ISSN 1330–0016
CODEN FIZBE7

LETTER TO THE EDITOR

HIGH-STATISTICS MEASUREMENT OF DOUBLE-PHOTON AND DILEPTON PRODUCTION IN THE PROTON-PROTON SCATTERING AT 190 MeV

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Paper devoted to honour the memory of Professor Nikola Cindro

Received 4 April 2003; revised manuscript received 6 June 2003
Accepted 16 June 2003 Online 20 September 2003

The first high-statistics measurement of double-photon and dilepton yields in proton-proton scattering below the pion threshold has been performed. The data obtained will allow a detailed study of the proton-proton interaction.

PACS numbers: 21.30.-x, 13.75.Cs, 13.20.Cz UDC 539.171, 537.531

Keywords: proton-proton scattering, bremsstrahlung, double-photon, virtual bremsstrahlung, dilepton

We present our first results of second-generation experiments on the double-photon emission from the proton-proton scattering at 190 MeV. The emission of two photons (double bremsstrahlung) is a natural extension of the emission of one photon, but it opens the possibility of studying the emission of a virtual neutral pion and the existence of a dibarion resonance. The competing four-body process is virtual bremsstrahlung [1], a process in which a virtual photon, i.e. an electron-positron pair is emitted. Unlike to a real photon, a virtual photon has mass and longitudinal polarization. The cross section for virtual bremsstrahlung can be decomposed into 6 response functions, thus opening an additional possibility for a detailed comparison with theory. The study of both processes yields new information on the properties of the nucleon-nucleon interaction, which in turn is a necessary ingredient for the understanding of atomic nuclei and nuclear matter.

Both double-photon and dilepton emission processes have lower cross sections than real bremsstrahlung and require sophisticated equipment and analysis to be measured and distinguished one from another. The experiments were performed at the KVI, Groningen, using the high-intensity proton beam from the AGOR superconducting cyclotron, a liquid hydrogen target and two dedicated detector systems: SALAD and Plastic Ball. SALAD [2] consists of a multiwire chamber, which measures the direction of protons emitted at forward angles. A set of scintillators, placed behind the multiwire chamber, is used to measure proton energies, and veto scintillators, placed behind them, are used to reject unwanted (mostly elastic) events. SALAD scintillators are designed in such a way that protons emerging from inelastic scattering cannot pass through the energy scintillators and, therefore, they do not produce signals in the veto detectors. For bremsstrahlung events, one demands that the difference between the number of signals in the energy detectors and the number of signals in the veto detectors should be greater than one. Plastic Ball [3] is a 4π array of 550 phoswitch detectors (a 4 mm CaF_2 layer in front of a 36 cm-thick plastic scintillator), which permit the discrimination of emitted leptons and photons and determine their direction and energy. Since charged particles, in contrast to photons, deposit some energy in the CaF_2 detectors, a pulse-shape analysis makes possible the discrimination between leptons and photons by applying a simple cut (see Fig. 1). Particles in the plastic scintillators produce electromagnetic showers which can be discontinuous causing misidentification of particles in the adjacent scintillators. Therefore, signals in the neighbouring scintillators are clustered to avoid such a problem. This procedure rejects events with an opening angle between two photons that is smaller than 15°.

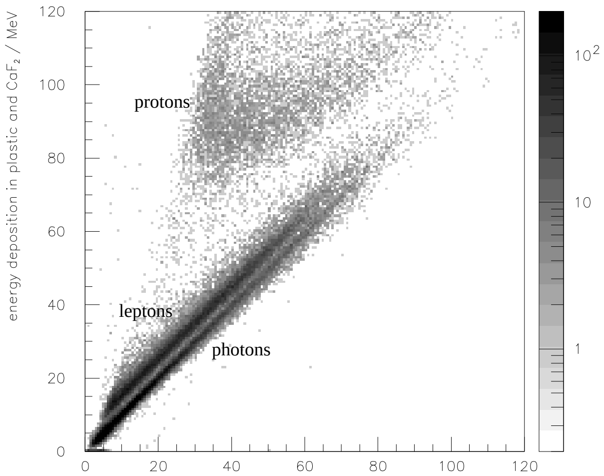

Fig. 1. Pulse-shape plot which allows to distinguish between leptons and photons. Photons lie on the diagonal and leptons slightly above the diagonal.

In order to collect reliable double-photon events and to reduce the background already in data acquisition, coincidence of at least two signals in Plastic Ball and at least two inelastic proton signals in SALAD were required. In the off-line analysis, energy and momentum conservation are required for each event, in addition to the requirement that the coincidence time should be consistent with a single vertex. A kinematical overdetermination permits a good selection of proper events. Measured polar and azimuthal angles of each particle are used for the reconstruction of each event. If such a reconstruction is possible, the reconstructed energies are compared with the measured ones. Using this procedure, about 80 000 good double-bremsstrahlung events were extracted from the entire data set.

