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FZR Preprint 92 - 04
September 1992

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# Estimates of dielectron production in pp and pd reactions at 1 - 2 GeV

# Estimates of dielectron production in pp and pd reactions at 1 - 2 GeV

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**Abstract:** Estimates of elementary cross sections for dielectron production in pN and pd reactions are presented. We use the vector dominance model for all hadron-hadron-photon vertices. Dynamical suppression mechanisms (off-shell behavior of two-body T-matrix, mass dependent $\Delta$ production rate) bring the elementary rate near to previous estimates which did not use vector meson dominance. However, near to $\rho$ mass a characteristic shoulder appears in our approach. We consider $\Delta, \eta$ Dalitz decays and bremsstrahlung at 1- 2 GeV as dominant sources of dielectrons. At higher energies the bremsstrahlung contribution is only a subclass of direct vector meson decays. Relying on a realistic deuteron wave function we predict the ratio of dielectron production in pd to pp reactions

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## 1. Introduction

Dielectrons represent one of the promising signals [1] which can probe directly dense and hot nuclear matter produced in heavy-ion collisions at intermediate energies. The electron pairs are created in various elementary reactions of hadrons. The reliable description of these elementary reaction channels serve as input in theoretical models and event generators for simulating heavy-ion collisions [2, 3, 4, 5, 6]. Such simulations are needed to unfold dielectron spectra and to get the wanted signal of compressed and heated nuclear matter.

There are several calculations of the elementary production mechanisms of dielectrons in pN reactions [2, 3, 4, 5, 6, 7, 8]. The corresponding available experimental data [9] is yet rare and with low statistics. New data with high statistics is expected in near future. Then the theoretical estimates can be tested, since they depend on some model parameters, which are difficult to fix without experimental data. In particular the off-shell behavior of the strong interaction part is probed in a wider kinematical regime than in case of real photon bremsstrahlung or elastic scattering.

The aim of the present note is to re-estimate dielectron production cross sections in elementary nucleon-nucleon subprocesses and apply them in pp and pd reactions at 1 and 2 GeV. These reactions and energies serve just as the needed input for theoretical models of heavy-ion collisions at Bevalac and SIS energies. We rely here on the vector dominance model (VDM), which has been proven as useful guding principle for hadron-photon interactions [10]. The VDM form factor has been implemented, e.g., in Ref. [3] within a traditional approach. However, a strong overestimate of the rate near $\rho$ mass has been found, and consequently VDM has been disregarded. Here we present a careful improvement of the underlying microscopy and find indeed reasonable results within VDM.

## 2. Elementary processes

At energies considered and for invariant dielectron mass $M \leq 1$ GeV, we include $\Delta, \eta$ Dalitz decays and bremsstrahlung as main contributions [11]. Their gross features are described as follows. (Detailed formulae are too complex to display here. They will be published elsewhere.)

### 2.1 $\Delta$ Dalitz decays

We use a folding of the $t$ integrated $\Delta$ production cross section $\sigma_{NN\to\Delta N}(s, M_\Delta) = \int dt\, d\sigma_{NN\to\Delta N}/dt$ with $\Delta$ propagator squared, $D$, going into the $\Delta$ decay vertex which is described in turn by total width $\Gamma_\Delta(M_\Delta)$ and differential width $d\Gamma^{\Delta\to e^- e^+}/dM_\Delta^2$

[3, 4]. The final expression for dielectron cross section via $\Delta$ Dalitz decays reads

$$\frac{d\sigma^{\Delta\to e^+e^-}}{dM^2} = \int_{(m_N+m_\pi)^2}^{(\sqrt{s}-m_N)^2} dM_\Delta^2\, \sigma_{NN\to\Delta N}(s, M_\Delta)\, D(M_\Delta)\, \frac{1}{\Gamma_\Delta} \frac{d\Gamma^{\Delta\to e^+e^-}}{dM^2} \tag{1}$$

($s$ and $t$ are the Mandelstam variables). Observe the $M_\Delta$ dependence of the $\Delta$ production cross section which is usullay not included. It follows directly within a one-boson exchange model. Our cross section $\sigma_{NN\to\Delta N}$ is normalized so that the total $\Delta$ production cross section [12] is reproduced. The one-pion exchange model parameters are fitted to the experimental angular distribution $d\sigma_{NN\to\Delta N}/dt$ of $\Delta$'s. In the $\Delta N\gamma$ vertex [13] we include the electromagnetic form factor from VDM

$$F_\gamma^2(M^2) = \frac{m_\rho^4}{(M^2 - m_\rho^2)^2 + (m_\rho\Gamma_\rho)^2}. \tag{2}$$

