-talk or any ambient light.

To reduce costs, the readout is multiplexed. Each single plane of 512 fibres is grouped as two pairs of 256. These 256 are readout at both ends, using a clear fibre readout bundle in which the 256 fibres are potted into a square arrangement, 16 mm each way. Each bundle is then brought up to a Hamamatus R5900U photomultiplier‡, which has sixteen anodes, each 16 mm by 0.85 mm, and spaced by 1 mm. The PMT's at the two ends of the plane read the rows and columns of this bundle respectively. In the event of one single fibre hit, this allows the fibre number to be found.

Figure 4. The ends of two of the fibre bundles, potted into vacuum feedthroughs, waiting for the photomultipliers to be attached. Precision dowel holes can be seen, optically aligned to the photo-cathode.

The three double planes are mounted in a dedicated vacuum vessel, with twenty four fibre bundles, each coming to its own vacuum feedthrough. Two are shown in figure 4. While they are being potted the fibres naturally try to adopt a hexagonal packing, but need to be held in a square arrangement to match the photomultiplier. For this reason the success rate in manufacture was only about 50%.

‡ Hamamtsu Photonics, 325-6,Sunayama-cho,Hamamatsu City, Shizuoka Pref., 430-8587,Japan

The PMT's are readout using a custom sample-and-hold system, with a front end having a 2 μs time-constant. This means that the incident particle flux must be kept below 10^5 Hz or there will be pile-up issues to consider. The electronic noise is very low, well below the level of a single photoelectron.

The complete tracker has been tested using cosmic rays and proton and pion beams at RAL. Pedestal uniformity is good, and there are few noisy channels. There are no precise numbers on efficiency to date, but it is better than 90%. The mean signal size is somewhat disappointing, being between 3 and 4 photo-electrons at each end of the detector. This is however adequate, especially when it is recalled that there are three planes in the tracker, while only one is required to establish the outgoing particle angle. Cosmic ray tracks have been reconstructed, demanding 3 hits in each of x and y, with an efficiency around 50%.

The detector seems stable and should be able to make the measurements required.

5. Collimators

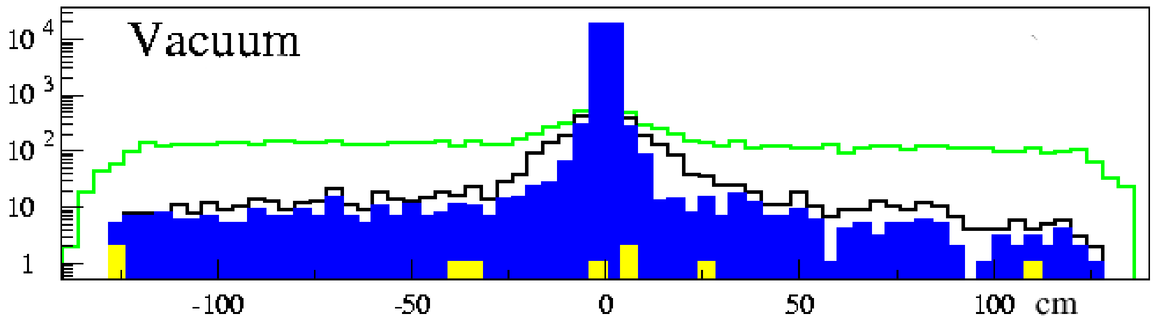

Figure 5. The expected particle arrival position distribution at the detectors with no target. The upper grey line shows the original collimation system, while the black gives the effect of an improved improved passive collimation and the solid area shows the expectation when using an active collimator in addition. The light grey contribution at the bottom corresponds to the effect of muon decays in flight.

The good agreement between simulation and data in figure 3 gives confidence that Geant 4 can be used to improve the details of the collimation system. Revisions have been made to the jaw angles, the shape and position of additional cleaning collimators inside the collimation tube, and extra lead shielding has been added. These are partially because the collimation system was being used for momenta higher than it was originally designed, and also due to problems identified with experience. Furthermore, a new active collimator has been added to clean up some of the tails in the distribution.

This last comprises two scintillator bars, each 3 mm square an 24 mm long, which are positioned just above and just below the inlet to the final collimator. These should catch muons which rather than flying through the collimation gap instead hit the front face of the lead, and then scatter and emerge in the final collimation jaw. Such particles have a much larger range of angles than normal, and would complicate the measurement of the scattering distribution significantly.

6. Time of flight

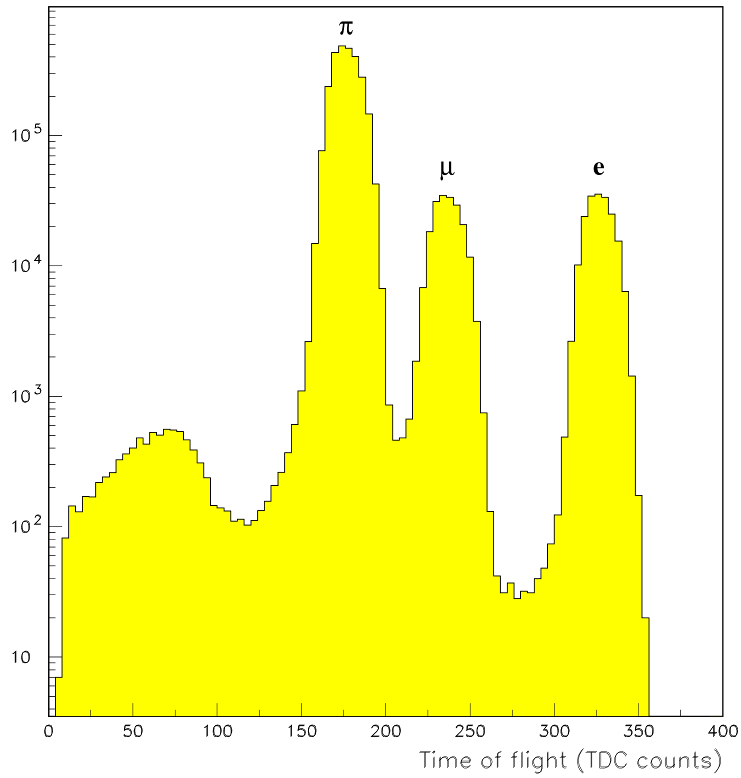

Figure 6. The time of flight distribution measured in M11 using the first acceptance scintillator and the beam period monitor. The clean separation of pion, muon and electron peaks can be seen.

The beamline used at Triumf, M11, has a beam which is 80 to 90% pions with a contamination of 5-10% of muons and electrons. The muon component can be easily identified using the time of flight information from the beam defining scintillator, as seen in figure 6. For the final experiment this information will be supplemented by a timing signal from the SciFi tracker, which may be comparable in accuracy when several measurements are combined. This last measurement, being after the collimator jaws, may also be able to remove particles which have interacted with the jaws and slowed down.

7. Conclusions and prospects

The MuScat experiment had a very useful engineering run, and have proceeded to construct a brand new scintillating fibre tracker. This has been built and is undergoing tests.

A beam allocation at Triumf for March 2003 has been made, and MuScat will take data with liquid hydrogen and a range of solid targets there then. Thee is much software work still to be done in understanding the fibre tracker and working out how best to use the information from it, but we can be confident that one year from now detailed multiple scattering data will be available.

[1] V.V. Parkhomchuk and A. N. Skrinsky, Ionization cooling: Physics and Applications, Proc. 12th Int. Conf. on High Energy Accelerators, 1983, eds. F. T. Cole and R. Donaldson.,
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