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AN INTERIM REPORT ON THE PROBLEMS OF SPECTRUM DETERMINATION AND SHIELDING DESIGN FOR THE PROPOSED ν EXPERIMENT AT 24 GEV/C.

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1. INTRODUCTION

In this interim report a brief account is given of investigations of the problems of spectrum determination and shielding design for the forthcoming ν experiment in GARGAMELLE.

The starting point of the investigation has been the ν experiment (recently completed) which was performed in the NPA Heavy Liquid Chamber. On this occasion the ν-spectrum was determined using a program written by W. Venus and independently by programs written by H.W. Wachsmuth. Since Wachsmuth's programs were specifically designed to use muon flux measurements in the shield to determine the spectrum, attention has been restricted to these programs. (At present Wenus' program predicts the ν spectrum from a particle production spectrum at the target).

2. WACHSMUTH'S PROGRAMS

The main program is called DISMUNU. In this program the basic idea is to take a pion or kaon, produced in one of six target sections and characterized by a secondary momentum p_s and production angle θ, follow it through the focussing elements and allow it decay in one of ~20 decay bins into a muon and neutrino. The muon is followed through the shield until it stops. Thus the initial pion or kaon $| p_s \, \theta_s \rangle_{\pi/K}$ will yield a muon in several of the bins into which the shield is divided, and a neutrino of momentum p_ν and at a radius r in the bubble chamber. By repeating the process, i.e. allowing the parent particle to decay 100 times and integrating over the target sections, for each $| p_s \ \theta \rangle_{\pi/K}$ a series of probabilities is generated which give the chance that a muon appears at r_i and x_i in the shield and a neutrino at r_ν with momentum p_ν in the bubble chamber.

From the muon flux measurements in the shield and these muon probabilities it is possible to reconstruct the initial production spectrum at the target. (It is assumed that the spectrum may be represented by an empirical formula - Wachsmuth used the Sanford-Wang parametrization). Then the neutrino probabilities enable the neutrino spectrum to be determined. All the operation described in this paragraph are done in the second of Wachsmuth's programs.

In principle therefore the method works even if the initial production spectrum is unknown and thick target effects not understood.

However, the following effects lead to errors :

1) incorrect calibration of the muon flux,
2) incorrect multiple scattering and straggling calculations in the shield,
3) incorrect focussing conditions

and 4) the incomplete subtraction of the Hadronic component at small depths in the shield.

The only check on the procedure outlined above is to feed in an initial production spectrum and check that the muon spectrum in the shield agrees with the measurements. Of course in addition to the four uncertainties mentioned above the possible errors in the production spectrum measurements,(uncertainty in any method of extrapolation used and thick target effects),are further complications.

It is noted that the author has changed the original program Dismunu in two respects. Firstly the straggling is taken to be Gaussian - the f.w.h.h. depending on the momentum according to Sternheimer) and the decay in the π or K c.m.s. has been more completely randomized.

3. THE CHECK ON THE MUON FLUX DISTRIBUTION IN THE SHIELD

In a previous report Wachsmuth presented a graph showing good agreement between the predicted and observed muon fluxes. Unfortunately since that time a factor of 1.37 was discovered in the absolute normalization of the fluxes and thus no longer may good agreement be claimed. In this comparison it must be remembered that an input spectrum at 19.2 GeV/c was used, whereas the experiment was performed at 20.6 GeV/c. It turns out that the failure to extrapolate, to 20.6 GeV/c and the error in normalization almost cancel out ! Hence an explanation for the good agreement claimed hitherto !

The prime requirement for the comparison is extensive and reliable input data. At 19.2 GeV/c there exists the data of Allaby et al. for pions and kaons, the secondary momenta of which range from 6 to about 16 GeV/c. Since secondary particles of momenta down to about 2 GeV/c are required and since the incident beam momentum was 20.6 GeV/c a reliable method of extrapolation must be found.

The Sanford-Wang and the Trilling formulae failed to give good fits. Finally W. Venus suggested that these empirical formulae should be multiplied by a term containing an additional parameter :

$$\left(\frac{p_{inc} - p_s - p_s \theta - m}{p_{inc}} \right)^V$$

The quality of the fits obtained were good - typically 5 % and at worst about 10 %, provided the secondary momentum was not too close to the incident momentum.

