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dr hab. Elżbieta Stephan
Instytut Fizyki
Uniwersytet Śląski
ul. 75 Pułku Piechoty
41-500 Chorzów
tel. (32) 3497646
elzbieta.stephan@us.edu.pl

Recenzja rozprawy doktorskiej / Referee report of doctoral dissertation :
Narenda Shankar Singh Rathod
Study of e^+e^- production in π^-p collisions in HADES at GSI.

The doctoral Thesis of Mr. Narenda Rathod is devoted to studies of dilepton production in pion-proton collisions. Dileptons are considered excellent probes to study the hot and dense nuclear matter created in heavy ion collisions. Elementary nucleon-nucleon and pion-nucleon scattering provide information indispensable for understanding the dilepton production mechanisms, necessary for interpreting dilepton spectra measured in heavy ion collisions. The research presented in the dissertation is a part of studies of these processes with the HADES spectrometer, focusing on the production of the electron-positron pairs as a result of the virtual bremsstrahlung in π^-p collisions.

In Chapter 1, the context and motivation of the dilepton production studies are presented, together with the status of experimental studies of the pion-nucleon bremsstrahlung and the theoretical description of this process within a soft-photon approximation. Basic information on dilepton production via virtual bremsstrahlung is also provided. Production and parameters of the pion beam, the HADES spectrometer and targets used in the experiment are described in Chapter 2. Chapter 3 is devoted to algorithms of particle identification and momentum reconstruction applied for analysis of the channels of interest. The Author particularly concentrates on algorithms for finding the rings in the RICH detector and the resulting efficiency of identifying dilepton pairs. Chapters 4-6 present the research conducted by Mr. Narenda Rathod and the obtained results for dilepton production in π-p collisions via virtual bremsstrahlung. Monte Carlo simulations, described in Chapter 4, play a crucial role in several aspects of the data analysis. The simulations are essential for controlling background channels, and determining total cross section based on the data collected within the limited acceptance of the detection system. Procedure of reconstruction of the reaction channels based on experimental data is presented in Chapter 5. Chapter 6 compares the data analysis with simulations to validate the simulations and, finally, determine the total cross section for the dilepton production. The results are summarized in Chapter 7. Appendix A presents calculations of the threefold differential cross section. The thesis is supplemented with lists of figures and tables and bibliography containing 101 positions.

The HADES spectrometer is characterized by high angular acceptance and very good performance with respect to discrimination between electrons, pions and heavier particles, as well as good momentum reconstruction. These features make it an adequate tool for studies of channels containing e^+e^- pairs. The virtual bremsstrahlung, $\pi^-p \rightarrow \pi^-p\ e^+e^-$, can be studied with HADES as an inclusive and exclusive process, with both approaches having advantages and disadvantages. Three- or four-body exclusive channels suffer from strongly reduced acceptance. The inclusive

channel has a much higher aceptance, but also high contribution of background from Dalitz decays, and the necessary cuts on missing mass reduce the available statistics. Therefore, in all the cases the statistics of data set is rather low, and complex analysis is required to extract the process of interest. Mr. Rathod discussed these problems in detail, indicated the possible background sources and studied them in the Monte Carlo simulations. This required combining input from several sources: PLUTO generating the process according to the phase space, experimentally measured angular distributions of elastic scattering, Partial Wave Analysis for Dalitz decay of neutral pions. It was found that the highest background contribution to all the studied channels originated from the π^0 Dalitz decay. In spite of a good description of this process within the Monte Carlo simulations, its dominating rate prevented bremsstrahlung studies in the region of the e^+e^- invariant mass below the π^0 mass. Therefore, all the inclusive and exclusive channels were studied for the invariant mass larger than 0.14 GeV/c^2, on the costs of their statistical accuracy. Contribution from the combinatorial background was succesfully controled with the simulations. As it was pointed out in the Thesis, the use of the polyethylene target introduced another problem of Carbon related background to be subtracted or modeled. Measurements with a Carbon target were used for this purpose, but the statistical and systematic accuracy of the results was further deteriorated. As stated in the Summary, replacement of polyethylene with a liquid hydrogen target would be highly recommended.

The Author took a lot of afford to find the best way of determining the bremsstrahlung contribution to the dilepton production. As as result, he has convincingly proven that the virtual bremsstrahlung played an important role in the pion-proton collisions, and the contribution was even dominating for the dilepton production above the π^0 mass. This conclusion is important for understanding the dilepton production, both in elementary pion-nucleon scattering and collisions of heavy nuclei.

The most challenging task of the presented analysis relied on determining the total cross for the virtual bremsstrahlung. This step required efficiency and acceptance corrections and extending the results to the region below the pion mass. The approach based on the soft pion approximation introduced large model dependent correction factors with uncontrolable systematic uncertainties. The problem was thoroughy discussed in the Thesis. Further advances in the theory of the virtual bremsstrahlung are needed to improve the situation.

The information contained in the dissertation is rich and complex yet presented in a very clear and systematic way. Editorial quality of the thesis is high: figures are clear, and the text is almost free of misprints and language errors. I have found a few minor editing errors, like eFTT instead of eTFF used several times for electromagnetic Transition Form-Factor, or twice Trigger Level LVL1 (instead of LVL1 and LVL2) written in Fig.2.15.

I have several questions and remarks:

- As I understand, the three shapes in Fig. 4.1 show the surface corresponding to a correlation between three kinematic variables: invariant mass, transverse momentum and rapidity of the bremsstrahlung process. Therefore, they are identical and do not provide any readable information on weights or cross sections. In order to present weights or any other variable in the function of these three coordinates, another axis should be added, maybe via color coding. Otherwise, the integration over at least one of these coordinates woud be necessary to present the observable. What was the reason to present three practically identical charts? The only cross section distribution is shown in the lower-right panel, obtained after projection (integration) reducing the number of coordinates to one.

- A simple linear relation connects two Gottfried-Jackson angles shown in Fig. 6.11, therefore presenting both distributions do not provide any new information and seems to be redundant. The same applies to the helicity angles in Fig. 6.12.
- There is a significant discrepancy between the measured and simulated missing mass spectra of the pe^+e^- channel, attributed by the Author to the proton rescattering and absorption in Carbon. Is there any other process or channel to be studied experimentally, potentially sensitive to the pion or proton rescattering effects in similar nuclei?

Summarizing: In the Doctoral Dissertation of Narenda Rathod: *Study of e^+e^- production in π^-p collisions in HADES at GSI* is an important step towards understanding the dilepton production via virtual bremsstrahlung. For the first time, the total cross section for this process was determined experimentally. In spite of the low statistics of the data and systematic uncertainties of the result, the quantitative information on this channel is an important input to description of the dilepton production in nuclear collisions. In addition, the studies indicated a limited applicability of the SPA, thus they can trigger theoretical efforts to correctly describe the virtual bremsstrahlung.

I conclude that the presented dissertation meets the requirements expected for Ph.D. theses. I recommend admission of the Candidate to the subsequent stages of the procedure, including the public defense.

I evaluate the scientific quality of the presented research as superior. Considering the scientific excellence of the presented work and importance of the subject, I recommend the dissertation for distinction.

Yours sincerely,

Elżbieta Stephan