These data were compared with a model based on the low-energy theorem [5]. In this model, the T-matrix for the bremsstrahlung process is expressed in terms of the T-matrix for the elastic proton-proton scattering calculated for an appropriate kinematical point. The model is accurately tested with the KVI data for real bremsstrahlung [4]. Apart from being just an extension of real bremsstrahlung (describing the sequential photon emission), it deals with virtual pion emission as well. In this paper, simulated events were produced by the GENBOD event generator [6] and weighted by the squared amplitude obtained from the model. Theoretical and experimental distributions of the invariant mass of two photons are shown in Fig. 2. The experimental yields are arbitrarily normalized to the theoretical distribution.

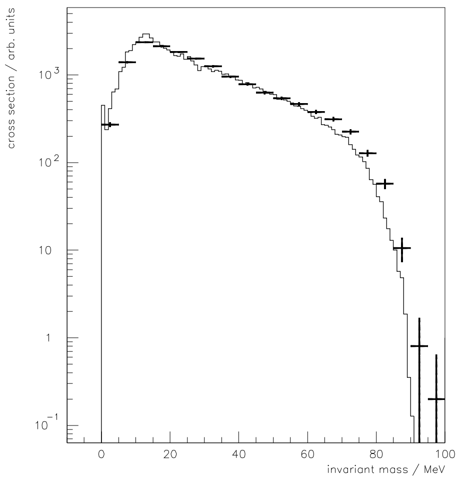

Fig. 2. Photon-photon invariant-mass distribution.

Figure 3 shows the energy sharing between two photons. The x-axis represents the difference between photon energies. Both theory and experiment show the same behaviour, i.e. unequal energy sharing is favoured. Such an energy sharing was observed in a previous work [1] where it was also observed that it differed from the energy sharing in virtual bremsstrahlung. The asymmetry of the distribution is due to the photon ordering according to the polar angle in the experiment (the same ordering was applied to the theoretical results).

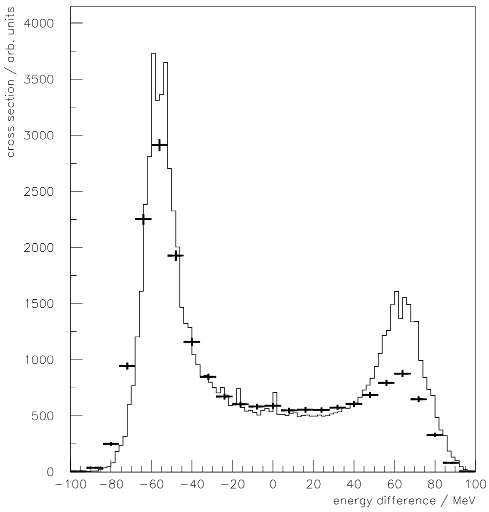

Fig. 3. The difference between photon energies.

To summarize, we have measured double-photon and dilepton yields from the proton-proton scattering at 190 MeV. Using the dedicated detectors and the analysis based on 4-body relativistic kinematics, we have been able to clearly identify two-photon and dilepton events and to separate them one from the other. In this way, a high-statistics data base (with some tens of thousands of events for each of the two processes) has been obtained. A preliminary analysis of two-photon data shows good agreement with the model [5] in invariant-mass and energy-sharing spectra. The analysis of high-statistics data for virtual bremsstrahlung will be presented in a separate paper [7]

References

[1] J. G. Messchendorp et al., Phys. Rev. C **61** (2000) 064007.

[2] N. Kalantar-Nayestanaki et al., Nucl. Instr. Meth. Phys. Res. A **444** (2000) 591.

[3] A. Baden et al., Nucl. Instr. and Meth. **203** (1982) 189.

[4] H. Huisman et al., Phys. Rev. Lett. **83** (1999) 4017.

[5] O. Scholten and A. Yu. Korchin, Phys. Rev. C **65** (2002) 054004.

[6] F. James, *Monte Carlo Phase Space*, CERN 68-15. (1968)

[7] M. Kiš et. al. to be published.

MJERENJE S DOBROM STATISTIKOM EMISIJE DVAJU FOTONA I DILEPTONA PRI PROTON-PROTON RASPRŠENJU NA 190 MeV

Izveli smo prvo mjerenje s dobrom statistikom emisije dvaju fotona i dileptona pri proton-proton raspršenju na energiji ispod praga za produkciju piona. Dobiveni podaci omogućuju dodatno proučavanje svojstava međudjelovanja protona.