COULOMB INTERFERENCE MEASUREMENTS AT A VERY HIGH ENERGY FIXED TARGET ACCELERATOR

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ABSTRACT

Measurements of the real part of the forward πp elastic scattering amplitude at incident momenta up to 15 TeV/c are discussed. Such measurements seem quite feasible using new track detectors that have a standard error of the order of 10 μm and a low energy recoil detector of a kind that has already been used for Coulomb interference at much lower energies.

The interest in determining the real part of the forward elastic scattering amplitude through Coulomb interference measurements is at least twofold. Firstly, using dispersion relations, the simultaneous experimental determination of the imaginary part of the amplitude - through total cross section measurements - and that of the real part, up to the highest available accelerator energy E_{max}, enables a reliable determination of the behaviour of the total cross section up to energies which are approximately an order of magnitude greater than E_{max}[1,2]. Secondly, experimental data on the real and imaginary parts can be used to check the validity of the dispersion relations in the energy region below E_{max} and in this way the validity of the principles underlying these relations, like the principle of causality at distances down to the order $1/E_{max}$[3], can in part be verified.

The momentum transfer squared t_{ci} at which the relative effect of Coulomb interference in elastic scattering is at maximum depends on the total hadronic cross section σ_{tot} and is about $|t_{ci}| = 0.003(GeV/c)^2$ for $\sigma_{tot} = 30$ mb. As σ_{tot} varies only slowly with the incident momentum p_i the scattering angle θ_{ci} corresponding to t_{ci} decreases approximately as $1/p_i$. At 300 GeV/c θ_c is about 180 μrad and at 15 TeV about 3.7 μrad ($\sigma_{tot} = 30$ mb). These values set the scale for the required angular resolution in the measurement of the forward particle. In contrast to this the value of the recoil kinematic energy T_{ci} that corresponds to t_{ci} is independent of incident momentum ($T_{ci} = |t_{ci}|/2\, m_p$, m_p = mass of the recoil proton) and equal to about 1.6 MeV ($\sigma_{tot} = 30$ mb). Recoil detectors developed for Coulomb interference measurements at low incident energies can thus be used, without modification, up to arbitrarily high energies[4].

Coulomb interference measurements at fixed target machines have been performed in three different types of experiments. In the first and the

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second type only the forward particle and the recoil particle, respectively, is measured for each event whereas in the third type both particles are measured.

A limitation in the first type of experiments is that the multiple Coulomb scattering of the incident particle in the target and in the particle detectors sets a definite and p_i-independent limit to the experimental resolution in t. Assuming that the matter in the target and in the detectors around the target represents about 5% of a radiation length implies that the lower limit to the standard error in t is of the order $\Delta t = 0.0004(\mathrm{GeV/c})^2$ in the Coulomb interference region ($|t| = 0.003(\mathrm{GeV/c})^2$). This is not enough if one wants to measure directly the steeply rising Coulomb cross section at the lower $|t|$ side in the interference region and the measured differential cross section therefore has to be "unconvoluted" using the apparent forward angle resolution function. This may be a delicate procedure in view of the relative smallness of the interference effect on the cross section.

In order to reject completely all inelastic events in this type of measurements the momentum of the scattered particle should be measured with a precision of the order $\Delta p = 0.14$ GeV/c, which at 15 TeV implies a $\Delta p/p$ of about 10^{-5}.

The second type of experiments, in which the observed particle is the recoil, has the main advantage that a resolution in recoil kinetic energy of the order of 50 keV can readily be obtained using semiconductors or ionization chambers to detect the recoil proton. This value corresponds to a resolution in t which is independent of the incident energy and equal to about $\Delta t = 0.0001(\mathrm{GeV/c})^2$ which is sufficient for measurements of $d\sigma/dt$ in the Coulomb interference region.

This kind of measurements have primarily been performed in experiments in which the internal beam of the accelerator hits a very thin hydrogen gas jet[5]. The luminosity in such an experiment is high, in spite of the very thin gas jet target, due to the multiple encounter of the intense internal beam with the jet. An important advantage of this very thin target is that the multiple Coulomb scattering of the recoil particle in the target volume becomes negligible. It is therefore possible to measure the recoil polar angle with very high precision which for the case when only the recoil particle is detected is quite necessary in order to enable a satisfactory rejection of inelastic background events at high energies. An important limitation of this method is however that it cannot be used for incident π's and K's. This reduces somewhat the interest for the method when discussing the very high energy domain, since proton-proton measurements can be made at the same centre of mass energy as that of a given fixed target machine using a proton storage ring of a far lower laboratory energy (e.g. a 340 TeV fixed target machine has the same $\sqrt{s}$ as ISABELLE).

In performing experiments of the third type in which the forward particle and the recoil particle both are measured one obtains the combined advantage of the high and p_i-independent t-resolution of the recoil measurement and that of a higher inelastic background rejection resulting from the comparison of the measured energy of the recoil particle and the measured angle of the forward particle. In addition the coincidence of the forward and recoil particle signals forms a valuable trigger condition to reduce the high background trigger rate.

