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Measurement of the polarisation of a 190 GeV muon beam at the CERN SPS.

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ABSTRACT

A muon beam polarimeter has been built for the SMC experiment at the CERN SPS. Two polarimetry methods are used. One method uses the asymmetry of polarised elastic muon electron scattering which is proportional to a theoretical asymmetry known from QED calculations, the measured electron polarisation and the beam polarisation. The other method is based on the measurement of the shape of the energy spectrum of the positrons coming from muon decay in flight. With this device, the longitudinal polarisation of the muon beam can be measured with an accuracy of 2.5 %.

Introduction

The SMC [1] measures the spin structure functions of the nucleon. They are extracted from the asymmetry measured in deep inelastic scattering of 100-190 GeV polarised positive muons off a polarised nucleon target. As this asymmetry is proportional to the beam polarisation it has to be known with a relative accuracy better than 5% in order to match other main sources of systematic error. Two polarimeters were built, one measuring the asymmetry of polarised muon-electron elastic scattering and the other measuring the shape of the spectrum of positrons from muon decay. The muons originate from the decay in flight of pions resulting from the interaction between the 450 GeV SPS proton beam and a beryllium target [2].

Polarimetry using $\mu^+ e^-$ scattering

The cross-section asymmetry $A_{\mu e}$ for the scattering of longitudinally polarised muons off longitudinally polarised electrons has been calculated in QED [3] and can be written to first order :

$$A_{\mu e} = \frac{d\sigma^{\rightleftarrows} - d\sigma^{\rightrightarrows}}{d\sigma^{\rightleftarrows} + d\sigma^{\rightrightarrows}} = y \cdot \frac{1 - y/Y + y/2}{1 - y/Y + y^2/2} \qquad (1)$$

where ($\rightrightarrows$) and ($\rightleftarrows$) refer to parallel and anti-parallel muon and electron spin configurations, $y = 1 - \frac{E'_\mu}{E_\mu}$ the fraction of energy lost by the muon and Y, the maximum value of y allowed by the kinematics (0.95 for a 190 GeV beam). The experimental asymmetry, $A_{exp} = P_e P_\mu A_{\mu e}$ is proportional to the theoretical asymmetry and to the electron and muon polarisations.

The apparatus (figure 1) is designed to detect the coincidence between the incoming muon, the scattered muon and the knock-on electron and to measure all the kinematical variables relevant to the 2-body elastic scattering. The momentum of the incoming muon is measured in a spectrometer 80 m upstream of the polarimeter (not drawn). The incoming muon is detected in a set of highly segmented scintillating counters (BH) and then scatters off the electron target. The knock-on electron and the scattered muon of opposite charges are deflected in a magnetic field. The scattered muon is identified in a plane of scintillating counters (HMU/S) located downstream of a 2 m thick iron absorber. The electron is identified in a lead glass calorimeter. The tracks are measured using multi-wire proportional chambers. The counting rates are normalized to the incoming muon flux measured using the random coincidence between the beam hodoscopes and a radioactive source.

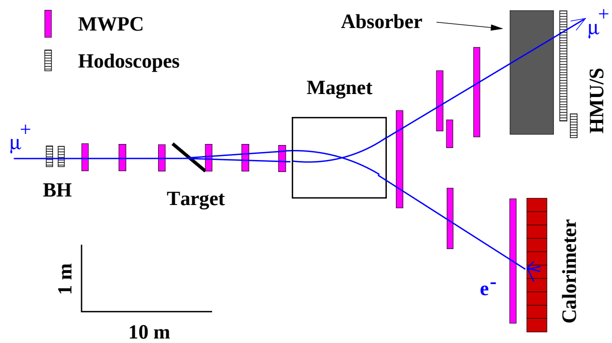

Figure 1: Experimental set-up

The polarised electron target is a 2.7 mm thick foil of ferromagnetic alloy (49 % Fe, 49 % Co, 2 % V) located in the gap of a H-type flat magnetic circuit. The foil is inclined at 25° from the beam axis leading to a longitudinal polarisation of $P_e^L = 0.0756 \pm 0.0009$, where the uncertainty stems mostly from the knowledge of the magnetic properties of the alloy. The electron polarisation is reversed every SPS spill (15 s). To cancel the false asymmetry arising from the vertical field of the target data are taken for two complementary orientations of the foil (25° and -25°). This procedure was checked with an unpolarised target.