Figure 1 shows the predictions of the modified Sanford-Wang formula at 19.2, 20.6 and 24.0 GeV/c together with the K/π value. The modified Trilling formula overestimates the cross section at low secondary momenta.

It is seen that the predicted spectrum at 20.6 GeV/c is in reasonable agreement with the measurements, except at low depths where of course the hadronic subtraction is large and perhaps uncertain (see Figure 2). The other points agree to 10 % or better. Of course it is impossible to find the reason for the disagreement - it could be that the extrapolation formula is incorrect or caused by thick target effects, incorrect focussing currents or the complex effects in the shield described earlier.

To procede further the following suggestions are made :

1) Before the main neutrino run, a run should be made at 19.2 GeV/c where at least good thin target data exist. Of course it would be even better to have more extensive measurements from a thick target. It is clear that the more effort made here the less uncertain becomes the muon flux comparison which is the only check on the system.

The inclusion of pick-up coils in the horns and reflectors should remove any uncertainty as to the reproducibility of the magnetic fields in the focussing elements.

2. More detailed investigation can be made on the phenomena occurring in the shield i.e. in addition to multiple scattering perhaps single and inelastic processes should be considered. Similarly for straggling. As a matter of interest the 24.0 GeV/c spectrum was also obtained leaving out the effects of straggling and multiple scattering (see figure 2 continued). Again effects of the order of 10 % may be produced in this rather extreme case. However, a more systematic investigation should yield the limits such uncertainties can produce in the ν spectrum. The subtraction of the hadronic component is another problem which needs further work. It goes without saying that to improve the quality of the muon flux comparison and the related but not quite equivalent problem of determining the ν spectrum will be difficult now that the errors are probably at the 10 % level.

4. THE DISTRIBUTION OF ION CHAMBERS FOR THE ν EXPERIMENT AT 24 GEV/C

This information may be inferred from the predicted muon distribution at 24.0 GeV/c. At 5.52 metres it is proposed to put 8 detectors ranging from - 90 to + 90 cm to check the symmetry of the beam. At 1.71, 3.06, 4.36, 6.76, 7.99, 9.22 and 10.00 4 detectors should be inserted which each scan three positions. In this way about 100 measurements may be used to determine the muon flux distribution. The last depth of 10.00 metres is probably sufficient since this depth corresponds to a neutrino momentum of about 10 GeV/c, or greater. (On the 24.0 GeV/c graph the ratio of M_K/M_π has also been included for further information).

5. THE SHIELD DESIGN

The request of the Swiss Authorities for the return of the steel ingots in the shield necessitated a redesign of the ν filter. This was done by modifying DISMUNU and feeding in the 24 GeV/c production spectrum. (The highest pion and kaon momentum was 23.75 GeV/c).

The configurations considered are shown in Fig. 3 and Fig. 4, together with the simple variation - for example figure 4 without the 4 m iron end pieces.

The decay sequences from parent particles produced at all secondary momenta and angles were followed into the shield. Particles entering the central core were examined at the successive filter depths to see whether they had emerged into the concrete. If so their subsequent paths were followed in the concrete. Particles which had sufficient energy to emerge from the concrete were assumed to multiple scatter into the chamber - a probability being calculated for this process. For particles which stop either in the concrete or in the iron the extra range (required for the particle to emerge) was calculated. This was then assumed to be the necessary straggling and the probability calculated.

In DISMUNU hitherto, the author has assumed a Gaussian distribution for straggling which is correct upto one standard deviation . For ranges above thus however, the probability drops much faster and a formula communicated by Prof. D.H. Perkins has been used. This is

$$P(R) \simeq 4.8 \exp\left(-80\left(\frac{R}{R_o} - 1\right)\right)$$

$$\text{for} \quad R > R_o + \sigma \quad (\sigma \simeq 5\ \%)$$

The following table gives the results in terms of μ's per burst (10^{12} protons) in Gargamelle.

Configuration	Focussed	Unfocussed	
I) (22-15)	5.8	2.5×10^{-6}	
II) (22-15)	2.75×10^{-10}	2.75×10^{-10}	Implies all particles stop
II) NO END PIECE(22-15)	$1.35 \times 10^{+3}$	--	
II) (20-17)			

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Figs. 1 and 2 available on request.