### 2.2 $\eta$ Dalitz decays

The contribution of $\eta$ Dalitz decay takes the form

$$\frac{d\sigma^{\eta\to e^+e^-}}{dM^2} = \sigma_\eta(s)\, \frac{\alpha}{3\pi M^2}\, 0.39 \left(1 - \frac{M^2}{m_\eta^2}\right)^3 . \tag{3}$$

We calculate the $\eta$ production cross section $\sigma_\eta$ in pN reactions as in Ref. [14]. When calculating the $\eta$ production in pd scattering we use a realistic deuteron wave function $\psi_d$ obtained within the Paris potential model [15]

$$\sigma_{pd\to\eta X}(s) = \int \mathcal{R}\, \left(\sigma_{pp\to\eta pp}(s'(p')) + \sigma_{pn\to\eta pn}(s'(p'))\right)\, |\psi_d(\vec{p}\,')|^2\, d\vec{p}\,' \tag{4}$$

where $\vec{p}\,'$ is the relative nucleon momentum in the deuteron, and $\mathcal{R}$ denotes the flux factor. The internal nucleon motion in the deuteron is important near and below the $\eta$ threshold. We also include short range correlations which describe simultaneous interaction of the proton with a correlated two-nucleon cluster in the deuteron wave function with a 5% probability as in Ref. [16].

### 2.3 Bremsstrahlung

The bremsstrahlung contribution in pp collisions is strongly suppressed because of destructive interference of exchange diagrams [7]. In Refs. [7, 8] the bremsstrahlung was estimated by diagrammatic calculation within a one-boson exchange model, but without VDM form factor. It was found that the result depends on the two-body T-matrix parameters which cannot be fixed only by fitting pn elastic scattering. To avoid these uncertainties we use here a model which resembles the soft-photon approximation, however, we use exact kinematical relations. The net result reads

$$\frac{d\sigma^{ab\to a'b'}}{dM} = \frac{\alpha^2\sqrt{s(s-4m_N^2)}}{16\pi^3 M^3} F_\gamma^2(M) \int dy\, dq_\perp^2\, dE_{b'}\, d\varphi_{b'}\, |q|^{-1} J_\mu\, J_\nu\, \mathcal{P}^{\mu\nu}\, \frac{d\sigma^{ab\to a'b'}}{dt} \quad (5)$$

with

$$J^\mu = \sum_{i=a,b,a',b'} \alpha_i\, g_i^2(\xi_i)\, \frac{2p_i^\mu}{(p_i-\alpha_i q)^2 - m_N^2}, \quad \alpha_{a,b}=1, \quad \alpha_{a',b'}=-1$$

and $\mathcal{P}^{\mu\nu} = -\frac{4}{3}(g^{\mu\nu}q^2 - q^\mu q^\nu)$ as projector, and $d\sigma^{ab\to a'b'}/dt$ denotes the elastic $ab \to a'b'$ scattering cross section. The factor $g_i(\xi_i)$ with $\xi_i = (p_i - \alpha_i q)^2/m_i^2$ controls the off-shell corrections. In the one-boson exchange model $g_i$ corresponds to an additional off-shell dependence of the nucleon-nucleon-boson vertex. We use a simple symmetric ansatz for $g(\xi)$, namely $g(\xi) = \kappa\left((1-\xi)^2+\kappa\right)^{-1}$. The parameter $\kappa = 6$ is found by a fit of the electromagnetic form factor which was calculated in a relativistic oscillator quark model of baryons [17].

For the pd interaction we assume that both pn and pp bremsstrahlung contribute. Due to the deuteron wave function the usual destructive exchange interference, which suppresses the pp contribution, is not operative here. Details of the lengthy derivation will be given elsewhere. This effect is to be included also in $\Delta$ and $\eta$ production.

### 3. Results

In Figs. 1 and 2 we display our results. For orientation we also display in Fig. 1 the results of the DLS collaboration [1] for p $^9$Be interaction (scaled by a factor $A_{^9Be}^{-2/3}$), which can be considered as dilepton production in p - isoscalar nucleon interaction. (Please note that we do not apply the experimental filter which is important below 250 MeV.) In calculating the $\Delta$ Dalitz decay in pd reactions we also take into account the internal motion of nucleons in the deuteron as in eq. (4). The integrations in eqs. (1, 3, 4) are performed with a Monte Carlo method. At 1 GeV we find the bremsstrahlung contribution nearly as strong as the $\Delta$ Dalitz decay. There is no significant contribution of the $\eta$ decay. To check this point we also employ the $\eta$ production cross section from Ref. [18] and do not find noticeable changes. Subthreshold effects are responsible for the larger invariant mass tails of the $\Delta$ and bremsstrahlung contributions in pd reactions. The vector dominance effects (i.e., the form factor) are not important; off-shell effects also not.