The background has been measured using a μ^- beam by inverting the polarity of the magnet and triggering on the coincidence between a μ^- and a e^+, measuring the charge conjugate process to the background entering the μ^+ measurement. The background to signal ratio is reduced from 4 % to 2 % by placing a cut on the energy balance of the reaction. Kinematical studies of the influence of the momentum of bound electrons were performed and this effect was found to be negligible.

The values for the polarisation measured in each bin of y are displayed on figure 2. Each bin gives an independent measurement with a comparable statistical accuracy. The data are compatible with a constant value and the average polarisation at a beam energy of 187.4 GeV is found to be: $P_\mu = -0.776 \pm (0.026)_{\rm stat} \pm (0.016)_{\rm syst}$. The leading contribution to the systematic error are the normalization to the incoming muon flux and the determination of the electron polarisation.

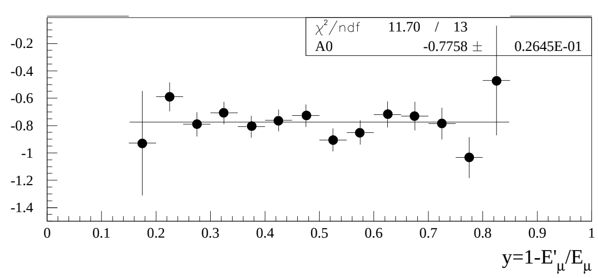

Figure 2: Measured polarisation

The decay polarimeter

In the laboratory frame, the spectrum of positrons from muon decay is [4] :

$$\frac{dN}{dy_d} = N_0 \left[\frac{5}{3} - 3y_d^2 + \frac{4}{3}y_d^3 - P_\mu \left(\frac{1}{3} - 3y_d^2 + \frac{8}{3}y_d^3 \right) \right] \quad (2)$$

where $y_d = p_e/p_\mu$ the ratio of positron to muon momentum, P_μ is the muon polarisation, and N_0 the number of decays. The decay process is identified and the momenta are measured for each event. The acceptance of the detector is estimated using a Monte Carlo simulation.

The experimental set-up used to perform this measurement is a simplified version of the scattering polarimeter. A lead foil is placed before the beam hodoscopes (BH) which are used as a shower-veto in order to reject the incoming positrons. Along the 30 m decay path of the muons (between BH and the magnet) we only use 3 beam chambers. The daughter positron is identified in the lead glass calorimeter.

A large amount of data has been taken using this method leading to a statistical precision of ± 0.009. The polarisation was found to be stable with time. Studies of the energy dependence of the polarisation were also performed. Figure 3 shows the polarisation measured for different incident muon energies. The results found for both method are in agreement with the behavior one expects from the kinematics of the pion decay. A polarisation of $P_\mu = -0.803 \pm (0.029)_{\text{stat}} \pm (0.029)_{\text{syst}}$ was measured for a previous sample of data. The systematic error entering this measurement comes mostly from the determination of the momenta and from the modeling of the acceptance.

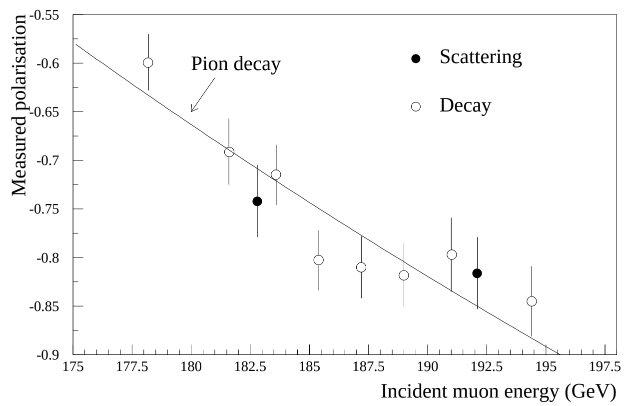

Figure 3: Polarisation as a function of energy.

Conclusions

The SMC muon beam polarisation is determined from two methods which are complementary : one has a low systematic error (the scattering method), one has high statistics (the decay method). Analysis of recent data taken for both methods should yield a total precision of the order of 2.5 % on the beam polarisation, while the uncertainty of the determination of the polarisation using a simulation of the beam transport is 6 % [1].

[1] A. Ogawa, these proceedings.

[2] N. Doble et al., NIM A343 (1994) 351.

[3] A.M. Bincer, Phys. Rev. Vol. 107 (1957) 1434.

[4] The Spin Muon Collaboration, NIM A343 (1994) 363.