New measurements of $pp \to pp\gamma$ reaction at 390 MeV

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Introduction

Proton-proton bremsstrahlung ($pp\gamma$) is one of the most fundamental inelastic processes of nucleon-nucleon (NN) scattering. Gamma rays coming from the reaction will bring out the characteristics of the hadronic process. So far the reaction was extensively studied to investigate nucleonic off-shell effect in NN interaction and differentiate between the various models. Recent works [1,2] at RCNP, with the higher energy regions beyond π^0 meson production threshold, shows much interests in reaction mechanism of $pp\gamma$ process including Δ current [3,4]. Increasing incident proton energy, those off-shell processes become more significant.

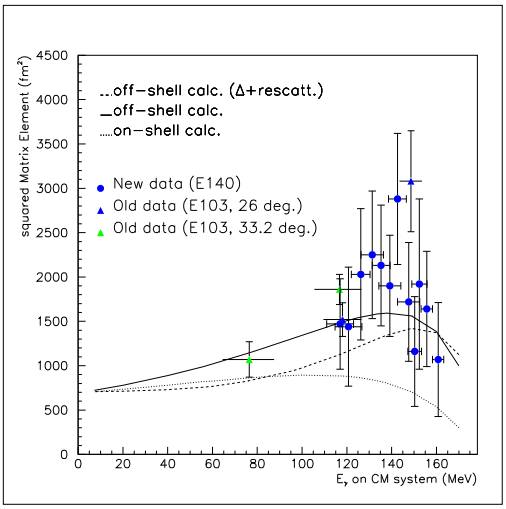
Data presentation as a photon energy dependence of the matrix element [1], may shows evolution of the reaction mechanism. The symmetric kinematics, where two protons are scattered symmetrically respect to beam direction, is very powerful to investigate a contribution of the off-shell term, since the leading term of on-shell contribution disappears. In the work [1] it was concluded, that further study may require the new $pp\gamma$ measurements at many points of the photon energy and the highest photon energy might be interesting.

Similar conclusion has been done in the work [2], where differential cross section and analyzing power for the $pp\gamma$ have been measured. The obtained cross section was larger than the theoretical predictions including the Δ current contribution at about $\theta_\gamma = 70^\circ$. A further theoretical study is needed to pin down the origin of this discrepancy [2].

Taken into account this two suggestions and great interest from the theoretical point of view for this subject, we analyze new experimental data which was proceeded as the RCNP program number E140 [5].

Experiment

The experiment was performed at the Research Center for Nuclear Physics (RCNP). Detail description of the experimental set-up and procedure are presented in the master thesis [6]. A 390 MeV proton beam from the RCNP ring cyclotron was delivered to a liquid hydrogen target. Two outgoing protons were detected by the plastic scintillator array in the angular range between 15° and 35°. The number of measured variables ($\theta_1, \theta_2, E_1, E_2$, and ϕ_1, ϕ_2=0 are assumed on the basis of coplanarity) are enough to determine the kinematics in final state. The mass of the missing particle is useful to identify the measured reaction. The energy of the proton was measured by plastic scintillators (E-counter), which can stop protons up to 250 MeV kinetic energy. The direction of the out-going particle are determined by the plastic scintillator hodoscopes, which were putted in front of the E-counter. The energy resolution of E-counter is better than 3% and the angular acceptance of the hodoscope is 2°. Anti-coincidence counter were set up to reduce accidental coincidence events from pp elastic



The squared matrix element as a function of the photon energy in the center of mass system.

scattering.

Results

Using missing-mass spectra, we obtained yield for $pp\gamma$ events, from which we extracted differential cross section [6]. The transformation from the differential cross section to the matrix element (assuming the obtained $|M(x)|^2$ is constant over the measured region) is calculated as:

$$|M|^2 = F \cdot \frac{d\sigma/d\Omega_1 d\Omega_2 d\theta_\gamma}{J} \tag{1}$$

where F is the flux factor for a collinear collision, and J is the Jacobian [1].

The figure shows the squared matrix element (S.M.E.) as a function of the photon energy (E_γ) in the center of mass system. The photon energy (E_γ), corresponding to the proton acceptance and to the range of θ_γ angles at around 0° and 180°, was calculated using Monte Carlo simulation. The data from the previous measurement (E103) are also presented. The new data cover more wide kinematical range of photon energy. On-shell and off-shell matrix elements are calculated by the computer code provided by Prof. O.Scholten [7]. The matrix elements including Δ current and rescattering processes are provided by Prof. K.Nakayama [8]. Although the error on the data are not small, the measured dependence is different from the theoretical calculations. The sharp enhancement at around E_γ=140 MeV maybe indicates some interesting physics connected with a cusp effect in the threshold $\gamma p \to \pi^+ n \to \pi^0 p$ reactions [9]. Attracting new theoretical view for such behavior might be interesting.

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