Contrary, at 2.1 GeV these latter effects are important. However, the strong enhancement of the bremsstrahlung contribution at the $\rho$ peak is reduced by strong off-shell effects. The net result is a shoulder in the sum of all contributions. This is not so clearly seen in pp reactions due to the kinematical limit. However in pd reactions, due to subthreshold effects it can be observed. Our net results are in the order of magnitude as those obtained in Ref. [3], but in Ref. [3] there is not the shoulder behavior in the $\rho$ region. Note that at higher energies (not displayed here) at $\rho$ position even a peak appears. In the low-mass region the $\eta$ contribution dominates at 2.1 GeV and above.

The ratio

$$R = \frac{\sigma_{pd}}{\sigma_{pp}} \quad (6)$$

(see Fig. 2) shows an energy dependence which is in agreement with preliminary data [9]. Most significant is the levelling-off due to the subthreshold production at kinematic limits. Our calculations predict that $R$ increases with decreasing energy because of increasing importance of bremsstrahlung at lower energies. At energies above 2.1 GeV more processes must be considered. In particular, direct vector meson decays must be included (cf. [5, 11] for some estimates) which introduce considerable more complexity. Double counting problems become important, because bremsstrahlung with form factor represents only a subclass of other processes.

## 4. Summary

In summary we re-estimate the dielectron production in pp and pd reactions at 1 and 2.1 GeV. We base our calculations on the VDM and find good agreement with available data when considering $\Delta, \eta$ Dalitz decays and bremsstrahlung with appropriate off-shell effects in the two-body T-matrix and mass dependent $\Delta$ production. The model for the off-shell T-matrix used here can be checked in independent processes, e.g., by real photon bremsstrahlung. Work in this line is in progress.

Acknowledgements: Useful discussions with W. Cassing, B. Friman, U. Mosel, V.D. Toneev, and G. Wolf are acknowledged. We thank A. Molockhov for assistance in calculating the $\Delta$ production. A.I.T. wish to thank the nuclear theory group in Research Center Rossendorf for the warm hospitalitity. This work is supported by BMFT under grant No. 06 DR 107.

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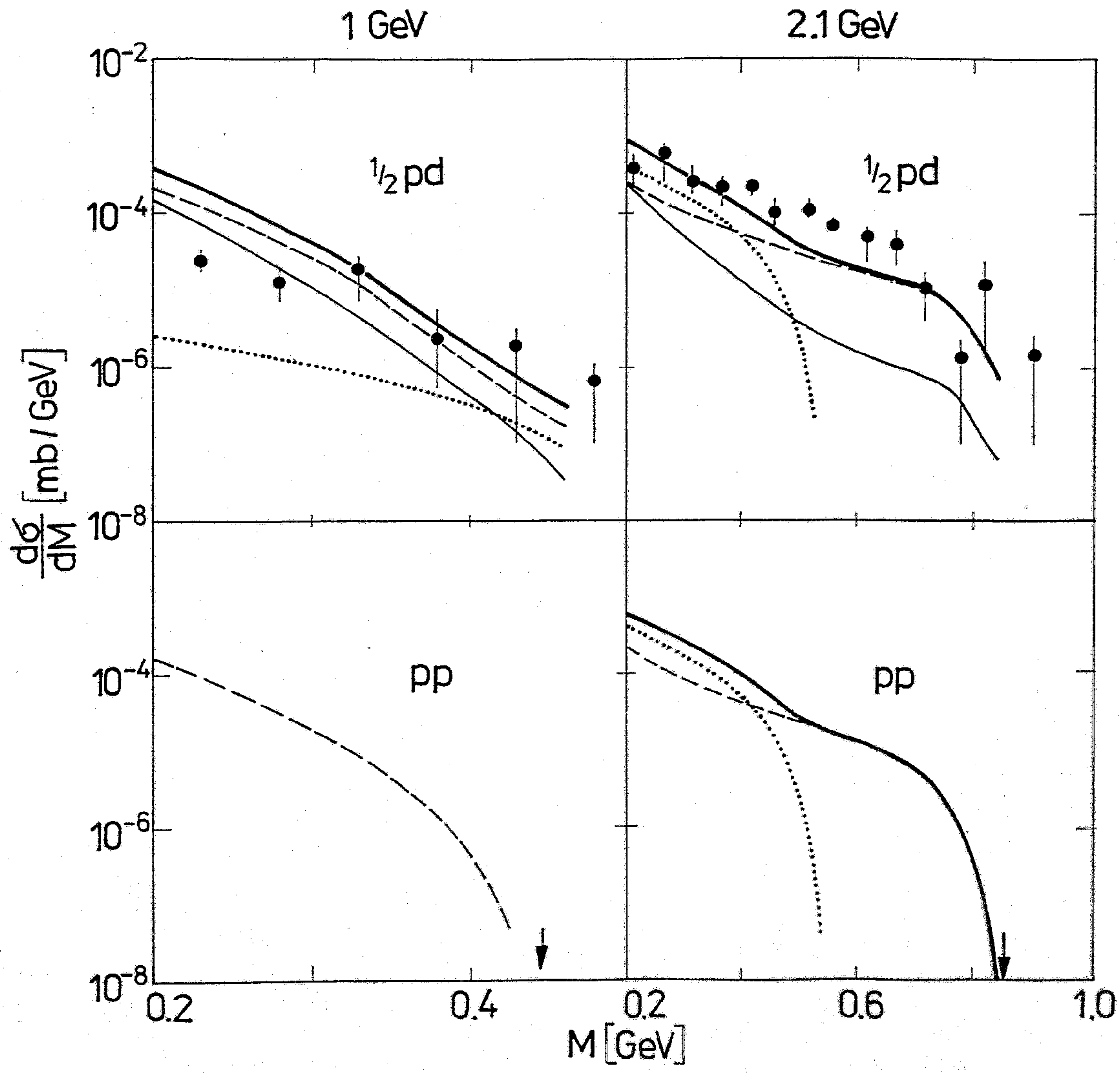


