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LETTER OF INTENT

HADRONIC INTERACTIONS AT VERY SMALL MOMENTUM TRANSFERS

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1. PHYSICS

One of the most interesting problems in high-energy physics at present is the asymptotic behaviour of the total hadronic cross-sections. In the ISR range, $\sigma_{tot}(pp)$ is rising with energy.

If it is assumed that the total cross-sections will tend asymptotically to a constant value and this is described in terms of pomeron exchange, then one is led to the conclusion that no inelastic states can be produced in the forward direction ($q_\perp = 0$) as the energy tends to very high values. Thus, at high energies the inelastic cross-section should have a dip in the forward direction according to this description. Furthermore, a finite value of the cross-section at $q_\perp = 0$ could only be due to pomeron cuts contributions and should decrease asymptotically at least as $\log^{-4} s$. This is a stronger energy dependence than that of the cuts contribution to the total cross-section. These are arguments developed, in particular, by Gribov et al.[1)].

If, on the other hand, the total cross-section is thought to continue rising even at the highest energies (Ter-Martirosyan, Migdal, Polyakov[2)] and Abarbanel, Bronzan[3)]) or to eventually start decreasing as the energy rises, then no dip is to be expected in the forward direction and the inelastic cross-section at $q_\perp = 0$ should increase in the region of rising total cross-sections. Thus, the observation of the inelastic cross-section as $q_\perp$ tends to zero and its energy dependence may serve as a sensitive probe to test the validity of these various theoretical approaches based on different assumptions of the total cross-section behaviour at very high energies.

We propose to investigate the reaction $\pi^- p \to \pi^- \pi^- \pi^+ p$ at very small momentum transfers down to $|t| = 0.002\ (\mathrm{GeV/c})^2$ in the three pion mass band $M_{3\pi} < 1.5$ GeV with beam momenta in the range 50 to 150 GeV/c. From such measurements one would be able to make a reliable extrapolation of the differential cross-section to $q_\perp = 0$, the result of the extrapolation being essentially independent of the possible contribution of the spin-flip terms to the amplitude in this region of very small momentum transfers. Thus the s-dependence of $d\sigma/dt$ ($q_\perp = 0$, $M_{3\pi}$ = const.) would be studied.

The above-mentioned three-pion mass band has been found experimentally to be dominated by the $A_1(1+)$ and $A_2(2+)$ particle waves at 20-40 GeV/c [4]. Of these only A_1 is suitable for our purposes since its production in the forward direction by pomeron pole exchange is not forbidden for kinematical reasons as in the case for the A_2. The A_1 is a suitable choice also for several other reasons. Firstly, it dominates strongly in its mass band. Secondly, the relatively low value of the A_1 mass means that pomeron exchange should dominate over secondary trajectories at lower s-values than in the case of more massive waves. Furthermore, there is experimental evidence[4] that spin correlation amplitudes contribute very little to the A_1 wave already at 20-40 GeV/c. Amplitudes with spin correlation can only exist in the case of three or more pomeron exchanges. Such amplitudes do not vanish as $q_\perp \to 0$ and should decrease with s as $\log^{-5}$ s according to both theoretical approaches discussed above. To simplify the interpretation of the data it is therefore preferable to exclude the effects of spin correlation. In the proposed experiment this will be done by defining the spin matrix element ρ_{00} of the three pion system. In the case of a pion beam, spin correlation terms must be absent in ρ_{00}. A partial wave analysis would also help in eliminating the contributions from the A_2 wave and other background.

If thus the pomeron pole contribution to the A_1 cross-section is assumed to go to zero in the forward direction, then there is only the contribution from pomeron cuts that remains at $q_\perp = 0$. This contribution should decrease at least as $\ln^{-4}s$, as mentioned earlier. On the other hand, if the pomeron pole term is supposed not to vanish at $q_\perp = 0$, then there would be destructive interference between the pomeron pole amplitude and the pomeron cuts amplitude and, as a consequence the forward cross-section would increase as the cuts amplitude decreases. A rough estimate of the possible decrease of the forward differential cross-section in the former case can be made using the following expression for the two-pomeron cut term[5)]

$$\rho_{00} \cdot d\sigma/dt(q_\perp = 0) \propto (R^2 + 2\alpha'_p \, \ell n \, s/m^2_{A_1})^{-4} \quad ,$$

where $R^2 = 6\ GeV^{-2}$ and $\alpha'_p = 0.3\ GeV^{-2}$. If s varies from 100 to 300 GeV^2 one obtains an estimated decrease of 25% in $\rho_{00} d\sigma/dt$.