An example of an experiment of this type is that of the Clermont-Ferrand-Leningrad-Lyon-Uppsala Collaboration (NA8)[6] at the CERN SPS. This experiment contains a forward spectrometer and a recoil spectrometer. The forward spectrometer consists of two groups of MWPC's separated by about 20 m and placed upstream of a gaseous hydrogen target and two other MWPC groups separated by about the same distance and placed downstream of the target, to measure the direction of the incident and the scattered beam particle, respectively. Further downstream a third pair of MWPC groups measures the direction of the scattered particle after it has passed through four spectrometer magnets, each 2 m in length. The effective standard error in the position determination of each MWPC group is of the order 0.1 mm and the total bending power of the spectrometer magnets is 15 T·m. The recoil spectrometer is a hydrogen ionization chamber[7] that measures the kinetic energy of the recoil with a standard error of about 60 keV. The total length of the experimental layout is about 70 m.

The NA8 set up has shown to work satisfactorily up to 300 GeV/c. If an installation of a similar type were to be used at 15 TeV with preserved performance no modifications of the recoil detector would be needed. The angular resolution of the forward spectrometer must however be increased. To accomplish this one could either expand the total length of the experiment to 3.5 km or reduce the effective standard error of the track position detectors to 2 μm. The first possibility does not seem very practical and the second is not feasible with todays technique. A combination of the two may however seem quite realistic.

K. Lanius has reported at this Workshop (Group 8) on tests of a liquid argon ionization chamber with very narrow (10 μm) and tightly spaced (10 μm) anode strips which has shown to give a position standard error of 8.4 μm in a test beam measurement. Furthermore, B. Dolgoshein has reported (also in Group 8) on model calculations on a high pressure helium scintillation drift chamber which indicate that a position standard error of 5-10 μm could be obtained with such a detector. Assuming that either of these techniques could be used to obtain an effective position standard error of 10 μ, the lever arms of the spectrometer could be kept at 100 m and the total length of the experiment at about 400 m (see fig. 1).

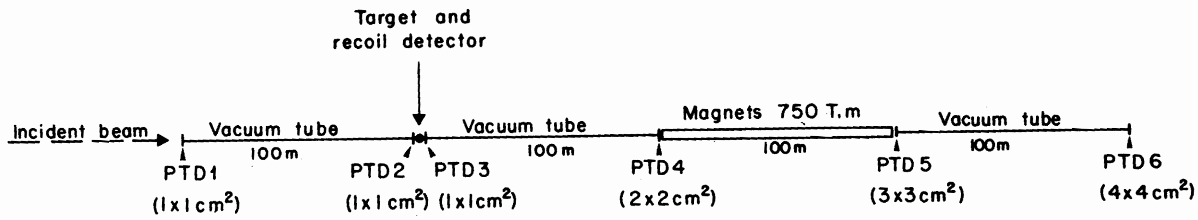

Fig. 1

Layout of the principal components in an experiment to measure elastic πp scattering in the Coulomb interference region for incident energies from 3 to 15 TeV. PTD indicates the positions of the Particle Track Detectors which have a standard measurement error of about 10 μm. The size of the active area of each such detector is indicated in parenthesis underneath.

In addition the bending power of the forward spectrometer magnets should be increased to about 750 T·m if one wants to preserve the absolute momentum resolution (Δp) at the same level. Assuming that magnets with a field strength of 8 T will become available in future this implies a magnetic field length of just below 100 m. It may be noted that this only represents a very small fraction of the magnetic field length needed for a 20 TeV accelerator (about 50 km at 8 T). With spectrometer lever arms of 100 m, assuming an effective secondary beam spot width of not more than 5 mm, a magnetic aperture of ± 15 mm will allow for measurements up to at least $|t| = 0.02\ (\mathrm{GeV/c})^2$ at incident momenta down to 3 TeV/c.

With respect to the SPS experiment mentioned above some extra care would possibly have to be taken in order to avoid beam particles interacting in vacuum windows, detectors and other objects in the beam upstream of the recoil detector. In such interactions hadronic showers are produced which may hit the recoil detector and disturb the recoil measurement [6]. As the multiplicity of these showers increases logarithmically with energy this kind of disturbance will be more important at 15 TeV, requiring increased shielding and filtering of the incident beam.

Taking these modifications into account it can be assumed that all essential features of the 15 TeV experiment will be the same as in the present SPS experiment. To collect of the order of 200 000 elastic πp events, needed to determine the ratio ρ of the real to imaginary parts with a standard error at the level of $\Delta\rho = 0.01$[8], a few days of beam time would be needed at a given incident energy. For the extrapolation of the total πp cross section to higher energies the measurement should be repeated at several (5-10) incident energies spanning the energy interval of the accelerator.

In conclusion we may thus note that provided that small area (a few cm^2) position detectors with a standard error of the order of 10 μm can be made available, the real part of the πp elastic amplitude could readily be measured up to energies of 15 TeV if secondary beams of such energy would come into operation. From the results of such measurements (and other measurements of the total πp cross section up to the same energy) the behaviour of the πp total cross section up to energies of about the order of 150 TeV could be deduced.

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