**Fig. 1:** The cross section of dielectron production in the pp (lower panels) and pd reactions (upper panels) at 1 GeV (left panels) and 2.1 GeV (right panels) proton energy (heavy full line: sum of all contributions, dashed/dotted/thin lines are for $\Delta/\eta$/bremsstahlung contributions). The experimental data (dots) of Ref. [1] for $p^9Be$ collisions are scaled by $A_{^9Be}^{-2/3}$. Arrows indicate the kinematical limits in pp reactions.

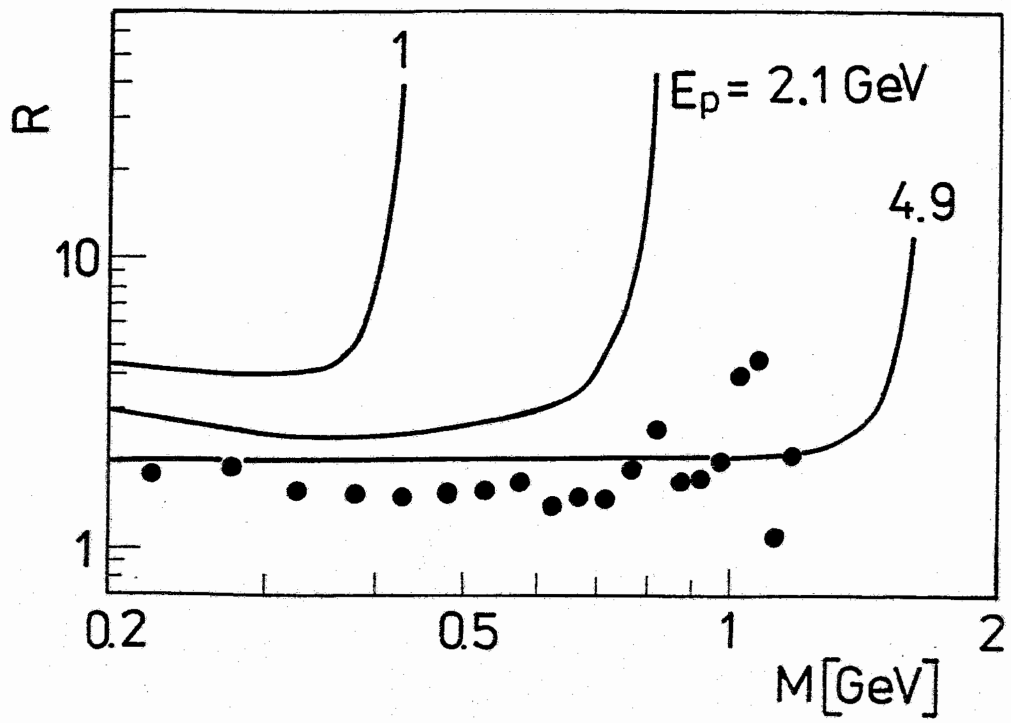


**Fig. 2:** The ratio (6) as function of the invariant dielectron mass for different energies. The preliminary experimental data for 4.9 GeV (dots) are from Ref. [9].