Another way of probing the asymptotic behaviour of the hadronic amplitudes is to determine the ratio η of the real to imaginary parts of the forward elastic amplitude by measuring the Coulomb interference effect. The determination of this ratio gives information supplementary to that of a total cross-section measurement. In principle, η should be even more informative on asymptotics than σ_{tot}, since the dispersion relations connecting these two quantities give η as an integral of σ_{tot}, taken over all energies. In practice, both η and σ_{tot} are needed to make a reasonable extrapolation of the hadronic amplitudes towards higher s-values. With the present precision in the σ_{tot} measurements an accuracy of ± 0.01 in η for $\pi^{\pm}p$ is required for these purposes.

In the Regge theory the contributions to η can only come from pomeron cuts and secondary trajectories, the pomeron pole exchange term being purely imaginary. The sign of the contribution to η is positive for cuts and negative for secondary trajectories. The former is thus supposed to dominate over the latter above the s-value at which η crosses zero from underneath. In $\pi^{\pm}p$ scattering this is expected to happen at around 80 GeV/c [6].

In the experimental set-up proposed below, the Coulomb interference in $\pi^- p$ and $K^- p$ elastic scattering would be measured in parallel with the A_1 production.

2. EXPERIMENTAL SET-UP

We propose to measure the above-mentioned reactions in an experimental set-up consisting of an ionizing chamber spectrometer for the recoil and a magnetic spectrometer for the forward-going particles.

The ionization chamber recoil spectrometer has been developed at the Leningrad Institute of Nuclear Physics[7] and is currently being used there for Coulomb interference measurements at up to 1.7 GeV/c beam momentum[8]. Later this year it will be used at Serpukhov to study $\pi^- p$ Coulomb interference at beam momenta up to 60 GeV/c [9].

The spectrometer consists of a cylindrical vessel containing hydrogen (or deuterium) gas at $\sim$ 10 atmospheres. The hydrogen serves both as target and as ionizing gas and the electron-ion pairs created by the low-energy recoil proton are collected on electrodes, mounted perpendicularly to the beam incident along the axis of the cylinder. By analysing the magnitude and rise-time of the pulses induced in the electrodes, both energy and polar angle of the recoil can be determined. The ionization due to the beam particles is compensated for by a special electronic circuit, which counts each beam particle.

The following figures are typical of the performance of this instrument. Maximum operating pressure 15 atmospheres, effective target length 50 cm, recoil kinetic energy range 1 to 10 MeV (corresponding to $0.002 < |t| < 0.02$ $(\text{GeV/c})^2$), maximum beam handling capacity approximately 10^6/per 2 sec pulse, kinetic energy resolution about 40 keV (FWHM) and missing mass resolution 0.2 GeV (FWHM) at 100 GeV/c.

By the time the Coulomb interference experiment at Serpukhov will have been carried out (Summer 1975) we will have acquired extensive experience of the operation of this instrument in a high-energy meson beam under conditions very similar to those which we will have at CERN.

To measure the forward-going particles the magnetic spectrometer proposed by the Amsterdam-CERN-Munich-Oxford-RHEL collaboration[10] seems very suitable. This spectrometer consists of five sets of wire spark chambers, two magnets and two sets of Cerenkov counters, and is essentially a further development of the CERN-Munich forward spectrometer at present set-up in the East Hall. The slow particles are measured with a relatively weak and short magnet directly after the target and the momentum of the fast forward-going secondaries are determined with a magnet of higher bending power, but with a reduced acceptance. The momentum determination of the secondaries with this spectrometer would improve on the mass resolution as obtained from the recoil spectrometer, and a partial wave analysis of the states produced in the forward direction would be possible.

The physicists having their names on this Letter of Intent are the members of our present collaboration. However, we would welcome other physicists and laboratories, with an interest in this field of research, who would like to join the experiment.

Acknowledgement

The first part of this Letter of Intent has been produced in close collaboration with Prof. V.N. Gribov and collaborators at the Theoretical Physics Department of the Leningrad Institute of Nuclear Physics. An extensive presentation of the physics connected to these questions has been worked out and published as Reference 5.

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